The effect of vertical growth pattern on mandibular incisor proclination in non-extraction Invisalign Teen® cases.

By

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A Thesis submitted to

The Faculty of Graduate Studies of

The University of Manitoba

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

(Orthodontics)

Department of Preventative Dental Science

College of Dentistry

Division of Orthodontics

University of Manitoba

Winnipeg, Manitoba

Abstract

Objectives: To investigate the effect of vertical growth pattern on the position of the mandibular incisors for non-extraction Invisalign teen® patients, with or without interproximal reduction.

Subjects and methods: A retrospective chart review consisting of 40 (26 girls;14 boys) Caucasian adoloscent patients in the permanent dentition (12- 18) was undertaken. Subjects were categorized into 4 groups based on the value of the pre-treatment lower dentition crowding and value of patients mandibular plane angle (MPA). Crowding was assessed as mild (0-3.9mm) or moderate (4-5.9mm) and MPA as normal growth (30-37°) or vertical growth (>37°). The sample provided 10 normal growth/mild crowding, 10 vertical growth/mild crowding, 10 normal growth/moderate crowding and 10 vertical growth/moderate crowding subjects. Measurements were taken from digitized cephalograms to determine the changes in the lower incisors from T0 (pre-treatment) to T1 (post-treatment). Interproximal reduction (IPR) and buccal expansion were recorded as contributing parameters to crowding resolution. Statistical analysis included a paired t-test and ANOVA.

Changes in parameters and the final lower incisor position were evaluated.

Results: No significant increase in buccal expansion between the 4 groups ($p<0.05$) was observed. IPR average values for the Normal and Vertical growth/ mild crowding groups were

1.25+/-1.37mm and 1.17+/-1.25mm respectively. IPR for the Normal and Vertical growth/moderate crowding was 1.54+/-1.38mm and 1.35+/-1.67mm.

Normal Growth/Moderate crowding showed statistically significant proclination of the lower incisors:L1/NB 3.0°+/-1.7°($p<0.05$),IMPA 3°+/-2.3°($p<0.05$), L1/APOG 3.1°+/- 1.9°($p<0.05$).

Vertical Growth/Moderate crowding showed statistically significant proclination of the lower incisors:L1/NB2.2°+/-1.8°($p<0.05$),IMPA2.7°+/-2.0°($p<0.05$),L1/APOG2.5°+/- 1.5°($p<0.05$).

Lower incisor protrusion was not statistically significant in any of the groups($p<0.05$).

Conclusion: L1 proclination was affected by the vertical growth pattern in non-extraction Invisalign teen® cases.

Acknowledgements

I would like to express my sincerest appreciation to my committee members, Dr. Robert Drummond, Dr. Anastasia Kelekis-Cholakis, Dr. Robert Schroth and Dr. Milos Lekic, for spending their generous time answering my questions, guiding me and helping make this project what it has become.

Thank you to Dr. Wiltshire for his continued encouragement. His guidance and leadership is what helps make the orthodontic program at the University of the Manitoba, one of the world’s finest.

Thank you to Dr. Laura Duncan, whose advice and resources were invaluable when conducting his study.

A special thank you to the class of 2020. To Dr. Tyrone Zybutz and Dr. Richa Sharma, Thanks for all the help, support, new friendship and laughs over the past 3 years. You helped make my residency so memorable and such a wonderful experience.

A massive thank you to my parents, Aidan and Patricia Hennessey. For their endless love and support and providing me with the opportunity to realize my dream of becoming an orthodontist.

Lastly to my wonderful Fiancée Jenni, The biggest thank you for your continuous love and encouragement throughout this journey. Three years ago you left everything behind to jump into this adventure without any hesitation and for that I am eternally grateful.

Dedication

This thesis is dedicated to my beautiful Fiancée Jenni and my wonderful Parents Aidan and Patricia. Your love has provided me with the most amazing life and I thank you all for giving me this gift.

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CHAPTER 1

Introduction

1.1 Background to key concepts in growth and development

Both orthodontists and dentists require a meticulous understanding of normal craniofacial growth patterns and development. This knowledge is vital in order to differentiate normal variation from abnormal or pathologic processes and for the manipulation of facial growth.

1.1.1 Growth and Development

In dentistry, growth and development have distinct meanings. Growth is defined as a physical increase in anatomical size, number or complexity, whereas development is defined as an increase, or specialization, in behavioural and physiological complexity (Proffit, Fields, and Sarver 2013).

1.1.2 Pattern, Variability and Timing

Growth pattern is an important concept in the area of craniofacial growth and development. Growth pattern can be defined as a set of complex proportional relationships at a specific point in time, and also the changes in these proportioned relationships as time passes. More specifically, this refers to the arrangement of a physical body at a certain point in time, which is a pattern of spatially proportioned parts. Changes to these parts are referred to as a pattern of growth (Proffit, Fields, and Sarver 2013).

Another key concept in physical growth and development studies is variability. As humans' can differ greatly in growth rates, defining variability allows dental clinicians to determine whether a patent’s growth is inside or outside the range of normal variation (Proffit, Fields, and Sarver 2013).

Variability in growth can arise due to different factors, including normal variation, outside influences such as illness, and from effects of timing. Timing is another important concept that can be linked to variability and growth. Variations in timing occur due to the differences in an individual’s biological clock, which will influence when certain physical, biological and developmental events occur. Timing variations can be an important contributor to variability (Proffit, Fields, and Sarver 2013).

Adolescence, which is associated with reaching sexual maturation, is a clear instance of when variations in growth and development occur due to timing. For example, growth effects due to timing variation can be clearly measured in female adolescents who have reached sexual maturity as indicated by the start of menstruation, which is linked with a rapid increase in growth. Females that mature earlier reach their growth peak at a younger age when compared with later maturing females (Thompson 1971).

In addition to chronologically measuring age, age can also be measured by determining which developmental stage has been reached. In order to reduce timing variability, developmental age should be used to determine the growth status of an individual (Thompson 1971).

A growth chart can be used to reveal similar patterns of growth when plotted using stages of sexual development (biological time scale) instead of a chronological time scale. Using a biological time scale can show that growth patterns are often expressed at different times chronologically, but not at different times physiologically. This reduces timing variability, and therefore, is a useful method in evaluating an adolescents growth status (Thompson 1971).

1.2 Methods for predicting and measuring physical growth

Different diagnostic methods can be used to predict physical growth, including using measurement approaches (i.e. craniometry, anthropometry, cephalometry); or the use of experimental procedures, i.e. vital staining, implant markers, comparative anatomy, natural markers) (Farkas 1994). There are multiple theories of craniofacial growth, which differ according to genetic control, cartilaginous, osseous, or extraskeletal growth (Petrovic 1974).

1.2.1 Cephalometric radiology

Cephalometric radiology is essential in the study of growth, and is used in the clinical evaluation and treatment planning of orthodontic patients. The technique is a standardized and reproducible form of skull radiography, used to assess the relationships of the teeth to the jaws and the jaws to the rest of the facial skeleton. The technique involves the precise orientation of the patients' head with control of magnification and allows direct measurements of bony skeletal dimensions. Measurements used in growth studies, or to monitor treatment progress, can be taken by superimposing a tracing of a later cephalogram over an earlier one and measuring differences (Proffit, Fields, and Sarver 2013).

Cephalometric radiology is commonly used by orthodontists to assess the morphology of the mandible, aiding in diagnosis and treatment planning. This assessment is important as the mandible is primarily responsible for the facial appearance, as mandibular growth patterns impact facial development. Additionally, mandibular shape and symphyseal characteristics are thought to reveal skeletal growth patterns (Gutermann et al. 2014).

1.3 Genetic Influences on Growth

Advances in molecular genetics and understanding of the human genome have revealed genes that are involved in controlling growth, including a large number of genes that are essential for craniofacial bone development. For example, the Homebox MSx genes, which determine the morphology of the skeleton, including normal craniofacial development (Berdal et al. 2009).

1.4 Skeletal growth and development

At a cellular level there are only three ways in which growth can occur: (1) hypertrophy which refers to an increase in the size of the individual cells; (2) hyperplasia referring to an increase in the number of the cells; and (3) the secretion of extracellular material, which contributes to an increase in size independent of the number or size of the cells (Thompson 1971). Growth of soft tissue is characterized by a combination of hyperplasia and hypertrophy, leading to interstitial growth. Interstitial growth will not occur in hard tissues (Proffit, Fields, and Sarver 2013).

Skeletal growth is dependent on all three mechanisms, but the secretion of extracellular material is especially important as this will later mineralize into calcified tissues that make up bones, teeth and cartilage. Ossification is the term used to indicate the process of bone formation. There are two types of ossification: intramembranous and endochondral (Proffit, Fields, and Sarver 2013).

1.4.1 Intramembranous and Endochondral ossification

Intramembranous ossification occurs when connective tissue membranes are replaced with bony tissue. The direct addition of new bone to existing bone is driven by the activity of cells in the periosteum, which is the soft tissue membrane covering bone. The bone is formed by the secretion of bone matrix within connective tissues without the formation of cartilage (Enlow 1996). This process is called direct or surface apposition of bone. The bones of the face, cranial bones, and the clavicles are formed by intramembranous ossification (Thompson 1971).

Most bones develop through the process of endochondral ossification, in which cartilage is replaced by bone to form the growing skeleton (Thompson 1971). This occurs as islands of bone emerge in cartilaginous centers of ossification. The cartilage will continue to grow but will be quickly replaced by bone (Thompson 1971).

1.5 Sites and types of Growth in the craniofacial complex

1.5.1 Cranial Base

The cranial base synchondroses are important growth centers of the craniofacial skeleton. Synchondroses grow via endochondral ossification with an area of cellular hyperplasia in the center, with bands of maturing cartilage cells extending away from the center, which will be converted into bone (Proffit, Fields, and Sarver 2013).

1.5.2 Maxilla (Nasomaxillary Complex)

The maxilla grows by intramembranous ossification. Growth occurs in two ways:

1. At the sutures, there is apposition of bone that connects the maxilla to the cranial base (Thompson 1971).
2. Surface remodelling also occurs. Growth at the cranial base which pushes the surface changes in the maxilla down and forward (Thompson 1971).

1.5.3 Mandible

The mandible is a bone of mixed ossification and grows via endochondral and intramembranous ossification. The body of the mandible grows longer by apposition of bone on its posterior surface and resorption on the anterior surface. The height of the mandible increases as the ramus grows via endochondral replacement at the condyle, accompanied by surface remodelling. The mandible translates downward and forward by growing upwards and backwards (Enlow 1996).

Endochondral replacement occurs at the mandibular condyle, which is covered in cartilage at the temporomandibular joint (TMJ). The rest of the mandible grows via surface apposition and remodelling (Purcell et al. 2009).

1.6 Adolescence and later stages of development

Adolescence is a transitional phase of life occurring between childhood and adulthood, during which rapid physical and psychological changes occur, resulting in sexual maturity. These changes are associated with the maturation of the sex organs, this allows for sexual reproduction, increase in height, weight and muscle mass, and the increase in secretion of sex hormones (Enlow 1996).

This stage of human development is of huge importance to orthodontists, as the majority of treatment is directed toward pre-adolescent and adolescent patients who are undergoing significant changes in their dentofacial structure. These changes include an increase in facial growth, differential growth of the jaws and the transition from mixed to permanent dentition (Enlow 1996). Predicting changes to the dentofacial structure can be complex, as each individual has a unique growth pattern influenced by their internal genetic make-up, as well as influences due to external environmental factors.

1.6.1 Timing of puberty

Females usually reach adolescence earlier than males, with a mean difference of two years for the onset of a pubertal growth spurt. Males reach maturation later but have a larger growth velocity peak than females. Girls also cease growing after early sexual maturation, leading to further differences in height between the adult sexes. The difference is due to the fact that individuals who mature later have already experienced a slow and steady level of growth before the growth spurt occurs. The epiphyseal plates have also been shown to close more slowly in males than females (Thompson 1971). Clinically, these differences suggest the need to start orthodontic treatment earlier in females, in order to take advantage of the adolescent growth spurt if required (Proffit, Fields, and Sarver 2013).

Individual variations in the timing of puberty and maturation mean that chronologic age is not a valid parameter to estimate skeletal maturity and can only be used as a imprecise guide of where an individual is developmentally. In addition to chronological age, secondary sexual traits should also be used for a more accurate prediction of the pubertal growth spurt (Thompson 1971). The timing of pubertal growth and sexual maturation can also be influenced by a variety of genetic and environmental factors. The timing and extent of mandibular growth spurts also vary with the differential timing of puberty. Significant differences are reported during the late stages of pubertal growth, with the mandible growing more than the maxilla (Enlow 1996).

1.6.2 Timing of Growth in Width, Length and Height

There is a strict sequence in which growth is completed in the maxilla and mandible. Firstly, growth in width, followed by growth in length and finally vertical growth (Thompson 1971). The vertical height of the face grows for a longer time period, compared to the growth in length,

Vertical growth occurs developmentally later, mainly in the mandible. Growth in facial height and eruption of teeth decline once an individual reaches adulthood (Proffit, Fields, and Sarver 2013).

Studies have demonstrated that alveolar growth occurs throughout life, even in the 4th and 5th decades of life (Arat and Rubenduz 2005). Large increases in alveolar heights occur between 25-45 years of age, with the greatest increase seen in maxillary anterior alveolar heights. These late stages of growth are adaptive rather than developmental (Arat and Rubenduz 2005); therefore, they are not assessed for orthodontic treatment.

1.7 Rotation of Jaws during growth

Professor Bjork, at the University of Copenhagen, developed an innovative experiment where inert pins were placed in the bones and the jaws (Bjork and Skieller 1983). These pins could be seen on a cephalogram and were well tolerated. This technique was revolutionary in helping the orthodontic field increase the accuracy of a longitudinal cephalometric analysis of growth patterns. It brought to light the remodelling changes of the jawbones, of which the rotational pattern was not properly understood (Bjork, Skieller 1983). The orientation change of the mandible and maxilla, measured by the palatal and mandibular planes, results from a combination of the internal and external growth rotation.

1.7.1 Components of mandibular rotation

In order to understand fully mandibular growth rotation, the process be divided into three different compartments: total rotation, intramatrix rotation and matrix rotation. These occur throughout the growth period and demonstrate a changing inter-relationship specific to each individual person (Bjork and Skieller 1983).

1. Total rotation: is the sum of the external and internal rotation. It is measured as inclination changes in the mandibular corpus relative to the anterior cranial base (Bjork and Skieller 1983).

2. Intramatrix rotation (internal): is the rotational change within the mandible. It is a change of the remodelling that occurs at the lower border of the mandible. This rotation is defined by the change in the inclination of the mandibular corpus relative to the tangential mandibular line. The centre of internal rotation is located in the corpus and not at the condyles (Bjork and Skieller 1983).

3. Matrix rotation (external): is rotational change of the mandible relative to the anterior cranial base. It is recorded from the angle of the tangential mandibular plane relative to the nasion-sella line. The external rotation can be forwards or backwards in the same individual during the growth period, with the condyles as the centre of rotation (Bjork and Skieller 1983).

In order to visualize the internal and external rotation of the jaws, the mandible should be studied first. It has been reported that in the majority of individuals, the core of the mandible can rotate during growth, this can decrease the mandibular plane angle (i.e. up anteriorly and down posteriorly). This occurs either by external rotation, which is a rotation around the condyle or by internal rotation, which is rotation centred within the body of the mandible. If there is more growth posteriorly than anteriorly, the rotation of the jaw is considered ‘forward’ and given a negative sign. When anterior dimensions are lengthened more, there is a ‘backward’ rotation and is given a positive direction (Bjork and Skieller 1983).

Bjork and Skieller described a forward rotation of the mandible as:

1. Downward movement of the lower border of the mandible
2. Apposition at the ventral aspects of the symphysis and body of the mandible
3. Resorption at the lower border in the gonial angle
4. Bone apposition at the posterior surface of the symphysis
5. Forward condylar growth (posterior border of the ramus)
6. Resorption at the anterior border and apposition at the lower part of the posterior border of the ramus
7. Proclination of the lower incisors

Backward rotation of the mandible is described as:

1. Resorption at the lower surface of the symphysis
2. Apposition below the gonial angle, at the posterior border of the ramus and the neck of the condylar process
3. Slender symphysis with considerable height
4. Soft tissue double chin
5. Acute interincisal angle (IMA) and retroclined lower incisors

Growth of the posterior facial height and the anterior facial height usually are synchronous. If there is a discrepancy between the relative growth of the anterior and posterior facial height, it results in a rotation of the mandible.

The eruption of the teeth and compensatory growth of the alveolar processes adapt to the height of the intermaxillary space. In most growing children, their occlusion is established and maintained during growth. When the anterior face height is significantly increased, vertical dentoalveolar compensation may be inadequate, resulting in the development of a skeletal anterior open bite (Houston 1988).

Vertical facial proportions are strongly linked to the rotations of the jaw (Bjork and Skieller 1983). In individuals with normal facial proportions, there is a 15-degree internal rotation from age 4 to adulthood. In this subset, approximately 25% of growth occurs from the external rotation of the condyle, and 75% results from the internal rotation within the body of the mandible. The mandibular plane angle representing total rotation decreases just 2-4 degrees. The external rotation tends to compensate, and that is why these changes are not seen clinically over time. The posterior section of the lower border of the mandible is an area of resorption, while the anterior part of the lower border is an area of minor apposition (Houston 1988).

Implants were also positioned above the maxillary alveolar processes to assess changes. A core of the maxilla that undergoes a small variable degree of rotation was also observed. This internal rotation is similar to the rotation seen within the body of the mandible (Bjork and Skieller 1983). For most individuals, the external rotation is opposite in direction and equal in magnitude to the internal rotation. This means that the two rotations cancel each other out, so the total change in jaw orientation when evaluated by the palatal plane is zero (Bjork and Skieller 1983). Variations from the normal pattern of rotation occur regularly. The occurrence of larger or smaller degrees of internal and external rotation can change the amount to which the external rotation compensates for the internal rotation. This means that there can be large differences in the rotational patterns of growth between the short and long facial types of vertical development (Bjork and Skieller 1983).

Short facial type individuals are characterized by short anterior lower face height. During growth, short face individuals have an excessive forward rotation of the mandible, and this is due to an increase in the normal internal rotation and a decrease in external compensation. This type of rotation is characterized by a horizontal palatal plane, low mandibular plane angle and a large gonial angle. There is usually a deep bite malocclusion with crowded incisors (Bjork and Skieller 1983).

In vertical long-faced individuals, patients have an excessive lower anterior face height, and the palatal plane rotates down posteriorly. The mandible shows a backward rotation, with an increase in the mandibular plane angle. The mandibular changes are due to a lack of normal forward internal rotation. The more prominent external rotation centred at the condyle is associated with anterior open bite malocclusion and mandibular deficiency (Bjork and Skieller 1983).

1.7.2 Interaction between Jaw rotation and tooth eruption

Divergent growth of the mandible away from the maxilla creates space into which teeth can emerge, with the level of rotational jaw growth influencing the level of tooth eruption. Rotational jaw growth can influence the direction of eruption and the anteroposterior position of the lower incisors.

In normal growth, the maxillary teeth erupt downward and forward. The maxilla rotates a few degrees forward and frequently rotates slightly downward. Forward rotation can tip the incisors forward, which can increase proclination. Individuals with vertical growth pattern (backward rotation), the teeth are directed posteriorly, causing them to become more upright (Bjork and Skieller 1983).

Internal rotation alters incisor eruption, which can upright them. As the incisors are uprighted, the molars migrate mesially during growth, more than the incisors, and this migration is reflected in the decrease in arch length that normally occurs (Houston 1988).

A study by Arat et al. indicated that vertical growth varied according to pubertal growth periods (Arat et al. 2001). Further clinical studies have also shown that the response of alveolar structures to orthodontic treatment can change depending on the growth period (Arat et al. 2001).

1.8 Vertical Skeletal Growth Patterns

Vertical facial form is a critical element of orthodontic assessment and treatment planning. Large variations in vertical dimension are observed in the population and must be taken into consideration for effective orthodontic treatment (Nanda 1988).

High angle malocclusion is characterized by an increased inclination of the mandible in relation to anterior cranial base, with individuals exhibiting a mandibular plane angle greater than 37 degrees (Betzenberger, Ruf, and Pancherz 1999, Riedel 1952). High angle malocclusion can present as hyperdivergency, long-faced syndrome, and adenoid face syndrome.

Dental compensation masks anterior-posterior and vertical basal bone inconsistencies in order to create a normal incisor relationship (Molina-Berlanga et al. 2013). In the vertical dimension, the compensation is established by changing the symphysis length and by incisor eruption (Krieger et al. 2012).

Dentolaveolar compensation has two main components in the vertical dimension. The first is the vertical development of the basal and dentoalveolar heights, and the second concerns incisor inclination (Duncan et al. 2016).

Studies showed that dentoalveolar compensation, in which the teeth and alveolar processes adapt to differing jaw-base relationships and maintain a functional occlusion, despite the increased divergence of the jaw bases. Therefore, the alveolar structure hides skeletal differences between the jaws (Arat and Rubenduz 2005, Schendel et al. 1976).

Schendel asserted that in adult patients, open bite and deep bite fall under long face syndrome (Schendel et al. 1976). Solow attributed this to a process of dentoalveolar compensation, with the teeth and alveolar processes adapting to differing jaw base relationships and maintaining a functional occlusion, despite the increased divergence of the jaw bases (Solow 1980).

The differences between open bite and deep bite are due to both discrepancies in dental morphology and the underlying skeletal pattern. Long faces can present with an open bite, a normal overbite or a deep bite; however, normal overbite or an open bite can also occur in individuals with a normal face height (Schendel et al. 1976). According to Kuitert, lower face height and overbite are not linked (Kuitert et al. 2006).

The sequence of vertical facial development is established in the mixed dentition (Nanda 1988). In a growing individual, differential eruption can hide vertical skeletal dysplasia. Maxillary molars are described as primary “bite openers” and mandibular incisors, the primary “bite closers” (Schudy 1968). Directing dentoalveolar growth is the standard treatment for managing skeletal deviations(Arat and Rubenduz 2005).

Posterior dental heights are primarily responsible for establishing the pattern of facial morphology, while anterior dental heights are associated with determining overbite (Huang 2002). For successful treatment, orthodontists must consider factors beyond overbite, as dentoalveolar compensation may have also taken place (Schudy 1968).

Hyperdivergent profiles can be more difficult to treat due to the extrusive nature of the treatment mechanics, high relapse rate and thin labial and lingual cortical plates (Nanda 1988). Lower anterior dental height and inclination showed significant associations with skeletal variables and likely compensated for differing vertical skeletal relationships(Nanda 1988).

The mandibular plane angle (MPA) demonstrated a negative relationship with L1-MP and a positive relationship with lower anterior mandibular height. Hence, as the vertical skeletal relationship increases, the lower incisors compensate by retroclining and by extruding. Therefore, the inclination for open bite is reduced (Anwar and Fida 2009). Lower anterior mandibular height and lower incisor inclination can compensate for vertical skeletal dysplasias (Anwar and Fida 2009).

Anwar reported that in high angle class I cases, there is a backward internal rotation. This is due to remodelling of the ramus and apposition along the posterior border, which includes the condylar process. Resorption occurs on the anterior Ramus. Lower molar eruption is impeded by this abnormal growth, which results in insufficient uprighting of the teeth to compensate for the internal rotation. Furthermore, there is a compensatory increased eruption of the lower incisors, and they become increasingly retroclined (Anwar and Fida 2009).

1.9 Symphysis Morphology

Multiple studies have been conducted to determine if symphyseal morphology has information on the growth pattern of the mandible (Gutermann et al. 2014). Bjork observed that with a backward rotation of the mandible, the anterior section of the symphysis is flattened (Bjork and Skieller 1983). In the anterior rotation, the frontal border gains prominence due to the rotation of the symphysis. Another study supported these findings by showing that symphysis morphology, mostly the ratio of height to width, can indicate the direction of mandibular growth (Aki et al. 1994). Individuals with shorter and wider symphyses demonstrated increased anterior mandibular growth when compared to individuals with longer and narrower symphyses (Aki et al. 1994).

Similarly, Molina-Berlanga evaluated the lower incisors’ compensations in Class I and Class III skeletal malocclusions, with different vertical facial patterns in adult patients (Molina-Berlanga et al. 2013). It was observed that in Class I and Class III cases, the increase in the mandibular plane angle involved a decrease in lower incisor angulation and an increase in lower incisor height. The mandibular symphysis elongates, which uprights the lower incisor. In a later study, Handelman et al., reported the same results (Handelman 1996).

Guntermann showed that a pronounced divergence of the jaws are related to retroclined lower incisors (Gutermann et al. 2014). This observed correlation is more pronounced in males compared to females, with great prominence in late childhood. The link between the patients incisor inclination and skeletal pattern should be respected during orthodontic treatment

(Gutermann et al. 2014). It is of interest to evaluate whether the angulation of the lower incisors could be linked to a certain symphyseal morphology or skeletal pattern in non-extraction cases in growing patients.

1.10 Invisalign®

The concept of aligning teeth using clear orthodontic appliances was first envisioned by Kesling in 1945 (Kesling 1945). But it was not until 1998 that these appliances could be used on a larger scale. This was the year that Align Technology first received FDA clearance to market the Invisalign® system.

Invisalign® involves the use of scans that are converted through the use of stereolithographic technology (.stl) into a digital model. The stl files can be read using proprietary software called ClinCheck®, which can be used to track the progress of a patient's treatment plan and assess predicted treatment outcomes. This technology works by visualising a three- dimensional (3D) virtual model of a patient's teeth. The software can predict individual tooth movement throughout treatment by calculating the maximum movement per each stage of treatment at the occlusal tip and root. The orthodontist uses ClinCheck® to review, modify and approve the treatment plan. A series of stereolithographic model are created for each stage of treatment using CAD/CAM laboratory techniques and 3D printing (Phan and Ling 2007, Tai 2018).

These plaster models can be used to form clear aligners made from polyurethane, which are designed to move teeth at a maximum velocity of .025mm, over a period of 1 to 2 weeks (Kravitz et al. 2009). The patient's compliance is imperative for successful treatment, as the appliance must be worn for a minimum of 22 hours per day to work effectively (Malik, McMullin, and Waring 2013).

Virtual 3D scanning can greatly improve orthodontist's treatment ability. Virtual models can be created before, and after treatment, which allows the proper assessment of treatment outcomes (Erten and Yılmaz 2018). Accurate 3D scans of the teeth are created using the iTero® digital confocal laser scanner and imaging system. A series of digital 3D models are created by capturing the intraoral coronal portion of the dentition (Erten and Yılmaz 2018).

1.11 Aesthetic Orthodontic Appliances

In today's society, there is an increasing demand for treatments that improve aesthetics and increase self-confidence (Lee 2011). This is reflected in the demand for Invisalign®, which is available in 103 countries and used to treat 5.8 million patients worldwide, including 1.3 million teens (Align Technology Inc 2018). Align Technology® also stated that there are now more than 136,000 Invisalign® trained general practitioners and orthodontists globally. Invisalign® is commonly known as a 'braces-free' orthodontic treatment and has been an alternative to conventional fixed multibracket appliances in treating minor to complex malocclusions for nearly two decades (Boyd 2007).

A study showed that increased patient demand for Invisalign® was due to improved aesthetics when compared to fixed appliances, with 87% of patients getting Invisalign® for anterior crowding (Meier, Wiemer, and Miethke 2003). Another study found that Invisalign® was seen as more attractive and aesthetically pleasing when compared with conventional braces (Fogel and Janani 2010). This was important for individuals that prefer an aesthetic appliance, which will not impact their appearance (Fogel and Janani 2010).

1.12 Treatment Modalities for the resolution of crowding

Crowding is one of the most common problems seen in orthodontic treatment (Weinberg and Sadowsky 1996). Crowding is a result of an excess in total mesio-distal tooth width compared to available arch length and often results in overlapping and rotation of the teeth (Weinberg and Sadowsky 1996).

The space for correcting crowding can be resolved by:

1. Buccal arch expansion
2. Anterior teeth proclination
3. Interproximal enamel reduction
4. Extraction of permanent teeth
5. Distalization of buccal segment teeth

A study by Wax et al. examined the efficacy of using Invisalign® to eliminate crowding in a group of Invisalign® patients and found a 91.4% decrease in mandibular crowding (Wax, Beck, and Firestone 2010). A study by Krieger et al. that examined Invisalign® treatment results showed that 48% of maxillary crowding was resolved by implementing interproximal reduction, whilst 58% of the subjects had their mandibular crowding resolved by interproximal reduction and incisor protrusion (Krieger et al. 2012). However, incisor proclination (long axis angulation of the incisor) was not examined in this study. Incisor proclination is measured on a lateral cephalometric radiograph and is an accepted treatment method when correcting anterior crowding (Krieger et al. 2012).

In a non-extraction based treatment, buccal arch expansion, interproximal reduction of enamel and incisor proclination and protrusion, can be used as methods to alleviate crowding (Meier, Wiemer, and Miethke 2003).

1.13 Buccal arch expansion

Buccal arch expansion can increase the transverse dimension of a dental arch, which also increases in arch length (Kravitz et al. 2009). Ricketts developed guidelines to predict an increase in arch length due to an increase in the transverse dimension (Ricketts et al. 1982). These guidelines suggest that incisor protrusion of 1mm will increase the arch length by 2mm, 1mm of intercanine width increase will increase the arch length by 1mm, and 1mm of intermolar width increase will increase the arch length by 0.25mm (Ricketts et al. 1982).

A study by Germane et al. used a mathematical model to determine that when the transverse dimension increased by 1mm increments, there is a related increase in arch length (Germane et al. 1991). Additionally, incisor advancement proclination is described to be up to 4 times more effective at increasing arch length, when compared to molar expansion (Germane et al. 1991). These results confirmed Ricketts earlier observations that arch length is increased further by incisor proclination (Germane et al. 1991).

1.14 Interproximal reduction

Interproximal reduction is an effective method to treat tooth mass discrepancies (Ballard 1944). This method aids in correcting tooth crowding by filing between the teeth to remove surface enamel in order to reduce tooth mass. This leads to an increase in space in the dental arch (Koretsi, Chatzigianni, and Sidiropoulou 2014). Interproximal reduction can reduce the need to use tooth extractions and can reduce relapse following treatment, by broadening contact points and maintaining inter-canine width (Aasen and Espeland 2005). To implement this method, orthodontists can use diamond strips, diamond polishing discs or air-rotor stripping (Jarjoura, Gagnon, and Nieberg 2006). A study by Sheridan et al., reported that proximal enamel can be reduced by 50% without causing dental and periodontal risks, with further studies supporting the use of interproximal reduction to reduce crowding, without long term damage (Sheridan 1985).

Studies have found that 2.5mm can be potentially removed from the five anterior contacts and 6.4mm from the eight buccal contacts per arch (Sheridan 1985). A study examining enamel thickness of posterior teeth found that due to increased enamel thickness, 50% of molar enamel can be removed using interproximal reduction. By additionally removing 0.25mm from the buccal and anterior teeth, there is the comprehensive potential to provide 9.8mm of additional space (Stroud, English, and Buschang 1998). Following the latest guidelines, 1mm (0.5 mm per proximal surface), can be removed from the contact points of the posterior teeth, while stripping of the lower incisors should not go beyond 0.75 mm at each contact point (Chudasama and Sheridan 2007). This is due to the thinner proximal walls (Chudasama and Sheridan 2007).

Due to variations in proximal enamel thickness in tooth categories and ethnic groups, the orthodontist should customize enamel surface preparation according to the individual characteristics. Orthodontists must practice caution, as there can be a significant variation in predicted versus actual enamel removal, frequently with less enamel removed than anticipated (Johner et al. 2013).

It has been shown by Scanning Electron Microscopic (SEM) that stripping methods such as interproximal reduction alters enamel morphology by producing rougher surfaces. Studies, including a 10 year post-treatment study, showed that despite morphological differences between teeth subjected to enamel reduction and control teeth, there was no increase in the incidence of caries, assuming the subject practices good oral hygiene (Koretsi, Chatzigianni, and Sidiropoulou 2014).

The use of topical fluoride products is recommended following interproximal reduction. However, research examining patients 6 years post-treatment concluded that the application of topical fluoride products in individuals, regularly exposed to fluoridated drinking water and toothpaste, may not provide any further benefit (Jarjoura, Gagnon, and Nieberg 2006).

1.15 Incisor angulation of position

Lower incisor position is of major importance in orthodontic treatment planning, as it impacts periodontal health, long term stability, aesthetics and the space available for tooth alignment (Schulhof et al. 1977). Incisor proclination can be used as a method to align teeth in non-extraction cases, with excessive overjet and mandibular crowding (Melsen and Allais 2005). Some studies have observed that excessive protrusion/proclination of the lower incisors during orthodontic treatment can cause gingival recession. This is due to the thin plate of alveolar bone located in the mandibular symphyseal area. However, Melsen and Allais found that gingival recession of mandibular incisors did not significantly increase during orthodontic treatment (Melsen and Allais 2005). To decrease the risk of gingival recession, orthodontists must be aware of both dental and gingival health, as well as the force used to procline the incisors during treatment (Melsen and Allais 2005).

A study analyzed more than 800 sets of patient records to look at stability and relapse of mandibular anterior alignment. In this long term study, Little (1999) examined treated vs untreated subjects, which demonstrated a decrease in arch length and width, as time increased (Little 1999). He found that the anterior teeth relapse due to lower incisor uprighting and decreased arch width, with no retention over time (Little 1999). Another retrospective study showed that following 10 years retention, relapse occurred in mandibular incisor angulation, with an average retroclination of 4.2 degrees in horizontal cases (Pollard et al. 2012).

1.16 Measurement of Lower incisor Position

Cephalometric analysis has become an indispensable tool for describing craniofacial morphology and analysis of incisor position. Early pioneers of cephalometric analyses include Ricketts, Steiner, Tweed and Downs (Ricketts 1981, Steiner 1953, Tweed 1953, Downs 1948), with their analysis still being implemented today. Cephalometric analyses are created using linear or angular measurements of distances between different landmarks, which can be calculated using millimetres or degrees (Roden-Johnson, English, and Gallerano 2008).

Multiple cephalometric variables are used together to quantify the lower incisor position and angulation.

These include:
Lower Incisor to A-Pogonion (mm)
Lower Incisor to A –Pogonion (degrees)
Lower Incisor to NB (mm)
Lower Incisor NB (degrees)
Lower incisor to MPA (degrees)

The incisor mandibular plane angle is created by the angle between the long axis of the lower central incisor and the mandibular plane. The incisor mandibular plane angle can be altered during treatment and must be considered in the diagnosis and treatment planning of each patient (Margolis 1943). This measurement is popular today and is still commonly used in cephalometric analysis (Ricketts 1981).

Mandibular incisor position relative to basal bone has been the subject of multiple orthodontic studies, starting with Brodie in 1941, Tweed in 1941, Margolis in 1943, and Spiedel in 1944 (Corlett 1947). Charles Tweed was an early supporter of using extraction during orthodontic treatment for an aesthetic facial profile and improved long term stability. Tweed believed that that uprighting and retraction into extraction spaces improved the position of the lower incisor in the medullary bone of the mandible, and maintained the inter-canine width, leading to better treatment results (Tweed 1969). Tweed highlighted the need to ensure stable anchorage to prevent proclination and protrusion of the lower incisors during orthodontic treatment (Tweed 1969).

Following further analyses, Tweed recommended that the lower incisor should be at 90 degrees to the mandibular plane, with only 5 degrees in variation (Tweed 1941). Tweed's hypothesis was further supported by research conducted by Speidel and Stoner (Spiedel and Stoner 1944), which looked at lower incisor position in relation to the lower mandible border. These studies recorded better treatment results, both in terms of aesthetics and stability, when the lower incisor is at 90 degrees and upright in basal bone (Spiedel and Stoner 1944).

Studies by Tweed and Margolis established the importance of the relation between the inclination of the lower incisor and the mandibular plane (Tweed 1941, Margolis 1943). Small variations can exist in the normal values for the mean in the lower incisor inclination to mandibular plane, this is due to the non-conformity of cephalometric landmarks depending on the different analyses (Tweed 1941, Margolis 1943).

Steiner determined that the value in measuring lower incisor angulation to mandibular plane is compromised, as different facial types will vary in mandibular plane angle (Steiner 1953). Steiner stated, “ The angulation of the lower incisor to such a line is much an appraisal of the length of the ramus as it is of the forward and backward inclination of the lower incisor” (Steiner 1953). Tweed developed the diagnostic facial triangle as a guide in determining the normal mesiodistal position of the teeth and to adjust for discrepancies in mandibular plane angle by using angular measurements(Tweed 1953). The planes used in the ‘Tweed triangle’ were Frankfort horizontal plane, Mandibular plane, and long axis of lower incisor (Tweed 1953).

A study by Down (1948) found that the mean value for the lower incisor as 91.4 degrees, with a range of 83-89 degrees (Downs 1948). This result contradicted Tweed's earlier findings of 90 degrees, with a range of 5 degrees (Downs 1948). These results could be attributed to differences in landmarks to construct mandibular plane angle(Downs 1948).

Steiner used 2 methods to measure the position of the lower incisor (Steiner 1953). Line NB is used as an angular measurement for the relationship between the line and the long axis of the mandibular incisor (Steiner 1953). The mean value is 25 degrees with a variation of 4 degrees. A linear measurement using a distance between the most labial on the lower incisor crown to the NB line. The measurement should be 4mm, with a variation of 2mm (Steiner 1953).

Ricketts promoted the use of A point to pogonion (APog) for locating the position of the mandibular incisor (Ricketts 1960). His research assessed the lower incisor position to the APog plane in thousands of his own orthodontic cases. The angular measurement is the long axis of the lower incisor to the APog plane, which equals 21 degrees, with a standard variation of 6.4 degrees (Ricketts 1960). The distance from the APog plane to the labial surface of the mandibular incisor is 0.5mm, with a standard variation of 2.7mm (Ricketts 1960).

1.17 Digital radiography and cephalometric landmark identification

Current literature reports high correlation and sensitivity when comparing hand traced cephalometric films to digital cephalometric images (Mclure et al. 2005, Erkan et al. 2011). Sayinsu et al. first demonstrated a high correlation of validity and reproducibility of digital radiographs using in the Dolphin Imaging Software, compared to conventional hand tracing methods (Sayinsu et al. 2007). Playfair later reported no difference in reliability between digital tracing using software (Dolphin® and Kodak®) and hand-based analysis (Playfair 2013). Therefore, the use of digital cephalometric imaging is a proven method and will be used in this study.

Baumind and Frantz (1971) examined the reliability of using cephalometric analysis and classified two sources of measurement error: (1) Errors of projection (2) Errors of identification (Baumrind and Frantz 1971). Errors of projection occur as the image is a two-dimensional image of a three-dimensional structure. Errors of projection occur due to the two-dimensional (2D) head film, which causes a shadow of the three-dimensional (3D) object (Baumrind and Frantz 1971). This error can be reduced by using a standardized method for reproducible head positioning of the patient. The X-ray beams are non-parallel and are generated from a small x-ray source, leading to radiographs that are imperfect (Baumrind and Frantz 1971).

“Errors of identification” occur due to errors in the identification of specific landmarks on the head films (Baumrind and Frantz 1971). This is considered to be the major source of cephalometric error by many orthodontists and can be caused by multiple factors, including improper head position affecting the landmark definition, poor image quality, or clinical experience (Baumrind and Frantz 1971). Good clinical judgement is also imperative to allow a comprehensive diagnosis. The benefits of digital radiography over conventional films include the ability to alter the image quality, which can enhance cephalometric landmark identification (Oshagh, Shahidi, and Danaei 2013). Archiving and transmission are additional benefits (Sayinsu et al. 2007).

1.18 Text Comparing to the Burlington Growth Study

Orthodontists need to be aware of the variances in facial traits and dentofacial patterns that arise in different ethnicities (Thilander 2009). Numerous studies have been conducted to determine ‘normal’ values in incisor position, which can be used to assist treatment planning. Dr. Robert Moyers started the Burlington Growth study at the University of Toronto in 1952, which included the participation of 1258 children, 307 parents and 111 siblings(Thompson and Popovich 1977).

The subjects were all of Caucasian ethnicity and chosen at specific age points during growth, with records taken from 3 to 21 years (Thompson and Popovich 1977). During the study, multiple records were taken at each visit, including cephalometric radiographs. For growth analyses, the measurement criteria for each individual is based on reproducible measurement objectives with minimum errors (Thompson and Popovich 1977).

Through the use of a data bank, researchers can use the data from the study as a control for normal growth and compare the changes that occurred in their patients' cephalometric radiographs over the course of treatment (Thompson and Popovich 1977).

1.19 Tooth movement: Invisalign® vs Fixed conventional appliances

With the increase in individuals seeking orthodontic treatment using clear aligners, appliance efficacy is of key importance. Align Technology reported that 20-30% of their cases require mid-course correction or refinement (Sheridan 2004). However, some orthodontists have reported 70-80% of their cases needed refinement, mid-course correction or switch to a fixed appliance (Kravitz et al. 2009). This can lead to extended treatment time for the patient and an increase in material costs for the orthodontist. These errors may be due to poor patient compliance or limited adherence to protocol (Kravitz et al. 2009).

Lagravere and Flores-Mir (2005) published a systematic literature review to evaluate the treatment outcomes achieved with Invisalign® (Lagravere and Flores-Mir 2005). This revealed no scientific evidence for the efficacy, treatment effects, or limitations of using Invisalign® (Lagravere and Flores-Mir 2005). Djeu conducted the first cohort study comparing conventional fixed appliances to Invisalign® treatment, using the American Board of orthodontics grading system (Djeu, Shelton, and Maganzini 2005). The study found that Invisalign® did not treat malocclusions as efficiently as full fixed appliances, especially for large discrepancies (Djeu, Shelton, and Maganzini 2005).

Kravitz et al. examined the ability to accurately predict anterior tooth movement by comparing the ClinCheck® models with treatment results. The types of movement reviewed include the expansion, constriction, intrusion, extrusion, mesiodistal tip, rotation and labiolingual tip. The study found that the use of Invisalign® has a low mean accuracy of 41% (Kravitz, Kusnoto, Begole , Obrez , Agran 2009).

Duncan looked at the effect of lower incisor proclination in non-extraction cases, with different crowding in non-growing patients using Invisalign® (Duncan et al. 2016). This was a retrospective cephalometric chart review assessing the lower incisor changes with groups of different pre-treatment crowding (Duncan et al. 2016). The results showed that there was a significant increase in buccal expansion in each of the 3 groups. The Lower incisor position and angulation changes were significant in the severe crowding groups (Duncan et al. 2016). The conclusion was that Invisalign® treatment can successfully resolve mandibular arch crowding using a combination of buccal arch expansion, interproximal reduction and lower incisor proclination (Duncan et al. 2016).

To date, there have been no cephalometric studies conducted to determine the effects of Invisalign® Teen on growing patients and whether the lower incisor position will be affected by different skeletal growth patterns in non-extraction cases.

CHAPTER 2

Purpose and Null hypothesis

2.1 Purpose

The purpose of this study was to assess the effect of vertical growth pattern on the position of the mandibular incisors for non-extraction Invisalign Teen® patients, with or without interproximal reduction.

2.2 Null hypotheses

1. The lower incisor position does not change when growing patients are treated for crowding with Invisalign Teen® in a non-extraction approach with/without interproximal reduction.

2. There is no difference in the lower incisor position from Pre-treatment (T0) to Post-treatment (T1) between the different treated groups.

3. There is no difference in the lower incisor position between the sample group and the control group at T0 and T1.

CHAPTER 3

Materials and Methods

3.1 Ethics

Ethics approval was granted by the Health Research Ethics Board at the University of Manitoba (Bannatyne Campus) prior to the start of this study.

3.2 Sample Selection

3.2.1 Patient Consent

Consent was obtained from each patient in a section of their new patient form (Appendix 1).

3.2.1 Case Selection

The database of patients records from a single orthodontic practice in Winnipeg, Manitoba, was used to randomly select cases that met the inclusion criteria.

Inclusion criteria:

- Permanent dentition
- Growing patients (aged between 11-18 years)
- Arches treated without extraction
- Caucasian
- Skeletal class I
- Orthodontic treatment exclusively using Invisalign Teen®, aligners made of Smart Track® material
- Good compliance during treatment as assessed by the practitioner,

- Treatment protocol followed by the practitioner – aligners worn for one week.

Exclusion criteria:

- Extraction cases
- Surgical cases
- Temporary anchorage devices (TADs)
- Class II and III elastics
- Presence of a cleft lip or palate or any other syndromic orofacial malformations.

3.3 Sample Size

To calculate the sample size, the three variables to eliminate crowding are assessed. In the 4 different groups, the modality of interproximal reduction prescribed in the ClinCheck® had a mean of 30% reduction in the crowding. Of the remaining 70%, it was predicted that buccal arch expansion in the canine, premolar and molar regions would have had a mean reduction in crowding of 25%, leaving a mean value of 45% in lower incisor proclination for the resolution of crowding. This means, with this clinical prediction, we expected up to a 45% (0.45) change in the lower incisor position from the mild crowding to the moderate crowding group. When determining sample size with an effect of 0.45, the standard deviation was 1, power was 80%, and the paired t-test was carried out with a correlation of 0.5. This determined the appropriate sample size at +/- 65 cases of equal distribution amongst the 4 different groups of mild and moderate crowding.

The total sample was eventually 40. There were 26 females and 14 males.

3.4 Data Collection

The sample was taken from a private orthodontic practice, using a single practitioner in Winnipeg, Manitoba. Patients who had treatment completed and had a full set of records were randomly selected based upon the inclusion/exclusion criteria.

The records of each patient were de-identified by creating a unique identification number for each set.

Pre and Post-treatment records were collected for each of the 40 samples and consisted of:

1. Digital study models created by .stl files from iTero® scans (iTero® , software version 4.0, Cadent Inc., Carlstadt, USA)
2. Digital lateral cephalometric radiographs were taken with the Planmeca Proline CC digital radiographic machine (Planmeca Inc., Helsinki, Finland).
3. Digital study models of the dentition provided as .stl files provided from Align Technology (Align Technology, San Jose, CA)

The iTero® scans taken pre-treatment and post-treatment were uploaded as .stl files into OrthoCAD® (version 3.5.0; Cadent, Carlstadt, NJ). This software can calculate linear measurements. OrthoCAD® was used to measure arch width and perimeter as well as the tooth width measurements. Studies have shown that digital measurement software was more accurate and reproducible than using traditional plaster casts (Grunheid et al. 2014).

Pre and post-treatment digital lateral cephalometric radiographs were imported into Dolphin® 11.5 software for each treated patient and for the control groups from the Burlington Growth study (Dolphin Imaging and Management Systems, Chatsworth, CA, USA).

Interproximal reduction was recorded as it was prescribed on each patient's ClinCheck®.

3.5 Calibration

The interclass correlation coefficient test (ICC) was used for intra-rater and inter-rater reliability of the lateral cephalometric radiographs and iTero® 3D models. 20% of the sample group and the control group were randomly selected and were re-measured by an independent examiner. Ten pre and post-treatment lateral cephalometric radiographs and 3D models were re-measured for intra-rater and inter-rater at a second interval 2 weeks apart from the first measurements. Statistical software SPSS® Statistical Premium software (IBM Corp, Chicago, USA) was used to analyze the data. A paired t-test was used that calculated average changes. The p-value was considered to be significant at $p \leq 0.05$, with a confidence interval of 95%.

The lateral cephalometric radiographs at pre-treatment (T0) and post-treatment (T1) were matched with the same identification number as the iTero® scans Each of the T0 and T1 lateral cephalometric radiographs were traced by a single investigator using the Dolphin® software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA). Film magnification was standardized for each radiographic using the Dolphin® software to calibrate to a 30mm ruler included in each film.

3.6 Defining Different Groups

Cases were divided into 4 groups – based on the value of pre-treatment lower incisor crowding and value of patients' mandibular plane angle (MPA).

Each pre-treatment iTero® scan was uploaded into OrthoCAD® (version 3.5.0; Cadent, Carlstadt, NJ). The amount of mandibular crowding was measured using Carey's method (Carey 1949). The sum of the mesiodistal widths of each tooth from the second premolar to the second premolar was calculated. The sum of the total widths is then subtracted from the arch perimeter. The arch perimeter can be calculated by adding the sum of the two posterior and anterior segments (Proffit, Fields, and Sarver 2013). The anterior segment extends from the midline of the mandibular central incisors to the distal of the canine. The posterior segment extends from the distal of the canine to the mesial of the first molar, as shown in Figure 3.1 (Weinberg and Sadowsky 1996). The crowding is categorized into mild (0-3.9mm) and moderate (4-5.9mm) crowding with approximately equal distribution.

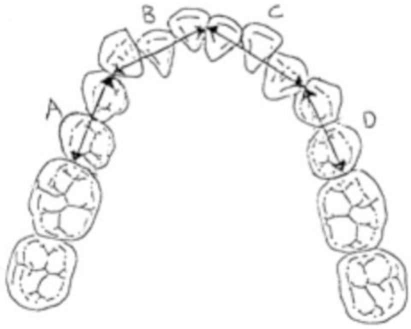

Figure 3.1 *Mandibular arch perimeter = A + B + C + D (Weinberg and Sadowsky 1996)*

The skeletal growth pattern for each sample was measured using the value of each patient's mandibular plane angle. Mandibular plane angle (MPA) was calculated. The mandibular plane is formed when the mandibular plane (Gonion-Gnathion) crosses the Sella-Nasion line. A parallel line is drawn to the mandibular plane that crosses the S-N plane on the radiograph to measure the Steiner mandibular plane angle.

Different Cephalometric analyses use different reference planes. Steiner uses the Sella-Nasion reference plane, but the Tweed and Down use the Frankfort plane (Porion- Orbitale) as a reference plane. The Frankfort plane intersects the mandibular plane line to form the Tweed mandibular plane angle. The normal value for Steiner mandibular plane angle is 32 +/- 2 degrees. A vertical growth pattern is present in individuals exhibiting a Steiner mandibular plane angle greater than 37 degrees (Riedel 1952). For the purpose of this study, a normal growth pattern was determined between the values of 30-37 degrees and >37 degrees was considered a vertical growth pattern. All subjects included were growing between the ages of 11-18 years old and in the permanent dentition. Bishara showed that arch perimeter decreases over time that can effect crowding (Bishara et al. 1998). There was a small mean treatment time between the four groups, ranging from 55 (+/- 21.1) weeks to 81.1(18.3) weeks. It was therefore assumed that the change in arch perimeter due to growth during this time is not statistically significant.

40 suitable cases were identified, and subjects were divided up into:

- 10 Normal growth/ Mild crowding
- 10 Vertical growth/ Mild crowding
- 10 Normal growth/ Moderate crowding
- 10 Vertical growth/ Moderate crowding

3.7 Cephalometric analysis

3.7.1 Image Quality

The lateral cephalometric radiographs that met the criteria were all of good diagnostic quality. In order to achieve this quality, the following assumptions were made

- Natural head position with Frankfort horizontal parallel to the floor.
- Correct exposure and dosage
- Correct orientation

Moorrees and Kean first established the idea of the ‘Natural Head Position’ to standardize the orientation of the head within the cepholostat and use extracranial reference lines (Moorrees and Kean 1958).

3.7.2 Digitized cephalometric radiography

The T0 and T1 lateral cephalometric radiographs were exported as JPEG (.jpg) files onto Dolphin® imaging software. Radiographic landmarks from Steiner and Ricketts cephalometric analysis that measure lower incisor angulation and position were completed. Identification was carried out by a single investigator to reduce errors.

3.8 Cephalometric Landmarks

Cephalometric landmark identification is an integral part of orthodontic diagnosis and treatment planning (Table 3.1 and Figure 3.2) (Ricketts et al. 1982). For the purpose of this study a modified analysis from Steiner and Ricketts was created to measure lower incisor position and angulation (Table 3.2 and Figure 3.3). Angular and linear measurements describing lower incisor position and angulation were used to show changes at T0 and T1(Ricketts et al. 1982).

Cephalometric Landmark Identified	**Definition**	**Reference**
Gonion (Go)	A point on the curvature of the angle of the mandible located by bisecting the angle formed by the lines tangent to the posterior ramus and inferior border of the mandible	(Jacobsen and Jacobsen 2006)
Nasion (N)	The most anterior point on the frontonasal suture in the midsagittal plane	(Jacobsen and Jacobsen 2006)
Pogonion (Pog)	The most anterior point of the chin	(Jacobsen and Jacobsen 2006)
Menton (Me)	The lowest point on the symphyseal shadow of the mandible seen on the cephalogram	(Malik, McMullin, and Waring 2013)
Sella (S)	Center of the pituitary fossa	(Jacobsen and Jacobsen 2006)
Incision inferius incisalis (Iii)	Incisal tip of the labial mandibular central incisor	(Basavaraj, Subhashchandra, and Phulari 2013)
Incision inferius apicalis (Iia)	The root apex of the most anterior mandibular central incisor	(Basavaraj, Subhashchandra, and Phulari 2013)

***Table 3.1** Description of cephalometric landmarks*

Measured Values	**Analysis**	**Definition**	**Reference**
L1 to NB (degrees)	Steiner	Acute angle formed by the intersection of the line Nasion-Point B and the line lower incisor apex-lower incisor edge	(Baumrind and Frantz 1971)
L1 to NB (mm)	Steiner	Distance in millimeters from the point lower incisor edge to the line nasion-B point, measured perpendicular to that line	(Baumrind and Frantz 1971)
L1 to MPA	Steiner Ricketts	Angle determined by the lower incisor edge, the intersection between the line lower incisor edge- lower incisor apex, and the line gonion-menton	(Baumrind and Frantz 1971)
L1 to APog (degrees)	Ricketts	Angle formed by the intersection of the line Point A-pogonion and the line lower incisor edge	(Baumrind and Frantz 1971)
L1 to APog(mm)	Ricketts	Perpendicular distance of the incisal edge of the mandibular central incisor to the APog line	(Baumrind and Frantz 1971)
Pg-NB	Ricketts	Prominence of the bony chin. Distance of pogonion(anterior point of the chin) to the reference NB line.	(Baumrind and Frantz 1971)

***Table 3.2** Description of angular and linear cephalometric measurements to define lower incisor position*

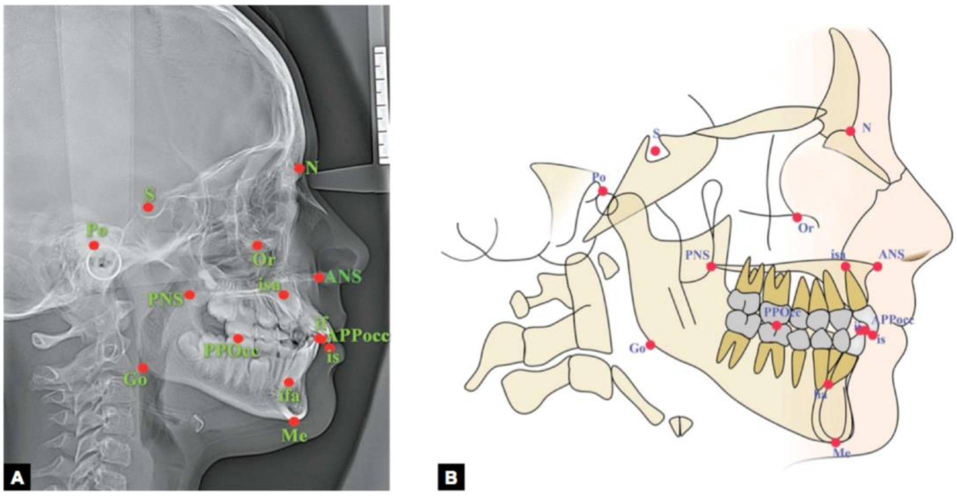

Figure 3.2 *Landmarks used for the traditional Steiner's cephalometric analysis (Basavaraj, Subhashchandra, and Phulari 2013)*

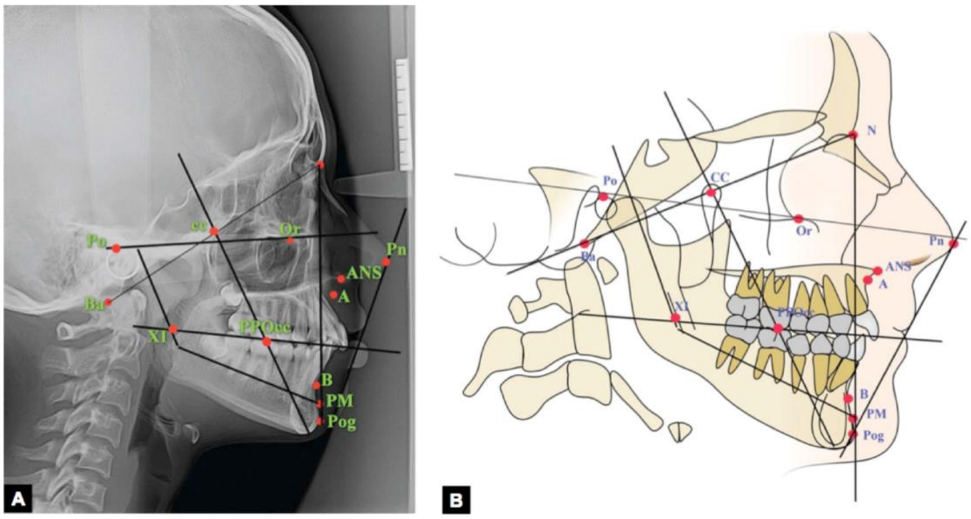

Figure 3.3 *Landmarks used for the traditional Rickett's cephalometric analysis (Basavaraj, Subhashchandra, and Phulari 2013).*

3.9 Study model Analysis

3D digital models were uploaded as a .stl file format and exported from iTero® into OrthoCAD®. A Carey's analysis was performed on the T0 and T1 treatment models. The mesio-distal width was measured from each tooth mesial to the first molar. The arch perimeter was calculated from the sum of the anterior and posterior segments, as shown in Figure 3.4 and Figure 3.6. Arch length discrepancy and the amount of crowding present in T1 was calculated by adding the sum of the posterior and anterior arch segments and subtracting the sum of the mesio-distal tooth dimensions. T1 space analysis was carried out to show that the crowding had completely resolved. The sum of the mesio-distal tooth dimensions at T0 and T1 were also compared to determine how IPR was performed.

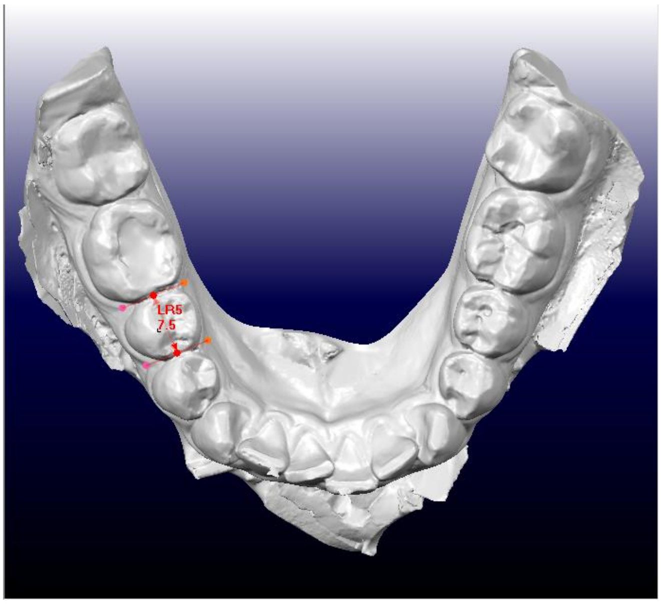

Figure 3.4 *OrthoCAD® software images of the measurement of the mesio-distal width of the lower right second premolar for Careys analysis*

Buccal arch expansion was also measured between T0 and T1. Change in inter-cusp distance between the molar, premolar and canine were measured between the T0 and T1 models. Intercanine distance was measured between the cusp tips of the mandibular canines. Palatal cusps of the first molars and the mesiolingual cusps of the first molar were also used as landmarks to measure a change in arch width between T0 and T1 (Figure 3.5) (Prado et al.

2014). Expansion was measured as a change in arch width. An increase in arch width will increase the arch perimeter, creating more space (Adkins, Nanda, and Currier 1990).

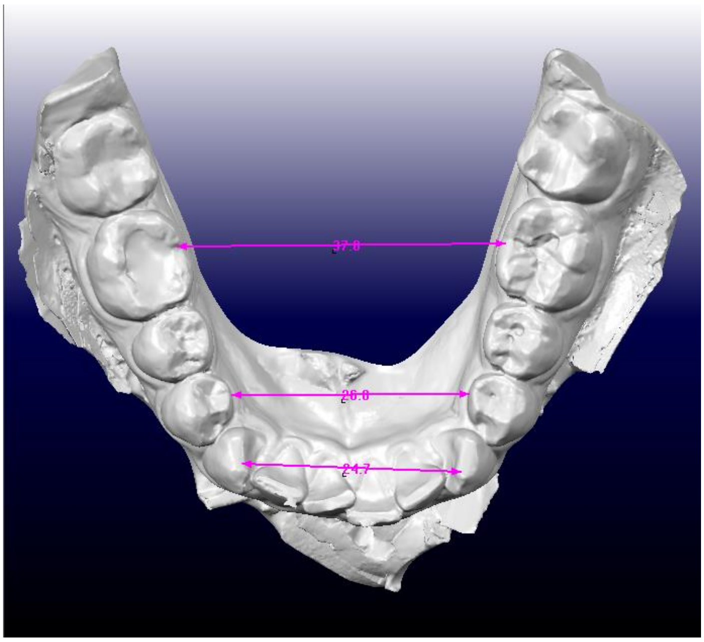

Figure 3.5 *OrthoCAD® images showing the T0 landmarks to measure canine, premolar and molar buccal expansion*

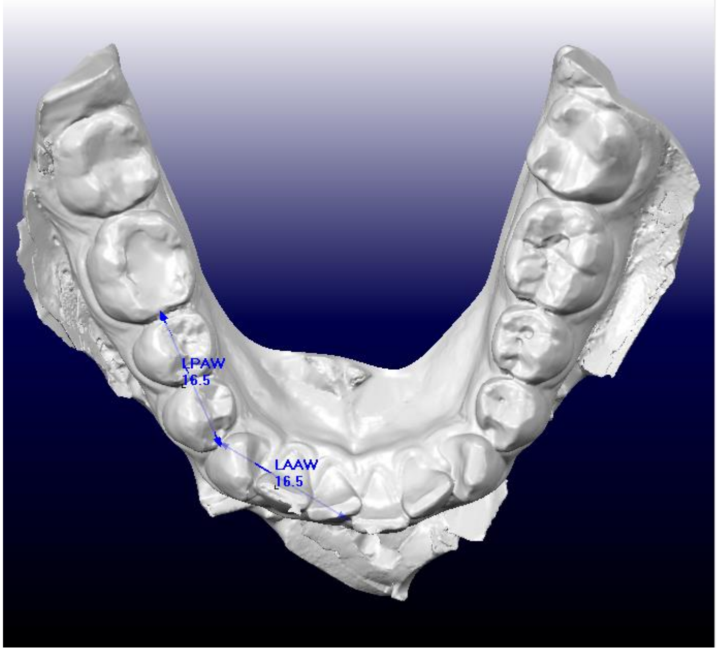

Figure 3.6 *OrthoCAD® images showing the anterior and posterior segments to calculate arch perimeter.*

3.10 Data Collection

A number of variables were recorded for statistical analysis. These variables included:

- Interproximal reduction measured in millimeters, as measured from the T0 and T1 digital models
- Treatment time taken for the lower arch
- Sex
- Age to establish that patients are within the inclusion criteria and are still growing
- Lower incisor position and angulation measurements from different cephalometric analysis at T0 and T1.
- Bony chin measurements at T0 and T1 to assess changes and possible effects on Lower incisor angulation.
- Arch width in the molar, premolar and canine at T0 and T1.

3.11 Statistical analysis

An ANOVA analysis of variants was carried out to analyse each of the variables. The ANOVA allowed us to analyse the effects that occur during Invisalign® treatment between each of the 4 groups and within each of the 4 groups. The variables that were measured at TO and T1 lateral cephalometric radiographs to assess changes included:

- L1 to NB (degrees)
- L1 to NB (mm)
- L1 to MPA (degrees)

- L1 to APog (degrees)
- L1 to APog (mm)
- Pog-NB

The ANOVA was also carried out to determine changes in arch width that was recorded using T0 and T1 3D models as .stl files. Variables include:

- Canine expansion (mm)
- Premolar expansion (mm)
- Molar expansion (mm)

3.12 Control

A control group of adolescents with Skeletal Class I malocclusions were chosen from the archives of the Burlington Growth Centre obtained via the American Association of Orthodontists Foundation (AAOF) website. All subjects were Caucasian. Matched as closely as possible to gender, age, and categorized into two groups: normal MPA (30-37°) and vertical (>37°). Lateral cephalometric radiographs taken at age 14 (T0) and age 16 (T1). Measured changes in the variables of lower incisor proclination/protrusion as stated above, were again measured to assess changes due to different growth patterns.

The results from the control were then compared to the treated sample by means of a Paired T t-test to compare changes of the lower incisor angulation and position. This allowed assessment to differentiate lower incisor changes due to growth and active treatment and to see if these changes differed due to the amount of crowding present and with different skeletal growth patterns.

CHAPTER 4

Results

4.1 Reliability

Intra-rater reliability was quantified using an intra-cluster correlation coefficient (ICC). The ICC values for both the lateral cephalometric radiographs and 3D models were in excess of 0.95 showing high reliability. These results show that the reproducibility of the 3D model measurements and cephalometric radiographs measurements are very reliable.

An inter-reliability test was done by conducting a paired t-test to calculate the average scores to test whether these values were statistically significant. The p-value in both the iTero® models and cephalometric radiographs was less than 0.05, indicating a high correlation between the two investigators.

4.2 Treatment time for each individual group.

Treatment time was determined by the total number of lower aligners worn by each patient. Each aligner was worn as prescribed for one week each. The results were divided into groups to determine the average treatment time of the normal/mild, vertical/mild, normal/moderate, vertical/moderate groups, as shown in Table 4.1. The treatment time increased as the lower incisor crowding increased. This is due an increase in the degree of tooth movement required to resolve the crowding.

Group	**Mean treatment time (Weeks)(+/-S.D)**
Normal/Mild	50.5(+/- 23.3)
Vertical/Mild	49.1(+/-24.2)
Normal/Moderate	62.7(+/-19.9)
Vertical/Moderate	65.4(+/-18.1)

Table 4.1 *Mean treatment time for the lower arch of each of the 4 groups*

4.3 Evaluation of cephalometric changes within each group between T0 and T1

A retrospective sample of 40 patients treated with Invisalign teen® was used. The subjects were divided into 4 groups, depending on the patients' skeletal growth pattern and degree of their initial crowding. The different groups were of mixed gender, consisting of 26 females and 14 males.

Cephalometric values were analyzed and measured using a paired t-test to determine if there were any statistically significant changes between the T0 and T1 cephalometric measurements for each of the different groups. The difference in these means established if there was a statistically significant change between the outcomes of T0 and T1 for the different variables.

4.4 Evaluation of cephalometric changes within the Normal Growth /Mild Crowding Group between T0 and T1

The results for the paired t-test are shown in Table 4.2. Each of the variables tested had an increase in their mean values. However, none of the changes were statistically significant. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	T0 mean	T1 mean	Difference in means	Difference means 95% Cl	p-value
L1-NB (deg)	24	25.2	1.2	(-0.087,1.213)	0.19
L1-NB (mm)	2.5	2.8	0.3	(0.04,1.39)	0.27
L1-MPA (deg)	90.2	91.4	1.2	(-2.89,0.89)	0.16
L1-APog (deg)	23.2	24.3	1.1	(-3.89,0.67)	0.17
L1-APog (mm)	2.8	3.1	0.3	(-0.98,0.67)	0.45
Pog-NB	2.7	3.0	0.3	(0.89,0.56)	0.37

Table 4.2 *Paired t-test of Normal Growth/ Mild Crowding variables. Statistically significant variables shown with an **

4.5 Evaluation of cephalometric changes within the Vertical Growth /Mild Crowding Group between T0 and T1

The results for the paired t-test are shown in Table 4.3. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	T0 mean	T1 mean	Difference in means	Difference means 95% Cl	p-value
L1-NB (deg)	23.4	24.5	1.1	(-0.067,1.31)	0.18
L1-NB (mm)	2.1	2.5	0.4	(0.08,1.24)	0.18
L1-MPA (deg)	90.6	90.5	-0.1	(-2.57,0.78)	0.19
L1-APog(deg)	24.3	25.1	0.8	(-3.34,0.89)	0.35
L1-APog (mm)	3	2.9	-0.1	(0.98,0.76)	0.55
Pog-NB	2.5	2.7	0.2	(0.79,0.96)	0.77

Table 4.3 *Paired t-test of Vertical Growth/ Mild Crowding variables.Statistically significant variables shown with an **

4.6 Evaluation of cephalometric changes within Normal Control between T0 and T1

The results for the paired t-test are shown in Table 4.4. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	T0 mean	T1 mean	Difference in means	Difference means 95% Cl	p-value
L1-NB (deg)	24.1	25.2	1.1	(-0.067,1.11)	0.29
L1-NB (mm)	2.5	2.6	0.1	(-0.07,1.89)	0.37
L1-MPA (deg)	89.9	90.9	1.0	(-1.89,0.59)	0.26
L1-APog (deg)	23.5	24.4	0.9	(-2.69,0.77)	0.37
L1-APog(mm)	2.5	2.8	0.3	(-0.78,0.37)	0.45
Pog-NB	2.6	2.8	0.2	(0.79,0.46)	0.57

Table 4.4 *Paired t-test of Normal Control variables. Statistically significant variables shown with an **

4.7 Evaluation of cephalometric changes within the Vertical Control Group between T0 and T1.

The results for the paired t-test are shown in Table 4.5. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	T0 mean	T1 mean	Difference in means	Difference means 95% Cl	p-value
L1-NB (deg)	25	24.2	-0.8	(-0.057,2.21)	0.69
L1-NB (mm)	2.5	2.3	-0.2	(0.09,1.46)	0.27
L1-MPA (deg)	90.9	89.8	-1.1	(-2.69,0.79)	0.16
L1-APog (deg)	24.5	23.8	-0.7	(-1.9,0.68)	0.47
L1-APog (mm)	3	2.7	-0.3	(0.58,0.47)	0.55
Pog-NB	3	2.9	-0.1	(0.49,0.69)	0.27

Table 4.5 *Paired t-test of vertical Control variables. Statistically significant variables shown with an **

4.8 Evaluation of cephalometric changes within the Vertical Growth /Moderate Crowding Group between T0 and T1.

The results for the paired t-test are shown in Table 4.6. There were statistically significant changes in the proclination variables between T0 and T1 in this group. The mean change difference in the L1-NB (deg), L1-MPA (deg) and the L1-APog (deg) between T0 and T1 were statistically significant.

Dependent Variable	T0 mean	T1 mean	Difference in means	Difference means 95% Cl	p-value
L1-NB(deg)	24.1	26.3	2.2	(-.2467,1.47)	0.018*
L1-NB(mm)	1.7	2.6	0.9	(-2.78,1.98)	0.29
L1-MPA(deg)	90.4	93.1	2.7	(-3.69,0.98)	0.005*
L1-APog(deg)	23.0	25.5	2.5	(-2.89,0.68)	0.034*
L1-APog(mm)	2.4	3	0.6	(0.48,0.97)	0.45
Pog-NB	3	2.9	-0.1	(0.29,0.79)	0.23

Table 4.6 *Paired T t-test of Vertical Growth/ Moderate Crowding variables. Statistically significant variables shown with an **

4.9 Evaluation of cephalometric changes within the Normal Growth /Moderate Crowding Group between T0 and T1

The results for the paired t-test are shown in Table 4.7. There were statistically significant changes in the proclination variables between T0 and T1 in this group. The mean difference change in the L1-NB (deg), L1-MPA (deg) and the L1-APog (deg), between the T0 and T1 was statistically significant.

Dependent Variable	**T0 mean**	**T1 mean**	**Difference in means**	**Difference means 95% Cl**	**p-value**
L1-NB(deg)	23.5	26.5	3.0	(-2.78,.2.43)	0.034*
L1-NB(mm)	2.6	2.9	0.3	(0.8,1.21)	0.37
L1-MPA(deg)	91.2	94.2	3.0	(-3.4,2.1)	0.01*
L1-APog(deg)	23.6	26.7	3.1	(-2.3,1.9)	0.02*
L1-APog(mm)	2.5	3.2	0.7	(-1,0.9)	0.45
Pog-NB	2.8	3.1	0.3	(0.9,0.46)	0.57

Table 4.7 *Paired t-test of Normal Growth/ Moderate Crowding variables. Statistically significant variables shown with an **

4.10 Evaluation of Cephalometric changes between each Group between T0 and T1

An analysis of variance (ANOVA) was used to analyze the difference between the groups means using a group p-value. The p-value value was at a 95% confidence interval to determine if the lower incisor position change was statistically significant between the four groups and two control groups. The different treated and control groups were then paired together to determine if the groups were statistically different to each other at the 95% confidence interval.

The variables were compared between the different groups to determine if the different growth patterns and the amount of crowding had a statistically significant difference in the change in the lower incisor position between each of the groups.

When the p-value was less than 0.05, the pairwise p-values indicated which of the groups had statistically significant between them for the mandibular incisor position for each of the variables. The results are shown in Table 4.8.

4.11 Evaluation of Cephalometric changes between each Group between T0 and T1

There was no statistically significant change in the growth of the bony chin (Pog-NB) between each of the different treated groups and Control Groups.

There was no statistically significant change in any of the protrusion variables (L1-NBmm and L1-APogmm) between each of the different treated groups and Control Groups.

4.11.1 L1-NB(deg) Variable

L1-NB(deg) showed statistically significant between the groups, with the overall group p-value for L1-NB(deg) at p=0.0178. There was a statistically significant difference between the Normal/Moderate group (3.0°+/-1.7°) and the Normal/Mild group (1.2°+/-0.8°), with p=0.0378. The change was also statistically significant between the Normal/Moderate group (3.0°+/-1.7°) and The Vertical/Mild group (1.1°+/-0.9°) with p=0.045.

L1-NB(deg) change was also statistically significant between the Vertical/Moderate group (2.2°+/-1.8°), the Vertical/Mild group (1.1°+/-0.9°) and Normal/Mild group (1.2°+/-0.8°), with a p-value of 0.048 and 0.039, respectively.

The Normal/Moderate group (3.0°+/-1.7°) and Vertical/Moderate group (2.2°+/-1.8°), also had a statistically significant with p=0.049 for the L1-NB variable.

The Normal/Moderate Group (3.0°+/-1.7°) change was statistically significant from the Normal/Control Group (1.1°+/-1.1°) with p=0.038 and the Vertical/Control Group (-0.8°+/-0.9°) with p=0.027 in the L1-NB variable.

The Vertical/Moderate Group (2.2°+/-1.8°) change was statistically significant from the Normal/Control Group (1.1°+/-1.1°) with p=0.041 and the Vertical/Control Group (-0.8°+/-0.9°) with p=0.032 in the L1-NB variable.

4.11.2 L1-MPA(deg) Variable

L1-MPA(deg) had a group p-value of 0.0098. Statistically significant pairwise p-value was evident between the Normal/Moderate group (3.0° +/-2.3°), the Normal/Mild group (1.2°+/-1.3°) with p=0.0018 and the Vertical/Mild group (0.9°+/-1.1°) with p=0.0026.

The Change was also statistically significant between the Vertical/Moderate group (2.7°+/-2.0°),Vertical/Mild group (0.9°+/-1.1°) with p=0.02 and Normal/Mild group (1.2°+/-1.3°) with p=0.039.

The Normal/Moderate group (3.0° +/-2.3°) and Vertical/Moderate group (2.7°+/-2.0°) also had a statistically significant difference with p=0.015.

The Normal/Moderate group (3.0° +/-2.3°) change was statistically significant from the Normal/Control group (1.0°+/-1.4°) with p=0.003 and the Vertical/Control group (-1.1°+/-1.0) with p=0.001 in the L1-MPA variable.

The Vertical/Moderate group (2.7°+/-2.0°) change was statistically significant from the Normal/Control group (1.0°+/-1.4°) with p=0.03 and the Vertical/Control group (-1.1°+/-1.0°) with p=0.003 in the L1-MPA variable.

4.11.3 L1-APog(deg)

L1-APog(deg) showed a significant difference with a group p-value of p=0.027. Between the groups, the statistically significant was evident between the Normal/Moderate group (3.1°+/-1.9°)- Normal/Mild group (1.0°+/-0.9°) with p=0.023 and Vertical/Mild group (0.8°+/-1.1°) with p=0.019.

There was also a statistically significant change in the difference between the Vertical/Moderate group (2.5°+/-1.5°)- Normal/Mild group (1.0°+/-0.9°) with p=0.034, and the Vertical/Mild group (0.8°+/-1.1°) with p=0.047.

The Normal/Moderate (3.1°+/-1.9°) and Vertical/Moderate group (2.5°+/-1.5°) also had a statistical significance between them with p=0.045.

The Normal/Moderate group (3.1°+/-1.9°) change was statistically significant from the Normal/Control group (0.9°+/-1.3°) with p=0.005 and the Vertical/Control group (-0.7°+/-0.8°) with p=0.001 in the L1-APog variable.

The Vertical/Moderate group (2.5°+/-1.5°) change was statistically significant from the Normal/Control group (0.9°+/-1.3°) with p=0.037 and the Vertical/Control group (-0.7°+/-0.8°) with p=0.002 in the L1-APog variable.

Overall, the Normal/Mild and Vertical/Mild groups and two Control groups had no statistical significance between them as the pairwise p-values were >0.05.

The Normal/Moderate group and the Vertical/ Moderate group were statistically significant from both the Normal/Mild and Vertical/mild groups. There was a statistically significant change in the lower incisor angulation between these groups, i.e. the group p-value was <0.05, the pairwise p-values that included the Normal/Moderate and Vertical/Moderate were significant at $p<0.05$.

The Normal/Moderate group and the Vertical/ Moderate group were statistically significant from both the Normal/Control and Vertical/Control groups. There was a statistically significant change in the lower incisor angulation between these groups, i.e. the group p-value was <0.05.

The Normal/Moderate group and the Vertical/Moderate group were statistically significant from each other in the Incisor angulation variables (L1-NB, L1-MPA, L1-APog)

Distribution of L1-APog (deg), L1-NB(deg), L1-MPA(deg) change was statistically significant between the four treated groups and 2 control groups ($p<0.05$). The largest mean change difference was noted in the Normal/Moderate Group for each of these three variables.

*__Table 4.8__ ANOVA test of variables between the different treated groups and control groups. Statistically significant variables shown with an **

Dependent Variable	**Group**	**Group p value**	**Group means**	**Pairwise p-values**	
L1-NB(deg)	Normal/Moderate	0.0178*	26.5	Norm/Mod vs Vert/Mod	0.049*
	Vertical/Moderate		26.3	Norm/Mod vs Norm/Mild	0.037*
	Normal/Mild		25.2	Norm/Mod vs Vert/Mild	0.045*
	Vertical/Mild		24.5	Norm/Mod vs Norm/Con	0.038*
	Normal/Control		25.2	Norm/Mod vs Vert/Con	0.027*
	Vertical/Control		24.2	Vert/Mod vs Norm/Mild	0.039*
				Vert/Mod vs Vert/Mild	0.048*
				Vert/Mod vs Norm/Con	0.041*
				Vert/Mod vs Vert/Con	0.032*
				Norm/Mild vs Vert/Mild	0.238
				Norm/Mild vs Norm/Con	0.067
				Norm/Mild vs Vert/Con	0.078
				Vert/Mild vs Norm/Con	0.089
				Vert/Mild vs Vert/Con	0.098
				Norm/Con vs Vert/Con	0.087

L1-NB(mm)	Normal/Moderate	0.7834	2.9	Norm/Mod vs Vert/Mod	0.087
	Vertical/Moderate		2.6	Norm/Mod vs Norm/Mild	0.068
	Normal/Mild		2.8	Norm/Mod vs Vert/Mild	0.078
	Vertical/Mild		2.5	Norm/Mod vs Norm/Con	0.065
	Normal/Control		2.6	Norm/Mod vs Vert/Con	0.055
	Vertical/Control		2.3	Vert/Mod vs Norm/Mild	0.098
				Vert/Mod vs Vert/Mild	0.067
				Vert/Mod vs Norm/Con	0.054
				Vert/Mod vs Vert/Con	0.087
				Norm/Mild vs Vert/Mild	0.098
				Norm/Mild vs Norm/Con	0.12
				Norm/Mild vs Vert/Con	0.09
				Vert/Mild vs Norm/Con	0.065
				Vert/Mild vs Vert/Con	0.23
				Norm/Con vs Vert/Con	0.43

L1-MPA	Normal/Moderate Vertical/Moderate Normal/Mild Vertical/Mild Normal/Control Vertical/Control	0.0098*	94.2 93.1 91.4 90.5 90.9 89.8	Norm/Mod vs Vert/Mod Norm/Mod vs Norm/Mild Norm/Mod vs Vert/Mild Norm/Mod vs Norm/Con Norm/Mod vs Vert/Con Vert/Mod vs Norm/Mild Vert/Mod vs Vert/Mild Vert/Mod vs Norm/Con Vert/Mod vs Vert/Con Norm/Mild vs Vert/Mild Norm/Mild vs Norm/Con Norm/Mild vs Vert/Con Vert/Mild vs Norm/Con Vert/Mild vs Vert/Con Norm/Con vs Vert/Con	0.015* 0.001* 0.002* 0.003* 0.001* 0.039* 0.02* 0.03* 0.003* 0.234 0.067 0.087 0.324 0.078 0.987

L1-APog(deg)	Normal/Moderate Vertical/Moderate Normal/Mild Vertical/Mild Normal/Control Vertical/Control	0.027*	26.7 25.5 24.3 25.1 24.4 23.8	Norm/Mod vs Vert/Mod Norm/Mod vs Norm/Mild Norm/Mod vs Vert/Mild Norm/Mod vs Norm/Con Norm/Mod vs Vert/Con Vert/Mod vs Norm/Mild Vert/Mod vs Vert/Mild Vert/Mod vs Norm/Con Vert/Mod vs Vert/Con Norm/Mild vs Vert/Mild Norm/Mild vs Norm/Con Norm/Mild vs Vert/Con Vert/Mild vs Norm/Con Vert/Mild vs Vert/Con Norm/Con vs Vert/Con	0.045* 0.023* 0.019* 0.005* 0.001* 0.034* 0.047* 0.037* 0.002* 0.087 0.068 0.078 0.089 0.076 0.067

L1-APog(mm)	Normal/Moderate	0.2856	3.2	Norm/Mod vs Vert/Mod	0.089
	Vertical/Moderate		3	Norm/Mod vs Norm/Mild	0.453
	Normal/Mild		3.1	Norm/Mod vs Vert/Mild	0.674
	Vertical/Mild		2.9	Norm/Mod vs Norm/Con	0.076
	Normal/Control		2.8	Norm/Mod vs Vert/Con	0.089
	Vertical/Control		2.7	Vert/Mod vs Norm/Mild	0.076
				Vert/Mod vs Vert/Mild	0.088
				Vert/Mod vs Norm/Con	0.673
				Vert/Mod vs Vert/Con	0.083
				Norm/Mild vs Vert/Mild	0.432
				Norm/Mild vs Norm/Con	0.216
				Norm/Mild vs Vert/Con	0.091
				Vert/Mild vs Norm/Con	0.451
				Vert/Mild vs Vert/Con	0.231
				Norm/Con vs Vert/Con	0.102

Pog-NB	Normal/Moderate	0.987	3.1	Norm/Mod vs Vert/Mod	0.089
	Vertical/Moderate		2.9	Norm/Mod vs Norm/Mild	0.067
	Normal/Mild		3.0	Norm/Mod vs Vert/Mild	0.078
	Vertical/Mild		2.7	Norm/Mod vs Norm/Con	0.123
	Normal/Control		2.8	Norm/Mod vs Vert/Con	0.234
	Vertical/Control		2.9	Vert/Mod vs Norm/Mild	0.087
				Vert/Mod vs Vert/Mild	0.098
				Vert/Mod vs Norm/Con	0.123
				Vert/Mod vs Vert/Con	0.487
				Norm/Mild vs Vert/Mild	0.077
				Norm/Mild vs Norm/Con	0.087
				Norm/Mild vs Vert/Con	0.067
				Vert/Mild vs Norm/Con	0.078
				Vert/Mild vs Vert/Con	0.123
				Norm/Con vs Vert/Con	0.098

4.12 Buccal expansion comparisons using the iTero® 3D models within the groups

Buccal expansion is a treatment modality that decreases the amount of crowding by increasing the arch perimeter (Houle et al. 2017). Buccal expansion was not a main dependent variable for the purpose of this study. However, its effect on the resolution of crowding cannot be disregarded.

The change of buccal expansion between the T0 and T1 iTero® 3D models was measured from the mesiopalatal cusp of the molar, the palatal cusp of the premolar and cusp tip of the canine. A paired t-test was performed in each of the four treated groups to assess whether there was a change in arch width.

Normal Growth/ Mild Crowding					
Outcome	**T0 Mean**	**T1 Mean**	**Difference in Means**	**Difference Means 95% Cl**	**p-value**
Canine	25.32	26.69	1.37	(1.89,0.987)	0.03*
Premolar	26.78	28.46	1.68	(2.012,0.67)	0.001*
Molar	32.14	34.12	1.98	(1.97,1.13)	0.02*

Table 4.9 *Paired t-test Normal Growth/ Mild Crowding Buccal expansion. Statistically significant variables shown with an **

Table 4.9 shows the difference in the means between T0 and T1 for the Normal Growth/Mild Crowding. These differences were statistically significant in the molar, premolar and canine widths. This reveals that there was a statistically significant expansion in the buccal segments of the three teeth.

Vertical Growth/ Mild Crowding					
Outcome	**T0 Mean**	**T1 Mean**	**Difference in Means**	**Difference Means 95% Cl**	**p-value**
Canine	24.12	25.79	1.67	(1.45,0.65)	0.04*
Premolar	25.57	26.91	1.34	(1.45,0.47)	0.02*

Molar	32.98	34.99	2.01	(1.83,1.08)	0.001*

Table 4.10 *Paired t-test Vertical Growth/ Mild Crowding Buccal expansion. Statistically significant variables shown with an **

Table 4.10 shows the difference in the means between T0 and T1 for the Vertical Growth/Mild Crowding. These differences were statistically significant in the molar, premolar and canine widths. This shows that there was a statistically significant expansion in the buccal segments of the three teeth.

Normal Growth/ Moderate Crowding					
Outcome	**T0 Mean**	**T1 Mean**	**Difference in Means**	**Difference Means 95% Cl**	**p-value**
Canine	23.65	25.63	1.98	(1.89,0.59)	0.03*
Premolar	24.97	26.74	1.77	(1.67,0.90)	0.003*
Molar	32.68	34.69	2.01	(1.45,1.98)	0.006*

Table 4.11 *Paired t-test Normal Growth/ Moderate Crowding Buccal expansion. Statistically significant variables shown with an **

Table 4.11 shows the difference in the means between T0 and T1 for the Normal Growth/Moderate Crowding. These differences were statistically significant in the molar, premolar and canine widths. This shows that there was a statistically significant expansion in the buccal segments of the three teeth.

Vertical Growth/ Moderate Crowding					
Outcome	**T0 Mean**	**T1 Mean**	**Difference in Means**	**Difference Means 95% Cl**	**p-value**
Canine	24.15	25.71	1.56	(1.65,0.79)	0.05*
Premolar	25.77	27.15	1.38	(1.89,0.80)	0.02*

Molar	31.32	32.99	1.67	(1.34,1.28)	0.003*

Table 4.12 *Paired t-test Vertical Growth/ Moderate Crowding Buccal expansion. Statistically significant variables shown with an **

Table 4.12 shows the difference in the means between TO and T1 for the Vertical Growth/Moderate Crowding. They are statistically significant in the molar, premolar and canine widths. This shows that there was a statistically significant expansion in the buccal segments of the three teeth.

4.13 Buccal expansion comparisons using iTero® 3D models between the Groups

Table 4.13 shows the results of ANOVA analysis used to compare the four treated groups. There were no statistically significant changes in the inter-molar, premolar and canine widths between the groups. This shows that even though that there was a statistically significant increase in the buccal arch expansion in each of the groups, the Skeletal Growth pattern and the amount of crowding didn't affect the amount of expansion achieved.

Outcome	**Group**	**Group p-value**	**Group means**	**Pairwise p-values**	*p<0.05
Canine	Norm/Mild	0.814	25.69	Norm/Mod vs Vert/Mod	0.98
	Vert/Mild		25.79	Norm/Mod vs Norm/Mild	0.78
	Norm/Mod		25.63	Norm/Mod vs Vert/Mild	0.06

	Vert/Mod		25.71	Vert/Mod vs Norm/Mild	0.34
				Vert/Mod vs Vert/Mild	0.75
				Norm/Mild vs Vert/Mild	0.56
Premolar	Norm/Mild	0.1134	28.46	Norm/Mod vs Vert/Mod	0.34
	Vert/Mild		26.91	Norm/Mod vs Norm/Mild	0.65
	Norm/Mod		26.74	Norm/Mod vs Vert/Mild	0.45
	Vert/Mod		27.15	Vert/Mod vs Norm/Mild	0.87
				Vert/Mod vs Vert/Mild	0.97
				Norm/Mild vs Vert/Mild	0.65
Molar	Norm/Mild	0.1437	34.12	Norm/Mod vs Vert/Mod	0.38
	Vert/Mild		34.99	Norm/Mod vs Norm/Mild	0.19
	Norm/Mod		34.69	Norm/Mod vs Vert/Mild	0.72
	Vert/Mod		32.99	Vert/Mod vs Norm/Mild	0.61
				Vert/Mod vs Vert/Mild	0.14
				Norm/Mild vs Vert/Mild	0.31

Table 4.13 *ANOVA test buccal expansion of different treated groups. Statistically significant variables shown with an **

4.14 Interproximal reduction comparisons

An ANOVA test was performed on the mean changes between the 4 treated groups. This was done to see if the amount of IPR carried out was similar in the 4 groups and whether the differences could affect our results.

Outcome	**Group**	**Group p value**	**Group means**	**Pairwise p-values** ***p< 0.05**	
IPR	Norm/Mild	0.614	1.25	Norm/Mod vs Vert/Mod	0.78
	Vert/Mild		1.17	Norm/Mod vs Norm/Mild	0.98
	Norm/Mod		1.35	Norm/Mod vs Vert/Mild	0.08
	Vert/Mod		1.54	Vert/Mod vs Norm/Mild	0.45
				Vert/Mod vs Vert/Mild	0.87
				Norm/Mild vs Vert/Mild	0.38

Table 4.14 *ANOVA test of IPR performed of different groups. Statistically significant variables shown with an **

Table 4.14 shows the results of ANOVA analysis used to compare the 4 treated Groups. There was no statistical significant in the amount of the IPR performed between the 4 groups.

CHAPTER 5

Discussion

To date, there have been no cephalometric studies conducted to determine the effects of Invisalign Teen® on growing patients and whether the lower incisor position will be effected by different skeletal growth patterns in non-extraction cases.

In this study, the parameters of buccal arch expansion, IPR and incisor proclination/protrusion were measured in 40 patients of different skeletal patterns and varying crowding severity.

Crowding is one of the main reasons why people seek orthodontic treatment to align their teeth (Meier, Wiemer, and Miethke 2003). Space can be achieved to resolve crowding by the following means, other than extracting permanent teeth:

- Anterior Proclination
- Buccal arch expansion
- Interproximal enamel reduction (IPR)
- Buccal segment distalization

In the non-extraction treatment plan in the mandible, orthodontists use buccal expansion, incisor proclination/protrusion and interproximal reduction (IPR) to alleviate crowding; as using distalization in the mandibular arch can be difficult to achieve (Vajaria et al. 2011, Weinberg and Sadowsky 1996).

There have been a few studies that have looked at the relationship between Invisalign® treatment and crowding resolution from both a methodology and a reliability point of view.

A study by Krieger, reported that 58% of the subjects had lower incisor crowding resolved by a combination of IPR and incisor protrusion. This study, however, focused on lower incisor position as opposed to proclination (Krieger et al. 2012).

Wax, Beck and Firestone (2010) reported reliability of 91.4% in the correction of the mandibular incisor crowding (Wax, Beck, and Firestone 2010). Another study found that predictability of tooth movement when resolving <5mm of crowding, was 41%. Both studies used Invisalign® as a treatment modality (Kravitz et al. 2009).

Duncan looked at the effect of lower incisor proclination in non-extraction cases, with different crowding in non-growing patients using the Invisalign® appliance. It assessed the lower incisor changes with groups of different pre-treatment crowding. The Lower incisor position and angulation changes were significant in the severe crowding groups. The conclusion was that Invisalign® successfully resolved mandibular arch crowding using a combination of buccal arch expansion, interproximal reduction and lower incisor proclination (Duncan et al. 2016).

5.1 Buccal arch expansion with the Invisalign Teen® appliance and its role in the resolution of crowding

Buccal arch expansion was measured on the 3D iTero® models from .stl files at pre-treatment (T0) and post-treatment (T1). Inter-molar, Inter-premolar and inter-canine widths were measured at both time spots.

Buccal arch expansion increases the arch perimeter (Ricketts et al. 1982). Another study by Weinberg and Sadowsky, found that in patients treated with conventional fixed braces, Changes in the arch perimeter accounted for 50% of crowding resolution with a combination of buccal arch expansion and incisor proclination (Weinberg and Sadowsky 1996).

Krieger et al., (2012) examined Invisalign® and its effect on anterior tooth movements, measuring inter-canine width, however, this study did not discuss perimeter (Krieger et al. 2012). The results of this study showed a statistically insignificant increase in mandibular inter-canine width (Krieger et al. 2012). These results may be due to the fact that the study included anterior Invisalign® treatment only. In addition, maintaining inter-canine width may have been a treatment goal, as studies have shown changes in inter-canine width are unstable (Little, Wallen, and Riedel 1981).

A Study by Houle, looked at the predictability of transverse changes using Invisalign® (Houle et al. 2017). He found that in the lower arch, there was a statistically significant difference between the ClinCheck® planned expansion and the final outcome. The overall mean accuracy of expansion in the lower arch was 87.7% (Houle et al. 2017).

Duncan et al., looked at the effect of buccal expansion and its effect on the resolution of crowding using Invisalign® as a modality in non-extraction cases (Duncan et al. 2016). The results showed buccal expansion played a significant role in crowding management. The mean increase in inter-molar width was 1.65mm in the mild crowding group, 1.86mm in the moderate and 2.65mm in the severe group (Anwar and Fida 2009, Duncan et al. 2016). The results also showed that between the groups for inter-canine, inter-premolar and inter-molar at T1, the expansion changes were not statistically significant ($p > 0.05$). The amount of initial crowding did not affect the post-treatment transverse dimension. The results of this study mirrored that of Duncan et al. (2016).

The mean increase in inter-molar-width was 1.98mm in the Normal Growth/Mild Crowding Group, 2.01mm in the Vertical Growth/Mild Crowding, 1.67mm in the Vertical/Moderate Group and 2mm in the Normal Growth/Moderate Crowding. Inter-Premolar widths increased 1.68mm, 1.34mm, 1.38mm, 1.77mm, respectively. Inter-canine widths increased 1.37mm,1.67mm, 1.56mm, 1.98mm respectively.

These results showed there were no statistically significant changes in the inter-molar, premolar and canine widths between the groups. This demonstrated that even though that there was a statistically significant increase in the buccal arch expansion in each of the groups, the skeletal growth pattern and the amount of initial crowding did not affect the amount of expansion achieved.

Ricketts et al.(1982) used a formula to determine the relationship between arch width and perimeter (Ricketts et al. 1982). It was reported that 1mm of molar expansion created 0.25mm of space, while 1mm of premolar expansion produced 0.7mm of space. Using this formula, in the four treated groups, the combination of mean molar and premolar expansion would have contributed mean arch perimeter increases of 1.54mm in the Normal/Mild Group, 1.47mm in the Vertical/Mild Group, 1.87 in the Vertical/Moderate Group and 1.99mm in the Normal/Moderate Group.

5.2 Lower Incisor Position and angulation with the Invisalign Teen® appliance and its role in crowding resolution

Studies have shown that lower incisor protrusion is four times more effective at space creation than buccal expansion. 1mm of protrusion of the lower mandibular incisors can create up to 2.5mm of space (Pandis et al. 2010).

Idealizing and measuring lower incisor angulation and position is a fundamental principle of orthodontic diagnosis and treatment planning. Other factors also have to be considered, including stability of the lower incisor position, aesthetics and periodontal health (Pollard et al. 2012). When considering the lower incisor position, it is important to use cephalometric norms as a reference. There are a number of different analyses with established values for different ethnic groups (Steiner 1953, Ricketts 1981).

For the purpose of this study, a comparison between the T0-T1 treated groups and T0-T1 control groups was essential. The control group was derived by using the lateral cephalometric radiographs from the Burlington growth study.

By comparing the treated and control groups with similar growth patterns at similar time points, we are able to determine how much of the change in the lower incisor angulation was due to active orthodontic treatment, but also could determine slight changes that occurred naturally due to growth in the control groups.

Krieger et al., (2012) examined tooth movement in the anterior region (Krieger et al. 2012). This study looked at the predictability of tooth movements by comparing pre and post-treatment models with post-treatment ClinChecks®. The results found that in the mandible for the resolution of crowding:

- IPR was used in 30% of patients
- 18% of the patients had protrusion of the lower incisors
- A combination of IPR and protrusion was seen in 40% of patients,

The conclusions of this study are debatable as there was no cephalometric analysis done. It was not possible to properly assess the axial inclination change in the lower incisor after treatment. The protrusion measurements were recorded visually on a 1.0mm grid with no stable reference points.

Another study that used conventional braces found an increase in the arch perimeter for each degree of proclination ranged from 0.34mm to 0.59mm (Mutinelli, Manfredi, and Cozzani 2000).

Duncan looked at the effect of lower incisor proclination in non-extraction cases with different crowding in non-growing patients using Invisalign Teen® (Duncan et al. 2016). It was a retrospective cephalometric chart review assessing the lower incisor changes with groups of different pre-treatment crowding (Duncan et al. 2016).

The incisor position and angulation were not statistically significantly increased during the correction of both the mild and moderate groups.

The lower incisor position and angulation changes were significant in the severe crowding groups when crowding exceeded 6mm.

The mean changes when crowding was >6mm were:

- L1-NB(deg) 4.71° +/- 4.79°
- L1-NB(mm) 1.56mm +/- 1.40mm
- L1-MPA(deg) 3.95° +/- 4.72°
- L1-APog(deg) 4.82° +/- 4.94°
- L1-APog(mm) 1.74mm +/- 1.62mm

The conclusion was that Invisalign® treatment could successfully resolve mandibular arch crowding using a combination of buccal arch expansion, interproximal reduction and lower incisor proclination (Duncan et al. 2016).

The subjects used in this study were non-growing patients, and the study didn’t take into consideration different skeletal growth patterns.

In this study, we examined the lower incisor angulation in relation to crowding correction and different skeletal growth patterns in growing patients. Data were obtained from digital models and lateral cephalometric radiographs, as previously outlined.

In this study, there was no statistically significant change in any of the protrusion variables (L1-NBmm and L1-APogmm) between each of the different treated groups and Control Groups.

There was also no statistically significant change in the growth of the bony chin (Pog-NB) between each of the different treated groups and Control Groups.

The Normal/Mild, Vertical/Mild groups, Normal and Vertical Control Groups had no statistical significance between them ($p > 0.05$).

In the Vertical Growth/ Moderate Crowding group, there were statistically significant increases ($p < 0.05$) in lower incisor angulation. Mean angulation changes were from 24.3° to 26.3° for L1-NB (deg), 90.4° to 93.1° for L1-MPA, 23.0° to 25.5° for L1-APog.

In the Normal Growth/ Moderate Crowding group, there were statistically significant increases ($p < 0.05$) in lower incisor angulation. Mean angulation changes were from 23.3° to 26.5° for L1-NB(deg), 91.2° to 94.2° for L1-MPA, 23.6° to 26.7° for L1-APog.

The Mean changes for the Incisor angulation in the Vertical growth/Moderate crowding was:

- L1-NB(deg) 2.2° +/- 1.8°
- L1-MPA(deg) 2.7° +/- 2.0°
- L1-APog(deg) 2.5° +/- 1.5°

The Mean changes for the Incisor angulation in the Normal growth/Moderate crowding was:

- L1-NB(deg) 3.0° +/- 1.7°
- L1-MPA(deg) 3.0° +/- 2.3°
- L1-APog(deg) 3.1° +/- 1.9°

The Normal/Moderate Group and the Vertical/Moderate Group were statistically significant from each other in the Incisor angulation variables (L1-NB, L1-MPA, L1-APog). The largest mean change difference was noted in the Normal/Moderate Group for each of these three variables.

The difference in these means could be due to the backward internal rotation that is simultaneously occurring in vertical growing patients, as previously reported by Bjork and Skieller (Bjork and Skieller 1983).

Remodeling of the ramus and apposition along the posterior border including the condylar process. Resorption occurs on the anterior ramus. The lower molar eruption is impeded by this abnormal growth, which results in not sufficiently uprighting of the teeth to compensate for the internal rotation. There is a compensatory increased eruption of the lower incisors, and they become more retroclined (Bjork and Skieller 1983, Anwar and Fida 2009). This mechanism could account for the difference in mean changes between the vertical growth/Moderate crowding and Normal growth/Moderate crowding groups.

Cephalometric norms for the lower incisor proclination variables used in this study were:

L1-MPA – 90° +/-5° (Tweed)

L1-NB- 25° +/- 4° (Steiner)

L1-APog 21° +/- 6.4° (Ricketts)

If we look at the T1 results for the 3 proclination variables (L1-NB, L1-MPA and L1-APog) in the Vertical growth/ Moderate crowding and the Normal growth/Moderate crowding groups. In the Vertical growth/Moderate crowding, the Mean T1 results for L1-NB (deg) was 26.3°, L1-MPA was 93.1°, L1-APog was 25.5°. In the Normal growth/Moderate crowding, the Mean T1 results for L1-NB (deg) was 26.5°, L1-MPA was 94.2°, L1-APog was 26.7°.

Although there was a statistically significant change in the proclination variables in these two groups, these results still fell within the cephalometric norms. In both these groups, there was not excessive proclination of the lower incisor.

A study by Yared, Zenobio and Pachero (2006), found that when an increase in lower incisor inclination to mandibular plane angle (L1-MPA >95°) occurs with free gingival thickness <0.5mm, that gingival recession was more likely ($p<0.05$) (Yared, Zenobio, and Pacheco 2006).

The fact that all groups fell below this threshold meant that gingival health was not compromised. Gingival phenotype, however, was found to be a more significant factor in contributing to gingival recession.

Results from this study were compared to the study by Duncan et al. (2016). They used non-growing patients in their study and did not take into account skeletal growth pattern (Duncan et al. 2016). In the study conducted by Duncan et al., mean changes for the Incisor proclination variables (L1-NB, L1-MPA,L1-APog) for the severe crowding group were larger than any of the groups in our study. Additionally, the Protrusion variables (L1-NBmm and L1-APogmm) in the severe group were statistically significant, whilst in all our 4 treated groups, they were not statistically significant.

5.3 Interproximal reduction and its role in the resolution of crowding

IPR was estimated by subtracting the sum of the mesio-distal tooth dimensions pre-treatment (TO) from post-treatment (T1).

The mean values for interproximal reduction for the groups were:

- Normal growth/Mild crowding group - 1.25mm (SD±1.37),
- Vertical growth/Mild crowding group - 1.17mm (SD±1.25),
- Vertical growth/Moderate crowding group - 1.35mm (SD±1.67)
- Normal growth/Moderate crowding group - 1.54mm (SD±1.38).

IPR was initially highlighted as programmed by the ClinCheck® software. Numerous studies have shown, the amount of IPR preformed was regularly less than predicted when comparing the different techniques- hand–pulled , motor driven and oscillating discs (Johner et al. 2013).

Clinical situations arise when more IPR is prescribed than the estimates crowding. These Clinical Situations can be described as mild class III camouflage or a Bolton discrepancy.

Bolton (1958) connected the sums of the upper and lower teeth from the first permanent molar to the contralateral one (Bolton 1958). The sums of these mesio-distal tooth widths were used to establish a ratio to achieve acceptable interdigitation of the teeth (Bolton 1958). The ratio is 91.1% for the maxilla and 77.2% for the mandible (Bolton 1958). A Bolton discrepancy, where extra IPR would be performed on the lower arch, would arise to accommodate excess tooth structure in the mandible.

Bolton discrepancies, where IPR is required in the lower arch, is twice as common as an excess in the maxillary arch and usually relate to smaller maxillary lateral incisors (Rakosi and Graber 2010).

During our data collection, two patients had to be excluded from our treated sample. These outliers were eliminated due to the malocclusion dictating the amount of IPR.

An ANOVA test was performed on the mean changes between the 4 treated groups. This was done to see if the amount of IPR carried out was similar in the 4 groups and whether the differences could affect our results.

The difference in mean values of the IPR in the 4 treated groups was less than 0.7mm. An increase in crowding did not correlate with a significant increase in IPR ($p>0.05$).

These results show that buccal arch expansion and lower incisor proclination were the predominant contributors to crowding resolution in the Vertical growth/Moderate crowding group and the Normal growth/Moderate crowding group.

5.4 Limitations of the study

There was an error in the space analysis carried out using the Carey's method (Carey 1949). There was a range of difference from -0.657mm and 0.465mm in a comparison between the pre-treatment and post-treatmentt models for tooth size arch length discrepancy. This inconsistency may be from the approximation that the Carey's method uses straight-line segments to arch form (Carey 1949).

Measurement error needs to be considered when trusting linear and angular measurements for data analysis from different sources. The intraclass and interclass correlation results showed good intra-rater and inter-rater reliability for each of the variables measured. Conversion of intra-oral scanners to .stl files has shown to be a valid and reproducible method of measuring distances (Cuperus et al. 2012). With these results, we assumed that the iTero® scans and the ClinCheck® model .stl files are accurate.

A study by Naidu (2013), examined the reliability of measuring digital models derived from the OrthoCad® software (Naidu and Freer 2013). The conclusion was that tooth widths and Bolton ratios could be calculated with excellent reliability and reproducibility and a high degree of accuracy (Naidu and Freer 2013).

The sample size for this study was low due to the strict inclusion criteria. 40 subjects were included in the study. This fell short of the number that was calculated when we were determining our sample size. This smaller sample size will affect our statistical results and is a limitation of this study.

5.5 Stability and relapse

Retaining well-aligned incisors, post-treatment, is a crucial aspect of orthodontic treatment. Not only for aesthetics and patient satisfaction, but also to provide occlusal stability (Aasen and Espeland 2005). The relapse of the lower incisors can be caused by different factors (Little 1999). Increasing the proclination to alleviate arch length discrepancy increases the potential for relapse (Germec-Cakan, Taner, and Akan 2010).

5.6 Revisiting the null hypothesis

1. The lower incisor position will not change when growing patients are treated for crowding with Invisalign Teen® in a non-extraction approach with/without interproximal reduction.
    - There was a statistically significant change in the lower incisor position from TO and T1; therefore we reject the null hypothesis ($p<0.05$).

2. There will be no difference in the lower incisor position from Pre-treatment (T0) to Post-treatment (T1) between the different treated groups.
    - There were statistically significant changes between T0 and T1 between the Normal growth/moderate crowding compared to the other treated groups.
    - There were statistically significant changes between T0 and T1 between the Vertical growth/moderate crowding compared to the other treated groups. Therefore we reject the null hypothesis ($p<0.05$).

3. There will be no difference in the lower incisor position between the treated groups and control groups at T0 and T1.
    - There were statistically significant changes between T0 and T1 between the Normal and Vertical growth/moderate crowding compared to the control groups. Therefore we reject the null hypothesis ($p<0.05$).

CHAPTER 6

Conclusions

- There was no statistically significant change in any of the protrusion variables (L1-NBmm and L1-APogmm) between each of the different treated groups and control groups.

- There were no statistically significant changes in the inter-molar, premolar and canine widths between the groups. This shows that even though that there was a statistically significant increase in the buccal arch expansion in each of the groups, skeletal growth pattern and the amount of initial crowding did not affect the amount of expansion achieved.

- The difference in the mean values of the IPR in the 4 treated groups was less than 0.7mm. An increase in crowding did not correlate with a significant increase in IPR. These results show that buccal arch expansion and lower incisor proclination were the predominant contributors to crowding resolution between the different groups.

- There was also no statistically significant change in the growth of the bony chin (Pog-NB) between each of the different treated groups and control groups.

- The Normal/Mild, Vertical/Mild groups, Normal and Vertical control groups had no statistical significance differences between them.

- In the Vertical growth/ Moderate Crowding group, there were statistically significant increases in lower incisor angulation.

- In the Normal Growth/ Moderate Crowding group, there were statistically significant increases in lower incisor angulation.

- The Normal/Moderate group and the Vertical/Moderate group were statistically significant from each other in the Incisor angulation variables. The largest mean change difference was noted in the Normal growth/Moderate crowding group, for each of these three angulation variables.

- The difference in these means could be due to the backward internal rotation that is simultaneously occurring in vertical growing patients.

- Even though there was a statistically significant change in the proclination variables in these two groups, they still fell within the cephalometric norms. In both these groups, there was not excessive proclination of the lower incisors.

6.1 Recommendations

In all the different treatment groups, there was no excessive proclination of the lower incisor and stayed within cephalometric norms at T1. In mild and moderate cases with different skeletal growth patterns, orthodontists can comfortably treat patients without worrying about excessive proclination and periodontal health and stability.

Post-treatment arch dimensions were similar between all 4 groups. Pre-treatment arch width could be used as an important predictor of how much space can be gained via buccal arch expansion. Clinicians should take advantage of how much space can be gained by using this modality.

6.2 Future studies

Future studies should concentrate on increasing the sample size in order to increase the power of the study and decrease the risk of error.

Future studies should also widen the inclusion criteria to include patients with severe crowding and patients with horizontal growth patterns.

A 5 year follow up study to investigate the long term stability of these patients would be of value.

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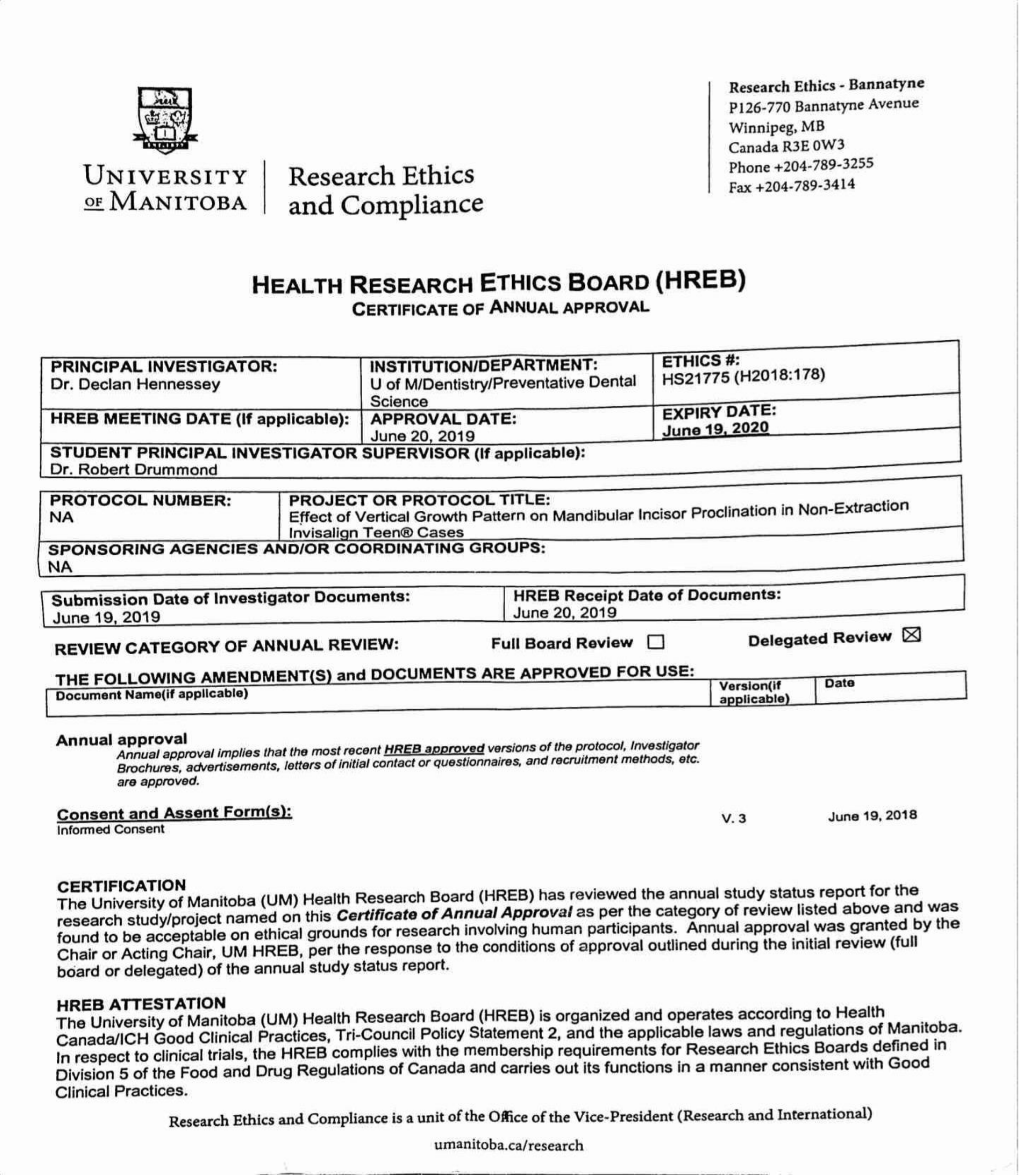
APPENDICES

Appendix 1 Ethics Approval



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HEALTH RESEARCH ETHICS BOARD (HREB)
CERTIFICATE OF ANNUAL APPROVAL

PRINCIPAL INVESTIGATOR: Dr. Declan Hennessey	**INSTITUTION/DEPARTMENT:** U of M/Dentistry/Preventative Dental Science	**ETHICS #:** HS21775 (H2018:178)
HREB MEETING DATE (If applicable):	**APPROVAL DATE:** June 20, 2019	**EXPIRY DATE:** **June 19, 2020**
STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable): Dr. Robert Drummond		

PROTOCOL NUMBER: NA	**PROJECT OR PROTOCOL TITLE:** Effect of Vertical Growth Pattern on Mandibular Incisor Proclination in Non-Extraction Invisalign Teen® Cases
SPONSORING AGENCIES AND/OR COORDINATING GROUPS: NA	

Submission Date of Investigator Documents: June 19, 2019	**HREB Receipt Date of Documents:** June 20, 2019

REVIEW CATEGORY OF ANNUAL REVIEW: **Full Board Review** ☐ **Delegated Review** ☒

THE FOLLOWING AMENDMENT(S) and DOCUMENTS ARE APPROVED FOR USE:

Document Name(if applicable)	Version(if applicable)	Date

Annual approval

*Annual approval implies that the most recent **HREB approved** versions of the protocol, Investigator Brochures, advertisements, letters of initial contact or questionnaires, and recruitment methods, etc. are approved.*

Consent and Assent Form(s):		
Informed Consent	V. 3	June 19, 2018

CERTIFICATION
The University of Manitoba (UM) Health Research Board (HREB) has reviewed the annual study status report for the research study/project named on this ***Certificate of Annual Approval*** as per the category of review listed above and was found to be acceptable on ethical grounds for research involving human participants. Annual approval was granted by the Chair or Acting Chair, UM HREB, per the response to the conditions of approval outlined during the initial review (full board or delegated) of the annual study status report.

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

Research Ethics and Compliance is a unit of the Office of the Vice-President (Research and International)

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Appendix 2 Journal Article

The effect of vertical growth pattern on mandibular incisor proclination in non-extraction Invisalign Teen® cases.

Objectives: To investigate the effect of vertical growth pattern on the position of the mandibular incisors for non-extraction Invisalign teen® patients, with or without interproximal reduction.

Materials and methods: A retrospective chart review consisting of 40 (26 girls; 14 boys) Caucasian growing patients in the permanent dentition (12- 18) was undertaken. Subjects were categorized into 4 groups based on the value of the pre-treatment lower dentition crowding and value of patients mandibular plane angle (MPA). Crowding was assessed as mild (0-3.9mm) or moderate (4-5.9mm) and MPA as normal growth (30-37°) or vertical growth (>37°). The sample provided 10 normal growth/mild crowding, 10 vertical growth/mild crowding, 10 normal growth/moderate crowding and 10 vertical growth/moderate crowding subjects. Measurements were taken from digitized cephalograms to determine the changes in the lower incisors from T0 (pre-treatment) to T1 (post-treatment). Interproximal reduction (IPR) and buccal expansion were recorded as contributing parameters to crowding resolution, using a paired t-test and ANOVA.

Results: No significant increase in buccal expansion between the 4 groups. No significant difference in the amount of IPR performed between the 4 groups.

Normal Growth/Moderate crowding showed statistically significant proclination of the lower incisors.Vertical Growth/Moderate crowding also showed statistically significant proclination of the lower incisors. ANOVA test showed more variance in proclination associated with normal growth/moderate crowding group.

Conclusion: L1 proclination was the most significant in the normal growth/moderate crowding group. The lower incisors did not protrude in any of the 4 groups

Introduction

Align technology ® launched Invisalign® in 1998, which uses 3D scans that are converted using stereolithographic technology (.stl) to a "virtual' study model. Clincheck® is their proprietary software, which is a 3D modeling program that allows for virtual simulation of ideal tooth alignment. Aligners are worn between 7-10 days each, allowing the teeth to move a maximum of 0.33mm per aligner[1].

Vertical facial form is a critical element of orthodontic assessment and treatment planning. Large variations in vertical dimension are observed in the population and must be taken into consideration for effective orthodontic treatment[2].

High angle malocclusion is characterized by increased inclination of the mandible in relation to anterior cranial base, with individuals exhibiting a mandibular plane angle greater than 37 degrees[3]. High angle malocclusion can present as hyperdivergency, long faced syndrome and adenoid face syndrome.

Dental compensation masks anterior-posterior and vertical basal bone inconsistencies in order to create a normal incisor relationship. In the vertical dimension, the compensation is established by changing the symphysis length and by incisor eruption[4].

Anterior crowding is one of the main complaints why people seek out orthodontic treatment[5]. Resolution of crowding in non-extraction cases can be achieved primarily through reduction in tooth mass with IPR, increase in arch perimeter with buccal expansion or incisor protrusion in the mandibular arch[6].To date there has been a couple of retrospective studies, that have looked to determine incisor angulation and position in non-extraction cases using Invisalign®

appliance[7]. These studies however, were done in non-growing patients. Our study used cephalometric analysis to determine incisor positon changes in growing patients after treatment and whether a vertical growth pattern had an effect on incisor position.

Materials and Methods

A sample of 40 Caucasian patients were selected from a single orthodontic practice. They were treated non-extraction with or without IPR using the Invisalign Teen® appliance. This retrospective chart review received ethical approval prior to the commencement of the study from the institutions research ethics board.

Cases was divided into 4 groups – based on the value of pre-treatment lower incisor crowding and value of patients' mandibular plane angle (MPA). The crowding is categorized into mild (0-3.9mm) and moderate (4-5.9mm) crowding using the Carey's analsyis[8]. For the purpose of this study a normal growth pattern was determined between the values of 30-37 degrees and >37 degrees was considered a vertical growth pattern[9]. All subjects included were growing, between the ages of 11-18 years old and in the Permanent dentition.

40 suitable cases were identified and subjects were divided up into:

- 10 Normal growth/ Mild crowding
- 10 Vertical growth/ Mild crowding
- 10 Normal growth/ Moderate crowding
- 10 Vertical growth/ Moderate crowding

Data Collection

Pre and Post treatment records were collected for each of the 40 samples and consisted of:

1. Digital study models created by .stl files from iTero® scans(iTero® , software version 4.0, Cadent Inc., Carlstadt, USA)
2. Digital lateral cephalometric radiographs taken by the Planmeca Proline CC digital radiographic machine (Planmeca Inc., Helsinki, Finland).
3. Digital study models of the dentition provided as .stl files provided from Align Technology (Align Technology , San Jose , CA).

Reliability testing

Interclass correlation coefficient test (ICC) was used for intra-rater and inter-rater reliability of the lateral cephalometric radiographs and iTero® 3D models. 20% of the sample group and control group were randomly selected and were re-measured by an independent examiner. 10 pre and post treatment lateral cephalometric radiographs and 3D models were re-measured for intra-rater and inter-rater at a second interval 2 weeks apart from the first measurements. Statistical software SPSS® Statistical Premium software (IBM Corp, Chicago, USA) was used to analyze the data.

Data measurement

The iTero® scans taken pre-treatment and post-treatment were uploaded as .stl files into OrthoCAD® (version 3.5.0; Cadent, Carlstadt, NJ). This software can calculate linear measurements OrthoCAD® was used to measure arch width and perimeter as well as the tooth width measurements.

Digitized cephalometric radiography

The T0 and T1 lateral cephalometric radiographs were exported as JPEG (.jpg) files onto Dolphin® imaging software. Radiographic Landmarks from Steiner and Ricketts cephalometric analysis that measure lower incisor angulation and position were completed[1213]. Identification was carried out by a single investigator to reduce error.

A number of variables were recorded for statistical analysis. These variables include:

- Interproximal reduction measured in millimeters, as measured from the TO and T1 digital models
- Treatment time taken for the lower arch
- Gender
- Age to establish that patients are within the inclusion criteria and are still growing
- Lower incisor position and angulation measurements from different cephalometric analysis at T0 and T1.
- Bony chin measurements at T0 and T1 to assess changes and possible effects on Lower incisor angulation.
- Arch width in the molar, premolar and canine at T0 and T1.

An ANOVA analysis of variants was carried out to analyse each of the variables. The ANOVA allowed us to analyse the effects that occur during Invisalign® treatment between each of the 4 groups and within each of the 4 groups. The variables that were measured at TO and T1 lateral cephalometric radiographs to assess changes included:

- L1 to NB(degrees)
- L1 to NB(mm)
- L1 to MPA(degrees)
- L1 to APog(degrees)
- L1 to APog(mm)
- Pog-NB

Arch expansion

The ANOVA was also carried out to determine changes in arch width that was recorded using T0 and T1 3D models as .stl files. Variables include:

- Canine expansion(mm)
- Premolar expansion(mm)
- Molar expansion(mm)

IPR

An ANOVA test was performed on the mean changes between the 4 treated groups. This was done to see if the amount of IPR carried out was similar in the 4 groups and whether the differences could affect our results.

Control

The control group with Skeletal Class I malocclusions was chosen from the archives of the Burlington Growth Centre obtained via the American Association of Orthodontists Foundation (AAOF) website. All subjects were Caucasian. Matched as closely as possible to gender, age, and categorized into two groups: normal MPA (30-37°) and vertical (>37°).Lateral cephalometric radiographs taken at age 14 (T0) and age 16 (T1). Measured changes in the variables of lower incisor proclination/protrusion as stated above were again measured to assess changes due to different growth patterns.

The results from the control were then compared to the treated sample by means of a Paired T test to compare changes of the lower incisor angulation and position. This allowed us to differentiate lower incisor changes due to growth and active treatment and to see if these changes differed due to the amount of crowding present and with different skeletal growth patterns.

Results

Reliability

Intra-rater and Inter-rater reliability was quantified using an intra-cluster correlation coefficient (ICC). The ICC values for both the lateral cephalometric radiographs and 3D models were in excess of 0.95 showing high reliability. These results show that the reproducibility of the 3D model measurements and cephalometric radiographs measurements are very reliable.

Treatment time for each individual group

Treatment time was determined by the total number of lower aligners worn by each patient. Each aligner was worn as prescribed by 1 week each. The results were divided into groups to determine the average treatment time of the normal/mild, vertical/mild, normal/moderate, vertical/moderate groups and shown in Table 1. The treatment time increased as the lower incisor crowding increased. This is due an increase iin the degree of tooth movement required to resolve the crowding.

Table 1 *Mean treatment time between different groups.*

Group	**Mean treatment time (Weeks)**	**Standard deviation (Weeks)**
Normal/Mild	50.5	23.3
Vertical/Mild	49.1	24.2
Normal/Moderate	62.7	19.9
Vertical/Moderate	65.4	18.1

Lower incisor changes

Cephalometric values were analyzed and measured using a paired t-test to determine if there were any statistical significant changes between the T0 and T1 cephalometric measurements for each of the different groups. Difference in these means established if there was a statistically significant change between the outcomes of T0 and T1 for the different variables. The p-value was considered to be significant at $p \leq 0.05$ with the confidence interval of 95%. Statistically significant variables for the following tables were noted with an * at the 95% confidence interval.

Evaluation of cephalometric changes within the Normal Growth /Mild Crowding Group between T0 and T1

Results for the paired t-test are shown on Table 2. Each of the variables tested had an increase in their mean values, however, none of the changes were statistically significant. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	**T0 mean**	**T1 mean**	**Difference means**	**Difference means 95% Cl**	**p-value**
L1-NB(deg)	24	25.2	1.2	(-0.087,1.213)	0.19
L1-NB(mm)	2.5	2.8	0.3	(0.04,1.39)	0.27
L1-MPA(deg)	90.2	91.4	1.2	(-2.89,0.89)	0.16
L1-APog(deg)	23.2	24.3	1.1	(-3.89,0.67)	0.17
L1-APog(mm)	2.8	3.1	0.3	(0.98,0.67)	0.45

Pog-NB	2.7	3.0	0.3	(0.89,0.56)	0.37

***Table 2** Paired T test of Normal Growth/ Mild Crowding variables. Statistically significant variables shown with an **

Evaluation of cephalometric changes within the Vertical/ Growth /Mild Crowding Group between T0 and T1

Results for the paired t-test are shown on Table 3. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	**T0 mean**	**T1 mean**	**Difference means**	**Difference means 95% Cl**	**p-value**
L1-NB(deg)	23.4	24.5	1.1	(-0.067,1.31)	0.18
L1-NB(mm)	2.1	2.5	0.4	(0.08,1.24)	0.18
L1-MPA(deg)	90.6	90.5	-0.1	(-2.57,0.78)	0.19
L1-APog(deg)	24.3	24.1	0.8	(-3.34,0.89)	0.35
L1-APog(mm)	3	2.9	-0.1	(0.98,0.76)	0.55
Pog-NB	2.5	2.7	0.2	(0.79,0.96)	0.77

***Table 3** Paired T test of Vertical Growth/ Mild Crowding variables. Statistically significant variables shown with an **

Evaluation of cephalometric changes within Normal Control between T0 and T1

Results for the paired t-test are shown on Table 4. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	T0 mean	T1 mean	Difference means	Difference means 95% Cl	p-value
L1-NB(deg)	24.1	25.2	1.1	(-0.067,1.11)	0.29
L1-NB(mm)	2.5	2.6	0.1	(0.07,1.89)	0.37
L1-MPA(deg)	89.9	90.9	1.0	(-1.89,0.59)	0.26
L1-APog(deg)	23.5	24.4	0.9	(-2.69,0.77)	0.37
L1-APog(mm)	2.5	2.8	0.3	(0.78,0.37)	0.45
Pog-NB	2.6	2.8	0.2	(0.79,0.46)	0.57

***Table 4** Paired T test of Normal Control variables. Statistically significant variables shown with an **

Evaluation of cephalometric changes within the Vertical Control Group between T0 and T1

Results for the paired t-test are shown on Table 5. There was no statistically significant change in the position and angulation of the lower incisor between T0 and T1.

Dependent Variable	T0 mean	T1 mean	Difference means	Difference means 95% Cl	p-value

L1-NB(deg)	25	24.2	-0.8	(-0.057,2.21)	0.69
L1-NB(mm)	2.5	2.3	-0.2	(0.09,1.46)	0.27
L1-MPA(deg)	90.9	89.8	-1.1	(-2.69,0.79)	0.16
L1-APog(deg)	24.5	23.8	-0.7	(-1.9,0.68)	0.47
L1-APog(mm)	3	2.7	-0.3	(0.58,0.47)	0.55
Pog-NB	3	2.9	-0.1	(0.49,0.69)	0.27

Table 5 *Paired T test of Vertical Control variables. Statistically significant variables shown with an **

Evaluation of cephalometric changes within the Vertical Growth /Moderate Crowding Group between T0 and T1

Results for the paired t-test are shown on Table 6. There was statistically significant changes in the proclination variables between T0 and T1 in this group. The mean change difference in the L1-NB (deg) , L1-MPA(deg) and the L1-APog(deg) between T0 and T1 was statistically significant.

Dependent Variable	**T0 mean**	**T1 mean**	**Difference means**	**Difference means 95% Cl**	**p-value**
L1-NB(deg)	24.1	26.3	2.2	(-.2467,1.47)	0.018*
L1-NB(mm)	1.7	2.6	0.9	(-2.78,1.98)	0.29
L1-MPA(deg)	90.4	93.1	2.7	(-3.69,0.98)	0.005*
L1-APog(deg)	23.0	25.5	2.5	(-2.89,0.68)	0.034*
L1-APog(mm)	2.4	3	0.6	(0.48,0.97)	0.45
Pog-NB	3	2.9	-0.1	(0.29,0.79)	0.23

Table 6 *paired T test of Vertical Growth/ Moderate Crowding variables. Statistically significant variables shown with an **

Evaluation of cephalometric changes within the Normal Growth /Moderate Crowding Group between T0 and T1

Results for the paired t-test are shown on Table 7. There was statistically significant changes in the proclination variables between T0 and T1 in this group. The mean difference change in the L1-NB (deg), L1-MPA(deg) and the L1-APog(deg) between the T0 and T1 was statistically significant.

Dependent Variable	**T0 mean**	**T1 mean**	**Difference means**	**Difference means 95% Cl**	**p-value**
L1-NB(deg)	23.5	26.5	3.0	(-2.78,.2.43)	0.034*
L1-NB(mm)	2.6	2.9	0.3	(0.8,1.21)	0.37
L1-MPA(deg)	91.2	94.2	3.0	(-3.4,2.1)	0.01*
L1-APog(deg)	23.6	26.7	3.1	(-2.3,1.9)	0.02*
L1-APog(mm)	2.5	3.2	0.7	(1,0.9)	0.45
Pog-NB	2.8	3.1	0.3	(0.9,0.46)	0.57

Table 7 *Paired T test of Normal Growth/ Moderate Crowding variables. Statistically significant variables shown with an **

Evaluation of Cephalometric changes between each Group between T0 and T1

An analysis of variance (ANOVA) was used to analyze the difference between the groups means using a group p-value. The p-value value was at a 95% confidence interval to determine if the lower incisor position change was statistically significant between the 4 groups and 2 control groups. The different treated and control groups were then paired together to determine if the groups were statistically significant to each other at the 95% confidence interval. Pairwise p-value was set at p ≤0.05.

The variables were compared between the different groups to determine if the different growth patterns and amount of crowding had a statistically significant difference in the change in the lower incisor position between each of the groups and shown in table 8. Statistical significance was when the p value was p ≤0.05.

Dependent Variable	**Group**	**Group p value**	**Group means**	**Pairwise p-values**

L1-NB(deg)	Normal/Moderate Vertical/Moderate Normal/Mild Vertical/Mild Normal/Control Vertical/Control	0.0178*	26.5 26.3 25.2 24.5 25.2 24.2	Norm/Mod vs Vert/Mod Norm/Mod vs Norm/Mild Norm/Mod vs Vert/Mild Norm/Mod vs Norm/Con Norm/Mod vs Vert/Con Vert/Mod vs Norm/Mild Vert/Mod vs Vert/Mild Vert/Mod vs Norm/Con Vert/Mod vs Vert/Con Norm/Mild vs Vert/Mild Norm/Mild vs Norm/Con Norm/Mild vs Vert/Con Vert/Mild vs Norm/Con Vert/Mild vs Vert/Con Norm/Con vs Vert/Con	0.049* 0.037* 0.045* 0.038* 0.027* 0.039* 0.048* 0.041* 0.032* 0.238 0.067 0.078 0.089 0.098 0.087

L1-NB(mm)	Normal/Moderate	0.7834	2.9	Norm/Mod vs Vert/Mod	0.087
	Vertical/Moderate		2.6	Norm/Mod vs Norm/Mild	0.068
	Normal/Mild		2.8	Norm/Mod vs Vert/Mild	0.078
	Vertical/Mild		2.5	Norm/Mod vs Norm/Con	0.065
	Normal/Control		2.6	Norm/Mod vs Vert/Con	0.055
	Vertical/Control		2.3	Vert/Mod vs Norm/Mild	0.098
				Vert/Mod vs Vert/Mild	0.067
				Vert/Mod vs Norm/Con	0.054
				Vert/Mod vs Vert/Con	0.087
				Norm/Mild vs Vert/Mild	0.098
				Norm/Mild vs Norm/Con	0.12
				Norm/Mild vs Vert/Con	0.09
				Vert/Mild vs Norm/Con	0.065
				Vert/Mild vs Vert/Con	0.23
				Norm/Con vs Vert/Con	0.43

L1-MPA	Normal/Moderate Vertical/Moderate Normal/Mild Vertical/Mild Normal/Control Vertical/Control	0.0098*	94.2 93.1 91.4 90.5 90.9 89.8	Norm/Mod vs Vert/Mod Norm/Mod vs Norm/Mild Norm/Mod vs Vert/Mild Norm/Mod vs Norm/Con Norm/Mod vs Vert/Con Vert/Mod vs Norm/Mild Vert/Mod vs Vert/Mild Vert/Mod vs Norm/Con Vert/Mod vs Vert/Con Norm/Mild vs Vert/Mild Norm/Mild vs Norm/Con Norm/Mild vs Vert/Con Vert/Mild vs Norm/Con Vert/Mild vs Vert/Con Norm/Con vs Vert/Con	0.015* 0.001* 0.002* 0.003* 0.001* 0.039* 0.02* 0.03* 0.003* 0.234 0.067 0.087 0.324 0.078 0.987

L1-APog(deg)	Normal/Moderate Vertical/Moderate Normal/Mild Vertical/Mild Normal/Control Vertical/Control	0.027*	26.7 25.5 24.3 25.1 24.4 23.8	Norm/Mod vs Vert/Mod Norm/Mod vs Norm/Mild Norm/Mod vs Vert/Mild Norm/Mod vs Norm/Con Norm/Mod vs Vert/Con Vert/Mod vs Norm/Mild Vert/Mod vs Vert/Mild Vert/Mod vs Norm/Con Vert/Mod vs Vert/Con Norm/Mild vs Vert/Mild Norm/Mild vs Norm/Con Norm/Mild vs Vert/Con Vert/Mild vs Norm/Con Vert/Mild vs Vert/Con Norm/Con vs Vert/Con	0.045* 0.023* 0.019* 0.005* 0.001* 0.034* 0.047* 0.037* 0.002* 0.087 0.068 0.078 0.089 0.076 0.067

L1-APog(mm)	Normal/Moderate	0.2856	3.2	Norm/Mod vs Vert/Mod	0.089
	Vertical/Moderate		3	Norm/Mod vs Norm/Mild	0.453
	Normal/Mild		3.1	Norm/Mod vs Vert/Mild	0.674
	Vertical/Mild		2.9	Norm/Mod vs Norm/Con	0.076
	Normal/Control		2.8	Norm/Mod vs Vert/Con	0.089
	Vertical/Control		2.7	Vert/Mod vs Norm/Mild	0.076
				Vert/Mod vs Vert/Mild	0.088
				Vert/Mod vs Norm/Con	0.673
				Vert/Mod vs Vert/Con	0.083
				Norm/Mild vs Vert/Mild	0.432
				Norm/Mild vs Norm/Con	0.216
				Norm/Mild vs Vert/Con	0.091
				Vert/Mild vs Norm/Con	0.451
				Vert/Mild vs Vert/Con	0.231
				Norm/Con vs Vert/Con	0.102

Pog-NB	Normal/Moderate	0.987	3.1	Norm/Mod vs Vert/Mod	0.089
	Vertical/Moderate		2.9	Norm/Mod vs Norm/Mild	0.067
	Normal/Mild		3.0	Norm/Mod vs Vert/Mild	0.078
	Vertical/Mild		2.7	Norm/Mod vs Norm/Con	0.123
	Normal/Control		2.8	Norm/Mod vs Vert/Con	0.234
	Vertical/Control		2.9	Vert/Mod vs Norm/Mild	0.087
				Vert/Mod vs Vert/Mild	0.098
				Vert/Mod vs Norm/Con	0.123
				Vert/Mod vs Vert/Con	0.487
				Norm/Mild vs Vert/Mild	0.077
				Norm/Mild vs Norm/Con	0.087
				Norm/Mild vs Vert/Con	0.067
				Vert/Mild vs Norm/Con	0.078
				Vert/Mild vs Vert/Con	0.123
				Norm/Con vs Vert/Con	0.098

Table 8 *ANOVA test between the treated groups and control groups variables. Statistically significant variables shown with an **

Buccal expansion comparisons using iTero® 3D models between the Groups

Outcome	Group	Group p value	Group means	Pairwise p-values *p<0.05	
Canine	Norm/Mild	0.814	25.69	Norm/Mod vs Vert/Mod	0.98
	Vert/Mild		25.79	Norm/Mod vs Norm/Mild	0.78
	Norm/Mod		25.63	Norm/Mod vs Vert/Mild	0.06
	Vert/Mod		25.71	Vert/Mod vs Norm/Mild	0.34
				Vert/Mod vs Vert/Mild	0.75
				Norm/Mild vs Vert/Mild	0.56
Premolar	Norm/Mild	0.1134	28.46	Norm/Mod vs Vert/Mod	0.34
	Vert/Mild		26.91	Norm/Mod vs Norm/Mild	0.65
	Norm/Mod		26.74	Norm/Mod vs Vert/Mild	0.45
	Vert/Mod		27.15	Vert/Mod vs Norm/Mild	0.87
				Vert/Mod vs Vert/Mild	0.97
				Norm/Mild vs Vert/Mild	0.65
Molar	Norm/Mild	0.1437	34.12	Norm/Mod vs Vert/Mod	0.38
	Vert/Mild		34.99	Norm/Mod vs Norm/Mild	0.19
	Norm/Mod		34.69	Norm/Mod vs Vert/Mild	0.72
	Vert/Mod		32.99	Vert/Mod vs Norm/Mild	0.61
				Vert/Mod vs Vert/Mild	0.14

				Norm/Mild vs Vert/Mild	0.31

***Table 9** ANOVA of Buccal expansion between the different groups. Statistically significant variables shown with an **

There was no statistically significant changes in the inter-molar, premolar and canine widths between the Groups shown in Table 9. This shows that even though that there was a statistically significant increase in the buccal arch expansion in each of the groups, Skeletal Growth pattern and the amount of crowding didn’t affect the amount of expansion achieved.

IPR

An ANOVA test was performed on the mean changes between the 4 treated groups. This was done to see if the amount of IPR carried out was similar in the 4 groups and whether the differences could affect our results.

Outcome	**Group**	**Group p value**	**Group means**	**Pairwise p-values**	**$^*p < 0.05$**
IPR	Norm/Mild	0.614	1.25	Norm/Mod vs Vert/Mod	0.78
	Vert/Mild		1.17	Norm/Mod vs Norm/Mild	0.98
	Norm/Mod		1.35	Norm/Mod vs Vert/Mild	0.08
	Vert/Mod		1.54	Vert/Mod vs Norm/Mild	0.45
				Vert/Mod vs Vert/Mild	0.87
				Norm/Mild vs Vert/Mild	0.38

Table 10 *ANOVA test showing amount of IPR between the different groups. Statistically significant variables shown with an **

Table 10 shows the results of ANOVA analysis used to compare between the 4 treated Groups. There was no statistically significance in the amount of the IPR performed between the 4 groups.

Discussion

To date, there has been no cephalometric studies done to determine the effects of Invisalign Teen$^{®}$ on growing patients and whether the lower incisor position will be effected by different skeletal growth patterns in non extraction cases.

The mean increase in Inter-molar-width was 1.98mm in the Normal Growth/Mild Crowding Group, 2.01mm in the Vertical Growth/Mild Crowding, 1.67mm in the Vertical/Moderate Group and 2mm in the Normal Growth/Moderate Crowding. Inter-Premolar widths increased 1.68mm, 1.34mm, 1.38mm, 1.77mm respectively. Inter-canine widths increased 1.37mm,1.67mm,1.56mm,1.98mm respectively.

These results showed there was no statistically significant changes in the inter-molar, premolar and canine widths between the Groups. This shows that even though that there was a statistically significant increase in the buccal arch expansion in each of the groups, Skeletal Growth pattern and the amount of initial crowding didn't affect the amount of expansion achieved. The amount of initial crowding did not affect the post-treatment transverse dimension . The results of this study mirrored that of Duncan et al (2016).

By comparing the treated and control groups with similar growth patterns at similar time points, we are able to determine how much of the change in the lower incisor angulation was due from active orthodontic treatment but also see the slight changes that occurred naturally due to growth in the control groups.

There was no statistically significant change in any of the protrusion variables (L1-NBmm and L1-APogmm) between each of the different treated groups and Control Groups.

There was also no statistically significant change in the growth of the bony chin (Pog-NB) between each of the different treated groups and Control Groups.

The Normal/Mild, Vertical/Mild groups, Normal and Vertical Control Groups had no statistical significance between them ($p > 0.05$).

In the Vertical Growth/ Moderate Crowding group there was statistically significant increases ($p < 0.05$) in lower incisor angulation. Mean angulation changes were from 24.3° to 26.3° for L1-NB (deg), 90.4° to 93.1° for L1-MPA, 23.0° to 25.5° for L1-APog.

In the Normal Growth/ Moderate Crowding group there was statistically significant increases ($p < 0.05$) in lower incisor angulation. Mean angulation changes were from 23.3° to 26.5° for L1-NB (deg), 91.2° to 94.2° for L1-MPA, 23.6° to 26.7° for L1-APog.

The Mean changes for the Incisor angulation in the Vertical growth/Moderate crowding was:

- L1-NB(deg) 2.2° +/- 1.8°
- L1-MPA(deg) 2.7° +/- 2.0°
- L1-APog(deg) 2.5° +/- 1.5°

The Mean changes for the Incisor angulation in the Normal growth/Moderate crowding was:

- L1-NB(deg) 3.0° +/- 1.7°
- L1-MPA(deg) 3.0° +/- 2.3°
- L1-APog(deg) 3.1° +/- 1.9°

The Normal/Moderate Group and the Vertical/Moderate Group were statistically significant from each other in the Incisor angulation variables (L1-NB, L1-MPA, L1-APog). The largest mean change difference was noted in the Normal/Moderate Group for each of these three variables.

The difference in these means could be due to the backward internal rotation that is simultaneously occurring in vertical growing patients as previously reported by Bjork[10].

Remodeling of the ramus and apposition along the posterior border including the condylar process. Resorption occurs on the anterior Ramus. Lower molar eruption is impeded by this abnormal growth which results in not sufficiently uprighting of the teeth to compensate for the internal rotation. There is compensatory increased eruption of the lower incisors and they become more retroclined[11]. This mechanism could account for the difference in mean Changes between the Vertical growth/Moderate crowding and Normal growth/Moderate crowding Groups.

Cephalometric norms for the lower incisor proclination variables used in this study were:

L1-MPA – 90° +/-5° (Tweed)

L1-NB- 25° +/- 4° (Steiner)

L1-APog 21° +/- 6.4° (Ricketts)

The difference in mean values of the IPR in the 4 treated groups was less than 0.7mm. An increase in crowding did not correlate with a significant increase in IPR ($p>0.05$).

These results show that buccal arch expansion and lower incisor proclination were the predominant contributors to crowding resolution in the Vertical growth/Moderate crowding group and Normal growth/Moderate crowding group.

Conclusions

The Normal/Mild, Vertical/Mild groups, Normal and Vertical Control Groups had no statistical significance between them.

In the Vertical Growth/ Moderate Crowding group there was statistically significant increases in lower incisor angulation.

In the Normal Growth/ Moderate Crowding group there was statistically significant increases in lower incisor angulation

The Normal/Moderate Group and the Vertical/Moderate Group were statistically significant from each other in the Incisor angulation variables. The largest mean change difference was noted in the Normal growth/Moderate crowding Group for each of these three angulation variables.

The difference in these means could be due to the backward internal rotation that is simultaneously occurring in vertical growing patients.

Even though there was a statistically significant change in the proclination variables in these two groups, they still fell within the cephalometric norms. In both these groups, there wasn't excessive proclination of the lower incisor

There was no statistically significant changes in the inter-molar, premolar and canine widths between the Groups. This shows that even though that there was a statistically significant increase in the buccal arch expansion in each of the groups, Skeletal Growth pattern and the amount of initial crowding didn't affect the amount of expansion achieved.

The difference in mean values of the IPR in the 4 treated groups was less than 0.7mm. An increase in crowding did not correlate with a significant increase in IPR. These results show that buccal arch expansion and lower incisor proclination were the predominant contributors to crowding resolution between the different groups.

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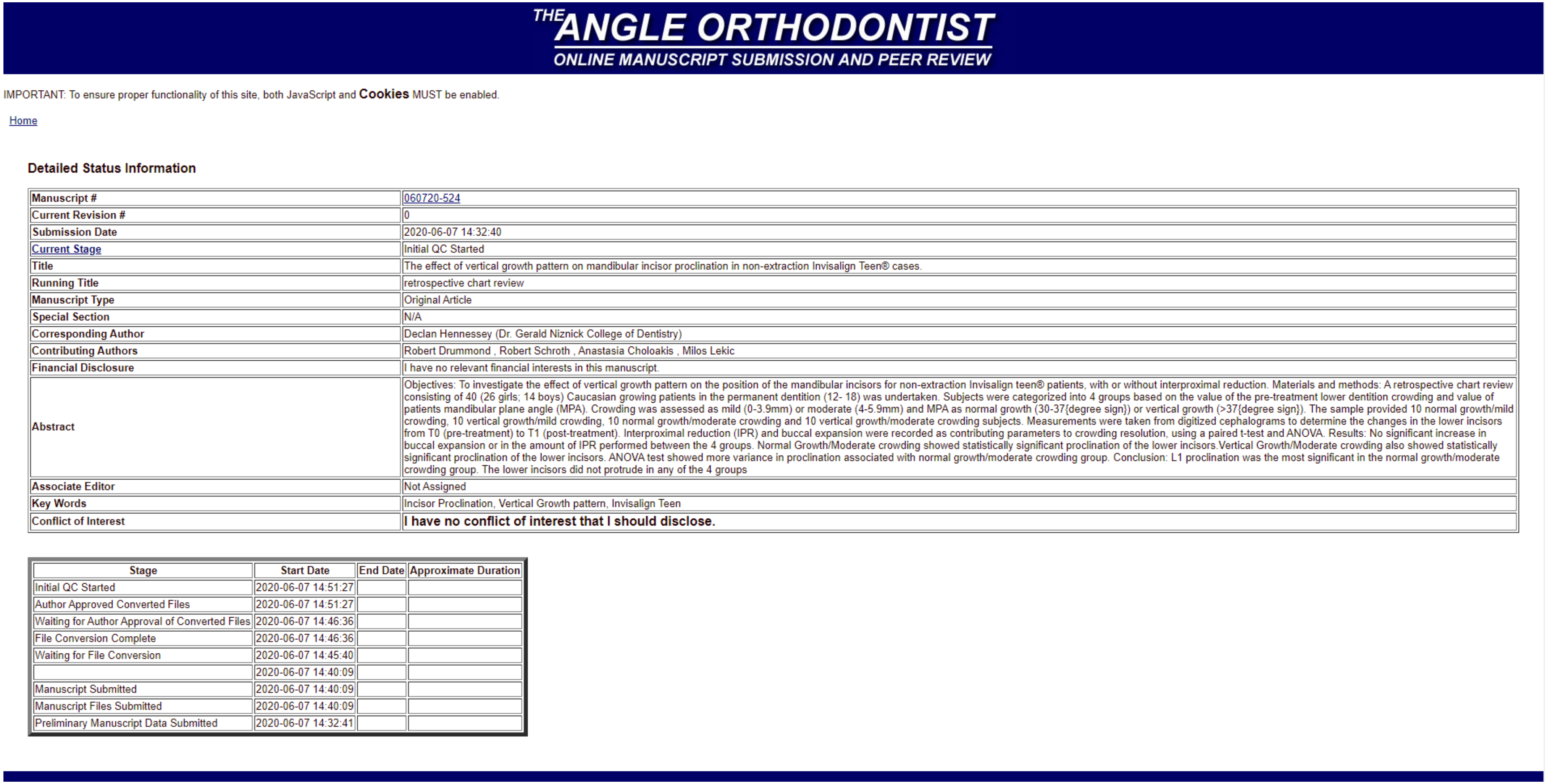

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Manuscript #	060720-524
Current Revision #	0
Submission Date	2020-06-07 14:32:40
Current Stage	Initial QC Started
Title	The effect of vertical growth pattern on mandibular incisor proclination in non-extraction Invisalign Teen® cases.
Running Title	retrospective chart review
Manuscript Type	Original Article
Special Section	N/A
Corresponding Author	Declan Hennessey (Dr. Gerald Niznick College of Dentistry)
Contributing Authors	Robert Drummond , Robert Schroth , Anastasia Choloakis , Milos Lekic
Financial Disclosure	I have no relevant financial interests in this manuscript.
Abstract	Objectives: To investigate the effect of vertical growth pattern on the position of the mandibular incisors for non-extraction Invisalign teen® patients, with or without interproximal reduction. Materials and methods: A retrospective chart review consisting of 40 (26 girls; 14 boys) Caucasian growing patients in the permanent dentition (12- 18) was undertaken. Subjects were categorized into 4 groups based on the value of the pre-treatment lower dentition crowding and value of patients mandibular plane angle (MPA). Crowding was assessed as mild (0-3.9mm) or moderate (4-5.9mm) and MPA as normal growth (30-37{degree sign}) or vertical growth (>37{degree sign}). The sample provided 10 normal growth/mild crowding, 10 vertical growth/mild crowding, 10 normal growth/moderate crowding and 10 vertical growth/moderate crowding subjects. Measurements were taken from digitized cephalograms to determine the changes in the lower incisors from T0 (pre-treatment) to T1 (post-treatment). Interproximal reduction (IPR) and buccal expansion were recorded as contributing parameters to crowding resolution, using a paired t-test and ANOVA. Results: No significant increase in buccal expansion or in the amount of IPR performed between the 4 groups. Normal Growth/Moderate crowding showed statistically significant proclination of the lower incisors.Vertical Growth/Moderate crowding also showed statistically significant proclination of the lower incisors. ANOVA test showed more variance in proclination associated with normal growth/moderate crowding group. Conclusion: L1 proclination was the most significant in the normal growth/moderate crowding group. The lower incisors did not protrude in any of the 4 groups
Associate Editor	Not Assigned
Key Words	Incisor Proclination, Vertical Growth pattern, Invisalign Teen
Conflict of Interest	**I have no conflict of interest that I should disclose.**

Stage	Start Date	End Date	Approximate Duration
Initial QC Started	2020-06-07 14:51:27		
Author Approved Converted Files	2020-06-07 14:51:27		
Waiting for Author Approval of Converted Files	2020-06-07 14:46:36		
File Conversion Complete	2020-06-07 14:46:36		
Waiting for File Conversion	2020-06-07 14:45:40		
	2020-06-07 14:40:09		
Manuscript Submitted	2020-06-07 14:40:09		
Manuscript Files Submitted	2020-06-07 14:40:09		
Preliminary Manuscript Data Submitted	2020-06-07 14:32:41		