Lower Incisor Stability Following Orthodontic Treatment using a Fixed Spring Induced Appliance (FSIA)

By

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Abstract

Objective: To evaluate the position of the lower incisors in subjects with different facial patterns following use of a fixed spring induced appliance (FSIA) and full fixed multi-banded/bonded orthodontic therapy (FMB treatment).

Materials and Methods: A retrospective sample of 115 subjects exhibiting class II malocclusions was used. Subjects were categorized into three growth types according to pre-treatment cephalometric variables (MP-SN and Y-axis), which yielded 28 brachycephalic, 54 mesocephalic, and 31 dolichocephalic subjects. An *ANOVA* test statistic was used to investigate the differences between the three facial groups. Lateral cephalograms were taken at initial treatment (T0), post-FSIA treatment (T1) & end of active FMB treatment (T2).

Results: Dental changes induced by the FSIA & FMB treatment (T2-T0) included: retroclination of the lower incisors (L1-MP: 1.7°±0.9, L1-APo: 3.4°±0.8, L1-NB: 2.2°±0.9), retrusion of the lower incisors (L1-APo: 1.7mm±0.3, L1-NB: 0.2mm±0.06), reduction in the overjet (4mm±0.2) and the overbite (2.8mm±0.3). Facial patterns were not significantly influenced by the FSIA and FMB treatment (MP-SN: 1.8°±0.6; Y-Axis: 0.9°±0.5). Reduction of the skeletal Class II relationship was represented by a significant decrease ($p<0.05$) of the Wits value (2.3mm±0.2) in all three groups. Lower incisor angular and linear changes at T2 were all proclined and protruded to the initial values at T0.

Conclusions: The lower incisors at the end of treatment (T2) remained within

normal cephalometric values. The overall change in the position of the lower incisors was proclination and protrusion at T2-T0 and retroclination and retrusion at T2-T1. When T2-T0 was compared, the lower incisors were proclined and protruded to their original position. Facial growth pattern appeared to be unrelated to the amount of dental movement and there was a trend for more pronounced dental retroclination and retrusion of the lower incisors in brachycephalic patients.

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Dedication

To my parents, Anne and Osmond, you are the most loving, supportive and selfless people in the world. Words cannot express how much I love you both. Without your patience, guidance, and support my education would not be possible.

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Chapter 1

Introduction

1.1 Preamble

A number of studies have investigated the stability of the mandibular incisors following orthodontic treatment and into the retention period. Their position has been the focus of numerous articles and is an important factor for treatment planning.

Orthodontists are commonly faced with Class II malocclusions in their practices. For years, research has been conducted to evaluate the differences among patients with Class II malocclusions, the etiology of Class II malocclusions and different methods to correct this malocclusion. There are a variety of techniques that may be used such as an extraction pattern, fixed appliances, distalizing appliances, extra-oral headgear, functional appliances, intermaxillary elastics, and surgical correction.

The main purpose of orthodontics can usually be defined as the creation of the best balance between occlusal relationships, dental esthetics and facial esthetics. Stability of the result as well as the long-term maintenance of the dentition is also critical (Proffit, 2000). As clinicians it is important to understand the effects that the appliances have and the bio-mechanics of the bracket preferences, in order not to violate the lower incisor position, or to minimize the change in the lower incisor position in order to achieve long-term stability, especially in Class II cases.

There are many methods and approaches today to help diagnose and treatment plan in order to obtain the most esthetic, balanced, functional and stable result. The use of cephalometric radiography has made it possible to examine and plan for a more ideal result best suited to the individual patient. Lower incisor position and stability has been a topic for many years. A crucial aspect in treatment planning is the initial position of the lower incisors, if it is reasonable to alter the position of the lower incisors and the expectations of long-term stability after treatment (Houston & Edler, 1990). Weinstein et al (1963) stated that the lower incisors are in a state of equilibrium between opposing pressure from the labial and lingual musculature. Due to this, their labio-lingual position should not be changed by orthodontic treatment. Mills et al (Mills, 1966) substantiates this through his research claiming the lower incisors lie in a narrow window of stability and their initial position should be accepted.

Studies have shown that different Class II correctors have a tendency to procline the lower incisors and therefore change their position, leading to an altered post-treatment position of the lower incisors. Studies have also shown that it is important to take into account the projected final position of the lower incisors because this will determine the retention protocol.

With the continuous advancements in technology, biomaterials and inventions with new appliances, clinicians should not only evaluate the immediate effects of Class II correctors but also post-treatment and long-term effects of appliances after full fixed multi banded/bonded orthodontic therapy (FMB treatment) is completed, on the position of the lower incisor. Understanding the benefits and limitations of different appliances has the potential to improve the mechanics and the final results. Knowing the limitations of these appliances can assist clinicians in realizing they may have to make changes to account for deleterious results or unanticipated side effects. The results from the use of a Class II corrector followed by FMB treatment suggest that treatment mechanics may play a significant role in the stability of the lower incisor position.

The purpose of this study was to evaluate lower incisor position following the use of a fixed spring-induced appliance (FSIA) and FMB treatment.

1.2 Purpose

The purpose of this study was to evaluate the lower incisor position after comprehensive full fixed multi-banded/bonded orthodontic therapy (FMB treatment) in conjunction with a fixed spring induced appliance (FSIA).

1.3 Null Hypothesis

#1. There will be no change in the lower incisors position between T0 and T2.

#2. There will be no change in the lower incisors position between T1 and T2

#3. There will be no change or effect on the facial pattern with the use of FSIA in conjunction with full fixed multi-banded/bonded treatment (FMB treatment).

T0 – Initial pre-treatment; T1 – completion of FSIA-treatment; T2 – post-orthodontic treatment.

Chapter 2

Literature Review

2.1 Classification of Malocclusion

Based on a study carried out by the National Health and Nutrition Estimates Survey III (NHANES III) between 1989-1994 in the U.S. population Class II malocclusion was prevalent in about 15% of the population. Approximately 16.1% had a unilateral Class II malocclusion and 22.7% exhibited a bilateral Class II malocclusion. Profitt et al. investigated this sample which included information on more than 7,000 individuals and assumed that individuals with an overjet of 5mm or more have a Class II malocclusion. They found that in 20% of children ages 8-11 years old had an overjet of 5mm or more. This percentage decreased to 13% in the adult population. The etiology of a Class II malocclusion is multifactorial and can be a dental and/or skeletal abnormality. A Class II malocclusion defined by Angle's classification is based on the mesial-buccal cusp of the first maxillary molar being ahead of or mesial to the buccal groove of the first mandibular molar. A Class II malocclusion has been further subdivided into two different types. The first type is a Class II division 1, characterized by the maxillary incisors in a proclined and protruded position resulting in an increased overjet and an increased overbite. The second type, is a Class II division 2 characterized by the maxillary central incisors in a retroclined position, the maxillary lateral incisors in a proclined position with a reduced overjet and an increased overbite relationship (Chana, 2013). These divisions of this malocclusion are characterized by a unilateral or bilateral relationship of the molars. Unilateral cases are termed as a subdivision to the affected side.

Transverse dental arch development of a Class II division 1 malocclusion occurred differently to the other types of Class II malocclusions. According to McNamara, a relative constriction of the maxillary arch was present at the earlier stages of the developing Class II malocclusion (McNamara Jr., 1981). However, there is still disagreement pertaining to this issue and it is thought by some authors to treat a transverse discrepancy as an anteroposterior discrepancy when a Class II malocclusion exists (Bishara, 2006). Cephalometric research of Class II malocclusions helps in delineating the key characteristics of the disorder. There are specific cephalometric characteristics of both divisions of the Class II malocclusions. According to Bishara (Bishara, 2006) the following features characterize a Class II division 1 malocclusion:

- Anterior location of the maxilla and teeth in relationship to the cranium.
- Anterior location of the maxillary teeth in a normally positioned maxilla.
- Posterior location of the mandible, which is of normal size.
- Deficient development of the mandible.
- Posterior placement of the mandibular teeth on a mandible situated in the normal position.
- A combination of any of the above characteristics.

Comprehensive studies of McNamara indicated that Class II malocclusions did not occur as a single clinical entity, and usually represents the result of numerous combinations of contributing factors. Moreover, only a small number of the reviewed cases included maxillary skeletal protrusion related to the cranial base structures, which indicates that the maxilla is predominantly found in the neutral position (McNamara Jr., 1981). The most typical characteristics of a Class II malocclusion were mandibular skeletal retrusion with excessive vertical development (McNamara Jr., 1981).

2.2 Class II Treatment

There are numerous options for the treatment of a Class II malocclusion depending on the etiology and treatment objectives. With the continuous advancements in technology and biomaterials, there is continuous development of new appliances. Class II malocclusions must first be distinguished if they are dental and/or skeletal in nature. Examples of appliances to correct dental class II malocclusions are fixed Class II correctors and removable class II correctors. Some examples of skeletal Class II correctors are functional appliances, such as a Bionator, Twin Block, and Frankel appliance. Functional appliances became popular in the 1930s in Europe with the Andresen activator and gained popularity in the United States in the 1980s (Proffit, Fields, & Sarver, 2012). The mechanism of action of functional appliances is through posturing of the mandible forward, protracting the condylar head out of the glenoid fossa and thereby moving the anterior teeth into an edge-to-edge relationship. This forward positioning was thought to ultimately enhance and stimulate mandibular growth with a subsequent correction of the skeletal and dental Class II malocclusions. Current research shows that an acceleration of mandibular growth occurs with no remarkable difference in total mandibular growth when growth is completed (Aelbers & Dermaut, 1996; Ormiston, Huang, Little, Decker, & Seuk, 2005). Ultimately a dento-alveolar effect was observed with functional appliances by restricting the forward movement of the upper molar and correcting the Class II malocclusion by anterior displacement of the mandibular dento-alveolar complex.

Fixed spring force induced appliances became another popular option for dentally correcting a Class II malocclusion because they take the responsibility and co-operation away from the patient, to obtain a positive treatment outcome. Some examples of such appliances include the Distal Jet, Xbow™ appliance, Jasper Jumper™, and Forsus™ spring, to name a few. Papadopoulos states, "Non-compliance approaches provide an important treatment alternative for patients with a Class II malocclusion who present minimal or no cooperation, especially when non-extraction protocols have to be utilized" (Papadopoulos, 2006). These fixed Class II correctors operate through distalization of maxillary molars to achieve a Class I relationship. The Herbst appliance differs from the other fixed spring force induced appliances by repositioning the head of the condyle.

The Herbst appliance was created in 1905 in Berlin and consists of an upper and lower fixed appliance linked by a telescopic mechanism (Figure 2.1). This mechanism holds the mandible forward in a protruded position throughout treatment to modify mandibular growth (Chaukse, 2011). It has proven to be an effective inter-arch method to correct Class II malocclusions with some skeletal influence (Mcsherry & Bradley, 2000)

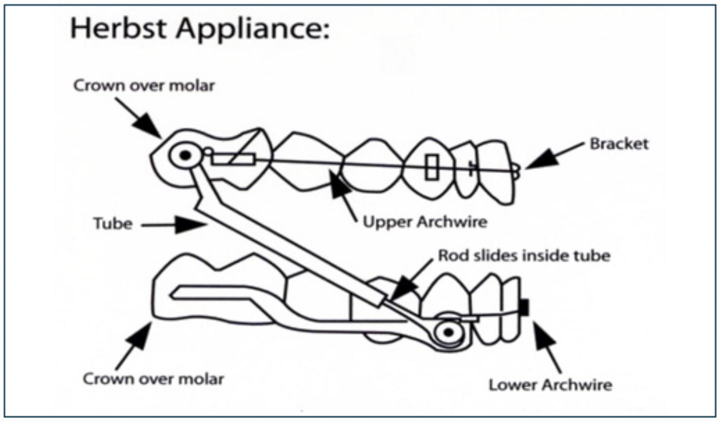

Figure 2-1. Herbst appliance (Chaukse, 2011)

The Jasper Jumper™ is made up of two vinyl coated auxiliary springs fitted to fully banded upper and lower fixed appliances (Figure 2-2). They are usually attached to the previously installed orthodontic appliances to facilitate their function. The flexible springs are attached to the maxillary first molar bands and an anterior attachment to the mandibular arch wire, which protrudes the mandible in order to correct the Class II malocclusion. (Chana, 2013)

Figure 2-2. Jasper Jumper™ (Mcsherry & Bradley, 2000)

The Xbow™ appliance consists of a maxillary Hyrax expander, a mandibular labial and lingual bow, and Forsus™ springs (3M Unitek, Monrovia, Calif). It is placed in the headgear tube of the maxillary first molar band and hooked around the labial bow.

The Forsus™ spring is stopped anteriorly by a Gurin lock (3M Unitek) around the mandibular canine area (Figure 2-3). The mandibular labial and lingual bow are in passive contact with the mandibular incisors. By contrast, with the Herbst and Jasper Jumper, the Xbow™ appliance does not rigidly hold the mandible forward and allows the patient to function in centric occlusion (Flores-Mir, Barnett, Higgins, Heo, & Major, 2009).

Figure 2-3. The Xbow™ appliance (Chana, 2013)

2.3 Effects on lower incisor position with the use of Functional Appliances and Fixed Appliances.

The position of the lower incisors in Class II malocclusions is crucial when determining the ultimate mandibular arch space, aesthetics and stability. According to Schulhof, Allen, Walters and Dreskin (1977) lingual and labial movements of the lower incisors induced increased orthodontic stability with the APo line acting as the guide in the positioning of the teeth on both the facial and mandibular plane in a comparative analysis pre (T1) and post treatment (T2) (Schulhof et al., 1977). However, predetermined cephalometric reference lines including NB, mandibular plane, and APo line did not affect relapse.

A number of researchers documented in the literature seek to explain the lower incisors' positional changes using Class II correctors. One such example was the use of the Xbow™ appliance in managing Class II malocclusions as documented by Aziz, Nassar and Flores-Mir (2012). This appliance, a fixed class II corrector, was used on adolescents and children effecting dental correction. The study used 249 subjects in the mixed dentition stage with Class II malocclusions using the Xbow™ appliance. The results deduced that lower incisal proclination occurred following this therapy. Comparative results of pre-treatment and post-treatment report a lower incisal proclination difference of 95.5º and 98.5º respectively. An overall improvement in maxillomandibular skeletal and lower incisal positioning was evident. Another research project by Flores-Mir, Young, Gresis, Woynorowski and Peng (2010), report a lower incisor proclination of 3.6° after treatment. Research by Chana et al (2013) showed protrusion and proclination of the lower incisor with the use of the Xbow™ appliance and more pronounced lower incisor movement in brachycephalic patients.

Another form of corrector for Class II malocclusions is the use of the Twin Block appliance and consists of bite blocks with inclined occlusal planes. The appliance has acrylic plates for the mandible and maxilla, and serves to effect change in dento-alveolar functioning, buccal distalization, anterior tooth retroclination, and lower labial proclination. Research by Sidlauskas (2005) showed dental and skeletal corrections on the forward lower incisor positioning with an increase of 0.7mm dentally and 0.3mm skeletally. These results differ from those of Toth and McNamara (1999) who attest to lower incisor proclination upon using the same appliance in a comparative analysis with an untreated control group. A study by Duggal, Jena and Parkash (2006) reported the effects of the Twin-Block model and explain it’s results as labial tipping of the lower incisors, improvement of the posterior and anterior facial height, as well as improved lip positioning upon use of the Twin-Block appliance. These conclusions were made after comparative analyses of the results prior to and after treatment with less or no significant effects in most of the participants. Although the aforementioned studies report different effects on dentition, musculature, and lower incisors using a Twin-Block appliance, they rely on evidence-based results to justify their findings.

Class II malocclusion management using a Twin Force Bite Corrector (TFBC), which is an inter-maxillary fixed appliance with inherent force to induce overjet correction, was also evident in a number of studies. The appliance was fitted with a ball-and-socket joint to facilitate lateral jaw motion. It also has mandibular and maxillary arch wires affixed on mandibular canines and first maxillary molars to enable edge-to-edge forward movement of the mandible. Rothenberg, Campbell and Nanda (2004) report on two case studies: In Case 1 after six months of treatment, there was incisal retraction and proclination as well as molar advancement in the mandible. However, there was a slight relapse after treatment completion (T3) compared to changes during (T2) and after treatment (T3). Analogous results in Case 2 also occurred but with reduced severity, a trend attributable to compliance differences in the patients. However, Chibber, Upadhyay, Uribe and Nanda (2013) stated that in evaluating the effect of TFBC on postpubertal and prepubertal Class II malocclusion patients, it established insignificant differences in normal prepubertal vs postpubertal patients following its application. In this case, age was an insignificant determinant of this appliance’s effectiveness. These results differ from those of Rothenberg, Campbell and Nanda's research (2004). The results also concur with the views of Altug-Atac, Dalci and Memikoglu (2008) who evaluated similar case reports using the effectiveness of the appliance. In using TFBC, there was congruence in its resultant effects including inferior and posterior maxillary movements, clockwise rotation of the palatal plane, increased mandibular length and protraction on the lower molar and the flaring of lower incisors. In all cases, pronounced dental effects in comparison to the skeletal effects were evident. The results however, were not solely correctional; they have some negative effects particularly on the position of the lower incisors.

The Herbst appliance is another Class II corrector, which is attached in the upper and lower arches and interconnected by a telescopic mechanism. Some authors have shown that after one year of using this fixed appliance, the lower incisors rebound by up to 2.6 degrees resulting in loss of the correction of the overbite and overjet (Jakobsone, Latkauskiene, & McNamara Jr., 2013).

Pancherz, Iemamnueisuk and Hansen (1988) found that recovery of the proclination of lower incisors occurred in 80% of their participants within a twelve (12) month period. Significant crowding was not associated with this rebound effect (Pancherz & Hansen, 1988). Hansen et al. (1995) further explained that the rebound effect was seen more in the intermolar and intercanine widths (Hansen, Iemamnueisuk, & Pancherz, 1995). Crowding in the mandibular anterior region owing to incisor inclination rebound after treatment, was also shown by Hansen et al. Ultimately, the irregularity index on these lower teeth was aggravated. The resulting proclination following the Herbst appliance on the lower incisors even induced gingival recession owing to its capacity to cause labial gingival connection collapse (Hansen et al., 1995)

Another fixed Class II corrector is the Mandibular Anterior Repositioning Appliance (MARA) which is comprised of stainless steel soldered crowns fixed on the first molars, a transpalatal bar and lingual arch to stabilize both the lower and upper molars. It corrects deficient mandibles and skeletal malocclusions according to the manufacturer. The appliance aids in pushing the upper molars posteriorly and the lower jaw anteriorly to reduce the overbite. Ultimately, the MARA induces dental and skeletal changes as reported by Huanca et al (Huanca Ghislanzoni et al., 2013) in a comparative analysis prior to and after orthodontic treatment. The appliance induces both proclination and protrusion of the lower incisors and the effect was more pronounced in children compared to adults making it effective only for selected groups of Class II malocculsions (Huanca Ghislanzoni et al., 2013). Chiqueto, Henriques, Barrosm and Janson (2013) share similar findings as Huanca regarding treatment with a MARA appliance in relation to the proclined position of the lower incisor.

In managing Class II malocclusions, safety, comfort, and aesthetics are priorities, hence the use of a Jasper jumper (figure 2.2). This is a fixed appliance designed to enhance mandibular functioning and protrusion, as well as counter some of the weaknesses of headgear therapy, such as compliance issues. The fixation of these appliances ensured effectiveness even without patient compliance. The literature documents a number of effects using this appliance after Class II malocclusion management (Henriques, Janson, Henriques, de Freitas, & de Freitas, 2009). It caused the maxilla's restricted anterior movement, as well as mandibular incisor proclination. The mandibular teeth located within the alveolar bone also experienced extrusions with the molars experiencing expansion following use with this appliance. Dento-alveolar changes prompted by clockwise movements of the occlusal plane enhanced correction unlike the aforementioned models that also relied on skeletal changes for analogous effects. A study by Jasper and McNamara (1995) observed similar movements of the anterior portion the of mandibular dentition and the buccal region of the maxilla upon using this model. The research gives details of the anterior teeth retraction and realignment of asymmetries using this appliance in comparison to dental changes before treatment.

2.4 Orthodontic Treatment Mechanics

In orthodontic corrections, irregularities of the lower incisors are a major challenge due to unforeseen development once growth is at the end of its period, or relapse in tooth movements in the course of treatment (Aasen & Espeland, 2005). Therefore, there was a need to examine the immediate and long-term effects of orthodontic therapy on the lower incisors' position and subsequent retention. The most common method used to analyze the position of these teeth is by method of a lateral cephalometric radiograph. Common cephalometric measurements used for the lower incisors are the following:

Lower labial incisal line angle to N-B line (linear measurement)

Lower labial incisal line angle and pogonion to N-B line (linear relationship)

Lower labial incisal line angle to A-Po line (linear measurement)

Lower incisor to N-B angulation (incisor inclination derived)

Lower incisor to mandibular plane angulation (incisor inclination derived)

Lower incisor to upper incisor angulation - interincisal angle (incisor inclination derived)

Several treatment philosophies have been developed and advocated in the literature for ideal positioning of the lower incisors to obtain maximum stability and decrease the chance of relapse potential.

Tweed's philosophy in the 1940's is one example that was prompted by premolar extraction studies leading to the preference of extraction in orthodontic treatment (Tweed, 1969;

Aasen & Espeland, 2005). The facial and functional failures in non-extraction cases were attributed to the lower incisor positions. For greater stability, he noted the importance of the position of the lower incisors including retroclining and up-righting them for better aesthetics and stability post-orthodontics. Tweed attested to many malocclusions having basal bone and teeth-based deficiencies that manifest as excessive forward tooth relationships with respect to he jaw bases, as is the case in Class II malocclusions (Tweed, 1969). Tweed formulated the facial triangle with 25, 90, and 65 degrees as the normal FMA (Frankfort Mandibular Angle), IMPA (Incisor Mandibular Plane Angle), and FMIA (Frankfort Mandibular Incisor Angle) values respectively (Tweed, 1969). In addition, he generated the FMA formula suggesting a 16 to 35 degree range with an average of 25 degrees as the normal value (Kowalski & Walker, 1971). Therefore, a FMA ranging 16 to 25 degrees does not require extraction compared to that beyond 30 degrees. Maintaining FMIA at 65 degrees demands mandibular incisors' IMPA to be uprighted to 85 degrees (Tweed, 1969). For successful orthodontic treatment, Tweed stressed the need to ensure stable anchorage to prevent the forward lower incisor shift during the basal bone movement of mandibular incisors and the application of intermaxillary force in therapy (Toth & McNamara Jr., 1999).

Several studies attempted to verify the postulations by Tweed, focusing on changes in the lower incisors. One such study was performed on 100 Nepalese adults aged 17 to 30 years (Rajbhandari, 2011). The study supported Tweed's hypothesis but Rajbhandari's findings were preliminary studies depicting many measurement variations with limited reliability. Another related study in both pre-school and school children in Northern India reported similar findings. Of emphasis in these studies is the inclusion of the lower incisors movement in orthodontic therapy to obtain sustainable and ideal occlusions. The studies concur that the best positioning of the teeth is at right angles with the mandibular plane, with a variation of five degrees, and 25 degrees to FMA and 65 degrees to FMIA.

Unlike the views of Tweed, Downs (1948) emphasized the need to maintain the mandibular plane at 91.7 degrees with a provision of an additional four degree. His objective was to develop a method to describe the nature of the facial and skeletal pattern of normal occlusion and the manner in which the teeth fit into it. In his first published paper, Downs analysis had 10 parameters, 5 dental and 5 skeletal. He used a sample of 20 Caucasian patients, males and females in a correlation and comparison study. The patients' age ranged between 12 and 17 years and they had excellent occlusions with no prior orthodontic treatment. His analysis justified his advances to correct the cephalometric and photographic facial shaping for individuals without a levelled Frankfort plane (Downs, 1952). Downs applied his principles to describe such patterns among Caucasians in North America (Downs, 1948). His conclusion was that facial patterns have variations; however, to achieve good esthetic balance and function, the aforementioned characteristics were required. Downs, in yet another study, found that orthodontic destabilization, particularly of the lower incisors was determined by the eruption stage of the patient, age-based contour modification, and the positioning of the incisors during treatment (Downs, 1952).

Downs compared his findings on the lower incisors axial inclination with those of Tweed utilizing a line drawn from A point-Pogonion (APo), as a reference line to relate the lower incisor position. Since the APo line is intended to represent the most anterior extensions of the maxilla and mandible, this method compensates for dental base discrepancy (Downs, 1956). Unlike Tweed who recommended a right angle (90 degrees) relationship of the mandibular plane and lower incisors, Downs recommends a 91.4° mean relationship with a range of 83 to 98°. He established four reference planes to the position of the lower incisors. The first reference plane referred to the cant of occlusal plane measuring the angles between the Frankfort Horizontal and occlusal plane. The second reference line was the interincisal angle often formed by the intersection of the mandibular incisors' and maxillary incisors' long axis. The third reference plane was the incisor-occlusal plane axis resulting from the intersection of the occlusal plane through the long axis of the mandibular incisors. The last plane referred to the maxillary incisors' protrusive measurement quantifying the distance between the maxillary central incisor incisal edge to a line drawn between the Pog and A-point (Downs, 1956).

In the 1950s Steiner developed a cephalometric analysis (Jacobson, 1995). His analysis entailed relating the upper and lower incisor teeth to their respective jaw and to each other. He also considered the lower incisor position in relation to the cephalometric Nasion-B point (NB line) and is measured angularly and linearly. The lower incisor position is individualized according to the projected dental base discrepancy as measured by the angle ANB and the relative prominence of the bony chin. The desired position for the lower incisors is determined from the following measurements ANB, L1-NB and NB-Pogonion. Steiner developed a range of values for the lower incisor position with varying ANB angles known as the 'acceptable compromises'. In order to graphically represented how his patients were different from the cephalometric "norms" previously established, Steiner created chevrons representing the ideal and acceptable compromises from the ideal (figure 2-5) (Steiner, 1953)

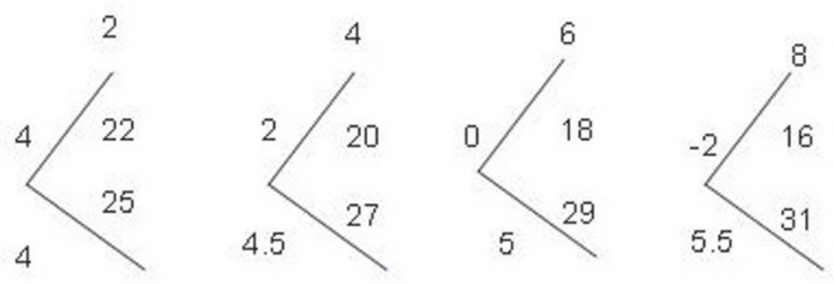

Figure 2.5: Normal and acceptable compromises for Steiner's chevrons (Steiner, 1953)

In an evaluation of a small number of treated cases showing a considerable esthetic improvement Lindquist (1958) observed that application of the Tweed, Steiner and APo line methods arrived at different incisor prognoses, and concluded that, while linear measurements were more anticipated than angular measurements, no method or formula was ideal. Riedel and Brandt (1976) agreed with Hixon's (1972) concepts that the only value of cephalometric analysis of lower incisor positioning lies in ensuring that it is not changed as a result of treatment. Riedel also pointed out that lingual movement by the amount that would occur normally as a result of facial growth changes should remain stable.

Another cephalometric analysis by Harvold and Vargervik (Harvold & Vargervik, 1971) explored the changes in jaw disharmony following orthodontic therapy. The author generated the unit length of the mandible and maxilla. These two measures attest to jaw differences prior to, during, and after orthodontic therapy, an effect extended to the lower incisors. Harvold's hypothesis however does not account for the vertical distance of the jaws, claiming that it was insignificant. A cephalometric study in Bangladeshi adults supported Harvold's hypothesis (Alam et al., 2013). Harvold emphasized the role of proper positioning of the lower incisors over the basal bone during orthodontic treatment since it determined the stability and aesthetic effects post-therapy (Harvold, 1947). Research by Ball and Hunt (1991) concerning Harvold's views established that during treatment, lower incisor restraint and intrusion was evident, enhancing relapse post-treatment. These events occurred due to the eruption and retroclination of the teeth, as well as continued growth and rotation of the mandible (Harvold, 1947).

Alexander (2001) developed his own model based on two fundamentals: (1) anchorage preparation seeking to hold the mandibular first molars and correct positioning of the lower incisors over the basal bone, and (2) the use of a headgear to alter the orthopaedic position. These views were analogous with those of Tweed, but more definitive in this case. Malocclusion treatment planning and diagnosis in this case was reduced to two steps: determining the desired alignment of such lower incisors and then selecting the optimal treatment to ensure maxillary dentition position in comparison to the arch positioning of the mandibular incisors. Alexander emphasized that ideal malocclusion management considered four core factors: the preference for non-extraction therapy unless unavoidable, the non-expansive nature of the cuspids, levelling of the Curve of Spee, and incisor positioning on the basal bone. Alexander strongly believed that the desired and stable position for lower incisors was their original position and his goal in orthodontic treatment was to maintain this position (Alexander, 2001). In extraction therapy, upright positioning of lower incisors was recommended. This can be achieved by advancing them to a maximum of three degrees beyond which, instability and a possible relapse is likely. However, during Class II, Division 1 and 2 malocclusion exhibiting deep bites, the lower incisors can be tilted beyond three degrees since they usually are retroclined. In assessing the dental effects of orthodontics, Alexander explained that sagittal control is imperative in precise mandibular incisor positioning whose determination was influenced by IMPA, Holdaway ratio, and APo line (Alexander, 2001). These factors determined the mandibular plane and incisor relationship.

In delineating aspects of retention and relapse, Alexander's technique depended on pre-adjusted advances based on its biomechanical principles in ensuring arch levelling with enhanced lower incisor control. To ensure stability and retention, he suggested the upright retention of lower incisors above the basal bone by using -5 degrees torque in his lower incisor bracket prescription. A -6° distal tip in the bracket prescription to upright the first mandibular molar further enhanced stability, preventing lower incisal flaring by generating an adequate arch length. As such, he suggested the use of a rectangular wire to position the lower incisors from the treatment outset. Research by Carcara, Preston and Jureyda (2001) also show that arch levelling of the Curve of Spee using Alexander's principles reduced the extent and speed of relapse following malocclusion treatment. In addition, better aesthetics, occlusion, and mandibular function resulted and better retention was possible. The study concluded that the Alexander Discipline resulted in effective arch levelling with relapse being evident and only to a small extent. However, the study did not incorporate a definitive measure of the Curve of Spee since it did not use cephalometric analyses, making the possibility of relapse unpredictable. This reduced the overall predictability of the results despite their evidence-based nature.

From this literature analysis, a unique relevance of lower incisor positioning in Class II malocclusion management was apparent, particularly in determining appropriate treatment technique and appliance choice during treatment planning. Of concern are the irregularities associated with such teeth following orthodontic therapy such as the instability, leading to relapse, which occurred in the form of incisal crowding affecting the lower labial stability and ideal facial development after orthodontic therapy. As such, these changes have prompted the use of permanent and transient retention appliances post-treatment. There have been many inconsistent approaches in the literature to discover the precise cephalometric landmarks directed to correct the position of the lower incisors, despite the inevitability of post-treatment problems regarding such tooth positions.

Another major challenge was that there were numerous factors affecting the lower incisor positioning, most of which were unquantifiable and were either known or unknown, making stability predictions challenging for teeth moved to different positions from their original position. Although cephalometric analyses using the hypotheses by Tweed, Downs, Harvold and Alexander have attempted to describe the ideal lower incisors positions definitively, they were subject to criticism since differential growth, postural development, and genotype of the patient are core determinants of the malocclusion.

With the confounding nature in documented claims on both orthodontic-based analysis and orthodontic therapy effectiveness, there is need to intensify the evidence-based research to describe the changes evident following orthodontic correction with regards to lower incisor positioning for better planning, retention, and long-term stability of such corrections. To date no studies have been performed on the evaluation of the lower incisor position immediately after full fixed orthodontic treatment in conjunction with a FSIA.

Chapter 3

Materials and Methods

3.1 Sample Selection

The treatment sample was obtained from the private orthodontic practice of an orthodontist in Winnipeg, Manitoba. All digital cephalometric radiographs were taken with a ProMax S3 Pan/Ceph (Planmeca, Inc. Helsinki, Finland).

Initial pre-treatment (T0), completion of FSIA-treatment (T1), and post-orthodontic treatment (T2) lateral cephalometric radiographs were taken between January 23rd, 2008 and July 30th, 2013. The total sample size of 115 consisted of 43 males and 72 females. The mean age of the patients was 13 years 5 months (SD 1yr. 5mo.) at T0 and 15 years 3 months (SD 1yr. 5mo.) at T2. The average treatment time for the subjects from T1-T2 was 1 year 7 months (S.D 0.58mo). The protocol for the FSIA involved activation of the springs every 4-6 weeks until a Class III overcorrection in the buccal segments was accomplished. Following the active phase (4.26 months SD 1.22 mo.), the appliance was passively retained for an additional average time of 3.07 months (SD 1.06 mo.). Therefore, the total mean time the appliance was in the mouth was 7.33 months (SD 1.82 mo.) at which time the appliance was removed and a T2 radiograph was taken (Chana, 2013). The subjects were then placed in full fixed multi-banded therapy using

0.022 Innovation R brackets (GAC, Dentsply, Woodbridge, ON). The treatment time of the full fixed therapy was carried out for was 12.7 months (S.D. 0.58 mo). A summary of the treatment sample is described in Table 3-1.

Parameter	***Mean***	***Min.***	***Max.***	***SD***
Age at T0 (years)	13.51	9.92	16.92	1.58
Age at T1 (years)	13.92	10.75	17.08	1.58
Age at T2 (years)	15.27	11.78	18.76	1.53
Total time between T0/T1 (months)	7.33	4.1	13.1	1.82
Total time between T1/T2 (months)	12.7	12.28	13.12	1.36
Total Time T0/T2 (months)	20.03	11.41	28.65	1.72

Table 3-1. Summary statistics for the treatment group.

The following inclusion criteria were used to select the subjects:

1. A complete permanent dentition;
2. Subjects with a ¾ to 1 full cusp bilateral Class II dental malocclusion initially;
3. Subjects treated with the FSIA appliance;
4. Subjects with pre, progress, and post treatment cephalometric radiograph of acceptable quality.

The subjects were excluded from the study based on:

1. Subjects missing either a pre or post treatment cephalometric radiograph;
2. Cephalometric radiographs of poor diagnostic quality;
3. Mutilated dentitions;

4. Congenitally missing teeth other than third molars;
5. Previous orthodontic treatment.

3.2 Data Collection

3.2.1 Calibration

The radiographs were labeled with a code for blinding purposes. No information on the radiographs indicated the age, gender, or the stage of treatment the radiograph was generated (pre, progress, or post treatment). All of the lateral cephalometric radiographs were digitally traced by a single investigator using the Dolphin™ 11.5 treatment planning software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA). Magnification was accounted for using a digital calibration within the software, which matched actual known ruler distances captured on the lateral cephalogram.

The intra and inter-examiner reliability of the measurements were assessed using an interclass correlation coefficient (ICC) test on 20% of the studied sample. Twenty-two cephalometric radiographs were chosen randomly and re-measured by two separate examiners 12 weeks after the original measurements to identify landmark identification error. A second examiner was used to reduce the potential error of landmark identification. Statistical software SAS 9.2 was used to analyze the data.

3.2.2 Growth Considerations

Post-treatment cephalometric radiographs used to examine the effects of FSIA treatment were taken on the day of removal of the appliance and also taken on the day the full fixed orthodontic therapy was completed. The mean treatment time with the FSIA in place was 7.33 months (SD 1.82 months) and the mean treatment time that full fixed multi-banded therapy was was used for 1 year 7 months (S.D 0.58mo). Dolphin Imaging™ 11.5 software was used to predict the amount of growth that occurred over the period of treatment. Lateral cephalometric radiographs were digitally traced from Dolphin Imaging™ 11.5 software using Steiner's (Jacobson, 2006) and Rickett's (Ricketts, 1979) cephalometric analysis and then T0 and T2 and T1 and T2 were superimposed on each other. Ricketts stated that there are five measurements that are not affected by the change with age. The measurements are:

1) Facial Axis - 90°±3°
2) Facial Taper - 68°±3.5°
3) Lower Face Height – 47°±4°
4) Lower incisor to Apo – 1mm±2mm
5) Mandibular Incisor Inclination – 22°±4°

The growth effects for skeletal and dental changes over the treatment period were assessed on 30% of the studied sample. Thirty-four post-FSIA treatment and post-orthodontic treatment cephalometric radiographs were chosen from each group randomly and were subject to comparison based on Rickett's five superimposition landmarks and the variables for the five measurements that are thought not to change with age. A Kolmogorov-Smirnov test was used to determine if the samples were of normal distribution. A paired t-test was used to determine if there was a significant difference between the cephalometric variables from post-FSIA treatment versus post-orthodontic treatment cephalometric variables. The p value was considered significant at $\alpha<0.05$.

The five measurements thought not to change with age (Ricketts, 1979) were used to determine if growth was neglible or not. Changes within the limit of four degrees were considered negligible. None of the selected subjects measurements showed any changes greater than four degrees. SNA and SNB angles were also evaluated and no change was observed that was greater than three degrees.

The following figure is an example of a growth prediction superimpositions using Rickett's five superimposition landmarks for this patient's specific treatment time of 1.89 years (Figure 3-1).

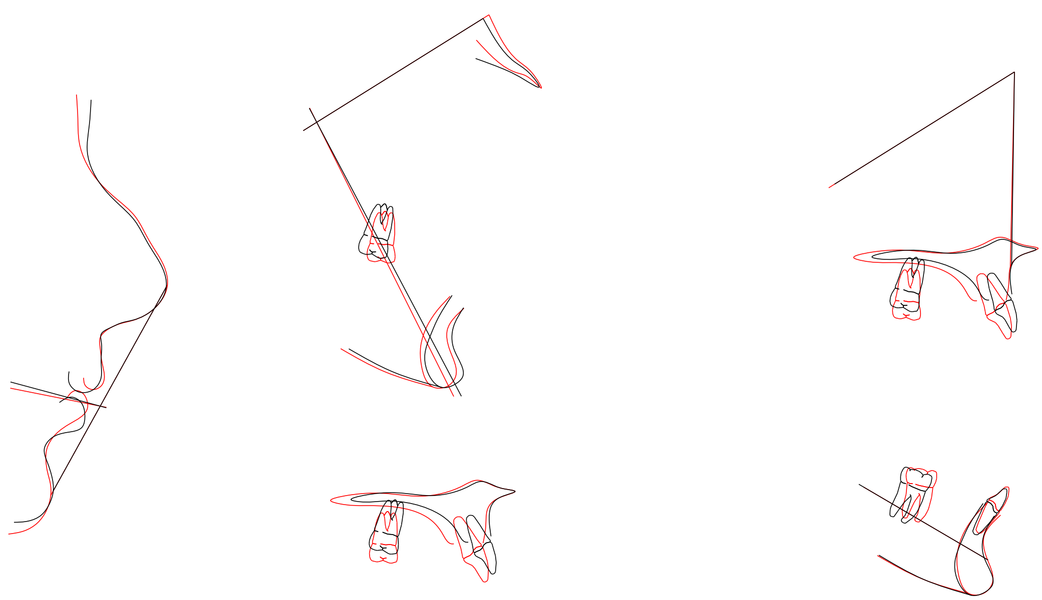

Figure 3-1. An example of a growth prediction superimposition using Ricketts five superimposition landmarks. A (black)- post-FSIA treatment (T1), B (red)- post-orthodontic treatment (T2).

3.2.3 Defining Facial Patterns

Based on the pre-treatment cephalometric variables obtained from tracing the cephalometric radiographs, subjects were then categorized into three growth types. Two cephalometric variables were used to separate the subjects: Growth axis (Y-axis) and mandibular plane angle (MP-SN). Subjects with values within one standard deviation for growth axis (66°, SD 5°) and two standard deviations for mandibular plane angle (32°, SD 2°). This yielded 31 dolichocephalic, 28 brachycephalic, and 54 mesocephalic subjects.

A histogram or Kolmogorov-Smirnov test was used to determine if the samples were of normal distribution. A paired *t*-test was used to determine if there was a significant difference between the three facial groups. The p value was considered significant at $\alpha<0.05$. Group 1 represents the brachycephalic group with mean Y-axis of 64.1°±0.6° and a mean MP-SN of 25.8°±0.6°. Group 2 represents the dolichocephalic group with a mean Y-axis of 72.2°±0.5° and a mean MP-SN of 38.6°±0.6°. Group 3 represents the mesocephalic group with a mean Y-axis of 68.0°±0.4° and a mean MP-SN of 31.9°±0.5°. A summary of the three groups prior to FSIA and FMB treatment is described in Table 3-2.

Variables	Group 1 (Brachy)	Group 2 (Dolico)	Group 3 (Meso)	p-value
Y-Axis (SGn-SN) (º)	64.1±0.6	72.2±0.5	68.0±0.4	<0.0001
MPA (MP-SN) (º)	25.8±0.6	38.6±0.6	31.9±0.5	<0.0001

Table 3-2. Differences between groups prior FSIA and FMB treatment (T0). Group 1 – brachycephalic (brachy), Group 2 – dolichocephalic (dolico), Group 3 – mesocephalic (meso).

3.3 Statistical Analysis

All study variables were found to be normally distributed. This was determined by a Kolmogorov-Smirnov test. Descriptive statistics were presented as mean, standard deviation and standard error for age and treatment time.

A mixed model with repeated command (repeated ANOVA model) was used for the normally distributed variables (Table 3-3). The Log transformation was run to normalize any skewed variables. An analysis of variance (ANOVA) statistic was used to analyze the effects of treatment over time between the three groups (skeletal and dental effects). Statistical software SAS 9.2 was used to analyze the data. Confirmation was recieved that the distribution of the sample could be assumed to follow a normal distribution by a Kolmogorov-Smirnov test. To examine the reliability of the tracings an inter-rater correlation test was performed. The p-value was considered to be significant at $\alpha<0.05$ with a confidence interval of 95%.

The main effect 'group' and 'time' and interaction effect 'time group' in the model was controlled. A Post-hoc analysis had been done to find out the pairwise differences using Tukey's test.

Variable	***Distribution***	***Statistical Analysis***
Occ Plane to SN (º)	Normal	ANOVA
MP - SN (º)	Normal	ANOVA
Wits Appraisal (mm)	Normal	ANOVA
Interincisal Angle (U1-L1) (º)	Normal	ANOVA
IMPA (L1-MP) (º)	Normal	ANOVA

L1 Protrusion (L1-APo) (mm)	Normal	ANOVA
L1 - NB (º)	Normal	ANOVA
L1 - NB (mm)	Normal	ANOVA
L1 to APo (mm)	Normal	ANOVA
Y-axis (º)	Normal	ANOVA
Overjet (mm)	Normal	ANOVA
Overbite (mm)	Normal	ANOVA
Holdaway (L1-NB:NB-Pog)	Normal	ANOVA

Table 3-3. Variables examined, distribution and type of statistical analysis.

3.4 Full Fixed Orthodontic Treatment

The FSIA treatment was completed and retained for an average retention period of 1-3 months and then full fixed therapy was initiated using Innovation R brackets from GAC, Dentsply (Woodbridge, ON). The slot size of the bracket was a 0.022" dimension. The prescription in the brackets was a Roncone prescription with a high torque prescription for the maxillary teeth from #1.5 - #2.5, a low torque bracket setup in the mandibular arch on #3.5 - #4.5. For the maxillary and mandibular first molars, a Roth prescription was used with a low torque prescription. The maxillary and mandibular second molars used a low torque prescription, -19° torque for the maxillary teeth and -10° torque for the mandibular teeth.

The arch wire sequence was as follows: 0.014" NiTi was used for ten (10) weeks as the initial archwire for leveling and aligning, 0.020" x 0.020" BioForce was used for continuation of the leveling process and to obtain some torque expression, 0.019" x 0.025" TMA archwire was then used as the final arch wire for detailing. If there were spaces to close 0.016" x 0.022" stainless steel or 0.017" x 0.025" stainless steel arch wire was placed and spaces were closed with powerchain. Spaces were consolidated during treatment and final alignment and detailing of the teeth was performed. The brackets and the remaining cement were removed and the teeth were polished. Full records including impressions for fabrication of retainers and final models, a lateral cephalogram, a panoramic radiograph and intra-oral and extra-oral photos were taken. A retainer was delivered within 3 days after bracket removal.

3.5 Cephalometric Analysis

3.5.1 Natural Head position

The radiographic technique in the office was documented, consistent, well established, understood and followed throughout record taking. Judging by the documents radiographic technique and quality of the radiographs selected for analysis, the patients were positioned in the natural head position for the radiograph. The concept of natural head position was introduced by C. F. A. Moorrees and M. R Kean in 1958 (Jacobson, 2006). Natural head position is a standardized orientation of the head that is reproducible for each individual and is used as a means of standardization during analysis of dentofacial morphology both for photos and radiographs (Jacobson, 2006). To accomplish natural head position, the patient was asked to gaze ahead as if he/she were looking at the horizon with the interpupillary line parallel to the floor.

All radiographs for this study were taken with the same Pan/Ceph ProMax S3 (Planmeca, Inc. Helsinki, Finland). The radiograph was taken with the x-ray beam perpendicular to the patient’s sagittal plane. The beam entered on the patient’s left side, with the film cassette adjacent to the patient's right side. Each radiograph was analyzed with the patient's face oriented to the right.

3.5.2 Computerized Cephalometrics

The cephalometric data was transferred in JPEG digital format into Dolphin Imaging™ 11.5 for cephalometric analysis. The images were then 'digitized' to allow for tracing the digital image. Digitization is the conversion of landmarks on a radiograph or tracing to numerical values on a two dimensional coordinate system, usually for the purpose of computerized cephalometric analysis (Jacobson, 2006). The process allows for automatic measurement of landmark relationships. Once digitized manual landmark identification was carried out by a single investigator (JC).

3.5.3 Superimposition

Superimposition is the process of placing two or more radiographic images upon each other. The images are registered on structures that remain relatively stable during the time period. This allows for a greater visualization of the changes brought about by growth and/or treatment (Jacobson, 2006).

3.5.4 Cephalometric Landmarks

A cephalometric landmark is a recognizable point on a tracing that represents a hard or soft tissue anatomical structure called anatomical landmarks. Landmarks involving the intersections of lines are called constructed landmarks.

Landmarks are used as reference points for the construction of various lines or planes and for subsequent numerical determination of cephalometric measurements (Jacobson A, 2006). Rickett's and Steiner's analyses were used to analyze the skeletal and dental changes before and after full fixed orthodontic treatment. The cephalometric landmarks used in a modified Steiner's analysis are shown in Figure 3.2. Landmarks used in a Rickett's analysis are shown in Figure 3.3.

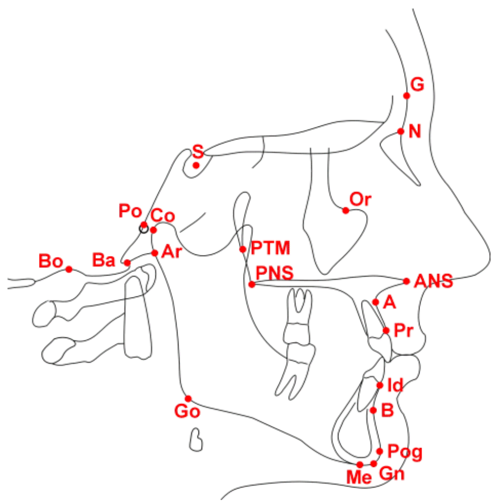

Figure 3.2. Landmarks used in a modified Steiner's analysis (Adapted from Jacobson, 1995)

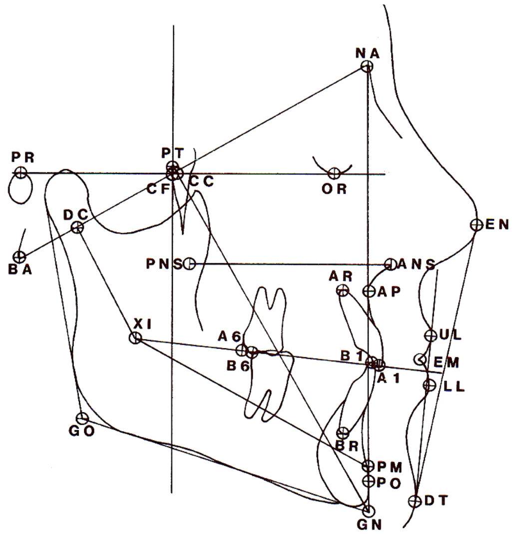

Figure 3.3. Landmarks used in a modified Rickett's analysis (Adapted from Jacobson, 1995)

A description of the landmarks used in this study is provided in Table IV. It is important to note that some of the cephalometric landmarks are repeated in the three analyses. By convention 'midsagittal' identifies landmarks lying on the midsagittal plane, 'unilateral' identifies landmarks corresponding to unilateral structures and 'bilateral' applies to landmarks corresponding to bilateral structures (Jacobson, 2006).

Landmark	***Analysis***	***Description***	***Midsagittal/Bilateral***	***Reference***
A-point (Subspinale, ss)	Steiner Ricketts Pancherz	Deepest, most posterior midline point on the curvature between the ANS and	Midsagittal	Broadbent, 1975 Jacobson, 1995

		prosthion.		
Anterior nasal spine (ANS)	Steiner Ricketts	Tip of the bony anterior nasal spine at the inferior margin of the piriform aperture, in the midsagittal plane. Used to define the anterior end of the palatal plane of the nasal floor.	Midsagittal	Broadbent, 1975 Jacobson, 1995
Articulare (Ar)	Steiner Ricketts	Constructed point representing the intersection of three radiographic images: the inferior surface of the cranial base and the posterior outlines of the ascending rami or mandibular condyles.	Bilateral	Broadbent, 1975 Jacobson, 1995
B-point (Point B, Supramentale,	Steiner Ricketts	Deepest most posterior midline point on the	Midsagittal	Broadbent, 1975

sm)	Pancherz	bony curvature of the anterior mandible, between infradentale and pogonion.		Jacobson, 1995
Basion (Ba)	Steiner Ricketts	Most anterior inferior point on the margin of the foramen magnum, in the midsagittal plane. Located on the inferior border of the basilar part of the occipital bone to its posterior limit, superior to the dens of the axis.	Midsagittal	Broadbent, 1975 Jacobson, 1995
Bolton (Bo)	Steiner Ricketts	The highest points on the outlines of the retrocondylar fossae of the occipital bone, approximating the center of the foramen magnum.	Bilateral	Broadbent, 1975 Jacobson, 1995

CC Point (CC) Ricketts	Ricketts	Crossing of the facial axis with the BaN plane known as the Cranial Center	Midsagittal	Broadbent, 1975 Jacobson, 1995
Condylion (Co)	Steiner Ricketts	Most superior posterior point on the head of the mandibular condyle.	Bilateral	Broadbent, 1975 Jacobson, 1995
DC Point (Ricketts)	Ricketts	Center of the neck of the condyle on the Basion Nasion line.	Bilateral	Broadbent, 1975 Jacobson, 1995
Glabella (G)	Steiner Ricketts Pancherz	Most prominent point of the anterior contour of the frontal bone in the midsagittal plane.	Midsagittal	Broadbent, 1975 Jacobson, 1995
Gnathion (Gn)	Steiner Ricketts	Most anterior inferior point on the bony chin	Midsagittal	Broadbent, 1975

	Pancherz	in the midsagittal plane. A constructed landmark by using the mid point between the anterior (pogonion) and inferior (menton) points of the bony chin.		Jacobson, 1995
Gonion (Go)	Steiner Ricketts Pancherz	Most posterior inferior point on the outline of the angle of the mandible. Constructed by bisecting the angle formed by the intersection of the mandibular plane and the ramal plane and by extending the bisector through the mandibular border.	Bilateral	Broadbent, 1975 Jacobson, 1995
Infradentale (Id)	Steiner	Most superior anterior point on the	Midsagittal	Broadbent, 1975

Inferior prosthion Pr	Ricketts Pancherz	mandibular alveolar process, between the central incisors.		Jacobson, 1995
Incision inferius (Ii) or B1 (Ricketts)	Steiner Ricketts Pancherz	Incisal tip of the most labially placed mandibular incisor.	Unilateral	Broadbent, 1975 Jacobson, 1995
Incision superius (Is) or A1 (Ricketts)	Steiner Ricketts Pancherz	Incisal tip of the most labially placed maxillary central incisor.	Unilateral	Broadbent, 1975 Jacobson, 1995
Menton (Me)	Steiner Ricketts Pancherz	Most inferior point of the mandibular symphysis, in the midsagittal plane.	Midsagittal	Broadbent, 1975 Jacobson, 1995
Nasion (N, Na)	Steiner Ricketts Pancherz	Intersection of the internasal and frontonasal sutures, in the midsagittal plane.	Midsagittal	Broadbent, 1975 Jacobson, 1995

Molar Upper First (Ricketts)	Ricketts	Point on the occlusal plane perpendicular to the distal surface of the crown of the upper first molar.	Bilateral	Broadbent, 1975 Jacobson, 1995
Molar Lower First (Ricketts)	Ricketts	Point on the occlusal plane perpendicular to the distal surface of the crown of the lower first molar.	Bilateral	Broadbent, 1975 Jacobson, 1995
Orbitale (Or, O)	Steiner Ricketts Pancherz	Lowest point on the inferior orbital margin.	Bilateral	Broadbent, 1975 Jacobson, 1995
Pogonion (Pog, P, Pg)	Steiner Ricketts Pancherz	Most anterior point on the contour of the bony chin, in the midsagittal plane. Located perpendicular to mandibular plane,	Midsagittal	Broadbent, 1975 Jacobson, 1995

		tangent to the chin.		
Porion (Po)	Steiner Ricketts Pancherz	Most superior point of the outline of the external auditory meatus known as anatomical porion.	Bilateral	Broadbent, 1975 Jacobson, 1995
Posterior nasal spine (PNS)	Steiner Ricketts Pancherz	Most posterior point on the bony hard palate in the midsagittal plane; the meeting point between the inferior and the superior surfaces of the bony hard palate (nasal floor) at its posterior aspect. Located by extending the anterior wall of the pterygopalatine fossa inferiorly, until it intersects the floor of	Midsagittal	Broadbent, 1975 Jacobson, 1995

		the nose.		
Prosthion (Pr, Superior prosthion, Supradentale)	Steiner Ricketts Pancherz	The most inferior anterior point on the maxillary alveolar process, between the central incisors.	Midsagittal	Broadbent, 1975 Jacobson, 1995
Pterygomaxillary fissure (PTM, Pterygomaxillare)	Steiner Ricketts	A bilateral, inverted teardrop-shaped radiolucency, whose anterior border represents the posterior surfaces of the tuberosities of the maxilla.	Bilateral	Broadbent, 1975 Jacobson, 1995
Sella (S)	Steiner Ricketts Pancherz	The geometric center of the pituitary fossa (sella turcica).	Midsagittal	Broadbent, 1975 Jacobson, 1995
Mi, molar inferius	Pancherz	Mesial contact point of the mandibular first permanent molar by a	Bilateral	Wu JY, Pancherz H, et. al, 2010

		tangent parallel to OLp; when double projection give rise to 2 points, the midpoint is used.		
Mic	Pancherz	Mesiobuccal cusp tip of the mandibular first molar; when double projection gives rise to 2 points, the midpoint is used.	Bilateral	Wu JY, Pancherz H, et. al, 2010
Ms, Molar superius	Pancherz	Mesial contact point of the maxillary first permanent molar by a tangent parallel to OLp; when double projection gives rise to 2 points, the midpoint is used.	Bilateral	Wu JY, Pancherz H, et. al, 2010

Msc	Pancherz	Mesiobuccal cusp tip of the maxillary first molar; when double projection gives rise to 2 points, the midpoint is used.	Bilateral	Wu JY, Pancherz H, et. al, 2010

Table 3-4. Description of the cephalometric landmarks.

3.5.5 Cephalometric Planes

A description of the cephalometric planes used in this study is provided in Table 3-5. Most analyses utilize one or more cephalometric lines that joins two landmarks, are tangent to an outline from a landmark, or are perpendicular to another line from a landmark (Jacobson, 1995).

Plane	***Analysis***	***Description***	*Reference*
Basion-Nasion line (Ba-N)	Ricketts	Represent the cranial base similar to the SN line or the Bolton plane.	Broadbent, 1975 Jacobson, 1995
E-line (E-plane, Esthetic line of Ricketts)	Ricketts	Tangent to the chin and nose to assess lip fullness.	Broadbent, 1975 Jacobson, 1995
Facial axis of Ricketts	Ricketts	A line connecting gnathion with cranial point "Pt," defined as	Broadbent, 1975 Jacobson, 1995

		the lower border of the foramen rotundum and the most posterosuperior point of the outline of the pterygomaxillary fissure.	
Facial plane (FP, Facial line)	Steiner Ricketts	A line extending from nasion to pogonion.	Broadbent, 1975 Jacobson, 1995
Frankfort horizontal plane (FH, Frankfort horizontal line, Auriculo-orbital plane)	Steiner Ricketts	Horizontal plane passing through the lowest point in the floor of the orbit and the highest point on the margins of the external auditory meati (porion).	Broadbent, 1975 Jacobson, 1995
H-line (Harmony line of Holdaway)	Ricketts	A line tangent to the soft tissue chin and the upper lip to assess of the soft tissue profile.	Broadbent, 1975 Jacobson, 1995
Mandibular plane (MP, Mandibular line, ML)	Steiner Ricketts	A line passing through the mandibular borders (bilaterally) joining points gonion and gnathion.	Broadbent, 1975 Jacobson, 1995
Occlusal plane (OP)	Steiner	A line drawn through the	Broadbent, 1975

	Ricketts Pancherz	occlusal surfaces of the maxillary and mandibular first permanent molars and tip of the incisal edge of the lower incisor	Jacobson, 1995
Palatal plane (ANS-PNS, PP, Nasal line, Nasal floor, Spinal plane)	Steiner Ricketts	A line joining PNS and ANS.	Broadbent, 1975 Jacobson, 1995
S-line (Esthetic plane of Steiner)	Steiner	A line connecting the midpoint of the columella of the nose to the soft tissue pogonion.	Broadbent, 1975 Jacobson, 1995
Sella-Nasion line (SN, Nasion-Sella line, NSL)	Steiner	Reference line representing the anterior cranial base. A line joining points S and Na.	Broadbent, 1975 Jacobson, 1995
Y-axis (Growth axis)	Steiner Ricketts	A line connecting points sella and gnathion. This angle gives an indication of the direction of mandibular growth.	Broadbent, 1975 Jacobson, 1995
Angle of convexity (NAPog)	Steiner	Assessment of the degree of convexity (or concavity) of the	Broadbent, 1975 Jacobson, 1995

	Ricketts	skeletal profile. The angle is formed by the lines NA and A-Pog and has a positive value in convex and negative value in concave profiles.	
ANB angle	Steiner Ricketts	The difference between angles SNA and SNB. Is an evaluation of the anteroposterior relationship between the maxillary and mandibular apical bases.	Broadbent, 1975 Jacobson, 1995
SNA angle	Steiner Ricketts	Assessment of the anteroposterior position of the maxilla with regards to the cranial base. The inferior posterior angle formed by the intersection of lines SN and NA is measured.	Broadbent, 1975 Jacobson, 1995
SNB angle	Steiner Ricketts	Assessment of the anteroposterior position of the mandible in relation to the cranial base. The inferior posterior angle formed by the	Broadbent, 1975 Jacobson, 1995

		intersection of lines NA and NB is measured.	
Facial angle (FH-NPog)	Steiner Ricketts	The inferior posterior angle formed by the intersection of the Frankfort horizontal and the facial plane (N-Pog).	Broadbent, 1975 Jacobson, 1995
Facial axis angle of Ricketts (Ba-Pt-Gn)	Ricketts	The inferior angle formed by the intersection of the facial axis of Ricketts and the Ba-N line. This angle give an indication of growth pattern.	Broadbent, 1975 Jacobson, 1995
Facial height, Anterior; Posterior; and Total	Steiner Ricketts Pancherz	Vertical dimension appraisal of the face. The anterior lower facial height is expressed by the linear millimetric distance between the ANS and menton. The percent ratio of the previous linear measurement (ANS-Me) over the total anterior facial height (N-Me) provides an assessment of the relative proportionality of the anterior face in the vertical	Broadbent, 1975 Jacobson, 1995

		dimension. Similarly, the linear measurement from S to Go on the lateral cephalometric radiograph provides an assessment of posterior facial height. The ratio of posterior face height x 100/anterior face height can give an estimate of growth direction.	
Gonial angle (Angle of the mandible, Condylar angle)	Steiner	The anterior angle formed by the intersection of a line tangent to the posterior border of the ramus and the mandibular plane. It may give an indication about mandibular growth direction.	Broadbent, 1975 Jacobson, 1995
Holdaway ratio (LI-NB/Pg-NB)	Steiner	Used to evaluate the relative prominence of the mandibular incisors, as compared to the size of the bony chin. It is calculated as the ratio of the linear distance from the labial surface of the mandibular central	Broadbent, 1975 Jacobson, 1995

		incisor to the NB line, over the linear distance of the chin to the same line.	
Interincisal angle	Steiner Ricketts	The angle formed by the intersection of the long axis of the maxillary and mandibular central incisors.	Broadbent, 1975 Jacobson, 1995
LI-to-AP distance	Steiner	The perpendicular distance of the incisal edge of the mandibular central incisors to the A-Pog line.	Broadbent, 1975 Jacobson, 1995
Mandibular plane angle	Steiner Ricketts	Assessment of the steepness of the mandibular plane in relation to the cranial base. The anterior angle formed by the intersection of SN and GoGn.	Broadbent, 1975 Jacobson, 1995
Nasolabial angle (NLA)	Steiner Ricketts	The anterior inferior angle formed by the intersection of a line tangent to the columella of the nose and a line drawn from subnasale to the mucocutaneous border of the upper lip.	Broadbent, 1975 Jacobson, 1995

Wits appraisal	Steiner	Perpendicular lines to functional occlusal plane from points A and B, and subsequently measuring the distance between the two points of intersection of the two perpendicular lines. The greater the deviation of this reading from 0 mm in females and 1.0 mm in males, the greater the degree of sagittal discrepancy between the maxilla and mandible.	Broadbent, 1975 Jacobson, 1995

Table 3-5. Description of cephalometric planes.

Chapter 4

Results

4.1 Introduction

The means for each facial group were calculated for each measurement. The differences between T0-T2 and T1-T2 were calculated and evaluated for each group and comparisons between the groups were performed. A mixed-model statistics with repeated command was performed. The main effect 'group" and 'time" and interaction effect 'time group' in the model was controlled. The post-hoc analysis was performed to determine the pairwise differences using Tukey's test. The least square means were reported. The p-value was considered significant at $\alpha < 0.05$ with the confidence interval at 95%.

In the tables below "brachy" indicates the brachycephalic group, "dolico" indicates the dolicocephalic group and "meso" indicates the mesocephalic group. 'FSIA' indicates fixed spring induced appliance and 'FMB treatment' indicates full fixed orthodontic treatment. Statistically significant findings were identified with an * at a 95% level of confidence. Linear and angular changes larger than 2mm and 2º respectively were identified below.

4.2 Reliability

The reliability of the measurements was assessed using an intra-rater correlation coefficient (ICC) test on 20% of the studied sample. Twenty-two cephalometric radiographs were chosen randomly and re-measured by two separate examiners 12 weeks after the original measurements, to identify landmark identification error. The level of reliability was assessed based on ICC values ranging from 0 (no agreement) to 1 (perfect agreement). The intra-examiner results showed a high consistency in the repeated measurements indicating reliable measurements. The most reliable measurement was the Holdaway ratio and the least reliable measurement was overbite (Table 4.1). An F test was used to confirm there were no significant differences between the cephalometric variables from T0, T1 & T2 (Table 4.1).

Variables examined TI to T2	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower limit	Upper limit	Value	df1	df2	Sig
Occlusal Plane-SN (º)	.943	.861	.977	33.90	22	22	0
MP - SN (º)	.979	.948	.992	94.72	22	22	0
Wits Appraisal (mm)	.981	.953	.933	105.93	22	22	0
Interincisal Angle (U1-L1) (º)	.990	.976	.996	207.91	22	22	0
IMPA (L1-MP) (º)	.949	.876	.980	38.27	22	22	0
L1 Protrusion (L1-APo) (mm)	.982	.955	.993	110.59	22	22	0
L1 - NB (º)	.984	.959	.993	121.18	22	22	0
L1 - NB (mm)	.963	.908	.985	52.339	22	22	0
L1-APo (º)	.987	.968	.995	153.17	22	22	0
Y-axis (º)	.884	.730	.952	16.21	22	22	0

Overjet (mm)	.846	.652	.936	11.99	22	22	0
Overbite (mm)	.824	.608	.926	10.37	22	22	0
Pog-NB (mm)	.928	.828	.971	26.82	22	22	0
Holdaway ratio (L1-NB: Pg-NB)	.999	.978	.998	256.85	22	22	0

Table 4-1. ICC and F test values for the intra-examiner reliability at T0.

Overall, the inter-examiner ICC values had a wider reliability interval (x) and overall lower average correlation (0.). The level of reliability was assessed based on ICC values ranging from 0 (no agreement) to 1 (perfect agreement). The inter-examiner results showed a high consistency in the repeated measurements indicating reliable measurements and the error of measurement for the variables. The most reliable measurement was the interincisal angle and the least reliable measurement was for overjet at T0 (Table 4.2). At T2 the most reliable measurement was L1-APo (mm) and the least reliable was L1-NB (mm) (Table 4.3). An F test was used to confirm there were no significant differences between the cephalometric variables at T0 and T2 (Table 4.2 & 4.3). Based on these results, the reproducibility of the cephalometric variables is reliable within a 12-week period.

Variables examined at T0	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower limit	Upper limit	Value	df1	df2	Sig
Occlusal Plane-SN (º)	0.956	0.937	0.969	44.61	114	115	0
MP - SN (º)	0.951	0.929	0.966	39.47	114	115	0
Wits Appraisal (mm)	0.951	0.929	0.966	39.42	114	115	0
Interincisal Angle (U1-L1) (º)	0.988	0.983	0.992	168.99	114	115	0

IMPA (L1-MP) (º)	0.976	0.965	0.983	81.46	114	115	0
L1 Protrusion (L1-APo) (mm)	0.948	0.926	0.964	37.59	114	115	0
L1 - NB (º)	0.976	0.966	0.984	84.06	114	115	0
L1 - NB (mm)	0.591	0.457	0.698	3.89	114	115	0
L1-APo (º)	0.936	0.909	0.955	30.34	114	115	0
Y-axis (º)	0.926	0.895	0.949	26.18	114	115	0
Overjet (mm)	0.474	0.319	0.604	2.80	114	115	0
Overbite (mm)	0.967	0.953	0.977	60.06	114	115	0
Pog-NB (mm)	0.565	0.427	0.678	3.60	114	115	0
Holdaway ratio (L1-NB: Pg-NB)	0.972	0.96	0.981	70.38	114	115	0

Table 4-2. ICC and F test values for the inter-examiner reliability at T0.

Variables examined at T2	Interclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower limit	Upper limit	Value	df1	df2	Sig
Occlusal Plane-SN (°)	0.957	0.938	0.97	44.9	114	115	0
MP - SN (º)	0.980	0.972	0.986	100.85	114	115	0
Wits Appraisal (mm)	0.743	0.649	0.815	6.795	114	115	0
Interincisal Angle (U1-L1) (º)	0.983	0.975	0.988	113.8	114	115	0
IMPA (L1-MP) (º)	0.981	0.972	0.967	102.7	114	115	0
L1 Protrusion (L1-APo) (mm)	0.960	0.943	0.972	49.57	114	115	0
L1 - NB (º)	0.988	0.983	0.992	169.26	114	115	0
L1 - NB (mm)	0.686	0.576	0.772	5.38	114	115	0

L1-APo (º)	0.982	0.974	0.987	109.29	114	115	0
Y-axis (º)	0.957	0.938	0.97	44.99	114	115	0
Overjet (mm)	0.761	0.672	0.828	7.37	114	115	0
Overbite (mm)	0.825	0.756	0.875	10.42	114	115	0
Pog-NB (mm)	0.704	0.598	0.785	5.75	114	115	0
Holdaway ratio (L1-NB: Pg-NB)	0.839	0.776	0.886	11.44	114	115	0

Table 4-3. ICC and F test values for the inter-examiner reliability at T2.

4.3 Growth Considerations

Dolphin Imaging™ 11.5 software was used to predict the amount of growth that occurred over the treatment period (mean time of 12.7 months, SD 0.58 mo. – T1/T2; and mean time of 20.03 months, SD 0.72 mo. – T0/T2). Lateral cephalometric radiographs were digitally traced from Dolphin Imaging™ 11.5 software using Steiner's and Rickett's (1979) cephalometric analysis and then T0 and T2 and T1 and T2 were superimposed on each other. Ricketts stated that there are five measurements that are not affected by the change with age (Ricketts, 1979). The measurements are:

Facial Axis - (90±3°)

Facial Taper - (68±3.5°)

Lower Face Height – (47±4°)

Lower incisor to APo – (1mm±2mm)

Mandibular Incisor Inclination – (22±4°)

The growth effects for skeletal and dental changes over the treatment period were assessed on 30% of the studied sample. Thirty-four post-FSIA treatment and post-orthodontic treatment cephalometric radiographs were chosen from each group randomly and were subject to comparison based on Rickett's five superimposition landmarks and the variables for the five measurements that are thought not to change with age. A Kolmogorov-Smirnov test was used to determine if the samples were of normal distribution. A paired t-test was used to determine if there was a significant difference between the cephalometric variables from post-FSIA treatment versus post-orthodontic treatment cephalometric variables. The p value was considered significant at $\alpha<0.05$.

The five measurements that are thought not to change with age as stated above by Ricketts were used to determine if growth was negligible or not. Changes within the limit of four degrees were considered negligible. None of the selected subject measurements showed any changes greater than four degrees. SNA and SNB angles were also evaluated and no change was observed that was greater than three degrees.

4.4 Differences Within Groups Before and after FMB treatment (T2-T0).

A retrospective sample of 115 patients exhibiting a Class II malocclusion treated with the FSIA and FMB treatment was used. Subjects were then categorized into three growth types based on pre-treatment cephalometric variables (MP-SN and Y-axis); 28 brachycephalic (group 1), 31 dolichocephalic (group2), and 54 mesocephalic (group 3).

4.4.1 Differences Between Initial (T0) and End of Active FMB Treatment (T2) for the Brachycephalic Group (n=28, T2-T0), Table 4.4.

i) **Growth Pattern** - Both Y-axis and MP-SN were significantly different before and after treatment ($p<0.05$), signifying there were distinct facial patterns at the specified time periods. However, the change from T2-T0 was not statistically significant ($p>0.05$) for both variables. Therefore FSIA and FMB treatment did not influence the original facial pattern in the brachycephalic group.

ii) **Skeletal Pattern** - Wits appraisal was statistically significant ($p<0.05$) following treatment, with a mean reduction of 2.0±0.4mm. The occlusal plane – SN angle was statistically significant following treatment, with a mean increase of 3.8±1.0º.

iii) **Dental Pattern** - The lower incisor angular and linear changes at T2 were all proclined and protruded to the initial value at T0. The change of IMPA demonstrated an increase of 1.7±1.6˚ and was not statistically significant ($p>0.05$). However, other lower incisor movements were statistically significant ($p<0.05$) with increased mean protrusion to APo (2.1±0.5mm) and NB (0.3±0.09mm) and an increased mean proclination to NB (3.4±1.4˚) and APo (4.9±1.3˚). Both the overjet and overbite were reduced towards normal with FSIA and FMB treatment and were statistically significant for both variables ($p<0.05$).

Variable	Mean±SE (T0)	p-value	Mean±SE (T2)	p-value	Difference at T2-T0±SE	p-value
MP-SN(º)	25.8±0.6	<.0001	28.1±0.6	<.0001	2.3±0.9	0.09
Y-Axis (º)	64.1±0.6	<.0001	65.3±0.6	<.0001	1.2±0.8	0.1
Occlusal plane	12.5±0.7	<.0001	16.2±0.7	<.0001	3.8±1.0	0.0001*

-SN(º)						
Wits (mm)	3.1±0.3	<.0001	1.1±0.3	<.0001	-2.0±0.4	<0.0001*
Interincisal Angle (U1-L1) (º)	128.9±1.7	<.0001	125.2±1.8	<.0001	-3.6±2.3	0.1
IMPA (L1-MP) (º)	97.6±1.2	<.0001	99.3±1.2	<.0001	1.7±1.6	0.3
LI-protrusion (L1-APo) (mm)	-0.1±0.4	0.69	2.0±0.4	<.0001	2.1±0.5	<.0001*
L1-APo (º)	21.8±0.9	<.0001	26.7±0.9	<.0001	4.9±1.3	0.0002*
L1-NB (º)	22.9±1.0	<.0001	26.3±1.3	1	3.4±1.4	0.02*
L1-NB (mm)	2.0±0.06	<.0001	2.3±0.06	<.0001	0.3±0.09	0.0002*
Pog-NB (mm)	1.3±0.1	<.0001	1.5±0.12	<.0001	0.1±0.2	0.4
Overjet (mm)	5.4±0.1	<.0001	1.2±0.1	<.0001	-4.2±0.2	0.004*
Overbite (mm)	5.3.±0.3	<.0001	2.1±0.3	<.0001	-3.2±0.4	<.0001*
Holdaway Ratio (L1-NB:Pg-NB)	2.7±0.3	<.0001	1.0±0.3	0.002	-1.7±0.4	<.0001*

Table 4-4. Difference between initial (T0) and end of active FMB treatment (T2) for the Brachycephalic group (n=28, T2-T0).

4.4.2 Differences Between Initial (T0) and End of Active FMB treatment (T2) for the Dolicocephalic Group (n=31, T2-T0) Table 4.5.

i) **Growth Pattern** - Both Y-axis and MP-SN were significantly different before and after treatment ($p<0.05$), signifying there were distinct facial patterns at the specified time periods. However, the change from T2-T0 was not statistically significant ($p>0.05$) for both variables. Therefore, FSIA and FMB treatment did not influence the original facial pattern in the dolicocephalic group.

ii) **Skeletal Pattern** - Wits appraisal was statistically significant ($p<0.05$) following treatment, with a mean reduction of 2.5±0.4mm. The occlusal plane – SN angle was statistically significant following treatment, with a mean increase of 3.5±0.9º.

iii) **Dental pattern** - Lower incisor angular and linear changes at T2 were all proclined and protruded to the initial value at T0. Movement of the lower incisor was significant ($p<0.05$) with increased mean proclination to MP (1.7±1.5˚) and APo (2.7±1.2˚), and an increased mean protrusion to APo (1.5±0.5mm) and a decreased mean protrusion to NB (0.4±0.08mm). Both the overjet and overbite were significantly reduced towards normal with FSIA and FMB treatment.

Variable	**Mean±SE (T0)**	**p-value**	**Mean±SE (T2)**	**p-value**	**Difference at T2-T0±SE**	**p-value**
MP-SN(º)	38.6±0.6	<.0001	40.2±0.6	<.0001	1.5±0.8	0.7
Y-Axis (º)	72.2±0.5	<.0001	73.3±0.5	<.0001	1.1±0.7	0.2
Occlusal plane –SN (º)	19.2±0.6	<.0001	22.7±0.6	<.0001	3.5±0.9	0.0001*
Wits (mm)	3.6±0.3	<.0001	1.1±0.3	<.0001	-2.5±0.4	<.0001*
Interincisal Angle (U1-L1) (º)	127.9±1.5	<.0001	125.6±1.6	<.0001	-2.2±2.2	0.3
IMPA (L1-MP) (º)	93.0±1.0	<.0001	94.7±1.4	<.0001	1.7±1.5	0.03*
LI-protrusion (L1-APo) (mm)	1.2±0.3	0.0003	2.7±0.4	<.0001	1.5±0.5	0.0003*
L1-APo (º)	20.8±0.8	<.0001	23.5±0.8	<.0001	2.7±1.2	0.03*
L1-NB (º)	24.4±0.9	<.0001	26.4±0.9	<.0001	1.9±1.3	0.1
L1-NB (mm)	3.6±0.06	<.0001	2.3±0.06	<.0001	-1.3±0.08	<.0001*
Pog-NB (mm)	0.8±0.1	<.0001	1.1±0.1	<.0001	0.3±0.2	0.06
Overjet (mm)	5.4±0.1	<.0001	2.2±0.1	<.0001	-3.2±0.2	0.001*

Overbite (mm)	5.1±0.3	<.0001	2.6±0.3	<.0001	-2.1±0.4	<.0001
Holdaway Ratio (L1-NB:Pg-NB)	1.9±0.3	<.0001	0.6±0.3	0.04	-1.3±0.4	0.001

Table 4-5. Difference between initial (T0) and end of active FMB treatment (T2) for the Dolicocephalic group (n=31, T2-T0).

4.4.3 Differences Between Initial (T0) and End of Active FMB Treatment (T2) for the Mesocephalic Group (n=54, T2-T0) Table 4.6.

i) **Growth Pattern -** Both Y-axis and MP-SN were significantly different before and after treatment (p<0.05), signifying there were distinct facial patterns at the specified time periods. However, the change from T2-T0 was not statistically significant (p>0.05) for both variables. Therefore, FSIA and FMB treatment did not influence the original facial pattern in the mesocephalic group.

ii) **Skeletal Pattern** - Wits appraisal was statistically significant (p<0.05) following treatment, with a mean reduction of 2.3±0.2mm. The occlusal plane – SN angle was statistically significant (p<0.05) following treatment, with a mean increase of 2.5±0.7º.

iii) **Dental pattern** - Lower incisor angular and linear changes at T2 were all proclined and protruded to the initial value at T0. Movement of the lower incisors was significant (p<0.05) with increased mean protrusion to APo (1.8±0.4mm) and NB (0.4±0.06mm) and an increased mean proclination to MP (1.6±1.2˚), NB (1.3±1.1˚) and APo (1.8±0.4˚). Both the overjet and overbite were significantly reduced towards normal with FSIA and FMB treatment.

Variable	Mean±SE (T0)	p-value	Mean±SE (T2)	p-value	Difference at T2-T0±SE	p-value
MP-SN (º)	31.9±0.5	<.0001	33.23±0.5	<.0001	1.4±0.7	0.09
Y-Axis (º)	68.0±0.4	<.0001	68.4±0.4	<.0001	0.4±0.6	0.5
Occlusal plane –SN (º)	15.3±0.5	<.0001	17.8±0.5	<.0001	2.5±0.7	0.0005*
Wits (mm)	3.4±0.2	<.0001	1.0±0.3	<.0001	-2.3±0.2	<.0001*
Interincisal Angle (U1-L1) (º)	128.2±1.2	<.0001	124.9±1.2	<.0001	-3.3±1.7	0.06
IMPA (L1-MP) (º)	95.7±0.8	<.0001	97.3±0.8	<.0001	1.6±1.2	0.02*
LI-protrusion (L1-APo) (mm)	0.9±0.3	0.001	2.6±0.3	<.0001	1.8±0.4	<.0001*
L1-APo (º)	22.6±0.7	<.0001	25.2±0.7	<.0001	2.4±0.9	0.007*
L1-NB (º)	25.4±0.7	<.0001	26.7±0.7	<.0001	1.3±1.1	0.2
L1-NB (mm)	1.4±0.05	<.0001	1.8±0.05	<.0001	0.4±0.06	<.0001*
Pog-NB (mm)	1.0±0.08	<.0001	1.3±0.08	<.0001	0.3±0.1	0.03*
Overjet (mm)	5.7±0.08	<.0001	1.1±0.08	<.0001	-4.1±0.1	0.0004*
Overbite (mm)	4.8±0.2	<.0001	2.1±0.2	<.0001	-2.7±0.3	<.0001*
Holdaway Ratio (L1-NB:Pg-NB)	2.7±0.2	<.0001	0.6±0.2	0.0002	-1.9±0.3	<.0001*

Table 4-6. Differences Between Initial (T0) and End of Active FMB treatment (T2) for the Mesocephalic Group (n=54, T2-T0).

4.5 Differences Within Each Group After FSIA and After FMB Treatment (T2-T1).

4.5.1 Differences Between Fixed Spring Induced Appliance (FSIA) and (T1) and End of Active FMB Treatment (T2) for the Brachycephalic Group (n=28, T2-T1) Table 4.7.

i) **Growth Pattern** - Both Y-axis and MP-SN were significantly different before and after treatment ($p<0.05$), signifying there were distinct facial patterns at the specified time periods. However, the difference from T2-T1 was not statistically significant for both variables ($p>0.05$). Therefore, FMB treatment did not influence the original facial pattern in the brachycephalic group.

ii) **Skeletal Pattern** - Wits appraisal was statistically significant ($p<0.05$) following FMB treatment, with a mean reduction of 2.0±0.4mm. The occlusal plane – SN angle was not significantly changed during FMB treatment

iii) **Dental pattern** - Lower incisor angular and linear changes at T2 were all retroclined and retruded to the values at T1. Movement of the lower incisor was significant ($p<0.05$) with a decreased mean retroclination to MP (9.7±2.0˚), APo (6.5±1.8˚), and NB (8.2±1.9˚) and a increased mean retrusion to NB (0.3±0.09mm) and a decreased mean retrusion to APo (1.8±0.6mm). It is important to note that although a statistically significant difference was found the magnitude of the dental movement (retrusion) was small and may not be clinically meaningful. The overjet was reduced and overbite was improved to a more ideal position with FMB treatment.

Variable	Mean±SE (T1)	p-value	Mean±SE (T2)	p-value	Difference at T2-T1±SE	p-value
MP-SN(º)	26.0±0.6	<.0001	28.1±0.6	<.0001	2.1±0.9	0.7
Y-Axis (º)	64.6±0.6	<.0001	65.3±0.6	<.0001	0.8±0.8	0.4
Occlusal plane –SN (º)	17.5±0.7	<.0001	16.2±0.7	<.0001	-1.3±1.0	0.81
Wits (mm)	3.1±0.3	<.0001	1.1±0.3	<.0001	-2.0±0.4	<0.0001*
Interincisal Angle (U1-L1) (º)	120.8±1.8	<.0001	125.2±1.8	<.0001	4.4±2.5	0.08
IMPA (L1-MP) (º)	109.0±1.4	<.0001	99.3±1.2	<.0001	-9.7±2.0	<.0001*
LI-protrusion (L1-APo) (mm)	3.8±0.4	<.0001	2.0±0.4	<.0001	-1.8±0.6	0.03*
L1-APo (º)	33.2±1.3	<.0001	26.7±0.9	1	-6.5±1.8	0.0004*
L1-NB (º)	34.5±1.3	<.0001	26.3±1.3	<.0001	-8.2±1.9	<.0001*
L1-NB (mm)	2.0±0.06	<.0001	2.3±0.06	<.0001	0.3±0.09	0.0002*
Pog-NB (mm)	1.3±0.1	<.0001	1.5±0.12	<.0001	0.1±0.2	0.39
Overjet (mm)	2.4±0.1	<.0001	1.2±0.1	<.0001	-1.2±0.2	0.04*
Overbite (mm)	1.8±0.3	<.0001	2.1±0.3	0.002	0.3±0.4	0.003*
Holdaway Ratio (L1-NB:Pg-NB)	0.3±0.3	<.0001	1.0±0.3	<.0001	0.7±0.4	0.07

Table 4-7. Differences Between Fixed Spring Induced Appliance and (T1) and End of Active FMB treatment (T2) for the Brachycephalic Group (n=28, T2-T1).

4.5.2 Differences Between Fixed Spring Induced Appliance (FSIA) and (T1) and End of Active FMB Treatment (T2) for the Dolicocephalic Group (n=31, T2-T1) Table 4.8.

i) **Growth Pattern** **-** Both Y-axis and MP-SN were significantly different at T1 and at T2 ($p<0.05$), suggesting there were distinct facial patterns at the specified time periods. However, the difference from T2-T1 was not statistically significant for both variables ($p>0.05$). Therefore, FMB treatment did not alter the pre-existing facial pattern.

ii) **Skeletal Pattern** - Wits appraisal was statistically significant ($p<0.05$) following FMB treatment, with a mean reduction of 2.0±0.4mm. The occlusal plane – SN angle was not significantly changed by FMB treatment.

iii) **Dental pattern** - Lower incisor angular and linear changes at T2 were all retroclined and retruded to the values at T1. Movement of the lower incisor was significant ($p<0.05$) with a decreased mean retroclination to MP (5.3±1.9˚), APo (3.7±1.7˚), and NB (4.7±1.8˚) and an decreased mean retrusion to NB (3.4±0.09mm). The overjet was reduced and overbite was improved to a more ideal position after FMB treatment.

Variable	**Mean±SE (T1)**	**p-value**	**Mean±SE (T2)**	**p-value**	**Difference at T2-T1±SE**	**p-value**
MP-SN(º)	39.1±0.6	<.0001	40.2±0.6	<.0001	1.1±0.9	0.19
Y-Axis (º)	72.5±0.5	<.0001	73.3±0.5	<.0001	0.8±0.8	0.3
Occlusal plane –SN (º)	22.0±0.6	<.0001	22.7±0.6	<.0001	0.7±0.9	0.45
Wits (mm)	3.1±0.3	<.0001	1.1±0.3	<.0001	-2.0±0.4	<0.0001*
Interincisal Angle (U1-L1) (º)	124.5±1.7	<.0001	125.6±1.6	<.0001	1.1±2.3	0.64
IMPA (L1-	98.4±1.4	<.0001	94.7±1.4	<.0001	-5.3±1.9	0.004*

MP) (º)						
LI-protrusion (L1-APo) (mm)	3.2±0.4	<.0001	2.7±0.4	<.0001	-0.5±0.5	0.83
L1-APo (º)	27.2±1.2	<.0001	23.5±0.8	<.0001	-3.7±1.7	0.03*
L1-NB (º)	31.1±1.3	<.0001	26.4±0.9	<.0001	-4.7±1.8	0.009*
L1-NB (mm)	5.7±0.06	<.0001	2.3±0.06	<.0001	3-.4±0.09	0.0002*
Pog-NB (mm)	1.3±0.1	<.0001	1.1±0.1	<.0001	0-.2±0.2	0.39
Overjet (mm)	3.5±0.1	<.0001	2.2±0.1	<.0001	1.3±0.2	0.04*
Overbite (mm)	1.2±0.3	<.0001	2.6±0.3	<.0001	1.4±0.4	0.9
Holdaway Ratio (L1-NB:Pg-NB)	0.1±0.3	0.58	0.6±0.3	<.0001	0.5±0.4	0.21

Table 4-8. Difference between FSIA (T1) and End of Active FMB treatment (T2) for the dolicocephalic group (n=31, T2-T1).

4.5.3 Differences Between Fixed Spring Induced Appliance (FSIA) and (T1) and End of Active FMB treatment (T2) for the Mesocephalic Group (n=54), T2-T1) Table 4.9.

i) **Growth Pattern** - Both Y-axis and MP-SN were significantly different at T1 and at T2 ($p<0.05$), suggesting that there were distinct facial patterns at the specified time periods. However, the difference from T2-T1 was not statistically significant for both variables ($p>0.05$). Therefore, FMB treatment did not alter the pre-existing facial pattern.

ii) **Skeletal Pattern -** Wits appraisal was statistically significant ($p<0.05$) following treatment with only the FMB treatment, with a mean reduction of 2.0±0.4mm. The occlusal plane – SN angle was not significantly changed with only the FMB treatment.

iii) **Dental Variables -** Lower incisor angular and linear changes at T2 were all retroclined and retruded to the values at T1. Movement of the lower incisor was significant ($p<0.05$)

with a decreased mean retroclination to MP (8.4±1.5˚), APo (7.1±1.3˚), and NB (8.3±1.4˚) and an decreased mean retrusion to NB (2.5±0.09mm). The overjet was reduced and overbite was improved to a more ideal position after FMB treatment.

Variable	Mean±SE (T1)	p-value	Mean±SE (T2)	p-value	Difference at T2-T1±SE	p-value
MP-SN(º)	32.6±0.5	<.0001	33.3±0.5	<.0001	0.7±0.7	0.3
Y-Axis (º)	68.3±0.4	<.0001	68.4±0.4	<.0001	0.03±0.6	0.95
Occlusal plane –SN (º)	18.8±0.5	<.0001	17.8±0.5	<.0001	-1.0±0.7	0.2
Wits (mm)	3.1±0.3	<.0001	1.1±0.3	<.0001	-2.0±0.4	<0.0001*
Interincisal Angle (U1-L1) (º)	120.8±1.3	<.0001	124.9±1.2	<.0001	4.1±1.8	0.03*
IMPA (L1-MP) (º)	105.7±1.1	<.0001	97.3±0.8	<.0001	-8.4±1.5	<.0001*
LI-protrusion (L1-APo) (mm)	3.1±0.3	<.0001	2.6±0.3	<.0001	-0.5±0.4	0.2
L1-APo (º)	32.3±0.9	<.0001	25.2±0.7	<.0001	-7.1±1.3	<.0001*
L1-NB (º)	35.0±1.0	<.0001	26.7±0.7	<.0001	-8.3±1.4	<.0001*
L1-NB (mm)	4.8±0.06	<.0001	2.3±0.06	<.0001	-2.5±0.09	0.0002*
Pog-NB (mm)	1.0±0.1	<.0001	1.3±0.08	<.0001	0.3±0.2	0.4
Overjet (mm)	2.6±0.1	<.0001	1.1±0.08	<.0001	1.5±0.2	0.04*
Overbite (mm)	3.1±0.2	<.0001	2.1±0.2	<.0001	1.0±0.3	0.006*
Holdaway Ratio (L1-NB:Pg-NB)	0.2±0.2	0.42	0.6±0.2	<.0001	0.4±0.3	0.01*

Table 4-9. Differences Between FSIA and (T1) and End of Active FMB Treatment (T2) for the Mesocephalic Group (n=54, T2-T1).

4.6 Differences Between Groups Before FSIA & FMB Treatment (T0).

4.6.1 Differences Between Brachycephalic and Dolicocephalic Prior to FSIA and FMB Treatment (T0), Table 4.10.

i) **Growth Pattern** – Both Y-Axis and MP-SN were significantly different between the brachycephalic and dolicocephalic groups ($p<0.05$), signifying two distinct facial patterns prior to FSIA and FMB treatment.

ii) **Skeletal Pattern** – Wits appraisal was not statistically different between the brachycephalic and dolicocephalic group ($p>0.05$), classifying both groups as having a Class II skeletal pattern.

iii) **Dental Variable** – The facial pattern influenced the movements of the lower incisors, as they were significantly different between the groups ($p<0.05$) prior to treatment. As one would expect, dental compensations for varying facial patterns were reflected in the position of the lower incisor prior to treatment. The angular position of the lower incisor to mandibular plane was significantly different between the two groups ($p<0.05$), being more proclined in the brachycephalic group. The linear position of the lower incisors to APo and NB were significantly different, being more protruded in the dolicocephalic group. Both the overjet and overbite were excessive in both groups. The overbite was significantly different ($p < 0.05$) between the two groups prior to treatment being greater in the brachycephalic group.

Variable	Group 1 (Brachy)	Group 2 (Dolico)	p-value
	Mean±SE (T0)	**Mean±SE (T0)**	
MP-SN(º)	25.8±0.6	38.6±0.6	<.0001*
Y-Axis (º)	64.1±0.6	72.2±0.5	<.0001*
Occlusal plane –SN (º)	12.5±0.7	19.2±0.6	<.0001*
Wits (mm)	3.1±0.3	3.6±0.3	0.15
Interincisal Angle (U1-L1) (º)	128.9±1.7	127.9±1.5	0.66
IMPA (L1-MP)(º)	97.6±1.2	93.0±1.0	0.003*
L1-protrusion (L1-APo) (mm)	-0.1±0.4	1.2±0.3	0.005*
L1-APo (º)	21.8±0.9	20.8±0.8	0.40
L1-NB (º)	22.9±1.0	24.4±0.9	0.28
L1-NB (mm)	2.0±0.06	3.6±0.06	0.001*
Pog-NB (mm)	1.3±0.1	0.8±0.1	0.004*
Overjet (mm)	5.4±0.1	5.4±0.1	0.67
Overbite (mm)	5.3.±0.3	5.1±0.3	0.04*
Holdaway Ratio (L1-NB:Pg-NB)	2.7±0.3	1.9±0.3	0.52

Table 4-10. Differences between brachycephalic and dolicocephalic groups prior to FSIA and FMB treatment (T0).

4.6.2 Differences Between Brachycephalic and Mesocephalic Prior to FSIA and FMB Treatment (T0), Table 4.11.

i) Growth Pattern – Both Y-Axis and MP-SN were significantly different between the brachycephalic and mesocephalic groups ($p<0.05$), signifying two distinct facial patterns prior to FSIA and FMB treatment.

ii) **Skeletal Pattern** – Wits appraisal was not statistically different between the brachycephalic and mesocephalic group (p>0.05), classifying both groups as having a Class II skeletal pattern.

iii) **Dental Variable** – When comparing the brachycephalic group to the mesocephalic group, the facial patterns were similar enough not to influence the angular position of the lower incisors as they were not significantly different between the groups (p>0.05) prior to treatment. The linear position of the lower incisor to APo and NB were significantly different (p<0.05), being more protruded in the mesocephalic group. The dental compensations for the brachycephalic and mesocephalic groups were similar prior to treatment. Both the overjet and overbite were excessive in both groups and were not significantly different (p>0.05) between the two groups prior to treatment.

Variable	**Group 1 (Brachy)**	**Group 3 (Meso)**	**p-value**
	Mean±SE (T0)	**Mean±SE (T0)**	
MP-SN(°)	25.8±0.6	31.9±0.5	<.0001*
Y-Axis (°)	64.1±0.6	68.0±0.4	<.0001*
Occlusal plane –SN (°)	12.5±0.7	15.3±0.5	0.001*
Wits (mm)	3.1±0.3	3.4±0.2	0.63
Interincisal Angle (U1-L1) (°)	128.9±1.7	128.2±1.2	0.76
IMPA (L1-MP) (°)	97.6±1.2	95.7±0.8	0.49
LI-protrusion (L1-APo) (mm)	-0.1±0.4	0.9±0.3	0.02*
L1-APo (°)	21.8±0.9	22.6±0.7	0.47
L1-NB (°)	22.9±1.0	25.4±0.7	0.06
L1-NB (mm)	2.0±0.06	1.4±0.05	0.05*
Pog-NB (mm)	1.3±0.1	1.0±0.08	0.03*
Overjet (mm)	5.4±0.1	5.7±0.08	0.18
Overbite (mm)	5.3.±0.3	4.8±0.2	0.95

Holdaway Ratio (L1-NB:Pg-NB)	2.7±0.3	2.7±0.2	0.68

Table 4-11. Differences between brachycephalic and mesocephalic groups prior to FSIA and FMB Treatment (T0).

4.6.3 Differences Between Dolicocephalic and Mesocephalic Prior to FSIA and FMB Treatment (T0), Table 4.12.

i) **Growth Pattern** - Both Y-Axis and MP-SN were significantly different between the dolicocephalic and mesocephalic groups ($p<0.05$), signifying two distinct facial patterns prior to FSIA and FMB treatment.

ii) **Skeletal Pattern** - Wits appraisal was not statistically different between the dolicocephalic and mesocephalic group ($p>0.05$), classifying both groups as having a Class II skeletal pattern.

iii) **Dental Variable** - When comparing the dolicocephalic group to the mesocephalic group, the facial patterns were similar enough not to influence the linear position of the lower incisors as they were not significantly different between the groups ($p>0.05$) prior to treatment. However, the dolicocephalic group was more protruded than the mesocephalic group. Similar to the comparison of the lower incisor angular position to the brachycephalic facial pattern, when compared to the mesocephalic group the angular position of the lower incisor to mandibular plane was significantly different between the two groups, being more proclined in the mesocephalic group. Both the overjet and overbite were excessive in both groups. The overbite was significantly different ($p<0.05$) between the two groups prior to treatment being greater in the mesocephalic group.

Variable	Group 2 (Dolico)	Group 3 (Meso)	p-value
	Mean±SE (T0)	Mean±SE (T0)	
MP-SN (º)	38.6±0.6	31.9±0.5	<.0001*
Y-Axis (º)	72.2±0.5	68.0±0.4	<.0001*
Occlusal plane –SN (º)	19.2±0.6	15.3±0.5	<.0001*
Wits (mm)	3.6±0.3	3.4±0.2	0.63
Interincisal Angle (U1-L1) (º)	127.9±1.5	128.2±1.2	0.84
IMPA (L1-MP) (º)	93.0±1.0	95.7±0.8	0.006*
LI-protrusion (L1-APo) (mm)	1.2±0.3	0.9±0.3	0.37
L1-APo (º)	20.8±0.8	22.6±0.7	0.09
L1-NB (º)	24.4±0.9	25.4±0.7	0.43
L1-NB (mm)	3.6±0.06	1.4±0.05	0.08
Pog-NB (mm)	0.8±0.1	1.0±0.08	0.30
Overjet (mm)	5.4±0.1	5.7±0.08	0.37
Overbite (mm)	5.1±0.3	4.8±0.2	0.02
Holdaway Ratio (L1-NB:Pg-NB)	1.9±0.3	2.7±0.2	0.24

Table 4-12. Differences between dolicocephalic and mesocephalic groups prior to FSIA and FMB Treatment (T0).

4.7 Differences Between Groups following FSIA and FMB Treatment (T2).

4.7.1 Differences Between Brachycephalic and Dolicocephalic after FSIA and FMB Treatment (T2), Table 4.13.

i) **Growth Pattern** – Both Y-Axis and MP-SN were significantly different between the brachycephalic and dolicocephalic groups ($p<0.05$) following FMB treatment. Therefore, FSIA and FMB treatment did not change the pre-existing facial pattern.

ii) **Skeletal Pattern** – Although there was a reduction in Wits following treatment, Wits appraisal was not statistically different between the brachycephalic and dolicocephalic group ($p>0.05$) at T2.

iii) **Dental Variable** – The facial pattern influenced the movements of the lower incisors, as they were significantly different between the groups ($p<0.05$) following FSIA and FMB treatment. The final angular position of the lower incisor to mandibular plane was significantly different between the two groups being more proclined in the brachycephalic group. As one would expect, both the overjet and overbite were reduced with treatment in both groups and were not significantly different ($p>0.05$) at T2.

Variable	**Group 1 (Brachy)**	**Group 2 (Dolico)**	**p-value**
	Mean±SE (T2)	**Mean±SE (T2)**	
MP-SN (º)	28.1±0.6	40.2±0.6	<.0001*
Y-Axis (º)	65.3±0.6	73.3±0.5	<.0001*
Occlusal plane –SN (º)	16.2±0.7	22.7±0.6	<.0001*
Wits (mm)	1.1±0.3	1.1±0.3	0.42
Interincisal Angle (U1-L1) (º)	125.2±1.8	125.6±1.6	0.89
IMPA (L1-MP) (º)	99.3±1.2	94.7±1.4	<.0001*
LI-protrusion (L1-APo) (mm)	2.0±0.4	2.7±0.4	0.05
L1-APo (º)	26.7±0.9	23.5±0.8	0.009*
L1-NB (º)	26.3±1.3	26.4±0.9	0.97
L1-NB (mm)	2.3±0.06	2.3±0.06	0.02*
Pog-NB (mm)	1.5±0.12	1.1±0.1	0.0003*
Overjet (mm)	1.2±0.1	2.2±0.1	0.78
Overbite (mm)	2.1±0.3	2.6±0.3	0.37
Holdaway Ratio (L1-NB:Pg-NB)	1.0±0.3	0.6±0.3	0.64

Table 4-13. Differences between brachycephalic and dolicocephalic groups after FSIA and FMB Treatment (T2).

4.7.2 Difference Between Brachycephalic and Mesocephalic after FSIA and FMB Treatment (T2), Table 4.14.

i) **Growth Pattern** – Both Y-Axis and MP-SN were significantly different between the brachycephalic and mesocephalic groups ($p<0.05$) following FMB treatment. Therefore, FSIA and FMB treatment did not change the pre-existing facial pattern.

ii) **Skeletal Pattern** – Although there was a reduction in Wits following treatment, Wits appraisal was not statistically different between the brachycephalic and mesocephalic group ($p>0.05$) at T2.

iii) **Dental Variable** – The facial pattern between the two groups are similar enough not to have influenced the treatment induced movements of the lower incisors, as they were not significantly different between the groups ($p>0.05$) following FSIA and FMB treatment. The final angular position of the lower incisor to mandibular plane was significantly different between the two groups being more proclined in the brachycephalic group. As one would expect, both the overjet and overbite were reduced with treatment in both groups and were not significantly different ($p>0.05$) at T2.

Variable	**Group 1 (Brachy)**	**Group 3 (Meso)**	**p-value**
	Mean±SE (T2)	**Mean±SE (T2)**	
MP-SN (º)	28.1±0.6	33.3±0.5	<.0001*
Y-Axis (º)	65.3±0.6	68.4±0.4	<.0001*
Occlusal plane –SN (º)	16.2±0.7	17.8±0.5	0.07
Wits (mm)	1.1±0.3	1.1±0.3	0.42
Interincisal Angle (U1-L1) (º)	125.2±1.8	124.9±1.2	0.89
IMPA (L1-MP) (º)	99.3±1.2	97.3±0.8	0.03*
LI-protrusion (L1-APo) (mm)	2.0±0.4	2.6±0.3	0.15

L1-APo (º)	26.7±0.9	25.2±0.7	0.16
L1-NB (º)	26.3±1.3	26.7±0.7	0.16
L1-NB (mm)	2.3±0.06	2.3±0.06	0.77
Pog-NB (mm)	1.5±0.12	1.3±0.08	0.01*
Overjet (mm)	1.2±0.1	1.1±0.08	0.93
Overbite (mm)	2.1±0.3	2.1±0.2	0.78
Holdaway Ratio (L1-NB:Pg-NB)	1.0±0.3	0.6±0.2	0.26

Table 4-14. Differences between brachycephalic and mesocephalic groups after FSIA and FMB Treatment (T2).

4.7.3 Differences Between Dolicocephalic and Mesocephalic after FSIA and FMB Treatment (T2), Table 4.15.

i) **Growth Pattern** – Both Y-Axis and MP-SN were significantly different between the dolicocephalic and mesocephalic groups ($p<0.05$) following FMB treatment. Therefore, FSIA and FMB treatment did not change the pre-existing facial pattern.

ii) **Skeletal Pattern** – Although there was a reduction in Wits following treatment, Wits appraisal was not statistically different between the dolicoephalic and mesocephalic group ($p>0.05$) at T2.

iii) **Dental Variable** – The facial pattern between the two groups are similar enough not to have influenced the treatment induced movements of the lower incisors, as they were not significantly different between the groups ($p>0.05$) following FSIA and FMB treatment. The final angular position of the lower incisor to mandibular plane was significantly different between the two groups being more proclined in the mesocephalic group. As one would expect, both the overjet and overbite were reduced with treatment in both groups and were not significantly different ($p>0.05$) at T2.

Variable	Group 2 (Dolico)	Group 3 (Meso)	p-value
	Mean±SE (T2)	Mean±SE (T2)	
MP-SN (º)	40.2±0.6	33.3±0.5	<.0001*
Y-Axis (º)	73.3±0.5	68.4±0.4	<.0001*
Occlusal plane –SN (º)	22.7±0.6	17.8±0.5	<.0001*
Wits (mm)	1.1±0.3	1.1±0.3	0.56
Interincisal Angle (U1-L1) (º)	125.6±1.6	124.9±1.2	0.72
IMPA (L1-MP) (º)	94.7±1.4	97.3±0.8	0.006*
LI-protrusion (L1-APo) (mm)	2.7±0.4	2.6±0.3	0.42
L1-APo (º)	23.5±0.8	25.2±0.7	0.11
L1-NB (º)	26.4±0.9	26.7±0.7	0.81
L1-NB (mm)	2.3±0.06	2.3±0.06	0.19
Pog-NB (mm)	1.1±0.1	1.3±0.08	0.12
Overjet (mm)	2.2±0.1	1.1±0.08	0.68
Overbite (mm)	2.6±0.3	2.1±0.2	0.46
Holdaway Ratio (L1-NB:Pg-NB)	0.6±0.3	0.6±0.2	0.26

Table 4-15. Differences between dolicocephalic and mesocephalic groups after FSIA and FMB Treatment (T2).

4.8 AVERAGE VALUE FOR EACH VARIABLE AT T0 AND T2 AND THE AMOUNT OF CHANGE (Table 4.16).

The table below shows the overall mean for each variable and the amount of change with treatment (T2-T0), regardless of facial pattern. The largest changes can be seen in the L1-APo (º), occlusal plane-SN angle and interincisal angle (3.4º-3.3º), followed by L1-NB angle (º) and Wits (2.2º and 2.2mm).

Variable	T2(S.D.)	T0 (S.D.)	Amount of change from T2-T0
MP-SN (º)	33.8 (0.55)	32.1 (0.55)	1.8
Y-Axis (º)	69.0 (0.50)	68.1 (0.50)	0.9
Occlusal plane –SN (º)	18.9 (0.60)	15.7 (0.60)	3.2
Wits (mm)	1.1 (0.16)	3.4 (0.24)	- 2.3
Interincisal Angle (U1-L1) (º)	125.2 (1.47)	128.3 (1.48)	-3.1
IMPA (L1-MP) (º)	97.1 (0.98)	95.4 (0.98)	1.7
LI-protrusion (L1-APo) (mm)	2.4 (0.31)	0.7 (0.31)	1.7
L1-APo (º)	25.1 (0.80)	21.7 (0.80)	3.4
L1-NB (º)	26.5 (0.90)	24.2 (0.90)	2.3
L1-NB (mm)	2.1 (0.06)	2.3 (0.06)	-0.2
Pog-NB (mm)	1.3 (0.15)	1.0 (0.10)	0.3
Holdaway Ratio (L1-NB:Pg-NB)	0.7 (0.16)	2.4 (0.29)	-1.7
Overjet (mm)	1.5 (0.24)	5.5 (0.24)	-4.0
Overbite (mm)	2.3 (0.27)	5.1 (0.27)	-2.8

Table 4-16. Average value for each variable at T0 and T2 and the amount of change.

4.9 THE EFFECT OF LOWER INCISOR PROCLINATION ON MP-SN (Table 4.17).

A simple linear regression test was performed to evaluate the effect lower incisor proclination on MP-SN ($p<0.05$). IMPA was significant at T1 & T2 for the brachycephalic group indicating greater lower incisor movements. It is important to note that the dental movements were minimal in magnitude. Changes in the lower incisor inclination did not affect the facial patterns (Table 4.17).

Measurement	Group	post Beta coefficient (±SE)	p-value	pre Beta coefficient (±SE)	p-value
IMPA (L1 MP) (°)	Brachy	-0.17 (0.13)	0.2	-0.05(0.05)	0.3
	Dolico	-0.34 (0.1)	0.01	-0.09(0.05)	0.07
	Meso	-0.05 (0.07)	0.4	-0.08 (0.04)	0.04
L1-NB (°)	Brachy	0.10 (0.14)	0.5	-0.006(0.06)	0.9
	Dolico	0.15 (0.17)	0.4	-0.06(0.06)	0.3
	Meso	0.06 (0.07)	0.4	-0.02(0.03)	0.5
L1-APo (°)	Brachy	-0.06 (0.17)	0.7	0.006(0.06)	0.9
	Dolico	-0.003 (0.16)	0.9	-0.12(0.06)	0.06
	Meso	-0.004 (0.07)	0.9	-0.03(0.04)	0.5

Table 4-17. The effect of lower incisor proclination to change MP-SN by 1º.

Chapter 5

Discussion

The position of the mandibular incisors has always been a major deciding factor in treatment planning and achieving lower incisor stability has always been one of the major goals of orthodontic treatment. Several factors play a role in attaining lower incisor stability. Proclined lower incisors at the end of treatment have always been considered an undesirable side effect of orthodontic treatment and is considered disadvantageous for two main reasons: (1) it can lead to negative periodontal ramifications and (2) can result in reduced stability. A reduction in stability increases the potential for rebound. Rebound is a sequence of events by which a tooth reaches its most balanced occlusal position. Rebound after orthodontic treatment is continuous throughout life and while orthodontists disrupt that continuous physiologic rebound process, along with changes during orthodontic treatment, rebound will resume after orthodontic treatment is completed leading into the adult life. This rebound is often mistaken or wrongly termed as relapse (Horowitz & Hixon, 1969). There is normally a balance between dental, occlusal, esthetic, functional, and skeletal components. This study investigated the magnitude and direction of the lower incisor position following the use of a fixed spring induced appliance (FSIA) and full fixed multi banded/bonded orthodontic treatment (FMB treatment).

Lateral cephalograms taken at T0, T1, and T2 were traced to obtain measurements for baseline values at the beginning of treatment (T0), for values after use of a FSIA (T1), and at the end of active FMB treatment (T2). At T0, a mean IMPA (L1-MP) value of 95.7 ± 0.98° was observed. When analyzing cephalometric norms, some analyses consider the distribution of these values not within the range of normal for example, Steiner's and Rickett's analyses (Jacobson, 1995) and some consider it within the normal range, for example, Tweed and Downs (Downs, 1948; Tweed, 1969). Accordingly, there are variations in the range reported by different researchers. A mean IMPA (L1-MP) value at T2 of 96.1 ± 0.98° was obtained. At T1 the mean IMPA value (104.4 ± 1.29°) indicated that the mandibular incisors were in a more proclined position than at T2. Although there was tooth movement in the opposite direction at T2 when compared to T1, the lower incisors finished in a more proclined position at the end of orthodontic treatment when compared to the position at T0 but only by 0.37°, well within the error of measurement. This proclined position at T2 when compared to T0 indicates that the lower incisors move in the direction of their initial position without returning to the exact initial position. A possible explanation is that FMB treatment mechanics employed were able to reduce the side effects on lower incisor proclination observed at T1. In addition, relapse may have been occurring simultaneously possibly masked by the treatment mechanics used. Several authors have shown that the lower incisors tend to rebound after treatment (Shields, Little, & Chapko, 1985; Årtun, Garol, & Little, 1996). Årtun, Garol, and Little et al (1996), found that an average value for IMPA at T2 (the end of treatment) was 99.07 ± 5.07°. The IMPA value at T2 in this study was less than previous studies and yet was similar to the norms of some cephalometric analyses. This may indicate that the 'normal range' might be larger than suggested. This dental relationship (IMPA) may also be an expression of the postural muscle activity (McNamara Jr., 1981). Although the IMPA value at T1 showed undesirable side effects, such as proclined lower incisors, while at T2, the lower incisors were retroclined and retruded back towards their original position. This finding is clinically important because the final position of the lower incisor is critically important on the retention protocol and potential for relapse. The mean final position of the lower incisors was within acceptable normal ranges and favors stability. That said, changes should be monitored.

An interesting finding of the present study was the tendency for pronounced dental movements of the lower incisor in brachycephalic patients. Chana et al. (2013) studied the Xbow™ appliance in 2013 and evaluated the effects at T1. He found that brachycephalic patients had more pronounced dental movements, consistent with the results reported by Flores-Mir et al (Flores-Mir et al., 2010). The cephalometric changes for the lower incisor variables varied at T2-T0 and were statistically significant for each facial pattern and the brachycephalic group had the largest overall change (L1-APo: 4.9°±1.3 – Brachy; 2.7°±1.2 – Dolico; 3.6° ± 0.9 – Meso; $p<0.05$; L1-APo: 2.1mm ± 0.5-Brachy; 1.5mm ± 0.5 – Dolico; 1.8mm ± 0.4 – Meso; $p<0.05$; L1-NB: 0.3mm ± 0.09– Brachy; 1.3mm ± 0.08 - Dolico; 0.4mm ± 0.06 - Meso; $p<0.05$). Overall, the results indicated that mandibular lower incisors were proclined and protruded compared to the initial position indicating that they do not completely return to their initial position at T0. Only the brachycephalic group was statistically significant for L1-NB (3.4°±1.4). This may be explained by the strength of the musculature pattern of this group which exhibited larger dental compensations (Bjork & Palling, 1955; Janson, Metaxas, & Woodside, 1994; Enoki, Telles, & Matsumoto, 2004; Kuitert, Beckmann, van Loenen, Tuinzing, & Zentner, 2006; Flores-Mir et al., 2010) and by the treatment mechanics used. Explained further below.

Muscle strength is one reason for the variability of treatment responses. Posen (1976) measured the strength of the peri-oral musculature (with a perioral muscle meter (PMM) designed to measure and quantify the maximum tonicity of the lips) and proved there was a relationship between the maximum perioral strength and the forces generated by tonus and normal lip activity. He measured maximum tonicity in the perioral muscles and compared it to standards for normal, derived from a number of Caucasian males and females with good facial balance and acceptable occlusion. Posen found that during normal lip activity and while at rest, greater forces were exerted by the lips if the maximum tonicity or lip strength was high or hypertonic. He observed in Class II division 1 malocclusions that the maximum perioral tonicity varied and a greater posterior force was exerted by hypertonic lips than hypotonic lips, especially if a large overjet (>3mm) was present. This supports the results at T0 where the dolicocephalic patients exhibited a more protruded and upright lower incisor position (L1-NB mm) than the brachycephalic patients. He observed that a change in the oral environment due to a more normal denture position was accompanied by a change in the peri-oral musculature to more normal values for this malocclusion (110-320 grams). He found that the hypertonicity of the perioral muscles tend to retract the incisors more than the hypotonic musculature. This supports the findings in this present study where the lower incisor changes at T2-T0 and T2-T1 (L1-MP, L1-APo, L1-NB), resulted in greater angular changes from the brachycephalic facial group. Subtenly and other authors (Subtelny, 1959; Burstone, 1967; Anderson, Joondeph, & Turpin, 1973) stated that the soft tissues of the face played a major role in the stability of the lower incisors. These observations infer the more normal the position of the lower incisors minimizes relapse and enhances stability. Posen also stated that if the lower incisors are in a good anteroposterior inclination and relationship, moving them anteriorly interfered with the facial balance and lip function and could result in relapse of the incisor teeth (Posen, 1976). This supports the findings in the present study observed at T2-T1. The results of the present study at T2 showed a final position of the lower incisors close to their initial position so relapse/rebound may be minimal and stability favorable. Posen (1976) stated that when the arch form was altered the muscle pressure of the lips was altered and distribution of the forces over a greater area occurred (Posen, 1976). This may explain the results of the lower incisors at T2 being in a more protruded and proclined position than at T0.

Facial musculature pattern is another factor to be considered. Weak facial musculature is a characteristic facial feature of the long dolicocephalic facial pattern while the strong facial musculature is a characteristic of the brachycephalic facial pattern (Ricketts, 1979). The musculature pattern is thought to influence the underlying dental compensations that exist to counteract the vertical growth deviations in all three planes of space according to several authors (Bjork & Palling, 1955; Enoki, Telles, & Matsumoto, 2004; Janson, Metaxas, & Woodside, 1994; Kuitert, Beckmann, van Loenen, Tuinzing, & Zentner, 2006; Flores-Mir et al., 2010). For example, the cephalometric differences between the facial patterns for variables involving the lower incisor were calculated for the pre-treatment (T0) and post-treatment (T2) time periods (Table 4.10, 4.11 and 4.12), respectively. Only the brachycephalic group resulted in a statistically significant finding for the variables indicated, suggesting that the brachycephalic group has a tendency for greater retrusion and retroclination of the lower incisor when compared with the other groups. This is in agreement with a study by Posen (1976) indicating that hypertonic or strong facial musculature patterns exert more pressure resulting in a greater posterior force thus resulting in more movement than with hypotonic musculature (Posen, 1976). The pre-treatment lower incisor angular position was significantly different between the brachycephalic and the dolicocephalic groups, which was possibly a natural compensation to reduce the overbite and overjet in a Class II malocclusion. The significance of this for the clinician is that one can expect greater and less predictable dental movements (proclination and protrusion with a FSIA and retroclination and retrusion with FMB treatment) in the brachycephlic groups during treatment. Although the maximum tonicity of the lips may be determined genetically, this tonicity can be altered, i.e., strengthened by dento-alveolar retrusion of the lips.

The APo line has been recommended as a reliable reference line by Downs and Ricketts and the final position of the incisal edge of the lower incisors should be placed 1mm ahead of this line (Houston & Edler, 1990). This study showed a change in L1-APo position at T2-T0 ranging from 2.7°±1.2 (for the dolicocephalic group) to 4.9°±1.3 (for the brachycephalic group). The average L1-APo change was 3.4° (Table 4.16). These results were similar to other studies that evaluated the changes of the lower incisor position using other FSIA and FMB treatment. They reported a 3-5° range for the changes seen (Jones, Buschang, Kim, & Oliver, 2008; Flores-Mir et al., 2009; Aziz et al., 2012). The results indicated that the lower incisors are in a favorable stable position and treatment mechanics were controlled during FMB treatment.

In a study by Housten and Elder (1990), showed that when the lower incisors were placed more than 2mm ahead of the APo line at the completion of treatment there was a tendency for the incisors to move nearer to the line, especially after retention. Unfortunately, it is not possible to confirm the belief that the lower incisors that have been moved during treatment within 2mm of the APo line, are stable in that position without further long-term studies. However, the results of this investigation support the view of other authors that the initial position of the lower incisors provides the best guide to their position of stability (Mills, 1967; Hixon, 1972; Alexander, 2001). The lower incisors in the present study were well positioned to the APo line (mean value at T2 2.5± 0.31mm). Although the lower incisors started at a position that was within the normal range they showed to be in a slightly more retruded position at T2 (Mean value at T0 1.1±0.31mm). The position of the lower incisors may often be an adaptive response to the position of the mandibular skeletal structures relative to maxillary skeletal structures (McNamara, 1981). McNamara (1981) found the lower incisors, on average, to be within a 0-3mm range ahead of the APo line at the end of treatment, which did not involve a FSIA. These findings also supported the findings of the present study. The significance of this indicated that the average position for the lower incisor was within an acceptable normal range and this was in a favorable position for stability and that no one cephalometric variable should be used as a definitive conclusive option for determining the ideal final position and stability.

The effect of three (3) lower incisor variables (IMPA (°), L1-NB (°), and L1-APo (°)) relative to MP-SN were evaluated in the present study. The results are seen in Table 4.17. The results at T2 showed that when IMPA proclined by 0.17° ± 0.13 ($p>0.05$), MP-SN changed by 1° in the brachycephalic group, 0.34° ±0.01 ($p<0.05$) and 0.05°±0.07 ($p>0.05$) proclination was the result in the dolicocephalic and mesocephalic group, respectively (Table 4.17). In order for MP-SN to change by 1° at T1, IMPA proclined by 0.05° ±0.05 ($p>0.05$) in the brachycephalic group, 0.09° ±0.05 ($p>0.05$) in the dolicocephalic group and 0.08° ±0.04 ($p<0.05$). It was investigated whether the change in the lower incisor variables were correlated to MP-SN and Y-Axis, no correlation was found. The findings explained that changes to the lower incisor angulation had a minimal effect on the facial pattern. Thus the results suggested the mesocephalic group after FSIA treatment and the dolicocephalic group after FMB treatment had a tendency for greater lower incisor movement in order to have an effect on MP-SN, than the other facial types.

However, changes were minimal overall and similar dental movements during orthodontic treatment, independent of facial type may be expected.

The overall average change at T2–T0 for MP-SN was 1.8° ± 0.55 and 0.9° ± 0.50 for Y-Axis, the change is within the two standard deviations (Table 4.16). This confirmed that minimal growth was expressed during this study and the change in the lower incisor proclination had minimal influence on the facial pattern, and the changes during FSIA and FMB treatment were more dento-alveolar than skeletal. Another explanation was that the mandibular growth peak coincided with the FSIA and orthodontic treatment and the efficiency of the dento-alveolar Class II correction mechanics may have overpowered any mandibular growth contribution that may have otherwise been seen. In addition to the fact that FSIAs does not distract the condyle from the glenoid fossa, significant mandibular growth was not expected. This minimal change was consistent a study by Barnett et al. (Barnett, Higgins, Major, & Flores-Mir, 2008) who observed mandibular growth to be within a 1-3° range during the duration of their study. The results confirmed the accuracy of the initial grouping by facial type. The results demonstrated statistically significant results for MP-SN and Y-Axis at T0 and showed the change (T2-T0) was negligible and not significant ($p>0.05$) as previously stated in the results (less than 4 degrees of change) ranging from 1.4–2.3°for MP-SN and 0.4–1.2° for the Y-Axis. Clinicians can expect that the facial patterns will not be significantly altered with changes to the lower incisor position with subjects in the age range investigated. Clinicians should still be vigilant with treatment mechanics to avoid unfavorable side effects, such as downward and backward rotation of the mandible resulting in an open bite.

Changes were observed in the occlusal plane-SN angle and the Wits measurements for all 3 facial groups when comparing T2-T0, indicating an improvement in the skeletal Class II relationship. The occlusal plane-SN angle showed the brachycephalic group increased by 3.8º ± 1.0, the dolicocephalic group increased by 3.5º ± 0.9, and the mesocephalic group increased by 2.5º ± 0.7, which were statistically significant for occlusal plane-SN angle ($p<0.05$). The Wits changes were also statistically significant ($p<0.05$) for all three (3) facial patterns. The brachycephalic group reduced by 2.0mm ± 0.4, the dolicocephalic group reduced by 2.5mm ±0.4 and the mesocephalic group reduced by 2.3mm ± 0.2. A significant reduction of the Wits value in all three groups was seen in this study, which represents a reduction in the skeletal Class II relationship of the maxilla with the mandible. The Wits values are inversely related to the occlusal plane angle (Nalbantgil, Arun, Sayinsu, & Isik, 2005), and the amount of skeletal Class II correction is a result of more dento-alveolar changes than skeletal changes. In addition, the occlusal plane change influenced the correction of the Class II malocclusion evidenced by reduction in the overjet and levelling of the mandibular occlusal plane both related to changes in lower incisor position (Vargervik & Harvold, 1985). A study by Jin-Le, Chung How, and Min (2014), stated that growth and maturational changes within the cranial structures make the treatment-induced changes of the occlusal plane in adolescent subjects difficult to determine, an observation consistent with El-Batouti A, ∅gaard B, Bishara SE, (El-Batouti, øgaard, & Bishara, 1994; Stahl, Baccetti, Franchi, & McNamara Jr., 2008). Since there were no significant changes to the growth pattern, the changes in these variables related to dento-alveolar changes. The change of the occlusal plane angle in the present study could be related to any remaining growth potential expressed during treatment and correction in the Class II malocclusion a result of the treatment mechanics used, such as the use of Class II elastics, bracket prescription, levelling the Curve of Spee and changes in the lower incisors position (Vargervik K, Harvold E, 1985; Jin-le, Chung How, Min, 2014). The reduction in the Wits value and an increase in the occlusal plane angle demonstrated an improvement in the dento-alveolar Class II malocclusion.

There are many other factors that influence final lower incisor position after orthodontic treatment that may vary from their original position, beyond the cephalometric measurements discussed such as soft tissue factors, skeletal factors, tongue size, treatment mechanic choices, bracket prescription, length of treatment time, extraction treatment and non-extraction treatment (Shields et al., 1985; Årtun et al., 1996; Richardson & Gormley, 1998; Freitas, De Freitas, Henriques, Pinzan, & Janson, 2004; Ormiston et al., 2005; Barnett et al., 2008; Miller, Tieu, & Flores-Mir, 2013). Whilst many clinicians feel that lower incisor positioning is influenced more by soft tissue than skeletal factors, it is still unclear whether moving the lower incisors into more 'normal' relationship relative to the skeletal pattern will result in a favorable change in soft tissue pattern.

The tongue is another influence on incisor position and stability since imbalances between internal forces and external forces from the tongue, cheeks and lips contribute to lower incisors' position and can influence the treatment mechanics (Proffit, Fields, & Sarver, 2012). Larger tongue sizes in children, abnormal tongue position, and tongue habits influence jaw growth and dento-alveolar position (Proffit, Fields, & Sarver, 2012) before, during, and after orthodontic treatment. Proffit, Fields, & Sarver (2012) also stated the primary factors influencing balance within the dentition include pressure of the periodontal membrane, lips, and tongue. The sum of all forces from the periodontal membrane, lips and tongue must equal zero for equilibrium to occur. Orthodontic treatment can alter the hard tissue/soft tissue equilibrium due to retraction or protraction of the lower incisors and other dento-alveolar arch changes. Larger tongue sizes and wider arches can be expected in brachycephalic patients while a forward and lower tongue position is a result of lack of space within the oral cavity and has been observed in dolicocephalic patients. Another consequence of this lack of space causes the tongue to be in a lowered and a more forward position, resulting in open bites and spaces within the dentition, not typically observed in the brachycephalic patients. The size and position of the tongue can ultimately affect the final position of the lower incisors. If myofunctional exercises are not successful to reposition the tongue, orthodontic treatment may not be favourable (Proffit, Fields, & Sarver, 2012).

Clinicians must be aware of individual treatment responses among patients even when the same bracket prescription, appliances, and wires are utilized. In addition, modifications in the treatment mechanics to counteract the effects of the orthodontic forces for different musculature patterns should be considered and implemented during treatment (Ricketts, 1979). The results of this investigation were contrary to those of Flores-Mir (2009). He stated that growth pattern was unrelated to the amount of dental movement. The findings of this study suggest a clinician may expect similar angular and linear lower incisor movements amongst the different facial groups, with larger changes expected in the brachycephalic facial group in the correction of a Class II malocclusion.

Another important factor that must be considered in the final position of the incisors is the treatment protocol during the clinical use of the FSIA and FMB treatment when evaluating the lower incisor position. Alterations, such as changes to the arch form, expansion or uprighting of teeth, to the maxillary and mandibular arches, can result in spontaneous forward posturing of the mandible. This change in the arches affects the position of the incisors resulting in a reduction in the overjet and overbite (Cozza, Giancotti, & Petrosino, 2001). Also, a change in the inclination of the maxillary and mandibular incisors impacts the amount of overbite and overjet. After FMB treatment overjet reduction resulted ranging between 3.2mm – 4.2mm for the different facial groups and overbite reduction ranged from 2.1mm – 3.2mm for the different facial groups. The reduction of overbite and overjet were statistically significant, an anticipated positive result in the correction of a Class II malocclusion treatment mechanics. The position of the lower incisors were likely affected by fixed treatment mechanics in but not limited to reverse Curve of Spee, bracket prescription, Class II elastics, bracket positioning, arch wire sequence, and changes in the angulation of the maxillary and mandibular incisors.

Overbite can be reduced successfully by several means (molar extrusion, mandibular rotation, intrusion of the upper & lower incisors); Successful overbite reduction depends on alteration of the interincisal angle, changing the vertical position of the maxillary incisors from the lower lip and vertical facial growth (Lai & McNamara Jr, 1998), and other factors beyond the focus of this study. Miller (Miller et al., 2013) and other authors agreed with this statement (Lai & McNamara Jr, 1998; Barnett et al., 2008; Jakobsone et al., 2013).

Miller et al., (2013) did a systematic review of Class II malocclusions and found that the interincisal angle can be reduced and altered by changing the position and angulation of the maxillary and mandibular incisors. They concluded the movement and proclination of mandibular incisors was more successful in reducing overbite than maxillary incisors.

In the present study, due to the treatment rendered in both arches, the maxillary arch was expanded and aligned and the mandibular arch was expanded to interdigitation with the maxillary arch. This provided space within the mandibular arch allowing the movement and realignment of the lower incisors. This was similar to findings in two other studies (Heinig & Göz, 2001; Karacay, Akin, Olmez, Gurton, & Sagdic, 2006) resulting in a reduction in the overjet and overbite relationships. Karacay et al. (2006) evaluated and compared the effects of two (2) fixed spring induced appliances: (1) the Forsus™ Nitinol Flat Spring and (2) the Jasper

Jumper™. They found changes exhibiting a reduction of 3.7mm for the overjet and 1.0mm for the overbite with the Forsus™ and 3.2mm for the overjet and 1.3mm for the overbite with the Jasper jumper™. Heinig & Göz (2001) evaluated the clinical application and effects of the Forsus™ Spring and found a 4.6mm reduction of overjet and 1.2mm reduction for overbite. Although the reduction of overjet in this study was smaller, protocols were different and the sample size in Heinig & Göz's (2001) study was smaller. Although changes in the mandibular intercanine width by alterations in the arch form and/or bracket prescription for example, may affect the final position of the lower incisors, these variables were not evaluated in this study.

Some authors (Vogt, 2006; Alexander, 2001; Miller et al., 2013) suggested that negative torque (-6°) in mandibular incisor brackets would provide added resistance to proclination of the lower incisors thus resulting in a retroclined and retruded position. In this study, the lower incisor position at T2 demonstrated a retroclined and retruded position when compared to T1 but was still proclined and protruded in relation to the initial position (T0). A study by Miller (Miller et al., 2013), disagreed with this finding when he compared the effects of the Xbow™ appliance with the Forsus™ Spring. He found for the IMPA variable the lower incisors proclined an average of 3.4° for the Forsus™ Spring group and 4.8° for the Xbow™ group. By comparison, the present study, resulted in an average proclination of the lower incisors by 0.4°. One explanation for the increased proclination was the length of treatment time. The present study had a shorter average treatment time (21 months) while in Miller's study the average treatment time was of 33 months for males and 41 months for females. The longer treatment time might have influenced the position of the lower incisors (Miller et al., 2013). In the present study it could be suggested that the negative torque in the brackets along with the arch wire selection and treatment mechanics to the lower incisors influenced the final lower incisor position.

Levelling the Curve of Spee (COS) resulted in lower incisor proclination (Pandis, Polychronopoulou, Sifakakis, Makou, & Eliades, 2010) indicating that every millimeter of flattening or levelling of the COS resulted in lower incisor flare of 4°. This observation may of prevented the lower incisors from returning to their initial position at T0. Levelling the COS resulted in arch length change and new positions of the teeth within the bone. In addition, reduction of the COS results in a reduction in the overbite, overjet and lower incisor proclination.

Rebound, as described by Horowitz and Hixon (1969), are changes biologic in nature, e.g., changes in the peridontium, as well as physiologic in nature, e.g., eruption and migration of teeth. Normal dentitional changes, which occur throughout the adolescent growth period, are thought to continue into adult life (Horowitz & Hixon, 1969).

Rebound is a sequence of events by which a tooth reaches its most balanced occlusal position. Rebound after orthodontic treatment is continuous throughout life and while orthodontists disrupt that continuous physiologic rebound process, along with changes during orthodontic treatment, rebound will resume after orthodontic treatment is completed leading into the adult life. This rebound is often mistaken or wrongly termed as relapse (Horowitz & Hixon, 1969). The importance of understanding the term rebound is anticipated after treatment and should be taken in to consideration when planning retention.

The lack of strong correlation in the results may be attributable to large individual variation within the facial groups studied and the influence of other factors not evaluated in this study. The findings of this investigation, however, have clinical implications in relation to lower incisor stability. The amount of lower incisor retroclination and retrusion was difficult to predict. Clinicians should be aware that the cause of the rebound observed for the lower incisors is multifactorial and dependent upon variation between facial groups as well as among the individual patient.

In summary, the present study showed that after FSIA and FMB treatment the lower incisors remained proclined and protruded to their initial position. The treatment mechanics used for FSIA and FMB treatment was consistent across all facial patterns. A single provider was used throughout treatment ensuring the arch form, arch dimensions, bracket prescription, appliance design and arch wire sequence were all consistent across all facial patterns. Various parameters reported to be associated with the final position of the lower incisors were studied. No single causative factor could be determined for being the main reason for the final position of the lower incisors. Individual response was highly variable. The results suggested that the final position of the lower incisors was influenced by muscle strength, facial pattern, rebound, treatment mechanics, changes in the overjet and overbite and changes in the occlusal plane – SN angle. There were other factors not investigated but likely influenced the final position of the lower incisors such as peri-oral musculature, changes in the arch form and dimensions and levelling of the Curve of Spee.

Evaluation of the null hypotheses:

#1. There will be no change in the lower incisors position between T0 and T2.

This hypothesis is **rejected** because the position of the lower incisors retroclined and retruded.

#2. There will be no change in the lower incisors position between T1 and T2.

This hypothesis is **rejected** because the position of the lower incisors retroclined and retruded.

#3. There will be no change or effect on the facial pattern with the use of FSIA in conjunction with full fixed multi-banded treatment.

This hypothesis is **accepted** because there were only neglible changes in MP-SN and Y-axis.

Chapter 6

Conclusions

The following can be concluded from the present study:

- The lower incisors are stabilized at a point between the pre- and post-treatment positions.
- Many factors influence the final position of the lower incisors.
- After treatment, lower incisors generally reach values that are within the 'normal range'.
- The potential for further changes or relapse after the 'normal range' is reached should be minimal, if any at all. Further research is needed to determine if any long-term changes occur.
- Thorough diagnosis of each patient is critical and anatomical considerations and pretreatment lower incisor angulation should be considered when planning the treatment mechanics.
- Caution should be used with any Fixed Spring Induced Appliance (FSIA), especially in patients who can tolerate only mild to moderate lower incisor flaring.
- No one cephalometric variable or analysis is a conclusive option for determining

the ideal position of the lower incisor.

- Individual response is highly variable.
- Using this treatment approach (FSIA and FMB treatment) in Class II cases, overjet and overbite can be treated to within normal limits.
- This treatment approach may be used in all facial patterns.

6.1 RECOMMENDATIONS

- Clinicians should use negative torque brackets as a safe mechanism to control the lower incisors to end within normal limits.
- Further research on long-term changes should be examined.
- The brachycephalic group has larger dento-alveolar movements and clinicians should watch for changes in the gingival health and root resorption.

Chapter 7

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Chapter 8

Appendix

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8.1 The Error of Measurement for Each Variable at T0 and T2.

Variable	Error of Measurement at T0	Error of Measurement at T2
MP-SN (°)	1.4	0.7
Y-Axis (°)	1.2	0.7
Occlusal plane -SN(°)	0.2	0.2
Wits (mm)	0.2	0.1
Interincisal Angle (U1-L1) (°)	1.0	1.1
IMPA (L1-MP) (°)	0.8	0.8
LI-protrusion (L1-Apo) (mm)	0.2	0.1
L1-APo (°)	0.9	0.5
L1-NB (°)	0.6	0.3
L1-NB (mm)	0.2	0.1
Pog-NB (mm)	0.2	0.1
Overjet (mm)	0.2	0.1
Overbite (mm)	0.1	0.1
Holdaway Ratio (L1-NB:Pg-NB)	0.1	0.1

Table 8-1. The error of measurement for each variable at T0 and T2.

8.2 Abstract and Article

Lower Incisor Stability following Orthodontic Treatment using a Fixed Spring Induced Appliance (FSIA) and full multi banded/bonded treatment.

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ABSTRACT

Objective: To evaluate the lower incisor position after full fixed multi-banded/bonded orthodontic therapy (FMB treatment) in conjunction with a fixed spring induced appliance (FSIA) in different facial patterns.

Materials and Methods: A retrospective sample of 115 subjects exhibiting class II malocclusions was used. Subjects were categorized into three growth types according to pre-treatment cephalometric variables (MP-SN and Y-axis), yielding 28 brachycephalic, 54 mesocephalic, and 31 dolichocephalic subjects. An *ANOVA* test statistic was used to investigate the differences between the three facial groups. Lateral cephalograms were taken at initial treatment (T0), post-FSIA treatment (T1) & post-FMB treatment (T2).

Results: Dental changes induced by the FSIA & FMB treatment (T2-T0) included: retroclination of the lower incisor (L1-MP:1.7°±0.9, L1-APo:3.4°±0.8, L1-NB:2.2°±0.9), retrusion of the lower incisor (L1-APo:1.7mm±0.3, L1-NB:0.2mm± 0.06), reduction in the overjet (4mm±0.2) and overbite (2.8mm±0.3). Facial patterns were not significantly influenced by the FSIA and FMB treatment (MP-SN-1.8°±0.6; Y-Axis-0.9°±0.5). Reduction of the skeletal Class II relationship was represented by a significant decrease ($p<0.05$) of the Wits value (2.3mm±0.2) in all three groups. Lower incisor angular and linear changes at T2 were all proclined and protruded to initial values at T0.

Conclusions: The overall change in the position of the lower incisors was proclination and protrusion at T1-T0, retroclination and retrusion at T2-T1, and proclination and protrusion to their original position at T2-T0. Facial growth pattern appeared to be unrelated to the amount of dental movement. There was a trend for more pronounced dental retroclination and retrusion of the lower incisors in brachycephalic patients.

KEY WORDS: Class II; fixed spring induced appliance; lower incisor; facial type; orthodontic treatment

INTRODUCTION

Several studies have investigated the final position and stability of the mandibular incisors during treatment planning and after orthodontic treatment[1,2,3] . Due to reduced compliance with removable appliances, fixed spring force induced appliances (FSIA) have become a popular option for correcting Class II malocclusions. Some examples of such appliances include the Distal Jet, Xbow™ appliance, Japser Jumper, and Forsus™ spring which operate by advancement of the mandible or through distalization of maxillary molars to achieve a Class I relationship[1].

Multiple approaches have been proposed to achieve ideal positioning of the lower incisors for maximum stability and reduction of relapse potential[2-4]. Cephalometric analyses by Tweed, Steiner and others have attempted to define the ideal lower incisor position but have been criticized because multiple factors such as differential growth, postural development, and genotype of the patient are all core determinants of a malocclusion which may affect the lower incisor position[2-4].

Ricketts stressed the need to modify treatment procedures to accommodate individuals that have either stronger (brachycephalic) or weaker (dolichocephalic) musculature to counteract the effects of orthodontic forces[3]. Since different dental compensations exist for varying facial patterns, it is important to investigate the potential differences in lower incisor movement, taking facial type into consideration, during orthodontic treatment.

Therefore the purpose of this study was to evaluate the final position of the lower incisors in subjects with different facial patterns treated with FSIA and FMB appliances.

MATERIALS AND METHODS

Sample

The treatment sample was selected from the private practice of a certified orthodontist. Inclusion criteria for the sample were subjects with a complete permanent dentition including second molars and a ¾ to full cusp bilateral Class II molar relationship, treated with FSIA and FMB treatment. Subjects with a mutilated dentition and/or congenitally missing teeth other than 3rd molars were excluded from the sample.

A sample size of 115 subjects was evaluated. The mean age of the patients was 13 yr 5 mo (SD 1yr 5mo) at T0, 13yr 9 mo (SD 1yr 5mo) at T1 and 15 yr 3 mo (SD 1yr 5mo) at T2. Lateral cephalograms were taken prior to treatment (T0).

The FSIA consisted of a maxillary Hyrax expander, a mandibular labial and lingual bow and Forsus™ fatigue resistant device (FRD) springs. The Forsus™ springs were placed in the head gear tube of the maxillary first molar band and hooked around the labial bow, which was stopped by a Gurin lock (3M Unitek) around the mandibular canine area[9].

Transverse discrepancies were identified and corrected with the Hyrax appliance prior to AP correction. The Forsus™ springs of the FSIA were activated every 4-6 weeks until a class III overcorrection in the premolar buccal segments was accomplished.

Following the active phase (4.26 mo SD 1.22 mo), the appliance was passively retained for an additional average time of 3.07 mo SD 1.06 mo, at which time the appliance was removed and a T1 cephalometric radiograph taken.

Innovation R brackets (0.022" setup) were bonded on the teeth. The arch wire sequence was as follows: 0.014" NiTi for 10 weeks, 0.020"x0.020" Bioforce for 10 weeks and 0.019"x0.025" TMA for final arch wire detailing. The multi-banded therapy was removed and a T2 cephalometric radiograph taken.

Cephalometric analysis

All cephalometric radiographs were digitized using Dolphin Imaging™ 11.5 software. Rickett's and Steiner's analyses were used and then subjected to statistical analysis to quantify the skeletal and dental changes.

Subjects were categorized into three growth types according to two pre-treatment cephalometric variables: MP-SN and Y-axis. Subjects within two standard deviations for MP-SN (32° SD 2°) and one standard deviation for Y-axis (66° SD 5°) yielded; 28 brachycephalic, 54 mesocephalic, and 31 dolichocephalic subjects.

An intraclass correlation coefficient (ICC) test on 20% of the sample was used to examine measurement reliability. 22 cephalometric radiographs were chosen randomly and re-measured by two separate examiners, 12 weeks after the original measurements to identify possible landmark identification error.

To evaluate the possible influence of growth on any skeletal or dental movements over the treatment period, growth was assessed on 30% of the studied sample. 34 measured cephalometric radiographs at T0, T1 and T2 were chosen randomly, superimposed on each other and were subject to comparison based on Rickett's five superimposition landmarks and the variables for the five measurements demonstrated no change with age[3].

Statistical software SAS 9.2 was used to analyze the data. A Kolmogorov-Smirnov test was used to determine if the samples were of normal distribution. An *ANOVA* test statistic was used to determine if there was a significant difference in cephalometric variables following FSIA (T1) and FMB treatment (T2). The *p* value was considered significant at $\alpha<0.05$.

RESULTS

Reliability

The intra-examiner measurements were consistent; all ICC values were > 0.824 (overbite) and none of the 95% confidence limits had a lower boundary of < 0.608 (overbite). Inter-examiner reliability showed high consistency as well. The ICC values at T0 were >0.474 (overjet) and at T2 were >0.686 (L1-NB). Reproducibility of the cephalometric measurements were accurate within a 12-week period.

Growth patterns

A paired *t*-test was used to examine the differences between the cephalometric growth indicators of the groups. A summary of the three groups prior treatment is described in Table 1. All groups showed highly statistically significant differences.

Variables	**Group A**	**Group B**	**Group A**	**Group C**	**Group B**	**Group C**	**p-value**
Y-Axis°	64.1±0.6	72.2±0.5	64.1±0.6	68.0±0.4	72.2±0.5	68.0±0.4	<0.0001
MP-SN °	25.8±0.6	38.6±0.6	25.8±0.6	31.9±0.5	38.6±0.6	31.9±0.5	<0.0001

Table 1. Differences between groups prior to FSIA and FMB treatment (T0). A = Brachycephalic; B= Dolichocephalic; C= Mesocephalic.

OVERALL TREATMENT EFFECTS OF THE FIXED SPRING INDUCED APPLIANCE (FSIA) AND FULL FIXED MULTI-BA/BONDED TREATMENT (FMB Treatment).

Difference between initial (T0) and end of active FMB treatment (T2) for the Brachycephalic group, Table 2.

Skeletal Pattern – The Wits appraisal was statistically different ($p<0.05$) with a mean reduction of 2.0±0.4mm. The occlusal plane – SN angle was statistically significant following treatment, with a mean increase of 3.8±1.0º.

Dental Variables – The lower incisor angular and linear changes at T2 were all proclined and protruded compared to T0. The changes of IMPA demonstrated an increase of 1.7º±1.6, ($p>0.05$). However, other lower incisor changes were statistically significant ($p<0.05$) with increased mean protrusion to APo (2.1mm±0.5) and NB (0.3mm±0.09) and an increased mean proclination to NB (3.4º±1.4) and APo (4.9º±1.3). Both the overjet and overbite were reduced towards normal values ($p<0.05$).

Group A Brachycephalic Variables	T2-T0 Mean±SE	*p*-value
MP-SN (º)	2.3±0.9	0.09
Y-Axis (º)	1.2±0.8	0.1
Occlusal plane –SN (º)	3.8±1.0	0.0001**
Wits (mm)	-2.0±0.4	<0.0001**
Interincisal Angle (U1-L1)(º)	-3.6±2.3	0.1
IMPA (L1-MP)(º)	1.7±1.6	0.3
LI-protrusion (L1-APo) (mm)	2.1±0.5	<.0001**
L1-APo (º)	4.9±1.3	0.0002**
L1-NB (º)	3.4±1.4	0.02*
L1-NB (mm)	0.3±0.09	0.0002**
Pog-NB (mm)	0.1±0.2	0.4
Overjet (mm)	-4.2±0.2	0.04*

Overbite (mm)	-3.2±0.4	<.0001**
Holdaway Ratio (L1-NB:NB-Pg)	-1.7±0.4	<.0001**

Table 2. Difference between initial (T0) and final (T2) treatment for the Brachycephalic group (n=28).

* - statistically significant   ** - highly statistically significant

Difference between initial (T0) and final (T2) treatment for the Dolicocephalic group, Table 3.

Skeletal Pattern – Wits appraisal was significantly reduced ($p<0.05$) following treatment, with a mean reduction of 2.5mm±0.4. The occlusal plane – SN angle was increased significantly following treatment, with a mean increase of 3.5°±0.9 ($p<0.05$).

Dental pattern – Lower incisor angular and linear changes at T2 were all proclined and protruded to the initial value at T0. The lower incisor showed an increased mean proclination to MP (1.7°±1.5) and APo (2.7°±1.2), and an increased mean protrusion to APo (1.5mm±0.5) and NB (0.4mm±0.08) ($p<0.05$). Both the overjet and overbite significantly reduced towards normal values ($p<0.05$).

Group B Dolichocephalic Variables	T2-T0 Mean±SE	*p*-value
MP-SN (°)	1.5±0.8	0.7
Y-Axis (°)	1.1±0.7	0.2
Occlusal plane –SN (°)	3.5±0.9	0.0001**
Wits (mm)	-2.5±0.4	<.0001**
Interincisal Angle (U1-L1)(°)	-2.2±2.2	0.3
IMPA (L1-MP)(°)	1.7±1.5	0.03*
LI-protrusion (L1-APo) (mm)	1.5±0.5	0.0003**
L1-APo (°)	2.7±1.2	0.03*
L1-NB (°)	1.9±1.3	0.1

L1-NB (mm)	-1.3±0.08	<.0001**
Pog-NB (mm)	0.3±0.2	0.06
Overjet (mm)	-3.2±0.2	0.001*
Overbite (mm)	-2.1±0.4	<.0001**
Holdaway Ratio (L1-NB:NB-Pg)	-1.3±0.4	0.001*

Table 3. Difference between initial (T0) and final (T2) treatment for the Dolicephalic group (n=31).

Difference between initial (T0) and final (T2) treatment for the Mesocephalic group, Table 4.

Skeletal Pattern – Wits appraisal was significantly reduced ($p<0.05$) following treatment, with a mean reduction of 2.3mm±0.2. The occlusal plane – SN angle was increased significantly ($p<0.05$) following treatment, with a mean increase of 2.5^o±0.7 ($p<0.05$).

Dental pattern – Lower incisor angular and linear changes at T2 were all proclined and protruded to the initial value at T0. The lower incisor showed an increased mean protrusion to APo (1.8mm±0.4) and NB (0.4mm±0.06) and an increased mean proclination to MP (1.6^o±1.2), NB (1.3^o±1.1) and APo (1.8^o±0.4) ($p<0.05$). Both the overjet and overbite significantly reduced towards normal values ($p<0.05$).

Group C (Mesocephalic) Variables	T2-T0 Mean±SE	p-value
MP-SN (º)	1.4±0.7	0.09
Y-Axis (º)	0.4±0.6	0.5
Occlusal plane –SN (º)	2.5±0.7	0.0005**
Wits (mm)	-2.3±0.2	<.0001**
Interincisal Angle (U1-L1)(º)	-3.3±1.7	0.06
IMPA (L1-MP)(º)	1.6±1.2	0.02*
LI-protrusion (L1-APo)(mm)	1.8±0.4	<.0001**

L1-APo (º)	2.4±0.9	0.007*
L1-NB (º)	1.3±1.1	0.2
L1-NB (mm)	0.4±0.06	<.0001**
Pog-NB (mm)	0.3±0.1	0.03*
Overjet (mm)	-4.1±0.1	0.0004**
Overbite (mm)	-2.7±0.3	<.0001**
Holdaway Ratio (L1-NB:NB-Pg)	-1.9±0.3	<.0001**

Table 4. Difference between initial (T0) and final (T2) treatment for the Mesocephalic group (n=54)

Overall average value for each variables at T0, T2 and the amount of change Table 5.

Table 5 represents the overall mean for each variable regardless of facial pattern and the amount of change observed with treatment (T2-T0). The largest changes were seen in the L1-APo (3.4º), occlusal plane-SN and interincisal angle (-3.1º), followed by L1-NB (2.3º) and Wits (2.3mm).

Variables	**T2 (S.D.)**	**T0 (S.D.)**	**Amount of change**
MP-SN (º)	33.8 (0.55)	32.1 (0.55)	1.8
Y-Axis (º)	69.0 (0.50)	68.1 (0.50)	0.9
Occlusal plane –SN (º)	18.9 (0.60)	15.7 (0.60)	3.2
Wits (mm)	1.1 (0.16)	3.4 (0.24)	- 2.3
Interincisal Angle (U1-L1)(º)	125.2 (1.47)	128.3 (1.48)	-3.1
IMPA (L1-MP) (º)	97.1 (0.98)	95.4 (0.98)	1.7
LI-protrusion (L1-APo) (mm)	2.4 (0.31)	0.7 (0.31)	1.7

L1-APo (º)	25.1 (0.80)	21.7 (0.80)	3.4
L1-NB (º)	26.5 (0.90)	24.2 (0.90)	2.3
L1-NB (mm)	2.1 (0.06)	2.3 (0.06)	-0.2
Pog-NB (mm)	1.3 (0.15)	1.0 (0.10)	0.3
Overjet (mm)	0.7 (0.16)	2.4 (0.29)	-1.7
Overbite (mm)	1.5 (0.24)	5.5 (0.24)	-4.0
Holdaway Ratio (L1-NB:NB-Pg)	2.3 (0.27)	5.1 (0.27)	-2.8

Table 5. Overall average value for each variable at T0, T2 and the amount of change.

DISCUSSION

Comparing variables at T2-T1 the results showed the lower incisors to be retroclined and retruded, and yet proclined and protruded to T0. The average IMPA value at T2 was increased compared to the 'normal range' according to Steiner, for example[7]. The change in position indicated that the lower incisors move in the direction of their initial position without returning to the exact initial position. In addition, rebound may have been occurring simultaneously possibly masked by the treatment mechanics used. These results concur with other authors that the lower incisors tend to rebound after treatment[10-12].

A significant reduction of the Wits value in all three groups was seen, which represented a reduction in the skeletal Class II relationship and a significant increase was seen in the occlusal plane-SN for each facial group. The increase in occlusal plane-SN possibly contributed to the reduction in Wits with minimal skeletal change reflected by the inverse relationship of Wits to changes in the occlusal plane angle[13]. Suggesting the amount of Class II correction was a result of dentoalveolar changes rather than skeletal changes. Since no significant changes to the growth pattern were observed, change in these variables was likely dentoalveolar in nature.

Muscular strength and facial pattern were factors considered. Weak facial musculature is a characteristic facial feature of the long dolicocephalic facial pattern while the strong facial musculature is characteristic of the brachycephalic facial pattern[3]. The results showed that the brachycephalic groups had more pronounced changes than the other facial groups. These results support the study by Posen (1976) who indicated that hypertonic or strong facial musculature patterns exert more pressure resulting in a greater posterior force and more movement than with hypotonic musculature, especially if a large overjet (>3mm) was present [10]. The pre-treatment lower incisor angular position was significantly different between the brachycephalic and the dolicocephalic groups, possibly a dental compensation to reduce the overbite and overjet in a Class II malocclusion. The clinical significance is that one can expect greater and less predictable dental movements (proclination and protrusion with a FSIA and retroclination and retrusion with FMB treatment) can be expected in the brachycephlic patients during treatment. This supported the results at T0 where the dolicocephalic patients exhibited a more protruded and upright lower incisor position (L1-NB mm) than the brachycephalic patients. Changes for T2-T1 showed the lower incisors retroclined and retruded. This change is in agreement with Posen, indicating that anterior movement interfered with the facial balance and lip function and could result in rebound of the incisor teeth[10].

Imbalances between internal forces and external forces from the tongue, cheeks and lips contribute to lower incisors' position and can influence treatment mechanics[7]. Larger tongue sizes in children, abnormal tongue position, and tongue habits influence jaw growth and dentoalveolar position before, during, and after orthodontic treatment[7]. Orthodontic treatment can alter the hard tissue/soft tissue equilibrium due to retraction or protraction of the lower incisors and other dentoalveolar arch changes.

Another factor to consider was the treatment protocol during the clinical use of the FSIA and FMB tx when evaluating the lower incisor position. Alterations, such as changes to the arch form, expansion or uprighting of teeth to the maxillary and mandibular arches, can result in a new position of the mandible. This change in the arches affected the position of the incisors resulting in a reduction in the overjet and overbite. Also, a change in the inclination of the maxillary and mandibular incisors impacted the amount of overbite and overjet[15]. These changes influence the final position of the lower incisors due to the treatment rendered in both arches, the maxillary arch was expanded and aligned and the mandibular arch was expanded to interdigitation with the maxillary arch[15]. This provided space within the mandibular arch allowing the movement and realignment of the lower incisors. This was similar to findings in two other studies resulting in a reduction in the overjet and overbite relationships[13,14].

Some authors suggested that negative torque (-6 deg) in mandibular incisor brackets did provide added resistance to proclination of the lower incisors resulting in a retroclined and retruded position[15]. In this study, the lower incisor position at T2 demonstrated a retroclined and retruded position when compared to T1 but was still proclined and protruded in relation to the initial position (T0).

Rebound is a sequence of events by which a tooth reaches its most balanced occlusal position. Rebound after orthodontic treatment is continuous throughout life and while orthodontists disrupt that continuous physiologic rebound process, along with changes during orthodontic treatment, rebound will resume after orthodontic treatment is completed leading into the adult life[12]. No single parameter in cephalometrics should be relied on entirely and interpreted as an absolute value[13].

CONCLUSIONS

The following can be concluded from the present study:

- The lower incisors are stabilized at a point between the pre- and post-treatment positions.
- Many factors influence the final position of lower incisors.
- After treatment, lower incisors generally reach values that are within the 'normal range'.
- The potential for further changes or relapse after the 'normal range' is reached should be minimal, if any at all. Further research is needed to determine if any long-term changes occur.
- Thorough diagnosis of each patient is critical and pretreatment lower incisor angulation should be considered when planning the treatment mechanics.

- No one cephalometric variable or analysis is a conclusive option for determining the ideal position of the lower incisor.
- Individual response is highly variable.
- Using this treatment approach (FSIA and FMB treatment) in Class II cases, overjet and overbite can be treated to within normal limits.
- This treatment approach may be used in all facial patterns.

RECOMMENDATIONS

- In Class II division I cases the use of negative torque brackets may enhance control of the lower incisors.
- Further research on long-term changes should be examined.

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8.3 Ethics Approval and Renewal

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UNIVERSITY OF MANITOBA | BANNATYNE CAMPUS
Research Ethics Boards

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

PRINCIPAL INVESTIGATOR: Dr. D. Crichton	**INSTITUTION/DEPARTMENT:** UofM / Preventive Dental Science	**ETHICS #:** HS15871 (H2012:352)
APPROVAL DATE: November 28, 2012	**EXPIRY DATE:** November 28, 2013	
STUDENT PRINICIPAL INVESTIGATOR SUPERVISOR (If applicable): Dr. W. Wiltshire		

PROTOCOL NUMBER: NA	**PROJECT OR PROTOCOL TITLE;** Evaluation and comparison of lower incisor position after the use of the X-bow appliance and completion of full fixed orthodontic treatment on different facial types
SPONSORING AGENCIES AND/OR COORDINATING GROUPS: NA	

Submission Date of Investigator Documents: October 11, November 19 and 28, 2012	**HREB Receipt Date of Documents:** October 22, November 23 and 28, 2012

THE FOLLOWING ARE APPROVED FOR USE:

Document Name	Version(if applicable)	Date

Protocol:

Proposal received October 22 with clarification outlined in letter received November 23, 2012

Consent and Assent Form(s):

Other:

Data Capture Sheet received November 23, 2012

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

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

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QUALITY ASSURANCE
The University of Manitoba Research Quality Management Office may request to review research documentation from this research study/project to demonstrate compliance with this approved protocol and the University of Manitoba Policy on the Ethics of Research Involving Humans.

CONDITIONS OF APPROVAL:

1. The study is acceptable on scientific and ethical grounds for the ethics of human use only. ***For logistics of performing the study, approval must be sought from the relevant institution(s).***
2. This research study/project is to be conducted by the local principal investigator listed on this certificate of approval.
3. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to the research study/project, and for ensuring that the authorized research is carried out according to governing law.
4. **This approval is valid until the expiry date noted on this certificate of approval. A Bannatyne Campus Annual Study Status Report** must be submitted to the HREB within 15-30 days of this expiry date.
5. Any changes of the protocol (including recruitment procedures, etc.), informed consent form(s) or documents must be reported to the HREB for consideration in advance of implementation of such changes on the **Bannatyne Campus Research Amendment Form.**
6. Adverse events and unanticipated problems must be reported to the HREB as per Bannatyne Campus Research Boards Standard Operating procedures.
7. The UM HREB must be notified regarding discontinuation or study/project closure on the **Bannatyne Campus Final Study Status Report**.

Sincerely,

John Arnett, PhD. C. Psych.
Chair, Health Research Ethics Board
Bannatyne Campus

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Please quote the above Human Ethics Number on all correspondence.
Inquiries should be directed to the REB Secretary **Telephone:** (204) 789-3255/ **Fax:** (204) 789-3414

8.4 Manuscript Submission

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Detailed Status Information

Manuscript #	112814-853
Current Revision #	0
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Title	Lower Incisor Stability following Orthodontic Treatment using a Fixed Spring Induced Appliance (FSIA) and full fixed multi banded/bonded treatment (FMB treatment).
Running Title	lower incisor position after treatment
Manuscript Type	Original Article
Special Section	N/A
Corresponding Author	jonelle crichton (university of manitoba)
Contributing Authors	William Wiltshire , Frank Hechter , Stephen Ahing
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Abstract	Objective: To evaluate the lower incisor position after full fixed multi-banded/bonded orthodontic therapy (FMB treatment) in conjunction with a fixed spring induced appliance (FSIA) in different facial patterns. Materials and Methods:Retrospective sample of 115 subjects exhibiting class II malocclusions was used. Subjects were categorized into three growth types according to pre-treatment cephalometric variables (MP-SN and Y-axis), yielding 28 brachycephalic, 54 mesocephalic, and 31 dolichocephalic subjects. An ANOVA test statistic was used to investigate the differences between the three facial groups. Lateral cephalograms were taken at initial treatment (T0), post-FSIA treatment (T1) & post-FMB treatment (T2). Results: Dental changes induced by the FSIA & FMB treatment (T2-T0) included: retroclination of the lower incisor (L1-MP-1.7o.9, L1-APo-3.4o.8, L1-NB-2.2o.9), retrusion of the lower incisor (L1-APo-1.7mm.3, L1-NB-0.2mm± 0.06), reduction in the overjet (4mm.2) and overbite (2.8mm.3). Facial patterns were not significantly influenced by the FSIA and FMB treatment (MP-SN-1.8o.6; Y-Axis-0.9o.5). Reduction of the skeletal Class II relationship was represented by a significant decrease (p<0.05) of the Wits value (2.3mm.2) in all three groups. Lower incisor angular and linear changes at T2 were all proclined and protruded to initial values at T0. Conclusions: The overall change in the position of the lower incisors was proclination and protrusion at T1-T0, retroclination and retrusion at T2-T1, and proclination and protrusion to their original position at T2-T0. Facial growth pattern appeared to be unrelated to the amount of dental

	movement. There was a trend for more pronounced dental retroclination and retrusion of the lower incisors in brachycephalic patients.
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