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Comparison of treatment effects of the Forsus Fatigue Resistance Device in Class II patients with different underlying vertical skeletal patterns

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ABSTRACT

The purpose of this study was to evaluate the differences in dental and skeletal changes induced by the Forsus^{TM} Class II dentoalveolar corrector in Class II patients with varying vertical skeletal growth patterns. The sample consisted of 26 (mean age 12.9 ± 1.3 years) Brachyfacial (BF) (SN-MP $< 30^{o}$) consecutively treated Forsus subjects, 16 (mean age 13.1 ± 0.8 years) BF untreated Class II subjects (control subjects), 12 (mean age 12.3 ± 1.2 years) Nonbrachyfacial (NBF) (SN-MP $\geq 30^{o}$) consecutively treated Forsus subjects, and 8 (mean age 13.2 ± 0.9 years) NBF untreated Class II subjects (control). Lateral cephalograms were digitized and analyzed at the start (T1) and end (T2) of comprehensive orthodontic treatment or observation. The data was analyzed using Kruskal-Wallis non-parametric testing to determine statistical differences in the treatment changes (T2-T1) between treatment and control groups within the total sample, and within the vertical subgroups. In addition, the same statistical analysis was performed within the treatment sample comparing treatment changes between the BF and NBF subgroups.

The Forsus appliance demonstrated similar treatment changes when comparing BF and NBF treated subjects to the untreated controls. The treatment groups exhibited significant mesialization of the mandibular dentition with intrusion of the mandibular incisors. They also demonstrated significant distalization of the maxillary molar and restriction of the maxilla in the anteroposterior direction. The effects were not significantly different between the BF and NBF groups within treatment except for a greater restriction in maxillary length that was seen in the NBF group.

In conclusion, the Forsus appliance can be used to provide Class II correction in patients with different underlying vertical growth patterns with similar skeletal and dentoalveolar treatment effects.

Keywords: Class II malocclusion, Class II treatment, vertical growth, Forsus

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LIST OF ABBREVIATIONS

OJ: Overjet

OB: Overbite

MR: Molar relation

SN-FOP: Functional Occlusal plane

U6-A - Horizontal distance in mm of maxillary molar to maxillary skeletal base

U1-A: Horizontal distance in mm of maxillary incisor to maxillary skeletal base

U1-SN: Upper incisor proclination

L6-Pg: Horizontal distance in mm of mandibular molar to mandibular skeletal base

L1-Pg: Horizontal distance in mm of mandibular incisor to mandibular skeletal base

IMPA: Lower incisor proclination

U6-PP: Vertical distance in mm of maxillary molar to palatal plane

U1-PP: Vertical distance in mm of maxillary incisor to palatal plane

L6-MP: Vertical distance in mm of mandibular molar to mandibular plane

M1-MP: Vertical distance in mm of mandibular incisor to mandibular plane

SN-PP: The angle formed from the Sella-Nasion line to Palatal Plane

SN-MP: The angle formed from the Sella-Nasion line to Mandibular Plane

LAFH: Lower anterior face height as measured by Anterior Nasal Spine to Menton

SNA: maxillary position in reference to the cranial base

A-Na perpendicular: Horizontal distance in mm of A point to Nasion perpendicular line

Co-A: Maxillary length as measured by Condylion to A point

SNB:mandibular position in reference to the cranial base

Pg-Na perpendicular: Horizontal distance in mm of Pogonion to Nasion perpendicular line

Co-Gn: Mandibular length as measured by Condylion to Gnathion

ANB: Intermaxillary relationship measured by the angle between A-N-B points

Tx: Treatment

Ctrl: Control

BF: Brachyfacial

NBF: Nonbrachyfacial

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INTRODUCTION

Etiology and Prevalence of Class II malocclusion

Class II malocclusion is a significant problem in orthodontics affecting 23-33% of the population.[1,2] The malocclusion can occur as a manifestation of a skeletal discrepancy and/or as a dental discrepancy. Because of the common nature of this problem, it has been extensively studied in order to better understand the etiology, natural growth pattern, and efficiency of intervention.

Intraorally, Class II malocclusion (or distocclusion) presents with the mesiobuccal cusp of the upper first molar anterior to the mesiobuccal groove of the lower first molar. The malocclusion can be divided into two categories according to the proclination or retroclination of the upper incisors and further subdivided according to a unilateral presentation.[2] Class II malocclusion may or may not be accompanied by a skeletal discrepancy.[3]

The Class II patient is recognized extra-orally by the increased convexity of the profile. This occurs as a result of uncoordinated growth in the sagittal plane of the maxillary and mandibular jaws. They may present with a prognathic maxilla, retrognathic mandible, or any combination of the two. Further, these symptoms may be related to dysplastic growth of the jaw, or normal growth associated with retrusive or protrusive anteroposterior positioning.[2,4,5]

Historically, there was an interest in discovering which jaw is more commonly at fault for creating a Class II relationship. While a few studies[6-8] have demonstrated maxillary protrusion to be the major causal factor the majority of research supports the main cause to be a retrognathic mandible.[3, 9-12]

With the development of the cervical vertebral maturation stages as an indicator of development, recent studies have been able to be more specific regarding the changes that occur during growth.[13] Since then, growth studies have demonstrated that craniofacial growth in subjects with Class II malocclusion is essentially similar to that in untreated subjects with normal occlusion with the exception of a smaller increase in mandibular length and mandibular ramus height at the growth spurt.[10] The reduction in mandibular projection corresponds cephalometrically to an increased ANB, and a reduced SNB.[12] This can be said for the presentation of both the Class II division 1 patient and the Class II division 2 patient as no basic difference in skeletal morphology occurs between the two.[11] The Class II skeletal pattern has been shown to be present at age 7 and to remain through puberty without orthodontic intervention.[12]

A variety of vertical natures exist alongside the Class II skeletal pattern. Moyers described five vertical Class II facial types, three of which correspond to a normal facial height, one being long and the last was short.[14] Different results and corresponding vertical patterns have been presented in the literature. It was noted in one study that the mandibular plane angle, and facial height was on average smaller in both divisions of Class II malocclusion subjects.[11] Other studies using different methods and a different sample found Class II subjects to have increased vertical dimensions as demonstrated by a more open y-axis, mandibular plane angle,[12] and longer facial pattern.[15] It can be presumed from the present available literature that the major consistent finding of a Class II skeletal pattern is facial convexity related to either protrusion of the maxilla, retrusion of the mandible, or a combination of both, with a variety of associated vertical growth patterns.

The diagnosis of the Class II malocclusion must be identified by both severity, and cause in order to properly develop the appropriate mode of treatment. The malocclusion can be considered mild, moderate, or severe. It can also be described by which jaw is at fault in terms of maxillary prognathism, mandibular retrusion or a combination of both. Proper diagnosis will guide the appropriate selection of treatment modality as appliances tend to have a major effect related to their mode of action.

Treatment of Class II malocclusion

Treatment options for the Class II patient are dictated by the patients growth potential, severity of malocclusion, and location of discrepancy. Many Class II orthodontic and orthopedic correctors are available for use for growing patients in the orthodontic clinic. They can be categorized as intra-oral or extra-oral devices, that are fixed or removable, and rigid or flexible. These treatment modalities can be categorized according to whether the force provided acts to inhibit an excess of growth or promote growth of a deficiency. Additional treatment modalities can be selected with the goal of attaining correction via skeletal correction, as with surgical orthodontics, or dental compensation, with dental extractions. Below is a summary of the categories of different Class II corrective treatment modalities with emphasis on their skeletal and dentoalveolar effects.

Surgical Orthodontics

In non-growing patients with severe Class II malocclusion the ideal treatment plan may consist of surgical orthodontics where the correction is achieved by moving the jaws into a harmonious relationship. Surgical treatment allows for maximum correction of the underlying skeletal base discrepancy. Surgical correction of skeletal Class II problems became feasible with the introduction of the sagittal split and Le Fort I osteotomies in the 1960s.[16] This mode of treatment would be useful to consider in the patient that could not be successfully treated with orthodontic camouflage.

Surgical orthodontic treatment corrects a Class II molar relationship primarily by skeletal movement. Bilateral sagittal split osteotomy allows the surgeon to move the mandible forwards or backwards as well as rotate the tooth bearing segment if needed to provide anterior facial height changes.[2] While post-operative skeletal relapse is possible, the combination of maxillary impaction and mandibular advancement results in greater than 90% clinical success.[17] These two movements function to advance the mandible indirectly and directly as with mandible autorotation within the glenoid fossa with maxillary osteotomy. Functional benefits may be achieved for patients treated with mandibular advancement as the airway dimension improves along with advancement of the hyoid anteriorly.[18] Patients treated with surgical correction of a skeletal Class II discrepancy will experience a resulting change in their soft tissue profile. The result of treatment includes a reduction in facial convexity that corresponds to the increased prominence of the mandible.[19] One study reported the profiles of patients to have improved by reducing the facial convexity, increasing the lower facial height, decreasing the mentolabial sulcus and improving lip competency with lengthening, straightening and thinning of the lower lip.[20]

Extraction of Permanent Teeth

Treatment of non-growing patients can include removal of permanent teeth with dental camouflage to mask the skeletal discrepancy. This often includes extraction of maxillary premolars followed by retraction of the anterior segment.[21] The amount of retraction desired is important to consider in the diagnostic and treatment planning component as it would determine the teeth necessary to extract. Based on reciprocal anchorage, extraction of maxillary first bicuspids would provide on average 7.5 mm of space anteriorly for correction of the crowding and retraction of anterior teeth while extraction of maxillary second bicuspids would provide on average 5 mm of space.[22] The extraction pattern should be determined with the end of goal of positioning the maxillary incisors ideally in the patients face with the maxillary incisors 5 mm +/- 2 mm to NA line and the mandibular incisors 0.5 mm +/- 2 mm to NA line. It is important in the diagnosis that the profile will be acceptable once the maxillary dentition has retracted, because with dental camouflage there is no anterior advancement of the mandibular dentition or skeletal base.[21] Another important factor determining the success of orthodontic camouflage is the probability of vertical growth during treatment in order to prevent backward rotation of the mandible during treatment.[16] Because orthodontic fixed appliances commonly extrudes the dentition, in a non-growing patient, the resulting mandibular clockwise rotation may be detrimental to esthetic outcomes.

Functional Appliances

Some Class II patients may present with a retrognathic mandible and potential for continued growth. For these patients, an appropriate goal of treatment includes capitalizing on the patient's growth potential to enhance mandibular growth. In the 1970s, functional appliances become popular for use in North America due to the positive results found in the early literature.[2] The concept of functional appliances relies on the idea that soft tissue stretching occurs while a rigid appliance postures the mandible in a more anterior position. Appliances may be categorized into groups according to fixed or removable appliances and as active or passive appliances. Examples are shown in Figure 1 and Figure 2. Fixed appliances are those that are cemented in place and cannot be removed by the patient, such as the MARA or Herbst appliance. Removable appliances are compliance dependent as the patient can remove it for ease of oral hygiene. Examples of removable functional appliances include the Activator, Twin Block, and Frankel. An appliance is considered active when it requires muscle activation to hold the mandible in the postured position and passive when the appliance allows the musculature to rest in the advanced position.[2]

The soft tissue stretch, under the the Moss Functional Matrix of growth theory, is considered in some schools of thought capable of promoting bone growth.[24] However, currently the efficacy of such appliances is challenged and the effect of treatment by functional appliance therapy continues to be a viable area of research in the field. The treatment effects of functional appliances demonstrate differences according to which appliance is used for treatment.

Skeletal treatment effects of the MARA appliance have been found to primarily effect retrusion in the maxilla with little change in mandibular length or position.[25,26] The dentoalveolar changes found by clinical studies evaluating the treatment effects of the MARA were retroclination and retrusion of the upper incisors, proclination and protrusion of the lower incisors with distalization of the maxillary first molar and mesialization of the mandibular first molar. A meta-analysis that looked strictly at mandibular effects did find that the MARA produced a small increase in mandibular projection measured from gonion to pogonion by 1.13 mm per year.[27] The Herbst appliance studies report significant proclination of the mandibular incisors and an additional 2 mm increase in mandibular length compared to controls.[28] However, a review article by Barnett et al[29] found that while some articles show an increase in mandibular length to occur,[30-32] others do not.[33-36]

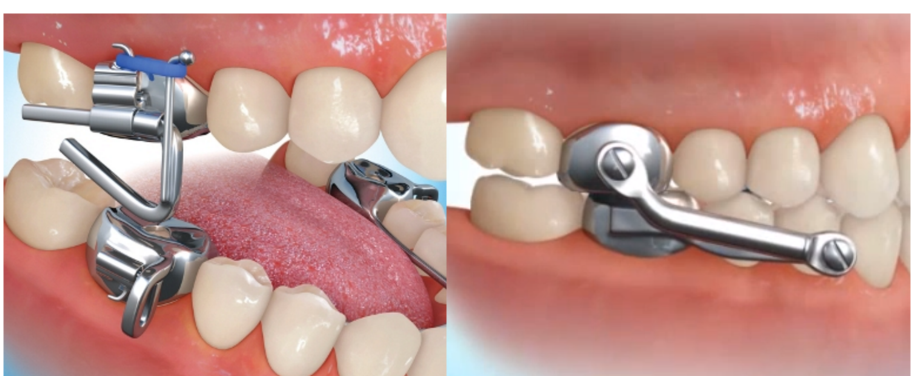


Figure 1: Examples of fixed functional appliances. MARA (left), Herbst (right).[23]

Removable functional appliances provide the flexibility of adjusting the appliance extra-orally, but their success is a function of patient compliance. The Frankel appliance has been shown to provide Class II correction by mean of mesializing the mandibular dentition, distalizing the maxillary dentition and producing a significant increase in mandibular length by 4 mm compared to the control sample.[37] A meta-analysis supports the finding of increased mandibular length, by an additional rate of 1.1 mm per year.[38] The twin block is commonly used in growing patients in the mixed dentition where an increase in mandibular projection is desired.[2] A systematic review by Ehsani et al[39] reports that the twin block appliance has been shown to include an increase in mandibular length (Co-Gn increase of 2.9 ± 0.55 mm) or anterior projection (SNB increase by 1.2 ± 0.12 mm). It was noted however, that the impact of the increased mandibular length is often reduced by the concurrent increase in facial height.[40] Due to the design of the twin block appliance, the vertical dimension can be altered according to the depth of the patients bite. Acrylic can be removed from the posterior bite pads to allow for mandibular molar extrusion.[40] Other consistently reported findings include proclination of lower incisors, retroclination of upper incisors, distal movement of upper molars and/or mesial

Figure 2: Examples of removable functional appliances. Activator (left), Twin Block (center), Frankel (right).[23]

movement of lower molars.[41,42] The effects for the Andresen Activator were found to be similar when compared to the twin block appliance regarding dental, skeletal and soft tissue changes that occur.[43,44] It is important to note that all appliances are capable of successful treatment of Class II malocclusion with reduction in overjet, overbite and ANB.

Extraoral Traction - Headgear

Headgear is utilized to provide heavy extra-oral forces in order to restrict maxillary forward growth. The force vector of the headgear can be modified by the direction of the strap which varies from high-pull, straight, and cervical headgear as seen in Figure 3. Some practitioners will select a combination of high-pull and cervical headgear to maximize control of the forces applied.[45] Further, the affect on the dentition can be modified by the length and position of the outer bow, creating various force vectors or moments at the center of resistance of the maxillary molar.[45] It was noted that extra-oral traction in combination with Class II elastics will result in a normalization of skeletal relationships.[3] Short-term treatment effects have been reported and include a more posterior position of the anterior maxillary border compared to untreated patients. This could be due to modification of maxillary growth, change of inclination

Figure 3: Examples of headgear appliances. From left to right: cervical headgear, high-pull headgear[23]

of the maxillary incisors, or rotation of the palatal plane.[46] It was reported that head-gear induced reduction of SNA is associated with a greater initial SNA thereby suggesting that skeletal effects of headgear are more pronounced in cased with greater maxillary prognathism.[46] Other studies reported that cervical headgear is responsible for the greatest retraction of the maxilla.[45,47] However, cervical headgear directs its force through the maxillary first molar that is not only distal, but extrusive as well. This extrusive force results in eruption of the upper first molar, and therefore a corresponding bite opening that rotates the mandible clockwise[48].

High-pull headgear produces an intrusive and distalizing force on the maxillary first molar which is helpful in preventing the clockwise rotation that can worsen the maxillo-mandibular relationship. Studies conflict regarding the effect of high-pull headgear on maxillary restriction, which may be due to varying magnitude of force delivered by the appliance between the studies.[49,50] One study demonstrated that a force of 500 cN per side, when worn over a six-month period, would allow for 2.6 mm of maxillary first molar distalization along with 0.54 mm of maxillary first molar intrusion.[50]

Molar Distalizing Appliances

Non-compliance distalizing appliances were introduced to correct the molar relationship via dentoalveolar changes rather than skeletal changes.[51,52] The pendulum appliance is an example of a molar distalizing appliance shown in Figure 4. Using the palatal mucosa and anterior maxillary dentition as anchorage, when activated, it produces a distal force onto the maxillary molar. This force results in a distal crown tip movement that occurs during pendulum appliance wear, but shown to relapse at least partly during subsequent comprehensive fixed appliance therapy.[53] Similarly, another type of intramaxillary Class II corrective appliance, the distal jet, is capable of distalizing the maxillary molar significantly. With only dental units as anchorage, anterior anchorage loss and mesialization of the maxillary premolars is an unwanted side effect of treatment.[54]

Figure 4: Example of pendulum appliance.[23]

Intermaxillary Elastics

Intermaxillary elastics are commonly used in orthodontic treatment to provide dental correction of mild to moderate Class II malocclusions. An example of a Class II elastic pattern is shown in Figure 5. The effect of elastics is understood by considering the force vector present at the center of resistance for each jaw. When the elastic force is attached from the maxillary canine to the mandibular first molar via bracket hooks, a clockwise rotational moment is present on both jaws. As the vertical forces on the attached teeth create extrusion of the mandibular molar and maxillary canine, rotation of the occlusal plane occurs.[55] The extrusion of the mandibular molar can lead to an opening of the vertical dimension associated with clockwise rotation of the mandible which can be detrimental to creating a greater increase in facial convexity that may not be

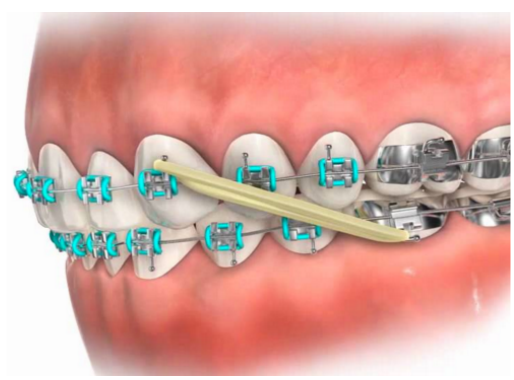


Figure 5: Example of intermaxillary elastics with a Class II corrective vector.23

acceptable for the skeletal Class II patient.[56] These extrusive forces may be counteracted by means of anchor bends to maximize the proportion of force that is horizontal.[57] Additionally, the vertical component of Class II elastics may be kept to a minimum by prescribing a vector of force with a greater horizontal direction.[58] This can be achieved by hooking the elastics more mesially to the maxillary archwire, and more distal on the mandibular archwire. The horizontal force of Class II elastics will tip the maxillary incisors lingually and the mandibular incisors labially[2,57]. The treatment effects of intermaxillary elastics are primarily dentoalveolar although some studies demonstrate a reduction of ANB primarily due to a reduction in SNA.[59-62]

Of course, a limiting factor preventing effectiveness of Class II intermaxillary elastics therapy may be patient compliance. The horizontal force vector is one hundred per cent dependent on the patient wearing the elastic bands, and placing them correctly on the prescribed teeth.

Fixed Dentoalveolar Correctors

Fixed appliances are independent of patient compliance. Additionally, they can be worn in association with fixed bracket appliances, thus having the benefit of a shorter treatment duration[63]. The Jasper Jumper™ (American Orthodontics) was the first fixed flexible Class II corrector used in modern orthodontics. The appliance design was intended to be similar to that of the Herbst appliance with distalizing pushing mechanics and an intrusive side effect. The effects reported initially by Cope et al[64] demonstrate the hypothesized horizontal dental changes, along with extrusion of the mandibular molar and maxillary incisors with intrusion of the maxillary molar and mandibular incisors. It was noted that the effects were greater in the mandibular arch. No significant changes in mandibular length were found in the study by Cope, as well as many others.[64-67] However, some studies demonstrate a significant though more modest increase in mandibular length than rigid functional appliances.[68]

The Forsus Fatigue Resistance Device (3M Unitek) seen in Figure 6 is an example of a fixed interarch appliance used for the correction of Class II dental malocclusion. A push rod is attached to the mandibular archwire, and a telescoping spring module attaches to the headgear tube on the maxillary first molar with an L-pin or EZ module.[69] The push rod has a built in stop that compresses the spring when the patient's mouth is closed. Fully compressed springs produce a force of 200 cN per side, however the springs are rarely fully compressed clinically and therefore provide a force level comparable to heavy Class II elastics. The force is transferred distally to the maxillary molars, using the mandibular arch as anchorage.[70] By examining the biomechanical forces and vectors, one would expect to see distalization and intrusion at the maxillary molar, proclination of the mandibular anterior segment, and clockwise moments occurring at the center of resistance of both maxillary and mandibular jaws[69].

Figure 6: Example of forsus fatigue resistance device.[23]

When comparing the effects of Forsus with untreated control subjects, it was shown that the Forsus has skeletal and dental effects contributing to the Class II correction. Significant restraint in the sagittal skeletal position of the maxilla as well as an improvement in the intermaxillary relationship occurred as demonstrated by reductions in SNA of 1.7^0 and ANB of 1.4^0 when compared to controls.[71,72] While an increase in lower anterior facial height was initially noted as a result of comprehensive orthodontic therapy with Forsus[71], it was shortly thereafter clarified that the increased lower face height occurs prior to the forsus from orthodontic levelling.[73] Regarding mandibular changes, an increase in mandibular length of 1.9 mm with no change in ANB was seen compared to controls, but these differences were not significant.[73]

Dentally, Forsus treatment induced significant reduction in overjet, overbite, interincisal angle, as well as improved molar relationship. A more retruded and extruded position of the upper incisors was noted. In the mandible, the lower incisors both proclined and intruded, while the first molars mesialized and extruded.[71,72] The posterior rotation of the occlusal plane was noted after Forsus removal, but after finishing had rebounded such that the forsus cases did not exhibit a change in occlusal plane.[73] The significant soft tissue change that occurred was the retrusive movement of soft tissue A point in the Forsus group.

Additionally, the use of the Forsus is generally well accepted by patients. The majority of patients had neutral to favourable response to their experience with the appliance (81.5%) and increase in comfort within 4 weeks time (89.8%).[74] The success of Class II treatment by Forsus has been reported at 87.5%.[71]

The long-term post-treatment changes affected by Forsus have also been reported.[73] One can expect to see relapse of the saggital retraction of the maxilla such that no significant sagittal or vertical skeletal changes were detected. Dental relapse that occurs includes a mild increase in overjet, overbite and significant relative intrusion of the upper incisors when compared to the control.

Vertical Growth

Vertical facial growth is strongly correlated with skeletal maturation and somatic growth.[75] Significant increases in growth of lower anterior face height occurs between 12-14 years of age during the pubertal growth spurt.[76] It is noteworthy that vertical growth progresses in males into their early twenties with females completing their vertical growth a few years prior.[2] It was found in a mixed longitudinal study that anterior facial height increases with skeletal maturation where growth starts at an earlier period, while posterior facial height increases in relation to growth pattern.[77] The same study also found that there were similar increases in vertical dimensions of both the face and alveolar height throughout the pubertal growth period in their 78 subjects. Additional findings include that while the maxillary base was not related to skeletal maturation, mandibular growth appears to correlate with the aforementioned factor. The mid-cranial base is known to complete its growth early in development, around the age of 10.[78,79] Dentoalveolar growth is found to be flexible and maintains its growth for many years with the purpose of achieving and maintaining occlusal relationships.[80]

As the maxilla is displaced it carries with it the maxillary dentoalveolar complex, the mandible and hence the mandibular dentoalveolar complex may then respond in one of three ways. The ramus may grow vertically and anteroposteriorly such that occlusal harmony is maintained, the ramus may grow insufficiently vertically, or the ramus may grow excessively vertically, the latter two disharmonies contributing towards a vertical malocclusion. These relationships are assessed using Bjork-Jarabak's cephalometric measurements comparing ratios of posterior facial height to anterior facial height. Clinically these ratios are utilized to assess the patient's direction of condylar growth and thus their vertical potential as famously reported by Bjork through means of implant studies.[78] The term facial divergence is a descriptive term that measures the angle between sella-nasion and the mandibular plane. Extremes of facial divergence are termed hypodivergent and hyperdivergent to indicate vertical variations. While the trend is for the hypodivergent patient to have a decreased lower facial height and a dental deep overbite and the hyperdivergent patient to have increased lower facial height and dental open bite, these presentations are not necessarily correlated[81,82]. One study evaluating incisor inclination in Class II open bite patients found that compared to the control Class I group, mandibular molar height was greater, maxillary incisor proclination was greater, and mandibular incisor proclination was comparable to the control.[83]

Influence of verticality on Class II correction

The literature is scarce with information regarding how a patients vertical nature may affect their Class II correction. A study by Deen and Woods[84] was performed to evaluate the effects of the Herbst on growing Class II patients with different underlying vertical nature. Their primary finding was that the intrusive force on the maxillary molar did not produce a mandibular autorotation and subsequent reduction of the mandibular plane angle in dolichofacial patients. Additional findings include that changes in ANB angle, overjet, and upper incisor protrusion that occurred during Herbst treatment were not significantly different for patients in brachyfacial, mesofacial, or dolichofacial groups. Another study by Greco et al[85] investigated the effects of the activator appliance in Class II patients with different underlying vertical patterns. They found significant differences in treatment effects between dolichofacial and brachyfacial patients regarding skeletal changes in both the maxilla and the mandible. The maxillary restraint and increase in mandibular length were both greater in the brachyfacial group.

Another study examined if cephalometric and morphologic predictors of successful twin block therapy exist.[86] This study demonstrated that a greater pre-treatment overjet, and a more retruded pogonion would be more favourable for a greater overjet reduction and also forward movement of pogonion. It was found in this study that the condylion-gonion-menton angle did not relate to the prognosis of twin block treatment effects.

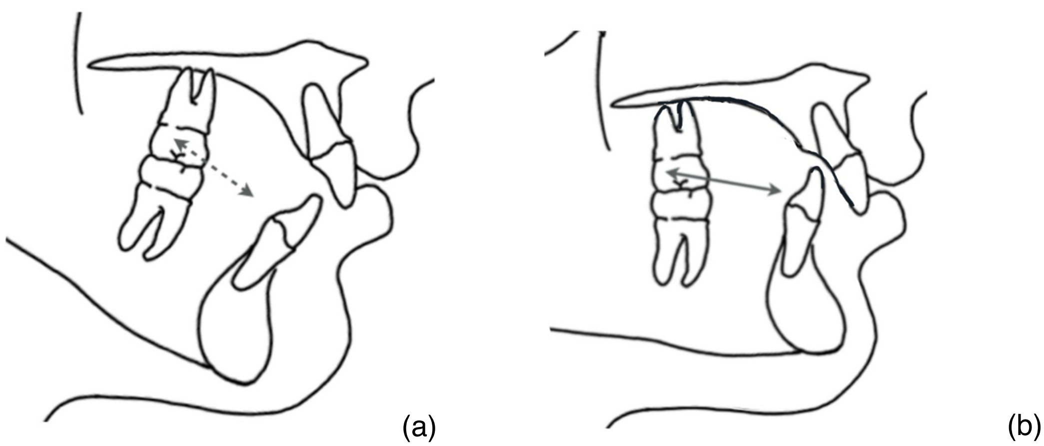


Figure 7: Theoretical force vectors of forsus appliance in dolichofacial patients (a) and brachyfacial patients (b).

There is no literature available at present that evaluates the difference in treatment effects of patients with different underlying vertical skeletal patterns and the use of the forsus appliance for Class II correction. One may hypothesize that in a hyperdivergent Class II patient, the vector of force provided by the forsus appliance could produce greater intrusion of the maxillary first molar (Figure 7a). This could provide the opportunity for counterclockwise autorotation of the mandible and improved vertical control by means of a decreased MPA and and lower anterior face height. This skeletal movement is favourable in Class II patients as it would also lead to an improvement in the profile.

Conversely, in a hypodivergent Class II patient where the force vector is more horizontal, one could hypothesize that treatment with forsus would create greater distalization of the maxillary first molar and greater proclination of the mandibular incisors (Figure 7b). Perhaps we may also expect to see greater mandibular skeletal changes that are not demonstrated in samples that consist of patients with all vertical growth patterns, due to a more horizontal growth pattern.

The purpose of this study is to evaluate whether differences exist in treatment effects of growing patients treated with fixed appliances and Forsus fatigue resistance devices in patients with Class II malocclusion with varying underlying vertical skeletal patterns. The null hypothesis is that the Forsus appliance will produce similar clinical effects regardless of the patient's vertical growth pattern.

METHODS

Sample

This study is a retrospective cohort cephalometric study. The sample consisted of 38 consecutive Class II patients that were treated at the University of Western Ontario (UWO) Graduate Orthodontic Clinic with Forsus™ Fatigue Resistance Device Class II corrector. A control sample was obtained from the Burlington Growth Study of 24 untreated Class 2 division 1 and 2 patients. The control patients had comparable Class 2 skeletal patterns to account for normal changes due to growth. The data for this study was comprised of pre- and post-treatment lateral cephalograms for each patient, as well as information derived from their treatment history. Full records were available for each patient, including pre- and post-treatment photos, radiographs and dental casts if needed.

The treatment sample was selected by reviewing UWO graduate orthodontic treatment charts from 2005 to 2015. All patients that were treated with the Forsus appliance were then reviewed further to determine whether they satisfied the inclusion and exclusion criteria. The patients were not grouped into brachyfacial, mesofacial or dolichofacial groups until the lateral cephalographs were traced, with the points confirmed by a second experienced examiner. The mesofacial group was assigned by an SN-MP angle of greater or equal to 30, and less than 34 degrees. This corresponds to the mean plus or minus 2 degrees, or one standard deviation.[87] The patients were separated into the brachyfacial group if they had a mandibular plane angle as measured from sella-nasion line (SN-MP) of less than 30 degrees. The dolichofacial group was designated by an SN-MP of greater or equal to 34. The resulting sample sizes were insufficient to conduct appropriate statistical testing, and therefore it was decided to group together the mesofacial (N_{tx}=7; N_{ctrl}=6) and dolichofacial groups (N_{tx}=5; N_{ctrl}=2) to evaluate the differences in treatment effects between a brachyfacial and non-brachyfacial group. Subgroups were formed for brachyfacial (SN-MP < 30; N_{tx}=26; N_{ctrl}=16) and dolichofacial (SN-MP > or = 30; N_{tx}=12; N_{ctrl}=8) treatment groups. Gender, age, and observation period were recorded for each subject. Initial and final dental occlusions, and crowding were assessed from patient charts and confirmed on photographs. Information gathered from the patient chart included length of time of the Forsus treatment, as well as information regarding excessive breakages, premature removal, or additional appliances used to correct the malocclusion.

Subjects were chosen based on consecutively treated cases that fulfilled the following inclusion criteria:

1) A full permanent dentition excluding third molars
2) Class II dental relationship with pretreatment molar relationship of at least 3 mm on one side
3) Minimal crowding of less than 4.0 mm
4) Non-extraction treatment
5) Non-surgical treatment
6) Good quality radiographs
7) Circumpubertal growth determined by a CVM of 2, 3, or 4 at the start of observation
8) Less than or equal to 15 years age

Subjects were excluded from the study for the following reasons:

1) Subjects that did not fulfill the inclusion criteria
2) Subjects who were also treated with orthognathic surgery, functional orthopedic appliances, or other Cl II correctors

Appliance Design

In the Forsus treatment group, a fixed, pre-angulated and pre-torqued edgewise appliance was used to level and align the dental arches. Upper first molars were banded, and the remainder of the teeth were bonded with brackets. Upon the completion of levelling, a heavy wire of either 0.016 x 0.022 inch stainless steel (in 0.018 inch slot brackets) or 0.019 x 0.025 inch stainless steel/TMA (in 0.022 inch slot brackets) was used in both arches. The lower wire was cinched distal to the molars. The Forsus was attached to the maxillary arch via the headgear tube and crimped to the mandibular archwire. A force of approximately 200 cN was provided.

The patients were followed every four to six weeks for evaluation of the occlusion and re-activation as needed. The appliance was removed when the Class II malocclusion was either slightly overcorrected, or in Class I. Class II elastics were sometimes used after Forsus removal to maintain the correction.

Cephalometrics

Skeletal and dental variables were measured by evaluating the pre- and post- treatment cephalogram for each patient.

Lateral cephalograms were either scanned films from an analog cephalostat, or jpg files obtained from a digital cephalostat. The image magnification values were standardized. Magnification factors for the UWO patients were 8% prior to 2008, 9.5% prior to 2015 and 0% after 2015. The magnification factor was 9.8% from the archives from Burlington Growth Center. Differences in magnification were corrected to 9.8% for each cephalogram.

Lateral cephalograms of the treatment groups were taken at pretreatment (T1) and post treatment (T2). T1 corresponds to the initial records taken prior to the start of orthodontic therapy, and T2 corresponds to the completion of comprehensive orthodontic treatment. Corresponding lateral cephalograms were traced for the control group at 12-14 years for T1 and 15-16 years for T2. Both films were traced for a single patient within the same session in order to reduce the method of error in determining landmarks. The examiner was blinded to which group a patient belonged by assigning random numbers to each patient and tracing the cephalographs in a randomized order.

A custom cephalometric analysis was constructed with Dolphin Imaging (version 11.9) and used for digitization of all cephalograms in this study. The cephalometric analysis measured 25 landmarks (from the analyses of Steiner[87], Pancherz[88], Tweed[89], and McNamara[90]) listed in Appendix IV. Sella-Nasion line was used to construct a horizontal reference line, constructed Frankfurt Horizontal line (Sn-7^0), by drawing a line 7^0 clock-wise from Sella-Nasion intersecting at Sella point. Sella vertical (Sv), the vertical reference line, was then constructed by creating a line perpendicular to the horizontal reference, intersecting at Sella point. The linear variables measured from the vertical reference line were made parallel to the horizontal plane as in the modified version of the Pancherz Analysis (Figure 11).[88] Values measured from the vertical and horizontal reference planes become more positive as they increase in distance from the reference line. For structures with bilateral images on the cephalogram, the median of the two images was used to identify the landmark.

The outcome variables for this study are listed below with the primary outcome for each variable delineated by asterisk.

1) Interdental relationship
    a. Overjet*
    b. Overbite
    c. Molar relation
    d. Functional Occlusal plane
2) Maxillary Horizontal Dental Position
    a. Horizontal distance in mm of maxillary molar to maxillary skeletal base: U6-A
    b. Horizontal distance in mm of maxillary incisor to maxillary skeletal base: U1-A
    c. Upper incisor proclination*
3) Mandibular Horizontal Dental Position
    a. Horizontal distance in mm of mandibular molar to mandibular skeletal base: L6-Pg
    b. Horizontal distance in mm of mandibular incisor to mandibular skeletal base: L1-Pg
    c. Lower incisor proclination*

4) Maxillary Vertical Dental Position

   a. Vertical distance in mm of maxillary molar to palatal plane: PP-U6*

   b. Vertical distance in mm of maxillary incisor to palatal plane: PP-U1

5) Mandibular Vertical Dental Position

   a. Vertical distance in mm of mandibular molar to mandibular plane: MP-L6

   b. Vertical distance in mm of mandibular incisor to mandibular plane: MP-L1*

6) Vertical Skeletal Measurements

   a. The angle formed from the Sella-Nasion line to Palatal Plane

   b. The angle formed from the Sella-Nasion line to Mandibular Plane

   c. Lower anterior face height as measured by Anterior Nasal Spine to Menton*

7) Maxillary Skeletal Horizontal

   a. SNA: maxillary position in reference to the cranial base*

   b. Horizontal distance in mm of A point to Nasion perpendicular line

   c. Maxillary length as measured by Condylion to A point

8) Mandibular Skeletal Horizontal

   a. SNB: mandibular position in reference to the cranial base*

   b. Horizontal distance in mm of Pogonion to Nasion perpendicular line

   c. Mandibular length as measured by Condylion to B point

9) Intermaxillary Relationships

   a. Intermaxillary relationship measured by the angle between A-N-B*

   b. Maxillomandibular differential in mm

Description of the landmarks, planes and cephalometric measurements are outlined in Appendix IV and V.

Statistics

A priori power study was conducted using G*Power 3.1 to the previously determined mean and standard deviation for ANB of 4.69 ± 1.81 from Ma et al.[91] The clinical effect was designated as 2 degrees and the required sample size of 13 patients per group was determined. This would provide a power of 0.80 with an alpha value of 0.05.

The data was collected from patient treatment charts and lateral cephalograms and analyzed using IBM SPSS statistical software program, version 24 (Armonk, NY: IBM Corp) . Descriptive statistics were generated for all study variables at T1, T2, and for the changes between T1 and T2. The distribution of variables was evaluated by visual inspection and the Shapiro-Wilk test for normality. Normal distribution was not observed and therefore the use of non-parametric statistical tests deemed appropriate.

A Kruskal-Wallis test was used to compare the pre-treatment variables of the treatment and control groups. Within the treatment sample, the BF and NBF groups were compared using a Mann-Whitney U test for demographic variables and a chi-square test for gender. Kruskal-Wallis testing was used to compare pre-treatment variables, and treatment changes for the treatment and control groups. This was done for the total samples as well as BF and NBF samples. Kruskal-

Wallis test was also performed for pre-treatment variables and treatment changes comparing the BF and NBF treatment groups.

Measurement errors in tracing and digitizing were assessed by randomly selecting 20 lateral cephalograms to retrace and re-measure 20 days apart. Measurement error and method of error were evaluated. Method of error was calculated by using the Dahlberg formula. Reproducibility of the measurements were evaluated with a requirement of 90% reproducibility considered acceptable for this study.[92]

RESULTS

The error study demonstrated that all outcome variables were within acceptable levels of reproducibility.[92] Both the measurement error and the Dhalberg reproducibility error are presented in Appendix I. The measurement error for linear measurements are within a range of 0.03 mm to 0.59 mm, and between 0.08 and 1.4 degrees for angular measurements. The Dahlberg reproducibility errors ranged from 0.91 to 0.98, all greater than the acceptable limit of 0.90.

Group	Males n (%)	Females n (%)	Age T1 (years) Mean (SD)	Duration of Forsus Appliance (Months) Mean (SD)	Treatment Duration T2-T1 (months) Mean (SD)
Forsus (FRD)	17 (44.7%)	21 (55.3%)	12.7 (1.3)	4.0 (1.9)	29.1 (9.1) *
BF group	12 (46.2%)	14 (53.8%)	12.9 (1.3)	4.4 (2.0)	30.5 (8.7)
NBF group	5 (41.7%)	7 (58.3%)	12.3 (1.2)	3.1 (1.2)	26.1 (9.6)
Control	14 (58.3%)	10 (41.7%)	13.1 (0.8)	-	34.4 (9.6)
BF group	9 (56.2%)	7 (43.8%)	13.1 (0.8)	-	35.1 (9.4)
NBF group	5 (62.5%)	3 (37.5%)	13.2 (0.9)	-	33.1 (10.6)

Table 1: Demographic data for treatment/control groups with brachyfacial and nonbrachyfacial subgroups. (* indicates statistical significance $p = 0.031$)

Demographic characteristics for treatment and control groups are shown in Table 1. The sample distribution of males to females in the Forsus treatment group was 17:21 and 14:10 in the control group. The mean age at T1 was 12.7 ± 1.3 years for the treatment group, and 13.1 ± 0.8 years for the control group. The treatment and control group were not significantly different with respect to proportion of males or females (p=0.297), or age at the start of observation (p=0.476). They were however statistically significantly different (p=0.031) when comparing the difference between observation period. The overall observation period for the treatment group was 5.3 months less than the control group. The mean duration of Forsus use was 4.0 ± 1.9 months. The brachyfacial (BF) and nonbrachyfacial (NBF) groups were not significantly different regarding their months of forsus appliance wear duration (BF = 4.4 ± 2.0 months; NBF = 3.1 ± 1.2 months; p = 0.058) or their total treatment times (BF = 30.5 ± 8.7 months; NBF = 26.1 ± 9.6 months; p=0.168). The Forsus was capable of providing successful Class II correction in 89.5% (34 of N=36) of patients as defined by correction of excess overjet, and buccal segment relationships to that of a Class I relationship.

Pre-treatment comparison

The means of the variables for the Forsus treated and untreated control groups at T1, and T2 can be found in Tables 2 and 3. The means of the variables for the BF and NBF patients for each time point are presented in Table 5. The values are also shown for T1 variables using pitchfork diagrams in Figures 8-11.

At T1, when comparing the total treatment and control groups for all variables, the majority of measurements were not significant ($p > 0.05$). The measurements that were significantly different between treatment and control groups at T1 include OJ (Tx = 6.78 ± 2.44 mm; Ctrl = 4.95 ± 1.33 mm; p = 0.002), OB (Tx = 6.22 ± 2.58 mm; Ctrl = 4.35 ± 2.50 mm; p = 0.007), MR (Tx = 2.80 ± 1.78 mm; Ctrl = 1.90 ± 2.09 mm; p = 0.019), U6-A (Tx = -28.14 ± 2.55

mm; Ctrl = -25.42 ± 2.17 mm; p = 0.000), UI-PP (Tx = 30.64 ± 2.92 mm; Ctrl = 28.62 ± 2.79 mm; p = 0.010), SN-MP (Tx = 27.66 ± 5.49^0; Ctrl = 26.64 ± 5.24^0; p = 0.020) and SNB (Tx = 76.38 ± 3.57^0; Ctrl = 77.98 ± 3.97^0; p = 0.044). When comparing only the BF treatment and control groups, the same variables were significantly different as with the total group at T1. The only exceptions were that a significance was found for L6-Pg with a more retrusive molar position (Tx = -22.66 ± 3.36 mm; Ctrl = -20.43 ± 2.83 mm; p = 0.036), L1-MP was more extruded (Tx = 42.77 ± 3.05 mm; Ctrl = 39.83 ± 2.10 mm; p = 0.001), ANS-Me was longer in the treatment group (Tx = 66.41 ± 4.46 mm; Ctrl = 63.20 ± 3.27 mm; p = 0.018) and SNA was reduced (Tx = 83.06 ± 3.64^0; Ctrl = 85.38 ± 2.99^0; p = 0.012) in the BF-treatment group. The NBF treatment and control groups were similar for almost all T1 variables, with differences shown only for IMPA (Tx = 89.58 ± 5.59^0; Ctrl = 94.68 ± 3.83^0; p = 0.017) and U6-A (Tx = -28.13 ± 1.97 mm; Ctrl = -24.41 ± 2.08 mm; p = 0.002). The NBF-treatment groups had more upright lower incisors and retrusive maxillary molars.

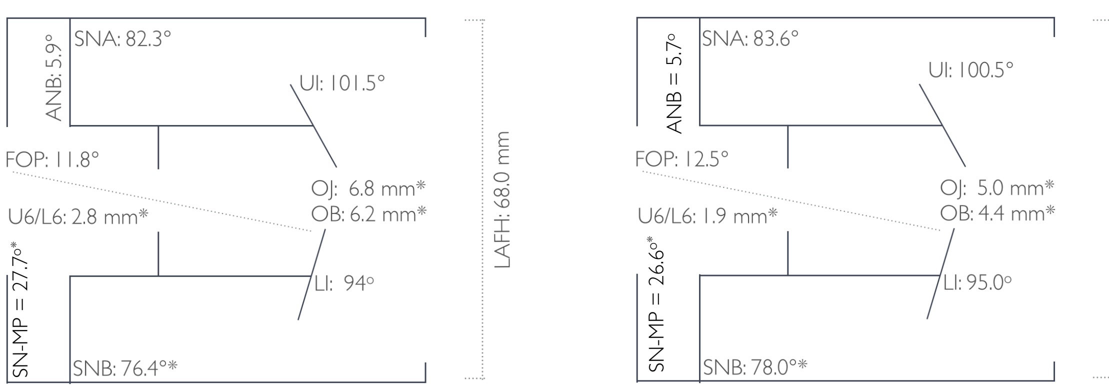


Figure 8: Pitchfork diagram of total treatment sample at T1; treatment (left), control (right). *indicates $p < 0.05$.

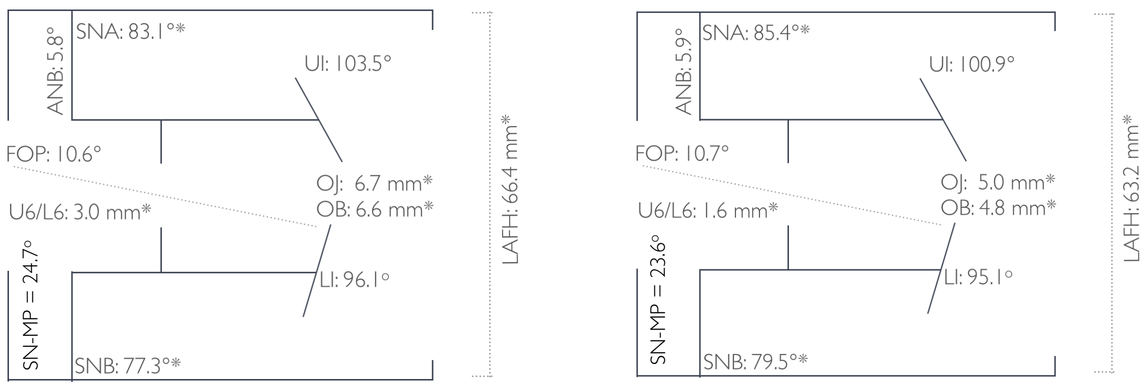


Figure 9: Pitchfork diagram of brachyfacial treatment sample at T1; treatment (left), control (right). *indicates $p < 0.05$.

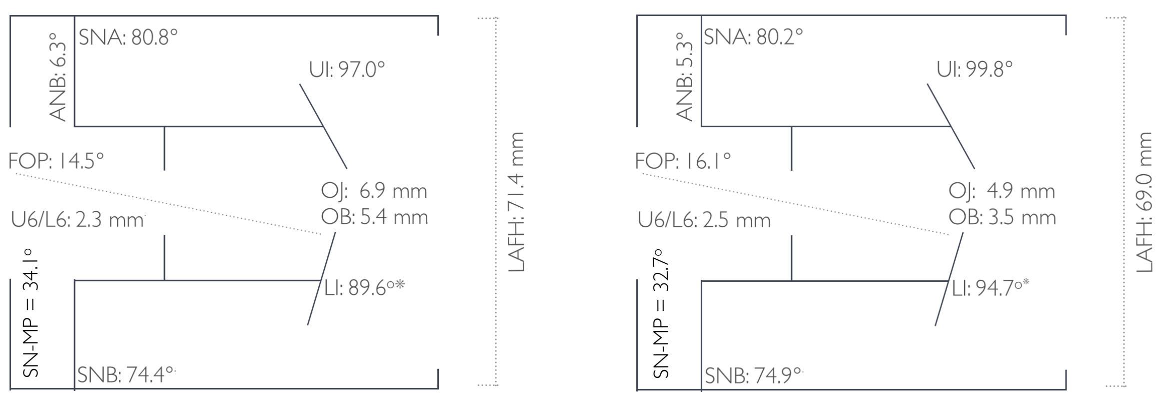


Figure 10: Pitchfork diagram of nonbrachyfacial treatment sample at T1; treatment (left), control (right). *indicates $p < 0.05$.

At T1, the BF and NBF treatment groups were dissimilar regarding SN-FOP (BF = 10.55 ± 3.24^0; NBF = 14.52 ± 2.53^0; p = 0.002), U1-SN (BF = 103.54 ± 11.47^0; NBF = 97.01 ± 8.78^0; p = 0.044), IMPA (BF = 96.11 ± 5.32^0; NBF = 89.58 ± 5.59^0; p = 0.001), L6-Pg (BF = -22.66 ±

3.36 mm; NBF = -17.03 ± 3.87 mm; p = 0.000), L1-Pg (BF = 6.33 ± 3.41 mm; NBF = 9.45 ± 4.63 mm; p = 0.044), and U1-PP (BF = 29.63 ± 2.49 mm; NBF = 32.83 ± 2.63 mm; p = 0.002).

Skeletal differences between the groups at T1 include ANS-Me (BF = 66.41 ± 4.46 mm; NBF = 71.44 ± 4.59 mm; p = 0.002), SN-MP (BF = 24.68 ± 3.50^0; NBF = 34.13 ± 2.62^0; p = 0.000), Co-A (BF = 96.94 ± 5.37 mm; NBF = 92.23 ± 4.75 mm; p = 0.026), SNB (BF = 77.28 ± 3.54^0; NBF = 74.44 ± 2.87^0; p = 0.010) and Pg-Na perpendicular (BF = -5.69 ± 5.66 mm; NBF = 9.68 ± 4.12 mm; p = 0.034).

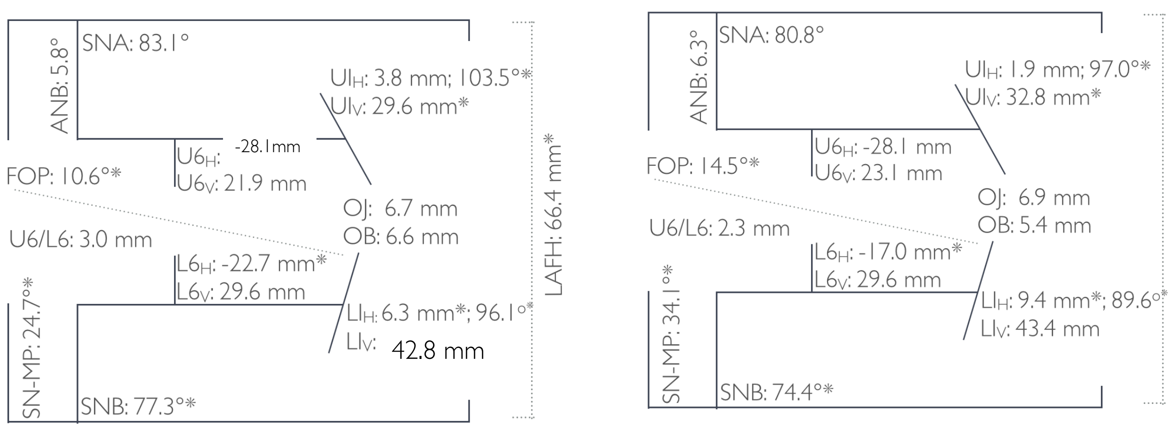
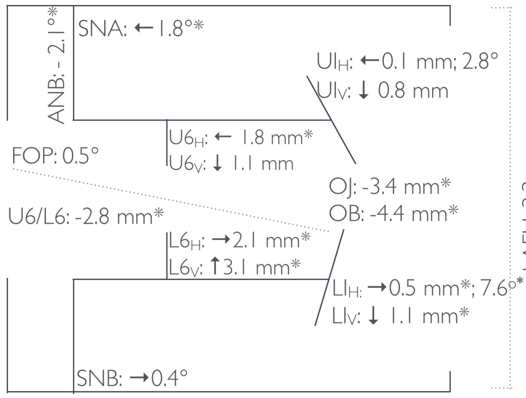


Figure 11: Pitchfork diagram of treatment vertical sample at T1; BF treatment (left), NBF treatment (right). *indicates $p < 0.05$.

Treatment Changes: T2-T1

The differences of the means of the variables (T2-T1) for the Forsus treated and untreated control groups can be found in Table 4, Figures 12-14. The changes with treatment for BF and NBF are presented in Table 5, and Figure 15.



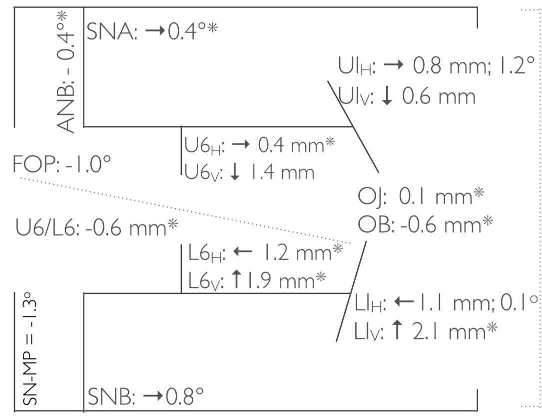
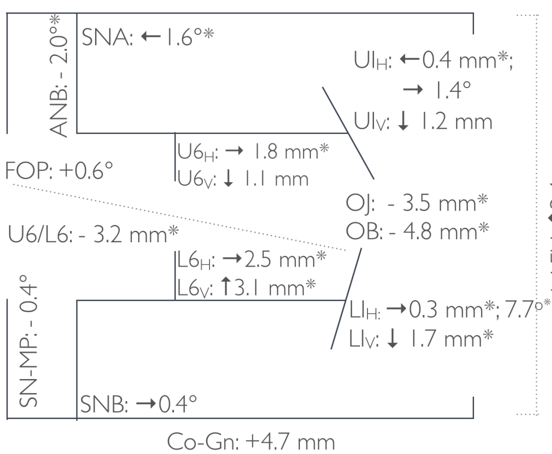


Figure 12: Pitchfork diagram of treatment changes (T2-T1) for total sample; treatment (left), control (right). *indicates $p < 0.05$.



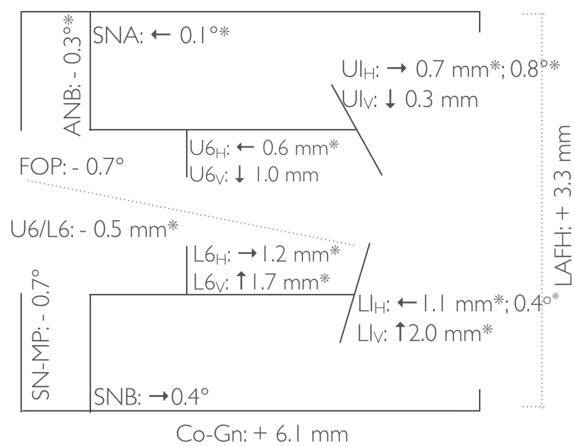


Figure 13: Pitchfork diagram of treatment changes (T2-T1) for brachyfacial sample; treatment (left), control (right). *indicates $p < 0.05$.

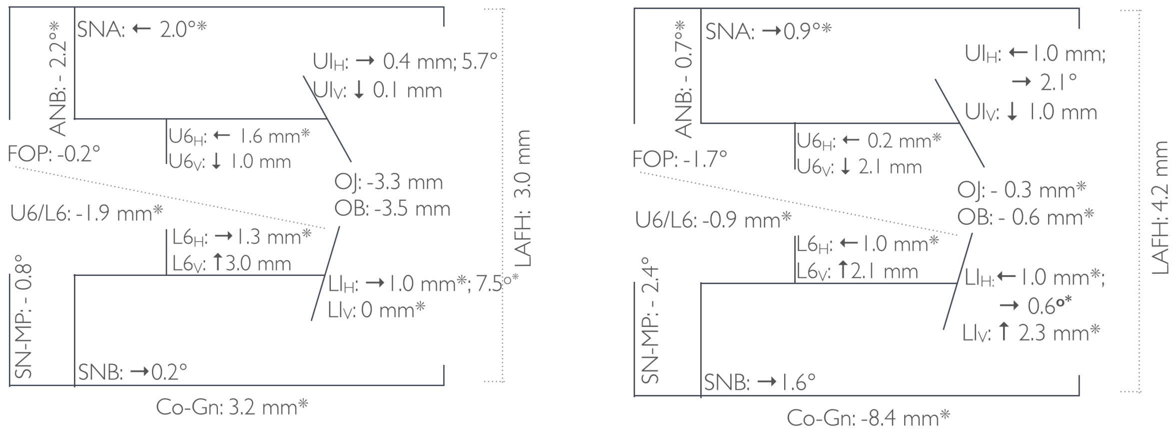


Figure 14: Pitchfork diagram of treatment changes (T2-T1) for nonbrachyfacial sample; treatment (left), control (right). *indicates $p < 0.05$.

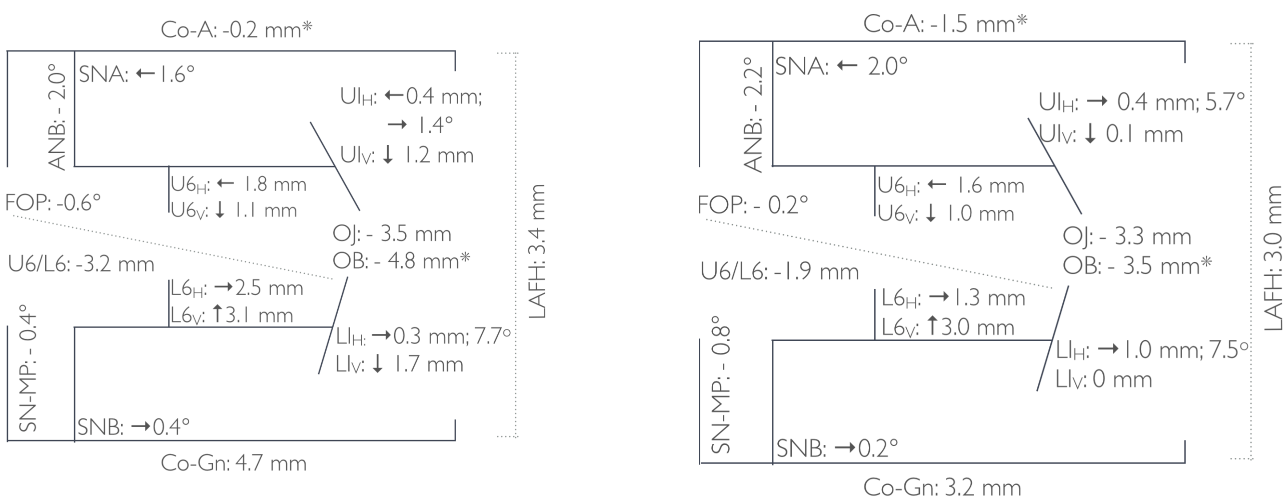


Figure 15: Pitchfork diagram of treatment changes (T2-T1) for treatment vertical subgroups; BF treatment (left), NBF treatment (right). *indicates $p < 0.05$.

Interdental Changes

The interdental changes were significantly greater for the forsus treatment group compared to the untreated controls. OJ (Tx = -3.45 ± 2.68 mm; Ctrl = 0.14 ± 1.81 mm; p = 0.000), OB (Tx = -4.41 ± 2.41 mm; Ctrl = -0.65 ± 2.02 mm; p = 0.000) and MR (Tx = -2.80 ± 2.06 mm; Ctrl = -0.64 ± 2.84 mm; p = 0.000) were all reduced significantly in the treatment group while the control group did not demonstrate notable changes from T1 to T2. Differences between treatment and control for BF and NBF subgroups were similar to those in the total group.

The interdental changes for the BF-treatment group when compared to NBF-treatment were not significant for OJ, MR or SN-FOP with both tending to improve similar amounts. Changes in overbite between the BF group and NBF group were statistically significant (BF = -4.85 ± 2.28 mm; NBF = -3.46 ± 2.51 mm; p = 0.050) with the overbite reducing to a greater degree in the brachyfacial group.

Dental Horizontal Changes

The maxillary dentition demonstrated significantly more distal movement of the molar (U6-A) in the total (Tx = 1.75 ± 2.57 mm, Ctrl = -0.36 ± 2.18 mm, p = 0.001) and BF (Tx = 1.82 ± 2.84 mm, Ctrl = -0.63 ± 2.45 mm, p = 0.004) treatment groups. The change of -0.40 ± 3.45 mm for U1-A were significant within the BF-treatment group (p = 0.037) compared to control (Ctrl = 0.74 ± 1.52 mm). The mandibular dentition exhibited mesial movement in the treatment group compared with the control group at a statistically significant level (L6-Pg: Tx = 2.11± 2.25 mm;

Ctrl = -1.15 ± 3.37 mm; p = 0.000, L1-Pg: Tx = 0.50 ± 2.31 mm; Ctrl = -1.09 ± 1.22 mm; p = 0.001, and IMPA: Tx = 7.63 ± 6.59^{o}; Ctrl = -0.06 ± 3.67^{o}; p = 0.000) for the total treatment group. The control group showed distal movement of the mandibular dentition. Differences were similar within the BF and NBF subgroups.

There were no statistically significant differences in the horizontal dental changes when comparing the BF and NBF treatment groups. The majority of measurements were coincident in direction (U6-A, L6-Pg, L1-Pg, L1-Apo).

Dental Vertical Changes

Within the total sample, and the BF and NBF subgroups, there were no significantly different maxillary vertical dental changes between treatment and controls. In the mandibular dentition, statistically significant differences occurred between total treatment and control groups with respect to the amount of molar extrusion that occurred (p = 0.011). The treatment group experienced 3.08 ± 1.91 mm of molar extrusion compared to 1.86 ± 1.41 mm of extrusion seen in the control group. The lower incisor intruded (-1.14 ± 2.48 mm) in the treatment group and extruded (2.08 ± 1.48 mm) in the control group at a statistically significant difference (p = 0.000).

Comparing treatment vertical subgroups, the BF and NBF groups experienced similar (p > 0.05) amounts of extrusion of the maxillary dentition (PP-U6, PP-U1) and mandibular molar (L6-MP), with intrusion of the mandibular incisors (L1-MP).

Skeletal Horizontal Changes

Skeletal changes for the maxilla consisted of a significantly more retruded final position as indicated by SNA (Tx = -1.75 ± 2.26°; Ctrl = 0.38 ± 1.36°; p = 0.000), A-Na (Tx = -2.25 ± 3.47 mm ; Ctrl = -0.23 ± 2.37mm; p = 0.010), and reduced Co-A (Tx = -0.36 ± 3.90 mm; Ctrl = 3.71 ± 2.63 mm; p = 0.000) in the treatment group compared to the control group. Differences were similar within the BF and NBF subgroups.

When comparing the BF and NBF treatment groups there was a similar amount of retrusion between groups after treatment. However, the NBF group experienced significantly decreased maxillary length (Co-A = -1.48 ± 3.57 mm, p = 0.050) when compared to the BF group (0.15 ± 4.00 mm).

There were no significant differences between both the treatment and control groups, their vertical subgroups, or the BF-treatment and NBF-treatment groups regarding the mandibular skeletal changes (p > 0.05). One variable that demonstrated significance was Co-Gn comparing NBF treatment to NBF controls (Tx = 3.17 ± 4.78 mm; Ctrl = 8.38 ± 3.25 mm; p = 0.011).

When comparing changes in measurements of the BF and NBF treatment groups, it was observed that the BF group experienced a greater increase in Co-Gn compared to that of the NBF group. These changes were not statistically significant (p > 0.05).

Skeletal Vertical Changes

There were no significant differences between treatment and control groups with regards to SN-PP, SN-MP, and ANS-Me within the total or BF and NBF vertical subgroups ($p > 0.05$). This was also the case when comparing BF and NBF-treatment groups ($p > 0.05$). An interesting finding that did not reach statistical significance was that within the NBF subgroup, the control sample experienced considerable clockwise rotation of the mandible (-2.38 ± 1.43^0) while treatment sample did not (-0.77 ± 2.97^0).

Skeletal Intermaxillary Changes

A statistically significant improvement in the skeletal anteroposterior relationship ANB was observed in the total treatment group as compared to control (Tx: -2.08 ± 1.69^0 ; Ctrl: -0.41 ± 1.31^0; $p = 0.000$). This was also observed in the BF subgroup. In addition, both BF and NBF treatment groups experienced similar changes ($p > 0.05$) in their intermaxillary measurements (ANB, Mx/Md differential).

DISCUSSION

This study evaluated and compared the dental and skeletal effects of the Forsus™ Fatigue Resistance Device in a treated and untreated sample. It also evaluated and compared the dental and skeletal effects of the Forsus between patients with a horizontal and vertical growth pattern within the treated sample. This study confirmed that the primary effects of the Forsus appliance are dentoalveolar with a limited "headgear" effect on the maxilla. There was no difference in the effects between patients with different vertical growth patterns.

<u>The sample at T1</u>

In this study there were some differences observed between the total treatment and control groups at the initial timepoint. Differences that were significant included OJ, OB, MR, U6-A, U1-PP, SN-MP, and SNB. Differences in OJ, OB, UI-PP and SN-MP may exist between groups as a result of the proportion of Class II division 1 malocclusion patients and Class II division 2 malocclusion patients. Also, it is possible that the control sample was better compensated, with a less severe malocclusion than the treatment group. This corroborates the possibility that controls were less interested in receiving orthodontic treatment.[93,94] A less severely affected control sample would also explain the differences in MR and U6-A, being more severe in the treated group. SNB was also more retrusive in the treatment group. However, because of a correspondingly retrusive, although not significant, SNA in the treatment group, both the treatment and control groups had similar ANB angles indicating similar maxillomandibular anteroposterior relationships. Also, the absolute difference of SNB at T1 was rather small with a value of 1.5^0.

When comparing the brachyfacial (BF) and nonbrachyfacial (NBF) subgroups and their treatment and control samples, the BF subgroup had similar differences between treatment and control as the total sample. The NBF treatment group on the other hand was not significantly different from the NBF control group at T1 for the majority of variables indicating these groups were similar, albeit with small sample sizes.

Within the treatment sample, BF and NBF groups had differences between groups at the start of treatment. These differences include SN-FOP, U1-SN, U1-PP, L1-Pg, L6-Pg, IMPA, ANS-Me, SN-MP, Co-A, SNB, and Pg-Na perp. These differences would be expected and correspond with the facial type descriptions by both Moyers and Sassouni where the brachyfacial type tends to have converging or flat facial planes and dolichofacial type will present with diverging facial planes.[5,14] SN-FOP and SN-MP were flatter in the brachyfacial group. Maxillary and mandibular incisors were more extruded from their vertical reference planes in the NBF group. This presentation corresponds to a greater facial plane divergence in the NBF group. An increase in U1-SN occurred in the BF group, although the initial OJ was similar between the two groups. The mandibular horizontal dental measurements indicate a more mesial mandibular dentition in NBF patients, although the MR between groups were similar. Co-A, SNB, and Pg-Na perp were found to be greater in the BF group at the start of observation, however, the intermaxillary measurement of ANB demonstrated no differences between skeletal base relationships at T1. The patients comprising BF and NBF groups are different in presentation, corresponding with the hypodivergent and hyperdivergent facial types.[5,14] The rationale for examining treatment effects in two distinct samples is supported by these differences.

Treatment Changes with Forsus: Treatment versus Controls

Changes occurring in the total treatment sample from Western exhibited dentoskeletal effects that were similar to those seen in studies by Franchi et al[95], Cacciatore et al[73,97] and others.[91,95,96] Successful correction of Class II malocclusion was achieved in 89.5% of the patients included in this study. This success rate is similar to what has been reported in a previous study.[71]

Interdental Changes

The interdental relationships were corrected with comprehensive orthodontic therapy with the Forsus. It was noted that a significant improvement of OJ (Tx = -3.45 ± 0.014 mm; Ctrl = 0.14 ± 1.81 mm), OB (Tx = -4.41 ± 2.41 mm; Ctrl = -0.65 ± 2.02 mm) and MR (Tx = -2.80 ± 2.06 mm; Ctrl = -0.64 ± 2.84 mm) all occurred in the total treatment group when compared to the untreated control group. The Class II correction was produced without an effect on the functional occlusal plane angulation which is similar to previous studies that showed an increase immediately after Forsus removal that rebounded with continued fixed appliance therapy[73]. Similar interdental changes were observed in the BF group when compared to BF controls. NBF-treatment experienced significant reduction in OJ and OB only. These findings indicate the Forsus was a suitable appliance in providing improved dental relationship in the Class II patient.

This study found that the reduction in OB was more significant in the BF group than the NBF group. This effect may be attributed to full fixed appliance therapy and orthodontic treatment goals rather than a specific effect of the Forsus appliance. The BF patients in this study began treatment with a slightly greater overbite than the NBF patients. In orthodontic treatment, and the expectation of rebound and relapse, it is common practice to overcorrect discrepancies.[2] It is probable that the practitioners made it a goal of treatment to overcorrect the deep overbite in the patients with a hypodivergent, deep-bite tendency. The change in L1-MP in the NBF group is consistent with another study evaluating treatment changes due to Forsus.[73] The greater amount of lower incisor intrusion in BF-treatment was probably related to intrusion bends on the archwire in the finishing stages of treatment that were not indicated in patients with normal to vertical mandibular plane angles.

Dental Horizontal Changes

The maxillary first molar was significantly distalized in the total (1.75 ± 2.57 mm) and BF-treatment groups (1.82 ± 2.84 mm) as seen in previous Forsus studies.[73,95-98] Significance in the NBF-treatment group was not detected, although the absolute change in U6-A is similar to the values for the other two treatment groups. Retraction of the maxillary incisor, (U1-A = -0.40 ± 3.45 mm), was only significantly different in the BF-treatment group.

Mesialization of the mandibular arch occurred as noted by the changes in L1-Pg (0.50 ± 2.31 mm) and L6-Pg (2.11 ± 2.25 mm) in the treatment group and both subgroups. These outcomes were all similar to those reported by Cacciatore et al[97], and Franchi et al[73,95] for the Forsus. The mandibular arch experiences less resistance to mesialization. It is not surprising to see a majority of the dental effects to be expressed in the mandibular dentition. Lower incisor proclination is a significant side effect of Forsus treatment that has been discussed in previous studies.[73,95-98] Proclination of lower incisors for total (7.63 ± 6.59 mm), BF (7.68 ± 6.40 mm) and NBF (7.53 ± 7.28 mm) treatment groups was significantly greater than their corresponding control groups. It is difficult to control the incisor angulation due to the amount of play between a 0.0195 x 0.025 inch wire a and an 0.022 inch slot bracket even with a cinched archwire, and a negative 6 torque prescription.[99]

The horizontal change in position of the maxillary first molars was similar for both BF and NBF groups. This finding does not support the hypothesis that a greater distalization occurs in the BF group due to a more horizontal forsus angulation. The mesialization of the lower dentition in BF and NBF treatment groups was similar. The change in L1-Pg, L6-Pog, and IMPA variables were not significantly different between groups. This amount of change in these variables was consistent with that of previous Forsus studies.[73,95-98] The findings of this study did not support those of Deen et al,[84] who found less proclination of the mandibular incisors in a dolichofacial sample treated with the Herbst appliance when compared to treated brachyfacial and mesofacial samples.

A trend observed in this study was the increased U1-SN and UI-A in the NBF-treatment group compared to the BF-treatment group. This finding is attributed to the treatment goals of comprehensive orthodontics. The maxillary incisor proclination of both groups finished to the same degree. Where the NBF group initially presented with more upright incisors, NBF patients required more proclination to achieve this result.[22,100,101] It is important to note that the Forsus was capable of providing a distal force vector to the maxillary dentition without further retroclining the upper incisors in the NBF-treatment group.

Dental Vertical Changes

The mandibular dental vertical changes that occurred during treatment were intrusion of the lower incisor and extrusion of the mandibular first molar. These changes were significant for total and BF groups. This finding is expected with the extrusive mechanics of full fixed appliances. Only the amount of lower incisor intrusion was significant in the NBF-treatment group. These finding correspond with those of other Forsus studies.[71,73]

Maxillary first molar and incisors extruded similarly within both BF and NBF treatment groups. This finding refutes the hypothesis that Forsus may provide intrusion of maxillary molars in vertical patients. Instead of anticipated intrusion of the maxillary molar in vertical patients, the opposite movement was observed in the NBF group but less than controls (Tx = 0.12 ± 1.93; Ctrl = 1.05 ± 1.17 mm).

Skeletal Vertical Changes

Skeletal vertical changes that occurred during the observation period was similar for treatment and control groups within the total group as well as BF and NBF subgroups. One notable difference in the results of this study and those of previous studies is that this study did not observe an increase in vertical dimension as measured by the lower anterior face height (ANS-Me). A previous study have shown an additional increase in vertical dimension of 1.3 mm[71] compared to the control group when evaluating comprehensive orthodontic treatment including Forsus treatment where this study showed no change. This finding may be related to the proportion of brachyfacial patients in the treatment sample.

Changes in SN-PP, SN-MP, and ANS-Me during treatment were similar between both BF and NBF groups. This may indicate an advantage to using the Forsus appliance instead of Class II elastics, which tend to exacerbate the extrusive side effects in weak muscled dolichofacial patients.[55] This finding supports the hypothesis of Jung[102] and corroborates the findings of his case study advocating this appliance for the use of vertical control.

<u>Skeletal Horizontal Changes</u>

The Forsus produces skeletal treatment effects in the maxilla. Skeletal changes incurred by all treatment groups were observed by a reduction of SNA in the total treatment group (-1.75 ± 2.26^{0}), BF-treatment (-1.62 ± 1.95^{0}) and NBF-treatment (-2.05 ± 2.89^{o}). This headgear effect has been noted in fixed appliances that are both rigid and flexible, including the Herbst, MARA and Forsus.[40,95,98,99,103,104] This degree of maxillary restriction has been reported in previous Forsus studies as well.[73,95-97] The only measurement not found to be statistically significant between treatment and control groups was the A-Na perpendicular measurement within the BF sample. The group experienced maxillary retraction, although the values did not demonstrate significance.

The Forsus appliance did not affect the projection of the mandible for the treatment groups when compared to untreated controls. This may be an important consideration in selecting a Class II corrector for a patient presenting with an acceptable profile. An unexpected significant finding was that the NBF control subgroup actually experienced a greater change in mandibular length than the corresponding treatment group. This finding is not consistent with the findings of longitudinal growth studies.[3] This finding is possibly an outlier related to the small NBF control sample size of this study.

The intermaxillary relationship was improved in all treatment groups. These values were only significant for the total (-2.08 ± 1.69^{0}) and BF (-2.02 ± 1.56^{0}) treatment groups although the absolute change in NBF (-2.20 ± 2.03) was similar to the other groups. The Forsus appliance was capable of improving the Class II skeletal relationship in treated patients as seen in previous studies.[73,95-97]

While only the change in Co-A was statistically significantly different between the BF patients (0.15 ± 4.00 mm) and the NBF patients (-1.48 ± 3.57 mm), the other variables that measure maxillary skeletal anteroposterior positioning tended to demonstrate a greater “headgear effect” on the maxilla in the NBF group. This finding has not been previously reported in studies using the Forsus appliance. The findings by Greco et al[85] indicate that A point was restricted

(2.00 degrees) more in their brachyfacial sample than the dolichofacial sample. The findings of Greco et al and the findings of this study are not concordant. The findings of this study could be related to a weaker vertical masticatory force in dolichofacial patients which may decrease their resistance to the anteroposterior compressive forces of the Forsus appliance.[105]

The mandibular horizontal changes that occurred were similar for both BF and NBF treatment groups. There was a slightly greater increase in mandibular length (Co-Gn) in the BF (4.66 ± 5.00 mm) patients compared to NBF (3.17 ± 4.78 mm). This is in agreement with the significant findings reported by Greco et al.[85] It is possible that the appliance stimulated growth potential in the horizontal direction in the BF group to a greater degree than the NBF group.[106]

The intermaxillary changes were similar degrees of improvement for both BF (-2.02 ± 1.56) and NBF (-2.20 ± 2.03) groups. It can be derived from this finding that the Forsus will provide similar Class II correction for patients of both skeletal growth patterns.

Study Limitations and Strengths

This study is a retrospective cohort design. This type of study is predisposed to flaws, including the inability to control for certain factors related to selection of patients to undergo treatment, as well as treatment itself. It would be ideal for example, to have lateral cephalographs for each patient immediately before insertion and after removal of the Forsus springs. With only the use of pre and post-treatment radiographs, additional orthodontic mechanics pose error unto the data. However, this does provide a true picture of the diversity of treatment mechanics in various private practices and treatment settings. Therefore, while the specific effects of the appliance itself are diluted, the general treatment effectiveness of the appliance incorporated into comprehensive care in the "real world" can be appreciated.

An additional limitation is the sample size. Due to the small sample available for this study the mesofacial and dolichofacial groups were combined to improve the power of the study. However, as the groups were combined, the variation between samples became smaller as patients could exist in separate groups with only 2 degrees of variable vertical growth.

Future Exploration

Future studies on this topic could be designed to explore the ability of the Forsus appliance to provide vertical control in vertical growing patients. This could be evaluated by examining the vertical skeletal and dental changes associated with treatment via vectors of force from the maxillary first molar to the distal of the mandibular canine versus the distal of the mandibular first premolars. The design of the study could be improved upon by gathering a larger sample in order to stratify the patients into groups of the three vertical growth patterns as well as to evaluate effects of the Forsus by obtaining a pre- and post- Forsus appliance lateral cephalograph. The long-term effects of the vertical control could also be evaluated as a follow-up study by evaluating the patients after a retention period where growth has ceased.

CONCLUSIONS

This cephalometric retrospective study of Class II patients evaluated the dentoskeletal treatment effects of the Forsus appliance in patients with brachyfacial and nonbrachyfacial growth patterns. The treatment effects of each group were also compared to a similar untreated group of Class II controls. The findings of this study include:

1. The Forsus appliance was effective in correcting Class II malocclusion in patients with both brachyfacial and nonbrachyfacial growth patterns.

2. The main treatment effects of the Forsus are:

   a. predominantly dentoalveolar with the most significant changes occurring in the mandibular arch

   b. via a headgear effect causing a retrusion of the maxilla

3. There is no clinical significant difference in the treatment effects that occur in patients with varying underlying vertical growth patterns when treated with the Forsus appliance

Figure 16: Cephalometric Landmarks

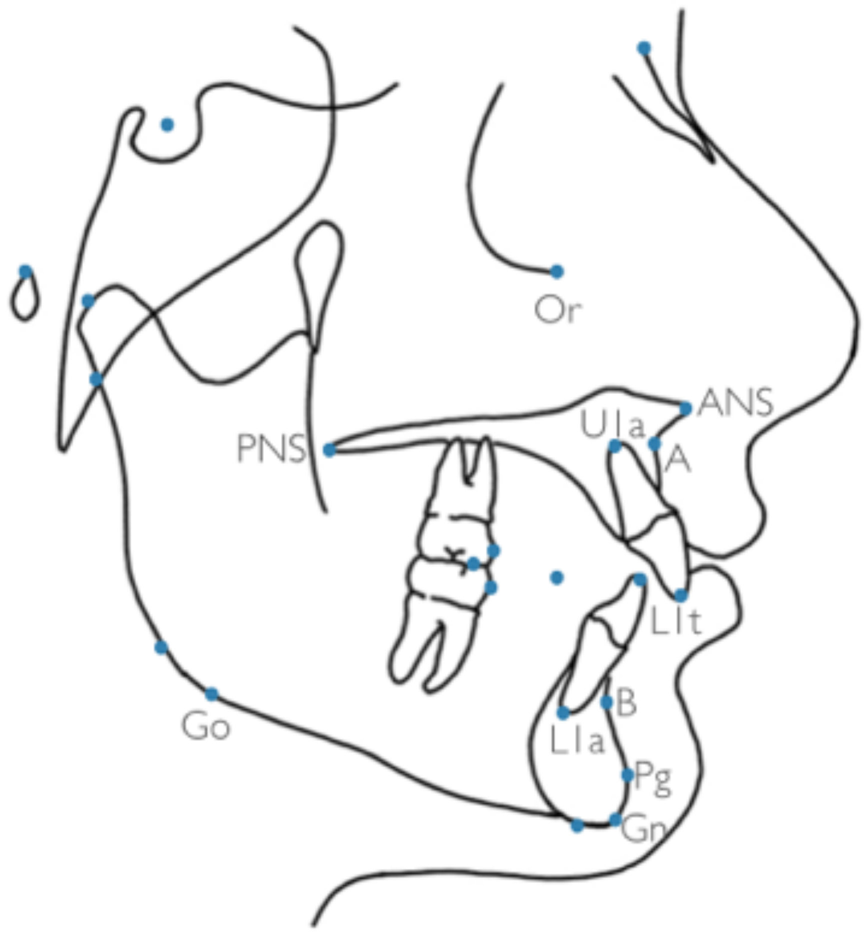


Table 2: Baseline (T1) Skeletal and Dental Characteristics of Groups

	Total							Brachyfacial Group							Nonbrachyfacial						
Cephalometric Measurement	Treatment Group			Control Group				Treatment Group (N=26)			Control Group (N=16)				Treatment Group (N=12)			Control Group (N=8)			
	Mean	StdDev	Median	Mean	StdDev	Median	p-value	Mean	StdDev	Median	Mean	StdDev	Median	p-value	Mean	StdDev	Median	Mean	StdDev	Median	p-value
Interdental																					
OJ (mm)	6.78	2.44	6.80	4.95	1.33	4.75	0.002*	6.72	2.31	6.95	4.96	1.48	4.45	0.009*	6.90	2.82	6.50	4.93	1.07	5.15	NS
OB (mm)	6.22	2.58	6.40	4.35	2.50	4.15	0.007*	6.62	2.61	7.25	4.78	2.84	4.75	0.039*	5.37	2.41	6.15	3.49	1.39	4.05	NS
Molar Relation (mm)	2.80	1.78	2.90	1.90	2.09	1.65	0.019*	3.05	1.76	3.05	1.62	2.18	0.50	0.009*	2.28	1.79	2.40	2.48	1.89	2.10	NS
SN-FOP (degrees)	11.80	3.53	12.30	12.52	4.76	12.90	NS	10.55	3.24	10.50	10.74	3.53	11.30	NS	14.52	2.53	14.15	16.09	5.10	15.35	NS
Maxillary Dental Horizontal																					
U6-A (mm)	-28.14	2.55	-28.50	-25.42	2.17	-25.35	0.000*	-28.15	2.81	-28.95	-25.93	2.10	-26.80	0.008*	-28.13	1.97	-28.10	-24.41	2.08	-24.30	0.002*
U1-A (mm)	3.23	3.93	3.50	2.29	3.43	2.10	NS	3.83	3.89	4.25	2.16	3.77	2.10	NS	1.94	3.87	1.20	2.54	2.86	1.90	NS
U1 - SN (deg)	101.48	11.01	102.80	100.53	9.63	101.05	NS	103.54	11.47	103.65	100.91	10.88	102.45	NS	97.01	8.78	95.05	99.79	7.05	99.10	NS
Mandibular Dental Horizontal																					
L1-Pg (mm)	7.32	4.05	6.80	6.66	3.98	6.70	NS	6.33	3.41	6.10	4.96	3.55	4.45	NS	9.45	4.63	8.80	10.06	2.25	10.15	NS
L6-Pg (mm)	-20.88	4.37	-21.65	-18.70	3.96	-19.30	NS	-22.66	3.36	-22.40	-20.43	2.83	-20.75	0.036*	-17.03	3.87	-17.20	-15.26	3.73	-15.25	NS
IMPA (deg)	94.04	6.15	94.50	94.95	6.58	96.20	NS	96.11	5.32	97.00	95.09	7.71	96.60	NS	89.58	5.59	88.40	94.68	3.83	96.20	0.017*
Maxillary Dental Vertical																					
U6-PP (mm)	22.26	2.08	22.00	21.39	1.97	21.00	NS	21.90	1.94	21.55	20.91	1.50	20.95	NS	23.06	2.24	23.15	22.35	2.52	22.55	NS
U1-PP (mm)	30.64	2.92	30.90	28.62	2.79	28.55	0.010*	29.63	2.49	29.65	27.74	2.26	28.15	0.026*	32.83	2.63	33.10	30.36	3.07	29.75	NS
Mandibular Dental Vertical																					
L6-MP (mm)	29.61	2.50	29.35	29.58	1.84	29.70	NS	29.62	2.19	29.20	29.11	1.76	29.45	NS	29.58	3.18	30.30	30.51	1.73	30.35	NS
L1-MP (mm)	42.96	3.30	42.40	40.53	2.60	40.55	NS	42.77	3.05	42.40	39.83	2.10	39.75	0.001*	43.38	3.89	42.65	41.93	3.07	41.25	NS
Skeletal Vertical																					
SN-PP (deg)	-1.01	2.47	-0.55	-0.18	3.33	-0.35	NS	-1.17	2.22	-0.55	-0.81	3.43	-0.50	NS	-0.68	3.02	-0.50	1.06	2.93	1.90	NS
SN-MP (deg)	27.66	5.49	27.55	26.64	5.24	25.70	0.020*	24.68	3.50	25.15	23.63	2.77	23.75	NS	34.13	2.62	33.30	32.66	3.40	31.05	NS
ANS-Me (mm)	68.00	5.03	67.80	65.13	4.60	63.85	NS	66.41	4.46	67.30	63.20	3.27	62.90	0.018*	71.44	4.59	70.90	68.98	4.59	68.85	NS
Maxillary Skeletal Horizontal																					
SNA (deg)	82.34	3.72	81.70	83.65	4.25	84.05	NS	83.06	3.64	82.25	85.38	2.99	84.50	0.012*	80.78	3.54	81.00	80.20	4.46	80.35	NS
A-Na perp (mm)	1.36	3.18	1.40	2.02	4.73	1.70	NS	1.57	3.45	1.40	2.84	3.84	1.85	NS	0.91	2.58	0.20	0.39	6.10	0.60	NS
Co-A (mm)	95.45	5.58	95.15	93.17	4.73	94.15	NS	96.94	5.37	96.45	93.88	4.11	94.65	NS	92.23	4.75	92.70	91.76	5.83	92.25	NS
Mandibular Skeletal Horizontal																					
SNB (deg)	76.38	3.57	76.10	77.98	3.97	78.40	0.044*	77.28	3.54	76.75	79.51	2.81	79.60	0.020*	74.44	2.87	74.15	74.93	4.34	74.70	NS
Pg-Na perp (mm)	-6.95	5.50	-7.15	-5.33	7.47	-4.85	NS	-5.69	5.66	-6.00	-3.85	4.67	-4.10	NS	-9.68	4.12	-9.70	-8.28	11.02	-7.60	NS
Co-Gn (mm)	118.10	5.94	117.15	114.77	6.75	115.40	NS	119.07	6.06	118.00	114.48	6.16	115.40	NS	115.99	5.28	115.10	115.36	8.23	116.10	NS
Intermaxillary																					
ANB (deg)	5.94	1.69	5.40	5.67	1.59	5.40	NS	5.75	1.41	5.40	5.86	1.67	5.70	NS	6.33	2.21	5.45	5.28	1.44	4.90	NS
Mx/Md differential (mm)	22.66	3.57	22.80	21.61	3.55	21.40	NS	22.15	3.52	21.90	20.61	3.06	20.45	NS	23.78	3.58	24.35	23.61	3.81	23.80	NS

* indicates statistical significance with $p < 0.05$

Table 3: T2 Skeletal and Dental Characteristics of Groups

	Total							Brachyfacial Group							Nonbrachyfacial						
Cephalometric Measurement	Treatment Group			Control Group				Treatment Group (N=26)			Control Group (N=16)				Treatment Group (N=12)			Control Group (N=8)			
	Mean	StdDev	Median	Mean	StdDev	Median	p-value	Mean	StdDev	Median	Mean	StdDev	Median	p-value	Mean	StdDev	Median	Mean	StdDev	Median	p-value
Interdental																					
OJ (mm)	3.33	0.86	3.30	5.09	2.36	4.50	0.001*	3.19	0.91	3.10	5.33	2.54	5.00	0.001*	3.63	0.66	3.75	4.60	2.00	4.10	NS
OB (mm)	1.81	1.00	1.65	3.70	2.63	3.20	0.007*	1.77	0.99	1.65	4.13	2.85	3.95	0.007*	1.91	1.06	1.75	2.84	2.02	2.35	NS
Molar Relation (mm)	0.01	1.64	-0.15	1.26	2.93	0.90	NS	-0.16	1.72	-0.15	1.09	3.12	-0.35	NS	0.36	1.47	-0.15	1.60	2.67	1.30	NS
SN-FOP (degrees)	12.26	4.46	12.00	11.50	5.11	13.10	NS	11.13	4.36	10.40	10.07	4.29	9.20	NS	14.72	3.74	15.55	14.38	5.69	15.75	NS
Maxillary Dental Horizontal																					
U6-A (mm)	-26.39	2.66	-26.15	-25.78	2.84	-25.65	NS	-26.32	2.60	-26.20	-26.55	2.93	-26.50	NS	-26.53	2.90	-26.10	-24.24	2.02	-24.50	NS
U1-A (mm)	3.10	2.25	3.30	3.12	3.52	2.90	NS	3.43	1.78	3.65	2.91	3.94	2.90	NS	2.38	2.99	1.75	3.55	2.68	2.95	NS
U1 - SN (deg)	104.24	6.23	105.30	101.72	9.43	101.55	NS	104.97	5.66	105.70	101.66	10.59	102.00	NS	102.67	7.34	101.60	101.85	7.22	101.25	NS
Mandibular Dental Horizontal																					
L1-Pg (mm)	7.82	4.35	7.45	5.57	4.23	5.60	NS	6.61	3.81	6.90	3.82	3.85	3.00	0.021*	10.43	4.47	9.30	9.08	2.43	8.40	NS
L6-Pg (mm)	-18.77	4.40	-18.80	-19.85	4.84	-20.15	NS	-20.17	3.74	-19.50	-21.66	4.32	-21.75	NS	-15.73	4.30	-16.20	-16.24	3.83	-16.40	NS
IMPA (deg)	101.67	6.56	101.25	94.90	7.93	95.75	0.001*	103.78	5.53	103.20	94.72	9.29	95.35	0.003*	97.10	6.46	97.05	95.25	4.63	96.05	NS
Maxillary Dental Vertical																					
U6-PP (mm)	23.34	2.19	23.95	22.80	2.69	22.40	NS	23.00	2.29	23.50	21.96	2.32	21.75	NS	24.06	1.82	24.35	24.48	2.73	25.55	NS
U1-PP (mm)	31.47	2.85	31.55	29.19	3.36	29.45	0.008*	30.79	2.61	30.75	28.08	2.98	28.35	0.004*	32.95	2.87	33.50	31.41	3.10	31.30	NS
Mandibular Dental Vertical																					
L6-MP (mm)	32.68	3.08	32.70	31.44	2.80	31.80	NS	32.74	2.76	32.40	30.83	2.83	31.55	0.043*	32.56	3.80	33.40	32.65	2.46	32.30	NS
L1-MP (mm)	41.81	3.65	41.70	42.60	3.77	42.35	NS	41.08	3.00	41.05	41.81	3.39	41.55	NS	43.40	4.52	42.65	44.20	4.21	43.35	NS
Skeletal Vertical																					
SN-PP (deg)	-0.73	3.24	-0.50	-0.34	3.03	-0.50	NS	-1.01	2.99	-0.85	-0.81	3.00	-0.70	NS	-0.14	3.79	-0.35	0.59	3.08	0.15	NS
SN-MP (deg)	27.17	6.15	27.10	25.37	4.72	24.65	NS	24.32	4.45	24.60	22.91	2.73	23.50	NS	33.36	4.59	32.65	30.29	3.97	29.50	NS
ANS-Me (mm)	71.28	5.93	70.90	68.78	5.50	68.75	NS	69.81	5.43	69.95	66.56	4.36	66.85	0.028*	74.48	5.92	76.20	73.23	4.96	71.95	NS
Maxillary Skeletal Horizontal																					
SNA (deg)	80.58	3.50	80.30	84.03	4.35	83.80	0.001*	81.44	3.65	81.05	85.51	3.46	84.60	0.001*	78.73	2.31	78.85	81.08	4.63	80.10	NS
A-Na perp (mm)	-0.89	3.49	-0.35	1.79	4.43	1.65	0.030*	-0.29	3.18	0.40	1.94	3.94	1.65	NS	-2.21	3.90	-0.70	1.49	5.58	1.65	NS
Co-A (mm)	95.09	5.86	95.05	96.88	5.75	97.25	NS	97.09	5.24	96.05	97.17	5.27	97.25	NS	90.75	4.80	91.50	96.31	6.96	96.15	NS
Mandibular Skeletal Horizontal																					
SNB (deg)	76.73	3.41	76.20	78.77	3.76	79.10	0.020*	77.72	3.37	77.20	79.91	3.16	79.70	0.028*	74.59	2.45	73.85	76.50	4.01	76.00	NS
Pg-Na perp (mm)	-6.94	6.35	-6.35	-4.72	7.22	-4.00	NS	-4.99	5.10	-4.70	-4.58	5.55	-3.85	NS	-11.16	6.94	-12.40	-5.01	10.25	-4.70	NS
Co-Gn (mm)	122.29	6.45	120.85	121.61	8.62	122.90	NS	123.73	6.80	121.95	120.54	8.41	122.45	NS	119.16	4.38	118.70	123.74	9.21	126.00	NS
Intermaxillary																					
ANB (deg)	3.86	2.05	3.85	5.26	1.75	5.40	0.005*	3.73	1.73	3.85	5.59	1.75	5.70	0.002*	4.13	2.68	3.90	4.60	1.68	4.85	NS
Mx/Md differential (mm)	27.21	3.68	27.05	24.74	4.79	24.30	0.022*	26.65	3.78	26.65	23.39	4.26	22.50	0.026*	28.41	3.27	28.90	27.44	4.90	28.10	NS

* indicates statistical significance with $p < 0.05$

Table 4: T2-T1 - Change in Skeletal and Dental Characteristics of Groups

	Total							Brachyfacial Group							Nonbrachyfacial						
Cephalometric Measurement	Treatment Group			Control Group				Treatment Group (N=26)			Control Group (N=16)				Treatment Group (N=12)			Control Group (N=8)			
	Mean	StdDev	Median	Mean	StdDev	Median	p-value	Mean	StdDev	Median	Mean	StdDev	Median	p-value	Mean	StdDev	Median	Mean	StdDev	Median	p-value
Interdental																					
OJ (mm)	-3.45	2.68	-3.30	0.14	1.81	-0.20	0.000*	-3.53	2.56	-3.70	0.37	1.74	0.00	0.000*	-3.27	3.04	-3.15	-0.33	1.98	-0.70	0.041*
OB (mm)	-4.41	2.41	-4.80	-0.65	2.02	-0.55	0.000*	-4.85	2.28	-5.35	-0.64	2.30	-0.50	0.000*	-3.46	2.51	-3.00	-0.65	1.42	-0.60	0.015*
Molar Relation (mm)	-2.80	2.06	-2.60	-0.64	2.84	-0.80	0.000*	-3.21	2.06	-2.60	-0.53	3.23	-0.85	0.001*	-1.92	1.86	-2.10	-0.88	2.02	-0.20	NS
SN-FOP (degrees)	0.46	3.71	-0.15	-1.02	2.87	-0.90	NS	0.58	3.63	-0.30	-0.67	3.17	-0.80	NS	0.20	4.03	0.95	-1.71	2.18	-1.30	NS
Maxillary Dental Horizontal																					
U6-A (mm)	1.75	2.57	1.80	-0.36	2.18	0.05	0.001*	1.82	2.84	1.75	-0.63	2.45	-0.05	0.004*	1.59	1.95	1.80	0.18	1.50	0.50	NS
U1-A (mm)	-0.13	3.56	-1.00	0.83	1.74	0.85	NS	-0.40	3.45	-1.45	0.74	1.52	0.80	0.037*	0.43	3.87	1.30	1.01	2.21	0.95	NS
U1 - SN (deg)	2.76	10.82	2.15	1.19	4.65	1.05	NS	1.42	10.45	0.15	0.75	4.61	0.40	NS	5.66	11.51	6.65	2.06	4.91	1.25	NS
Mandibular Dental Horizontal																					
L1-Pg (mm)	0.50	2.31	0.10	-1.09	1.22	-1.25	0.001*	0.28	2.48	0.05	-1.14	1.39	-1.35	0.027*	0.98	1.89	0.90	-0.99	0.84	-1.05	0.011*
L6-Pg (mm)	2.11	2.25	2.10	-1.15	3.37	-0.45	0.000*	2.48	2.35	2.60	-1.23	4.06	-0.35	0.001*	1.30	1.86	1.10	-0.98	1.40	-0.65	0.011*
IMPA (deg)	7.63	6.59	7.70	-0.06	3.67	-0.40	0.000*	7.68	6.40	7.70	-0.38	4.16	-1.30	0.000*	7.53	7.28	7.25	0.58	2.52	0.90	0.025*
Maxillary Dental Vertical																					
U6-PP (mm)	1.07	2.02	1.25	1.41	1.60	0.90	NS	1.11	1.83	1.15	1.05	1.69	0.70	NS	1.00	2.49	1.65	2.13	1.19	2.60	NS
U1-PP (mm)	0.83	1.83	0.95	0.58	1.38	0.70	NS	1.15	1.72	1.50	0.34	1.44	0.65	NS	0.12	1.93	0.15	1.05	1.17	1.05	NS
Mandibular Dental Vertical																					
L6-MP (mm)	3.08	1.91	2.95	1.86	1.41	1.75	0.011*	3.12	1.86	2.95	1.73	1.48	1.55	0.016*	2.98	2.09	3.00	2.14	1.29	2.05	NS
L1-MP (mm)	-1.14	2.48	-0.90	2.08	1.48	1.90	0.000*	-1.68	2.44	-1.00	1.98	1.62	1.75	0.000*	0.03	2.25	-0.15	2.28	1.25	2.55	0.012*
Skeletal Vertical																					
SN-PP (deg)	0.28	1.86	0.45	-0.16	1.71	0.00	NS	0.16	1.54	0.45	0.00	1.60	-0.15	NS	0.53	2.46	0.80	-0.48	1.97	0.30	NS
SN-MP (deg)	-0.49	2.45	-0.20	-1.27	1.76	-1.60	NS	-0.36	2.23	0.00	-0.72	1.68	-1.25	NS	-0.77	2.97	-0.30	-2.38	1.43	-2.50	NS
ANS-Me (mm)	3.28	3.72	3.50	3.65	2.56	2.90	NS	3.40	3.23	3.20	3.36	2.56	2.80	NS	3.03	4.77	3.60	4.25	2.62	3.55	NS
Maxillary Skeletal Horizontal																					
SNA (deg)	-1.75	2.26	-1.55	0.38	1.36	0.05	0.000*	-1.62	1.95	-1.60	0.14	1.22	-0.10	0.006*	-2.05	2.89	-1.05	0.88	1.59	0.80	0.013*
A-Na perp (mm)	-2.25	3.47	-1.70	-0.23	2.37	0.20	0.010*	-1.85	2.66	-1.80	-0.89	2.08	-0.60	NS	-3.12	4.82	-0.75	1.10	2.48	1.30	0.019*
Co-A (mm)	-0.36	3.90	-0.10	3.71	2.63	2.60	0.000*	0.15	4.00	0.80	3.29	2.77	2.45	0.003*	-1.48	3.57	-1.90	4.55	2.25	4.60	0.002*
Mandibular Skeletal Horizontal																					
SNB (deg)	0.35	1.53	0.50	0.79	1.12	0.80	NS	0.44	1.41	0.65	0.40	1.04	0.50	NS	0.15	1.81	0.50	1.58	0.85	1.35	NS
Pg-Na perp (mm)	0.01	5.53	-0.10	0.60	4.59	0.15	NS	0.70	4.83	0.80	-0.73	4.50	0.10	NS	-1.48	6.82	-2.00	3.26	3.73	2.80	NS
Co-Gn (mm)	4.19	4.92	3.90	6.84	3.93	6.20	NS	4.66	5.00	5.10	6.07	4.10	4.65	NS	3.17	4.78	3.15	8.38	3.25	7.45	0.011*
Intermaxillary																					
ANB (deg)	-2.08	1.69	-1.85	-0.41	1.31	-0.45	0.000*	-2.02	1.56	-1.85	-0.28	1.33	-0.30	0.000*	-2.20	2.03	-1.80	-0.68	1.32	-1.00	NS
Mx/Md differential (mm)	4.54	3.51	3.70	3.13	2.95	3.30	NS	4.50	3.37	3.55	2.78	3.23	2.60	NS	4.63	3.94	4.05	3.83	2.31	4.15	NS

* indicates statistical significance with $p < 0.05$

Table 5: Skeletal and Dental Characteristics of Treatment Groups at T1, T2 and T2-T1

Cephalometric Measurement	T1					T2					T2-T1				
	brachyfacial (N = 26)		nonbrachyfacial (N = 12)			brachyfacial (N = 26)		nonbrachyfacial (N = 12)			brachyfacial (N = 26)		nonbrachyfacial (N = 12)		
	Mean (std dev)	Median	Mean (std dev)	Median	p-value	Mean (std dev)	Median	Mean (std dev)	Median	p-value	Mean (std dev)	Median	Mean (std dev)	Median	p-value
Interdental															
OJ (mm)	6.72 (2.31)	6.95	6.90 (2.82)	6.50	NS	3.19 (0.91)	-3.70	3.63 (0.66)	-3.15	NS	-3.53 (2.56)	3.10	-3.27 (3.04)	3.75	NS
OB (mm)	6.62 (2.61)	7.25	5.37 (2.41)	6.15	NS	1.77 (0.99)	-5.35	1.91 (1.06)	-3.00	NS	-4.85 (2.28)	1.65	-3.46 (2.51)	1.75	0.050*
Molar Relation (mm)	3.05 (1.76)	3.05	2.28 (1.79)	2.40	NS	-0.16 (1.72)	-2.60	0.36 (1.47)	-2.10	NS	-3.21 (2.06)	-0.15	-1.92 (1.86)	-0.15	NS
SN-FOP (degrees)	10.55 (3.24)	10.50	14.52 (2.53)	14.15	0.002*	11.13 (4.36)	-0.30	14.72 (3.74)	0.95	0.011*	0.58 (3.63)	10.40	0.20 (4.03)	15.55	NS
Maxillary Dental Horizontal															
U6-A (mm)	-28.15 (2.81)	-28.95	-28.13 (1.97)	-28.10	NS	-26.32 (2.60)	1.75	-26.53 (2.90)	1.80	NS	1.82 (2.84)	-26.20	1.59 (1.95)	-26.10	NS
U1-A (mm)	3.83 (3.89)	4.25	1.94 (3.87)	1.20	NS	3.43 (1.78)	-1.45	2.38 (2.99)	1.30	NS	-0.40 (3.45)	3.65	0.43 (3.87)	1.75	NS
U1 - SN (deg)	103.54 (11.47)	103.65	97.01 (8.78)	95.05	0.044*	104.97 (5.66)	0.15	102.67 (7.34)	6.65	NS	1.42 (10.45)	105.70	5.66 (11.51)	101.60	NS
Mandibular Dental Horizontal															
L1-Pg (mm)	6.33 (3.41)	6.10	9.45 (4.63)	8.80	0.044*	6.61 (3.81)	0.05	10.43 (4.47)	0.90	0.021*	0.28 (2.48)	6.90	0.98 (1.89)	9.30	NS
L6-Pg (mm)	-22.66 (3.36)	-22.40	-17.03 (3.87)	-17.20	0.000*	-20.17 (3.74)	2.60	-15.73 (4.30)	1.10	0.010*	2.48 (2.35)	-19.50	1.30 (1.86)	-16.20	NS
IMPA (deg)	96.11 (5.32)	97.00	89.58 (5.59)	88.40	0.001*	103.78 (5.53)	7.70	97.10 (6.46)	7.25	0.007*	7.68 (6.40)	103.20	7.53 (7.28)	97.05	NS
Maxillary Dental Vertical															
U6-PP (mm)	21.90 (1.94)	21.55	23.06 (2.24)	23.15	NS	23.00 (2.29)	1.15	24.06 (1.82)	1.65	NS	1.11 (1.83)	23.50	1.00 (2.49)	24.35	NS
U1-PP (mm)	29.63 (2.49)	29.65	32.83 (2.63)	33.10	0.002*	30.79 (2.61)	1.50	32.95 (2.87)	0.15	0.041*	1.15 (1.72)	30.75	0.12 (1.93)	33.50	NS
Mandibular Dental Vertical															
L6-MP (mm)	29.62 (2.19)	29.20	29.58 (3.18)	30.30	NS	32.74 (2.76)	2.95	32.56 (3.80)	3.00	NS	3.12 (1.86)	32.40	2.98 (2.09)	33.40	NS
L1-MP (mm)	42.77 (3.05)	42.40	43.38 (3.89)	42.65	NS	41.08 (3.00)	-1.00	43.40 (4.52)	-0.15	NS	-1.68 (2.44)	41.05	0.03 (2.25)	42.65	NS
Skeletal Vertical															
SN-PP (deg)	-1.17 (2.22)	-0.55	-0.68 (3.02)	-0.50	NS	-1.01 (2.99)	0.45	-0.14 (3.79)	0.80	NS	0.16 (1.54)	-0.85	0.53 (2.46)	-0.35	NS
SN-MP (deg)	24.68 (3.50)	25.15	34.13 (2.62)	33.30	0.000*	24.32 (4.45)	0.00	33.36 (4.59)	-0.30	0.000*	-0.36 (2.23)	24.60	-0.77 (2.97)	32.65	NS
ANS-Me (mm)	66.41 (4.46)	67.30	71.44 (4.59)	70.90	0.002*	69.81 (5.43)	3.20	74.48 (5.92)	3.60	0.031*	3.40 (3.23)	69.95	3.03 (4.77)	76.20	NS
Maxillary Skeletal Horizontal															
SNA (deg)	83.06 (3.64)	82.25	80.78 (3.54)	81.00	NS	81.44 (3.65)	-1.60	78.73 (2.31)	-1.05	0.017*	-1.62 (1.95)	81.05	-2.05 (2.89)	78.85	NS
A-Na perp (mm)	1.57 (3.45)	1.40	0.91 (2.58)	0.20	NS	-0.29 (3.18)	-1.80	-2.21 (3.90)	-0.75	NS	-1.85 (2.66)	0.40	-3.12 (4.82)	-0.70	NS
Co-A (mm)	96.94 (5.37)	96.45	92.23 (4.75)	92.70	0.026*	97.09 (5.24)	0.80	90.75 (4.80)	-1.90	0.003*	0.15 (4.00)	96.05	-1.48 (3.57)	91.50	0.050*
Mandibular Skeletal Horizontal															
SNB (deg)	77.28 (3.54)	76.75	74.44 (2.87)	74.15	0.010*	77.72 (3.37)	0.65	74.59 (2.45)	0.50	0.005*	0.44 (1.41)	77.20	0.15 (1.81)	73.85	NS
Pg-Na perp (mm)	-5.69 (5.66)	-6.00	-9.68 (4.12)	-9.70	0.034*	-4.99 (5.10)	0.80	-11.16 (6.94)	-2.00	0.016*	0.70 (4.83)	-4.70	-1.48 (6.82)	-12.40	NS
Co-Gn (mm)	119.07 (6.06)	118.00	115.99 (5.28)	115.10	NS	123.73 (6.80)	5.10	119.16 (4.38)	3.15	0.043*	4.66 (5.00)	121.95	3.17 (4.78)	118.70	NS
Intermaxillary															
ANB (deg)	5.75 (1.41)	5.40	6.33 (2.21)	5.45	NS	3.73 (1.73)	-1.85	4.13 (2.68)	-1.80	NS	-2.02 (1.56)	3.85	-2.20 (2.03)	3.90	NS
Mx/Md differential (mm)	22.15 (3.52)	21.90	23.78 (3.58)	24.35	NS	26.65 (3.78)	3.55	28.41 (3.27)	4.05	NS	4.50 (3.37)	26.65	4.63 (3.94)	28.90	NS

* indicates statistical significance with $p < 0.05$

Figure 17: Angular Skeletal and Dental Cephalometric Measurements

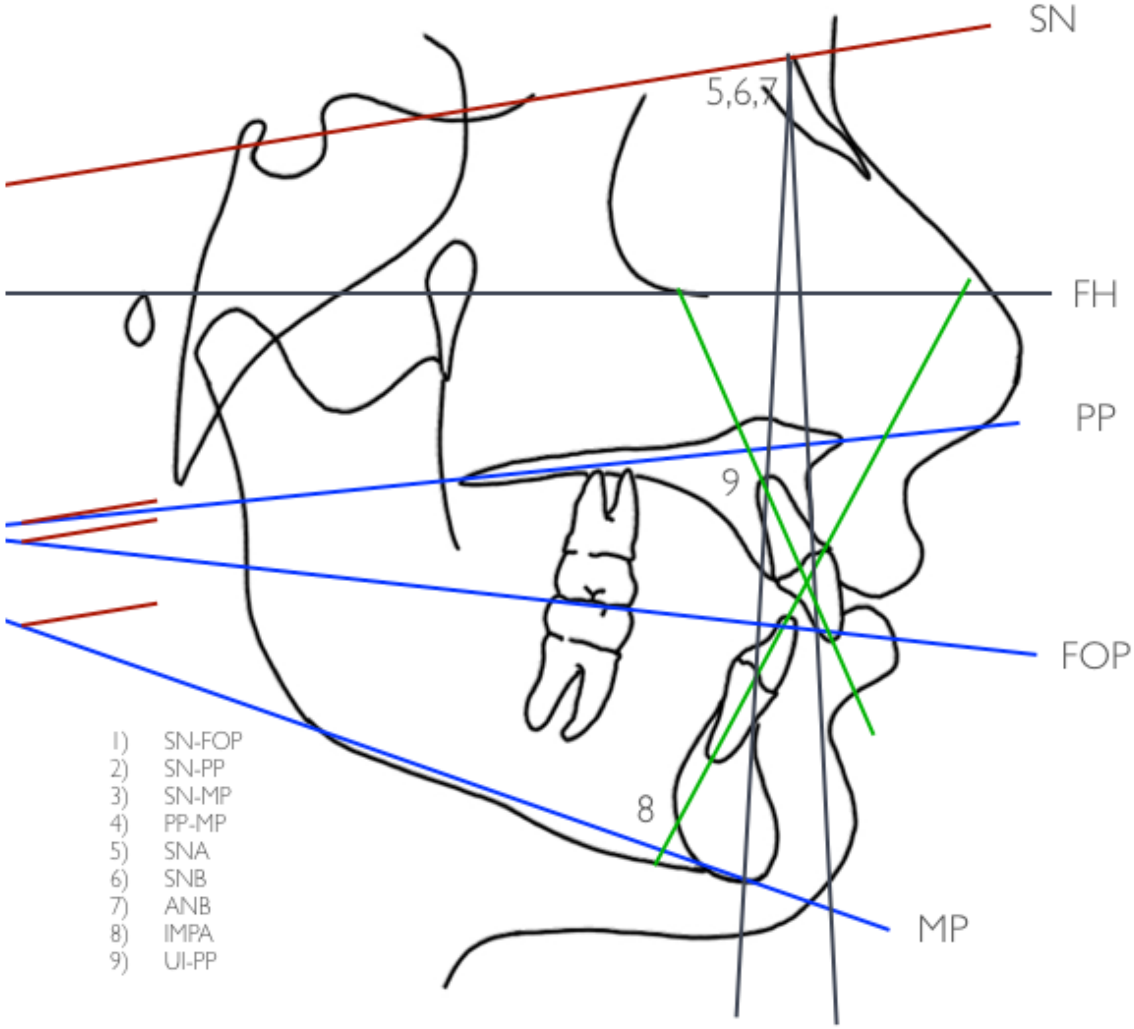


Figure 18: Vertical Dental Measurements

Figure 19: Horizontal Dental Measurements

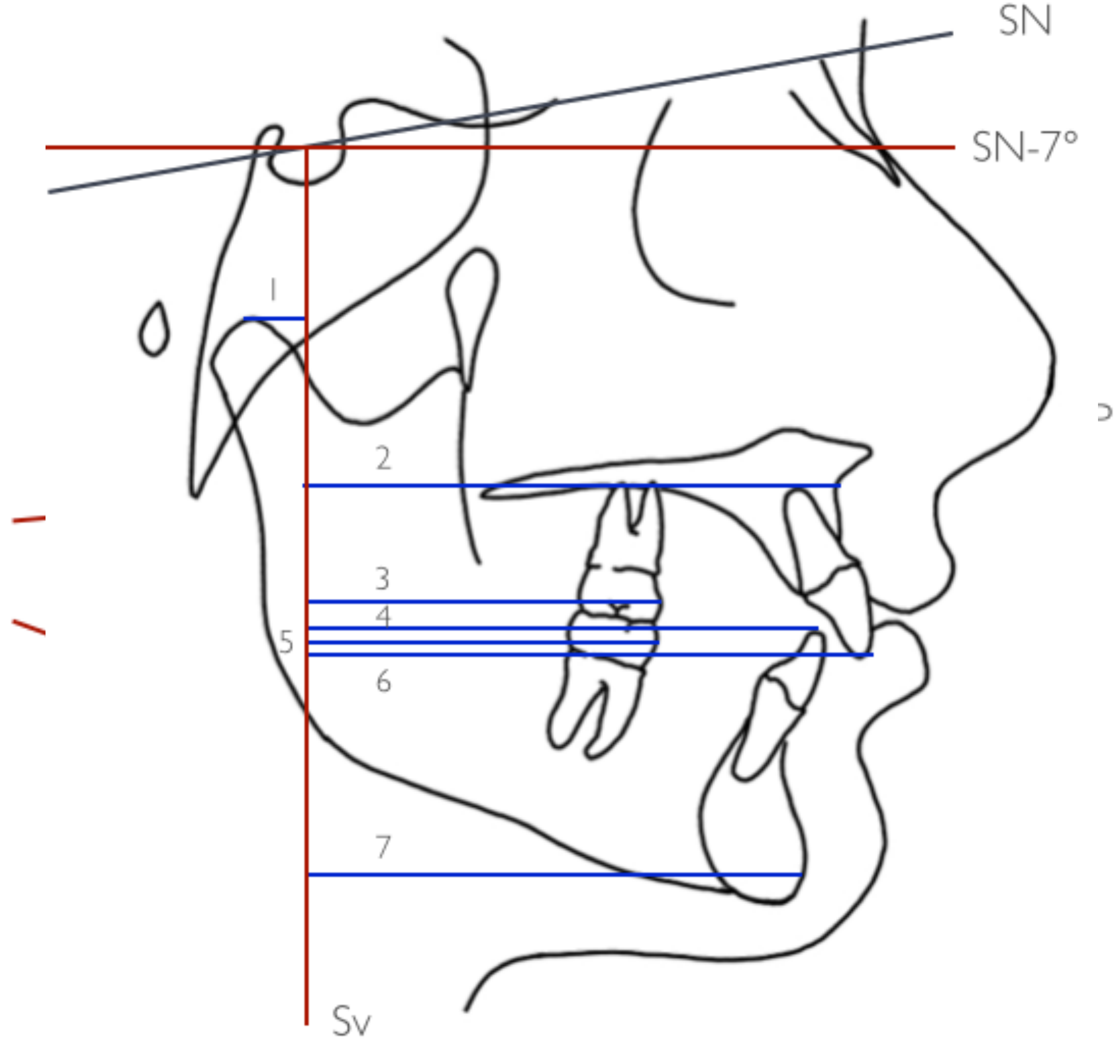
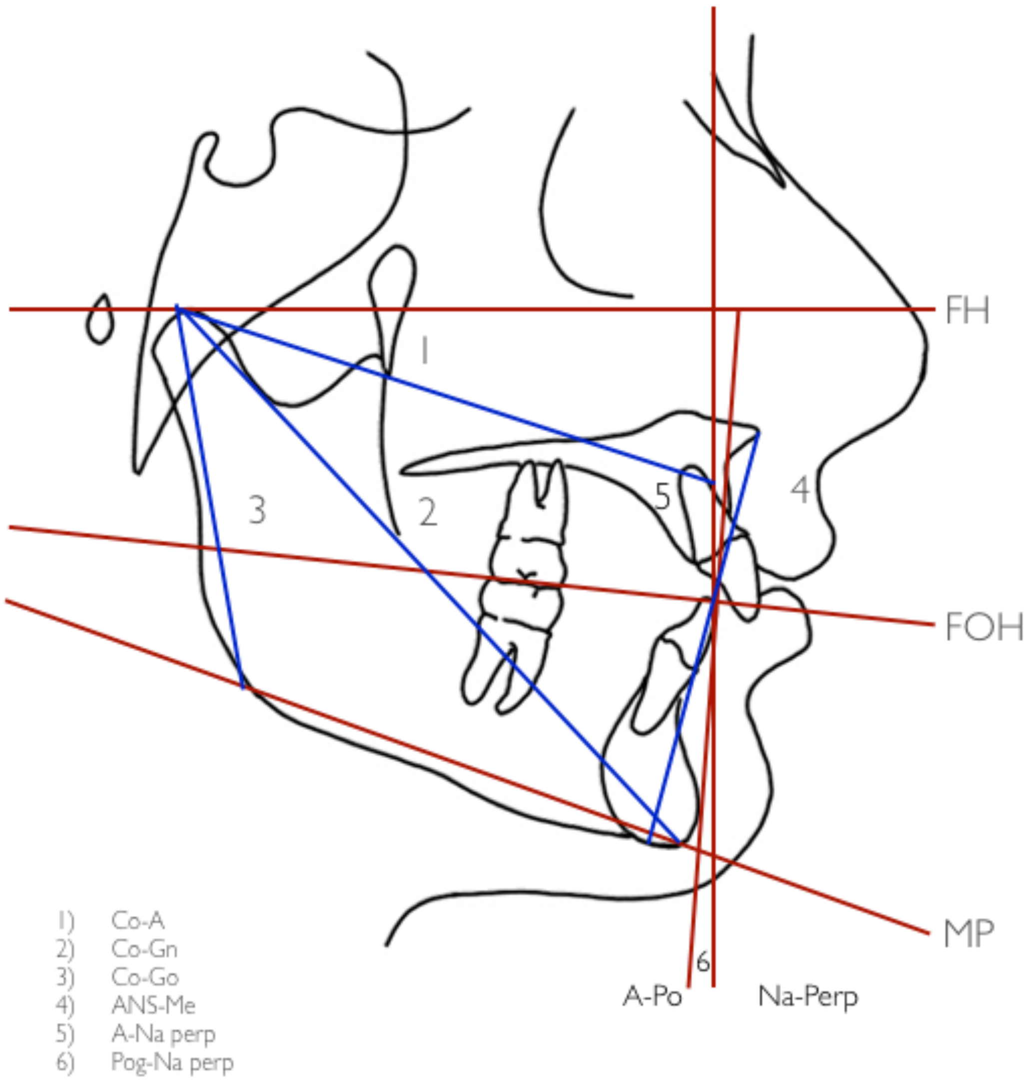


Figure 20: Additional Cephalometric Measurements



Appendix I

Appendix II

Control Subjects
Measure of Reproducibility
Burlington Growth Study Identification Numbers
(n = 24)

Measure	Measurement Error	Dhalberg Reproducibility
OJ	0.10 mm	0.96
OB	0.23 mm	0.95
Molar Relation	0.04 mm	0.95
SN-FOP	0.08 degrees	0.95
U1 - SN	0.83 degrees	0.93
IMPA	1.4 degrees	0.93
U6-A	0.25 mm	0.91
U1-A	0.30 mm	0.91
L1-Pg	0.14 mm	0.96
L6-Pg	0.06 mm	0.90
L1-APo	0.32 mm	0.96
PP-U6	0.59 mm	0.93
PP-U1	0.49 mm	0.93
L6-MP	0.30 mm	0.94
L1-MP	0.03 mm	0.98
SN-PP	0.55 degrees	0.91
SN-MP	0.16 degrees	0.99
ANS-Me	0.34 mm	0.98
SNA	0.78 degrees	0.93
A-Na perp	0.12 mm	0.91
Co-A	0.48 mm	0.97
SNB	0.31 degrees	0.97
Pg-Na perp	0.49 mm	0.92
Co-Gn	0.57 mm	0.98
ANB	0.48 degrees	0.92
Mx/Md differential	0.10 mm	0.93

Appendix III

Treated Subjects from the University of Western Ontario

UWO Identification Numbers

(n=37)

Number	Gender
257	F
272	F
416	F
482	F
717	F
855	F
1024	F
1392	F
2538	F
2572	F
183	M
186	M
289	M
352	M
804	M
930	M
1068	M
1085	M
1316	M
1336	M
2523	M
2563	M
2573	M
2602	M

110058	M
100113	F
12005	F
90159	F
13145	M
12144	M
90030	F
12107	F
110116	M
90228	F
100192	M
90204	F
100165	F

Appendix IV

Definition of Cephalometric Landmarks and Planes

Landmarks

A point (A)	The most posterior point on the curve of the anterior maxilla
Anterior Nasal Spine (ANS)	The most anterior point on the maxilla at the lower margin of the anterior aperture of the nose
Articulare (Ar)	The point of intersection of the inferior surface of the cranial base and the posterior surface of the mandibular condyle
B point (B)	The point most posterior to a line from the crest of the alveolus to the pogonion on the anterior surface of the symphyseal outline of the mandible
Basion (Ba)	The most inferior, posterior point on the anterior margin of the foramen magnum
Condylion (Co)	The most posterior superior point on the condyle of the mandible
Gnathion (Gn)	The most anterior and inferior point on the contour of the bony chin symphysis
Gonion (Go)	Midpoint of the curvature at the angle of the mandible
Constructed Gonion (cGo)	A point formed by the intersection of lines tangent to the Gonion inferior border of the mandible and the posterior ramus
Mandibular Incisor Tip (L1t)	The tip of the crown of the lower central incisor
Mandibular Incisor Apex (L1a)	The root apex of the lower central incisor
Mandibular First Premolar Cusp Tip (L4t)	The cusp tip of the lower first premolar
Mandibular First Molar Mesial Surface (L6m)	The mesial surface of the lower first molar at mid crown
Mandibular First Molar Mesiobuccal Cusp Tip (L6t)	The mesiobuccal cusp tip of the lower first molar
Maxillary Incisor Tip (U1t)	The crown tip of the upper central incisor
Maxillary Incisor Apex (U1a)	The root apex of the upper central incisor
Maxillary First Molar Mesial Surface (U6m)	The mesial surface of the upper first molar at midcrown

Maxillary First Molar Mesiobuccal Cusp Tip (U6t)	The mesiobuccal cusp tip of the upper first molar
Menton (Me)	The most inferior point on the symphysis of the mandible
Nasion (Na)	The junction of the frontonasal suture at the most posterior point on the curve of the bridge of the nose
Orbitale (Or)	The lowest point on the average of the right borders of the orbit
Pogonion (Pg)	The most anterior point on the symphysis of the mandible determined by a line from the nation tangent to the symphysis
Posterior Nasal Spine (PNS)	The most posterior point on the bony hard palate
Pterygoid Point (Pt)	The intersection of the inferior border of the foramen rotundum with the posterior wall of the pterygomaxillary fossa
Sella Turcica (S)	The centre of the pituitary fossa of the sphenoid bone as determined by inspection

Planes

Frankfurt Horizontal (FH)	A line joining Porion and Orbitale
Mandibular Plane (MP)	A line joining constructed Gonion and Menton
Palatal Plane (PP)	A line joining ANS and PNS
Sella-Nasion Plane (SN)	A line joining Sella Turcica and Nasion
Functional Occlusal Plane (FOP)	A line joining the mesiobuccal cusp tip of the lower first molar and the buccal cusp tip of the lower first premolar
SN-7	A line contracted by subtracting 7 degrees to the Sella-Nasion plane
Sella Vertical (Sv)	A vertical line constructed through Sella and perpendicular to SN-7

Appendix V

Definition of Angular and Linear Cephalometric Measurements

<u>Angular Measurements</u>

SNA	The angle formed by points Sella-Nasion-A point
SNB	The angle formed by points Sella-Nasion-B point
ANB	The angle formed by points A point-Nasion-B point
SN-PP	Palatal plane angle: The angle formed by the intersection of Sella-Nasion plane and Palatal plane
SN-MP	Mandibular plane angle: the angle formed by the intersection of the Sella-Nasion plane and Mandibular plane
SN-FOP	Functional Occlusal plane angle: The angle formed by the intersection of the Sella-Nasion plane and the functional occlusal plane
IMPA	Lower incisor to Mandibular plane angle: The posterior angle formed by the intersection of the long axis of the most prominent lower incisor and the mandibular plane
U1-SN	Upper incisor to Sella-Nasion angle: The posterior angle formed by the intersection of the long axis of the most prominent upper incisor and the Sella-Nasion plane

Linear Measurements

A-Na	A point to Nasion perpendicular: Distance in mm from A point to Nasion perpendicular. Nasion perpendicular is a line constructed from nation that passes through Frankfurt Horizontal at 90 degrees
Pog-Na	Pogonion to N perpendicular: Distance in mm from pogonion to Nasion perpendicular
Co-A	Maxillary length: The distance in mm from condylion to A point
Co-Gn	Mandibular length: The distance in mm fro condylion to Gnathion
ANS-Me	Lower Anterior Face Height: The distance in mm from ANS to Me
L1-Apo	Lower incisor to A-Po line: The horizontal distance in mm from lower incisor tip to the A-Po line parallel to FH
OJ	Overjet: Horizontal distance in mm from upper central incisor tip to lower central incisor tip
OB	Overbite: Vertical distance in mm from upper central incisor tip to lower central incisor tip
U6-L6	Molar Relation: (Sv-U6)-(Sv-L6)
U1-A	Sagittal position of maxillary central incisor in relation to the maxillary base (Sv-U1)-(Sv-A)
U6-A	Sagittal position of maxillary first molar in relation to the maxillary base (Sv-U6)-(Sv-A)
L1-Pog	Sagittal position of mandibular central incisor in relation to the mandibular base (Sv-L1)-(Sv-Pg)
L6-Pog	Sagittal position of mandibular first molar in relation to the mandibular base (Sv-L6)-(Sv-Pg)
U1-PP	Vertical position of the maxillary central incisor in relation to the palatal plane
U6-PP	Vertical position of the maxillary first molar incisor in relation to the palatal plane
L1-PP	Vertical position of the mandibular central incisor in relation to the mandibular plane
L6-PP	Vertical position of the mandibular first molar incisor in relation to the mandibular plane

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