AMERICAN UNIVERSITY OF BEIRUT

ANALYSIS OF THE EFFECTS AND PREDICTORS OF ORTHODONTIC FACE MASK THERAPY IN GROWING CLASS III PATIENTS

by
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AN ABSTRACT OF THE THESIS OF

Robin Fadi El Khoury for Master of Science
Major: Orthodontics

Title: Analysis of the effects and predictors of orthodontic Face Mask therapy in growing class III patients.

Introduction

Treatment of growing patients with Class III malocclusion (CL III) remains one of the most challenging problems to treat orthopedically because of the difficulty to predict the mandibular growth potential, thus the possible relapse after treatment with uncontrolled additional growth. Early prediction of the long-term outcome of Face Mask Therapy (FMT) will help fine-tune the treatment plan to deliver optimal treatment strategy and results.

Aims

Chapter 1 To investigate immediate and post-adolescent growth spurt changes induced by FMT and growth on the maxillo-mandibular inter-relationship.

Chapter 2 Investigate the Cephalometric, Facial and Dental predictors of successful and unsuccessful FMT, and the differences between gender and age groupings.

Chapter 3 Check the validity and accuracy of the different proposed predicting formulas in the literature.

Chapter 4 Propose a new prediction model for long term FMT outcome.

Methods

Records of 120 growing CL III patients who received a first phase of orthopedic treatment with facemask alone or with facemask and palatal expansion followed by comprehensive, preadjusted, edgewise therapy. The records were provided through the Dentofacial Clinic at the American University of Beirut-Medical Center and part-time faculty affiliated with the department. The radiographic images were collected at three different timepoints: Pre-treatment (T1), Post-facemask treatment (T2), post-pubertal follow-up (T3) indicated by skeletal maturation evaluation (CVSM 5 or 6).
Patients who simultaneously met 2 of the following inclusion criteria, at the time of the first evaluation (Pre-treatment, T1), were included in the study:

- Edge to edge relationship or negative overjet, reflecting a Class III dental malocclusion
- ANB angle of 0^o or less, reflecting a maxillo-mandibular discrepancy in relation to the cranial base

- Wits appraisal (AoBo) of -2.5mm or less

The final sample of CL III patients who met the criteria consisted of 85 patients having records at T1 and T2, of which 52 had an additional T3 post-pubertal follow up. The sample was divided into two groups, a favorable and unfavorable response group, based on the Overjet at T3 being OJ>0 or OJ<0 respectively.

Linear and angular measurements gauging relations among cranial base and both jaws were taken on pre- and post-treatment lateral cephalograms.

Various appropriate statistical analyses were applied, including discriminant analysis to determine pretreatment predictors of a favorable CL III orthopedic treatment outcome with face mask.

Results

FMT induced skeletal improvements, notably a significant increase in the ANB angle (T2-T1=1.58°, $p<0.05$) and in the Wits appraisal (T2-T1=3mm, $p<0.05$), as well as differential growth between the maxilla and the mandible, the maxilla moving forward 4 times as much as the mandible. It resulted also in dental compensations, with proclination of the maxillary incisors by 5° on average and retroclination of the mandibular incisors by 2°. All these changes contributed to the improvement of the overjet and the facial profile.

At the post-pubertal follow-up T3, 80.8% of the treated patients remained stable (successful) while 19.2% relapsed back into an anterior edge to edge occlusion or crossbite (unsuccessful). Relapse tendencies were observed in both groups, but mandibular growth was more noticeable in the unsuccessful group resulting in a more severe reversion. Male subjects are more prone for relapse than female subjects. The unsuccessful group exhibited a significantly more severe wits appraisal, a more obtuse gonial angle and a more hyperdivergent pattern at the initial timepoint when compared to the successful group. The application of predictive models was found to be deficient in forecasting either success and/or failure. The greatest correspondences were found in a discriminant model based on Wits and Gonial angle. (Success predicted correctly in 95%; failure predicted correctly in 30%)

Conclusion

Facemask therapy in growing subjects with CL III malocclusion is effective in the short term. However, the clinician should be aware of the potential of relapse on the long term and take it into consideration during treatment planning. The wits appraisal, the gonial angle and the vertical pattern as well as the gender might be early predictors of the long-term outcome. Early forecasting of treatment outcome remains challenging, since mandibular growth leading to relapse occurs post-pubertally after the orthopedic treatment period.

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CHAPTER 1

INTRODUCTION

While the three main objectives of orthodontic treatment were always related to function, dentofacial esthetics and stability, the emphasis and direction of orthodontic treatment planning philosophies over the past century is a story of perpetual change of balance. During the latter parts of the 19th century, Norman Kingsley emphasized the esthetic objectives of orthodontic treatment where dental occlusion was secondary to facial esthetics. This philosophy is in stark contrast to Edward Angle's emphasis on occlusion, which led him to teach that optimal facial esthetics always was a consequence of ideal occlusion and therefore it "took care of itself". Later, both Tweed and Begg challenged Angle's nonextraction philosophy partially on esthetic grounds. Although ideal occlusion remains the primary functional goal, it is now acknowledged that the esthetic outcome is critical for patient satisfaction, as well as long term stability of the outcome to avoid potential retreatments.

Patients with Class III malocclusion can be treated with one of three basic modalities: orthopedics, orthodontics, or surgery. Orthodontic treatment can be adjunct to early orthopedic treatment, antecedent to a surgical treatment, or most often a camouflage treatment of mild to moderate skeletal Class III malocclusions. Treatment approaches for the young patients with Class III malocclusion are usually directed towards growth modification using several appliances, most famously the orthopedic Face Mask. Dentofacial orthopedics or growth modification aims to correct or lessen the severity of dentoskeletal discrepancies in growing children. Despite a high rate of success of face mask treatment in compliant patients on the short term, post-pubertal growth remains a major cause of concern when treating growing Class III patients due to the sustained growth of the mandible following the completion of somatic growth. Class III patients tend to “outgrow” treatment effects.

As in all medical specialties, the individualization of treatment remains a challenge, particularly in malocclusions combining skeletal dysmorphology underlying the dental/occlusal irregularities. Treatment planning for such problems is guided by central tendencies gathered from research and randomized trials. The assessment of treatment outcomes has redirected research into associating modalities and timing of treatment with successful outcome in the individual patient. Unfortunately, despite contemporary attempts to predict growth tendencies, clinicians are still unable to accurately estimate the remaining amount of growth for individual malocclusions.

The focus of the present research is to study the main craniofacial components of Class III malocclusion, orthopedic treatment effects of face mask therapy, effect of gender and treatment timing, and discriminate between favorable and unfavorable treatment responses, based on the long term stability of the results. Treatment forecasting formulas from the literature will be tested for validity and accuracy.

CHAPTER 2

LITERATURE REVIEW

2.1. Concept of occlusion and malocclusion

In 18th century Europe, anatomist John Hunter was the first to describe a normal occlusion in an attempt to classify the teeth.

The need of functional prosthetic replacement of the teeth led to the development of the concept of normal occlusion and the definition of malocclusion. In the late 1800s, an American pioneering dentist, “Edward H. Angle”, introduced the definition of malocclusion, and established orthodontics as a specialty, for which he was considered as the “father of modern orthodontics”. [1]

His classification has 4 classes: normal occlusion, Class I malocclusion, Class II malocclusion and Class III malocclusion. This classification was based on the were based on the antero-posterior relationship of the first permanent molars in occlusion and the alignment of the teeth relative to the line of occlusion. This classification was quickly and widely adopted early in the twentieth century and is still incorporated within all contemporary descriptive and classification schemes.[1, 2]

While commonly used to this day, the Angle classification was not without its drawbacks. His classification was incomplete because it did not represent the myriad of the clinically encountered problems. It disregarded the relationship between the dentition and the facial profile, emphasized the antero-posterior dimension rather than a 3-dimensional analysis, and overlooked the skeletal discrepancies and problem complexity. Yet, Angle’s classification was simple enough to remain in use worldwide. Moreover, it constituted a solid baseline for all the refinement that came afterward. [3]

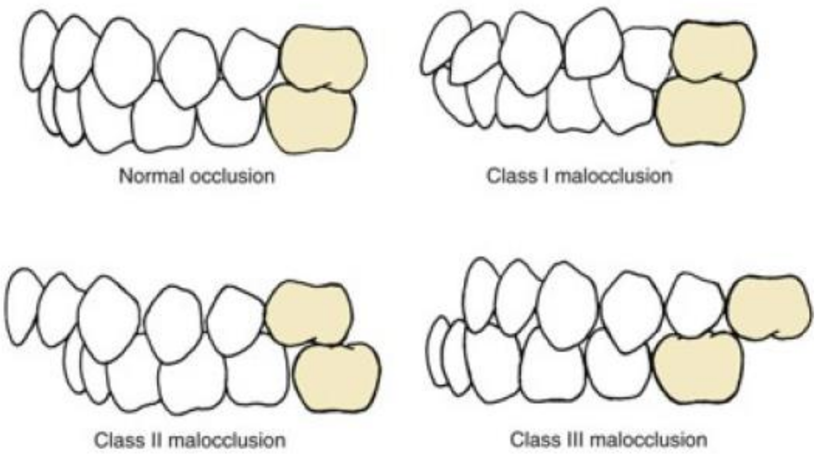

Figure 2.1: Normal occlusion and malocclusion classes as specified by Angle. The Class III malocclusion presents with mesially positioned mandibular first molar relative the maxillary first molar (Angle, 1907; illustrations adapted from Proffit et al, 2014)

Ackerman and Proffit (1969) were the first to describe a system of diagnosis encompassing five major characteristics of malocclusion to overcome the drawbacks of Angle's classification. They accounted for skeletal deviations in the three planes of space, crowding, protrusion, asymmetry within dental arches, and most importantly profile analysis (Fig. 2.2). The classification succeeded in highlighting the complexities of malocclusions but was not practical for wide use in clinical practice. [3]

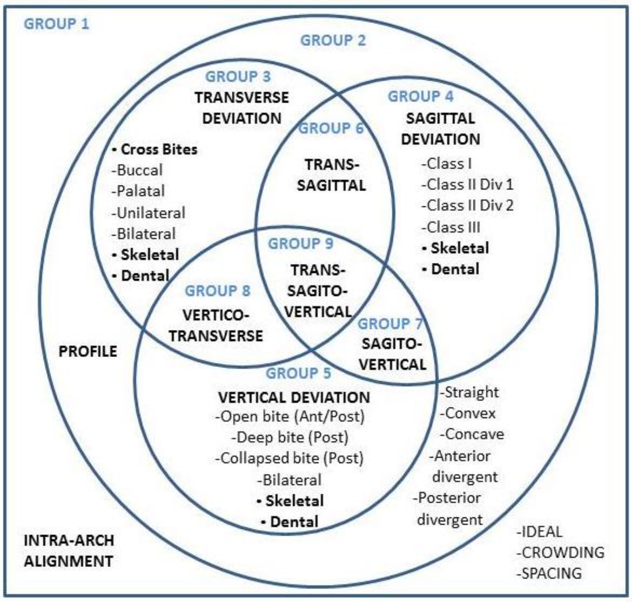

Figure 2.2: Venn diagram of Ackermann and Proffit classification System.

Finally, in 1972, Andrews defined 6 keys to normal occlusion, in order to highlight the ideal occlusion to aim for during the correction of malocclusion. The 6 keys included Angle's own Class I molar occlusion with additional definition of the contacts between the teeth, as well as more detailed dentally and occlusally related parameters. [4]

2.2. Prevalence of Class III malocclusion

Class III malocclusion is the least prevalent type of Angle's classification of malocclusion, in any ethnic background. According to Data from the third National Health and Nutrition Examination Survey (NHANES III), the prevalence of malocclusion of the U.S. population is the following: more than half (50% to 55%) of the population have Class I malocclusion, followed by the Class II malocclusion representing around 15% of the population and finally the Class III malocclusion which occurs in less than 1% of the total population [5].

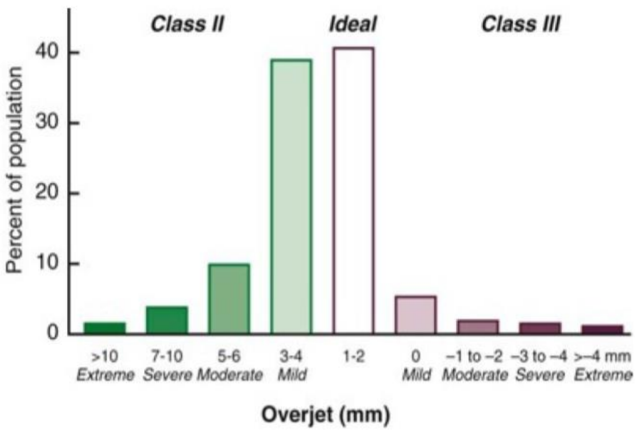

Figure 2.3: Overjet (Class II) and reverse overjet (Class III) in the U.S. population, 1989-1994. Only one-third of the population has ideal anteroposterior incisor relationships, but overjet is only moderately increased in another one-third. Increased overjet accompanying Class II malocclusion is much more prevalent than reverse overjet accompanying Class III. (After Proffit et al, 2014, p. 12).

However, some ethnic groups exhibit a greater tendency towards expression than others [6]. This occlusal relationship appears to be particularly common in those of Asian ancestry, followed by Hispanics, African-Americans and lastly Caucasians [5, 6]. In a recent meta-analysis about the prevalence of angle class III malocclusion [7], the average prevalence of Class III malocclusion across all studies was 7.04%. The studies included used lateral cephalogram X-ray, intraoral exams based on canine relationship or 1st molar relationship, or extraoral exams based on canine and 1st molar relationships from study casts as criteria for class III identification. The averages and ranges of the prevalence rates among different ethnic groups are summarized in table 2.1.

Table 2.1: Mean prevalence rates and ranges of class III malocclusion classified according to the ethnic subgroup [7].

Ethnic group	**Number of individuals**	**Mean prevalence**	**Range**
Southeast Asian	1874	15.80%	12.58% - 26.67%
Middle Eastern	4127	10.18%	9.48% - 11.38%
European	1290	4.88%	0.96% – 8.72%
African	7017	4.59%	1.22% - 19.72%
Indian	1595	1.19%	0% - 4.76%

Other epidemiological studies have used overjet or incisal relationship to assess Class III malocclusion. According to a US public health survey conducted in 1973 and in 1977 [8, 9], a negative overjet was more frequent in youth (12-17 years old) than in children (6-11 years old), occurring in 2.5% and 1% respectively, and more frequent in black population (4.8%) relative to the white American population (2.1%) in the youth category. In another European study [10], it was reported that 3.3% of males and 2.9% of females of Northern European ancestry had an anterior crossbite, and an additional 5.0% of males and 3.8% of females had an edge-to-edge incisal relationship.

2.3. Etiology of Class III malocclusion

The etiology of Class III malocclusion is still a topic of controversy, and researchers are yet to fully unravel the complex and intertwining role of genetics and environment in establishing the final size and position of the craniofacial components and their relation to each other. [11-13]

Tonsillar enlargement and nasal obstruction were thought to be the sole factors leading to a class III malocclusion, according to Angle [14], due to the forced forward mandibular position to allow breathing in such circumstances. Angle also considered other etiologic factors to be of minor importance and early treatment of the “throat ” and correction of the molar occlusion and its retention for a few months would correct the defect. [15]

Another theory on the development of the Class III phenotype is based on the fact that the failure of cranial base to flatten antero-posteriorly, or to orthocephalize, will lead to a more anterior mandibular positioning. [16] Bjork stated that the cranial base angulation occurs mainly through the spheno-occipital synchondrosis[17], therefore a premature synostosis of this synchondrosis can induce deficient orthocephalization, which in turn will lead to shape changes in the cranial base associated with Class III malocclusion. [18]

It has been known that a genetic component contributes to skeletal class III phenotype as illustrated with the Habsburg jaw observed over many generations in this royal family [19], but the extensive genetics studies still fail to congregate towards a defined inheritance pattern [20]. Some studies assume that the class III malocclusion follows a polygenetic inheritance, as supported by genetic analysis of families with this phenotypic trait [21, 22]. This type of inheritance of a phenotypic trait can be attributed to multiple genes and their interaction with the environment.[20] However, another model of monogenic inheritance has been reported based on data from unrelated European noble families who were known to have this particular phenotype[19, 23]. In contrast to the previously described inheritance pattern, monogenic inheritance results from a mutation of a single gene and follows the Mendelian inheritance pattern. In a recent research, the hypothesis of a single gene influencing mandibular prognathism in class III patients was further solidified, but environmental factors were found to modulate the penetrance of the trait[24].

It has been hypothesized that a class III due to a retrognathic maxilla is mainly due to environmental factors while genetic components are predominant in the presence of a macrognathic mandible [12]. Furthermore, the concept of “intragrowth orthopedics” supports the previous hypothesis by stating that a sustained anterior crossbite due to forward positioning of the mandible can inhibit maxillary sagittal growth, by generating forces against the maxillary growth vector [12, 25].

2.4. Morphological characteristics of Class III malocclusion

It has been established that a skeletal class III malocclusion can be caused by a prognathic mandible, a retrognathic maxilla or a combination of both [26-28]. In fact

Sanborn [27] distinguished 4 groups in adults with skeletal Class III: 45.2% with mandibular protrusion only, 33.0% with maxillary retrusion only, 9.5% with normal relationship of both jaws, and 9.5% with a combination of both. Similarly, Jacobson [29] and later on Ellis and McNamara [30] studied and grouped patients with Class III, but found different in the prevalence rates for the same groups.

Zeng [31] examined 300 Asian Class III patients and classified them into 6 groups with decreasing incidence: 1. mandibular prognathism with normal maxilla, 2. maxillary retrognathism with normal mandible, 3. normal maxilla and mandible type; 4. maxillary retrognathism and mandibular prognathism type, with a Class III skeletal face, 5. bimaxillary prognathism type, 6. bimaxillary retrognathism. Contrastingly, Bui et al. [32] looked at a sample of 309 Caucasian skeletal Class III subjects and grouped them into 5 different phenotypes. Unlike the previous study, the most prevalent group was maxillary retrognathism with a high mandibular plane angle, while the least prevalent group exhibited mandibular prognathism and long facial height. The contrasting results illustrate the racial differences amongst Class III subjects.

2.5. Classification of Class III malocclusion

In 1899, Angle [33] was the first to classify malocclusions strictly based on the first molars antero-posterior relationship and the alignment of teeth relative to the line of occlusion. Therefore, his classification was limited to the dento-alveolar component of Class III malocclusion.

Tweed [34] further classified Class III malocclusions into Category A: pseudo-Class III with normal mandibular development; and Category B: skeletal Class III with large mandible or an underdeveloped maxilla.

Moyers [35] classified Class III malocclusion into dental, skeletal or muscular based on the etiology of the problem, stating that in pseudo-Class III, a tooth contact relationship can lead into a forward positioning of the mandible and therefore the positional relationship becomes an acquired neuro-muscular reflex. [36]

For a better diagnostic and treatment intent, Park [37] classified Class III patients into 3 groups:

- Type A: true mandibular prognathism with normal maxilla.
- Type B: overgrowth of maxillary and mandibular bony bases with anterior crossbite.
- Type C: maxillary hypoplasty with anterior crossbite.

In a more recent study on a Chinese population [38], a sample of 144 patients with Class III malocclusion were classified into four different subtypes:

Subtype 1: subjects with mild mandibular prognathism and a steep mandibular plane.

Subtype 2: subjects with a combination of prognathic mandible and retrusive maxilla with a flat or normal mandibular plane.

Subtype 3: subjects with severe mandibular prognathism and a normal mandibular plane.

Subtype 4: subjects with a mild maxillary deficiency and severe mandibular prognathism with a low mandibular plane angle.

2.6. Growth of Class III malocclusion

2.6.1. Cross Sectional Studies

Guyer et al. [26] studied a cross-sectional sample of 144 Class III subjects between the ages of 5 and 15 years old and attempted to characterize them at different developmental stages by studying their lateral cephalograms. Their sample was divided into four age groups according to chronological age and was compared to the Bolton standards. Differences in craniofacial form between Class I and Class III individuals were present in all four age groups, with the class III sample displaying a shorter maxillary length, a longer mandibular length, more proclination of the maxillary incisors and retroclination of the mandibular ones, as well as greater vertical lower facial height.

A similar methodology was applied by Battagel [39] in a Northern European Caucasian sample in which she compared 285 Class III subjects with 210 controls. Males and females were examined separately and classified into 4 age groups: 7–10 years, 11–12 years, 13–14 years, and 15 years and older. The results showed that the facial morphology was different between the cases and the controls in all facial areas examined. The cranial base angle was smaller, the maxilla smaller and more retrusive and the mandible bigger and more prominent partially due to a more anterior position of the mandibular articulation. The individual variation had a wide range and few of the class III patients had all the characteristic features. Male subjects showed their greatest increments of growth between 14 and 17 years of age in both groups, while in females growth remained active for longer in class III subjects.

Reyes et al. [40] studied a sample of 949 untreated patients with class III malocclusion between the ages of 6 and 16 years old and compared them to subjects from subjects included in the University of Michigan Growth Study. The study showed that while no difference was observed between the sagittal position of the maxilla, the sagittal position of the mandible and its size were significantly larger in the Class III group and the mandibular growth peak occurred approximately 1 year later than in

Class I subjects. Class III subjects also exhibited an increased amount of additional growth during the pubertal peak that on average lasted longer than that of Class I subjects.

In a more recent, Baccetti et al. [6] analyzed growth trends in white subjects with Class III malocclusion using both skeletal and dental maturation staging. The sample consisted of 1091 pretreatment lateral cephalometric records of Class III patients (560 females, 531 males), divided into 12 age groups. The results showed that, in Class III malocclusion, the average increases in total mandibular length is about 8 and 5.5 mm in Class III boys and girls respectively during the peak of growth. Growth of the mandible continued until young adulthood (18 years old on average), with post pubertal increases in length that were 2 times larger in class III females when compared to normal females, and 3 times in class III males compared to class I controls. The profile worsened with subsequent growth in class III patients along with an increase with the lower vertical dimension of the face in later developmental stages in concomitance with the eruption of the second and third molars.

A large cross-sectional study of growing class III population was conducted by Miyajima et al. [41] on a sample of 1376 Japanese females, between the ages of 2.7 to 47.9 years. The subjects were stratified in groups according to Hellman's stages of dental development. The results showed that the maxilla assumed a retrusive position at an early developmental stage and its anteroposterior relationship relative to the cranial base structures does not worsen with continued development. Similarly, the mandible was found to be protrusive early in development but became increasingly prognathic with age explaining the worsening in profile observed in post-pubertal class III patients.

While gender differences are noted mainly for size of jaws and related severity in class III population, patterns of Class III development tend to be recognized early and get worse with further growth.

2.6.2. Longitudinal Studies

Longitudinal designs are paramount when assessing growth in a malocclusion group. Individual variability is inevitable among patients when looking at cross-sectional studies and can lead to confounded results. Most cephalometric data denoting skeletal relationships, described in the cross-sectional literature, are an average of different individuals at various time points. While longitudinal analysis are able to provide a more accurate representation of actual skeletal changes in individual patients, they are scarce, especially in Caucasian population, because of the low prevalence of the malocclusion and the proved benefits of early treatment of this malocclusion. [42] Baccetti et al. [43] investigated longitudinal changes in 22 Caucasian Class III subjects between the ages of 8 and 15 with a mean observational period of 6 years and 5 months. A class III skeletal pattern was established early in life and is not self-correcting if left untreated. It was found that the disharmony tends to worsen around the growth peak and continues to do so until complete skeletal maturation. Furthermore, a maxillary retrusion is usually present and is maintained during the growth period even though incremental maxillary growth can be normal. Cephalometric changes were also noted, where the ANB angle decreased on average by 2° and the Wits appraisal by 2.7mm. The amount of mandibular length gained yearly was significantly higher in the untreated class III group (3mm) when compared to subjects with normal occlusion (2mm).

A recent longitudinal study on Class III subjects investigated the longitudinal records of 103 Caucasian subjects with untreated Class III malocclusions from the age of 4 till the age of 20 but did not include a control group. [44] The adolescent spurt in mandibular growth occurred between the ages of 10 and 12 years for females and 12 and 15 years for males. The maximal average midfacial length increase during the growth spurt in the class III sample was 0.5mm less than the averages of the normal growing population. The amount of annual increase in mandibular length in Class III males was consistently over 3 mm between 12 and 15 years old, thus describing an extended duration of a mandibular growth spurt for Class III males and confirming findings of previous studies.

In a study by Wolfe et al. [45], longitudinal records of untreated Class III Caucasian subjects were matched in age and gender to untreated Class I subjects in an effort to compare developmental differences. Subject ages ranged from 6 to 16 years of age. Seven variables (mandibular plane angle, gonial angle, maxillary length, mandibular ramus length, mandibular length, ANB angle, and SNB angle) were significantly different between the two groups and remained so over time. Four variables (lower anterior facial height, maxillary-mandibular differential, mandibular body length, and WITS appraisal) were significantly larger in the class III group and increased significantly more than the controls between the ages of 6 and 16. Male class III subjects showed larger linear measurement values when compared to female class III subjects, but angular measurements were similar as well as the antero-posterior maxilla-mandibular relationship.

In an attempt to determine whether growing class III patients have a different growth spurt than the normal population, Lee et al. [46] gathered data for a duration of

12 years on 55 class III subject and 37 non class III subject. 6 stature growth parameters were measured: age at takeoff, stature at takeoff, velocity at takeoff, age at peak height velocity, stature at peak height velocity, and velocity at peak height velocity. No significant differences were found in the different growth parameters between Patients with Class III prognathism when compared with non-class III subjects.

2.6.3. Sexual dimorphism in class III malocclusion

Sexual dimorphism studies on the differences in growth between genders are abundant in the literature. Classical studies, like Ursi et al. for example, have looked at the dimorphism existing in normal growth and reported that the effective lengths of both jaws were similar in both sexes up to 14 years; after which in females this length remained relatively constant while in males it kept on increasing. The direction of facial growth was similar for both sexes, with a tendency towards a more horizontal growth pattern in females. [47]

However, studies focusing solely on gender differences in Class III subjects are scarce due to the low prevalence of the malocclusion. In Class III malocclusion, the pubertal peak in mandibular growth occurred between stages 3 and 4 of cervical vertebral maturation, and the average increase in total mandibular length was about 8 and 5.5 mm in Class III boys and girls, respectively. Total mandibular length kept increasing until young adulthood (18 years on average) and was twice as large as in subjects with normal occlusion for the Class III females, and three times as large as in subjects with normal occlusion for the Class III males. [48]

Alexander et al. found that the adolescent spurt in mandibular growth occurred between the ages of 10 and 12 years in class III females and between 12 and 15 years in class III males, whereas the peak in midfacial growth occurred at prepubertal ages in both sexes.[44] Statistically significant changes in the average increments of growth of 3 fundamental cephalometric measurements (lower anterior face height, midfacial length, and mandibular length) occurred between all subjects from 12 to 15 years. The approximated average increments of growth for the Class III girls between the ages of 6 to 16 years were 1 mm in lower anterior face height, 1 mm in midfacial length, and 3 mm in mandibular length. During the same time interval, the Class III boys increments of growth were 0.5 mm greater than for the girls at every measurement during the same period.

Battagel reported that Class III females showed a tendency for more growth in the horizontal direction compared to Class III males, who showed more of a vertical direction of growth. [39]

Baccetti et al. [6] reported that male and female Class III subjects show little skeletal differences prior to the age of 13. However, differences start to appear around the pubertal spurt, with the females generally displaying shorter linear measurements in the anterior cranial base, midface and mandibular length and shorter anterior face heights when compared to their male counterparts. The class III female face showed a tendency for more growth in the horizontal direction compared to Class III males, who showed more of a vertical growth pattern.

2.7. Treatment of class III Malocclusion

Nonsurgical treatment of Class III problems remains a challenge in the orthodontic profession. However, sound diagnosis and early intervention to correct a Class III malocclusion may be helpful to reduce the extent of the burden in late adolescence. [49] For the growing Class III patient, orthopedics, orthodontics or a combination of both can be used to address the malocclusion. [50] Early orthopedic treatment of Class III malocclusion has been advocated as an effective modality to improve the jaw discrepancy on the short term, but the stability on the long term remain questionable. [51]

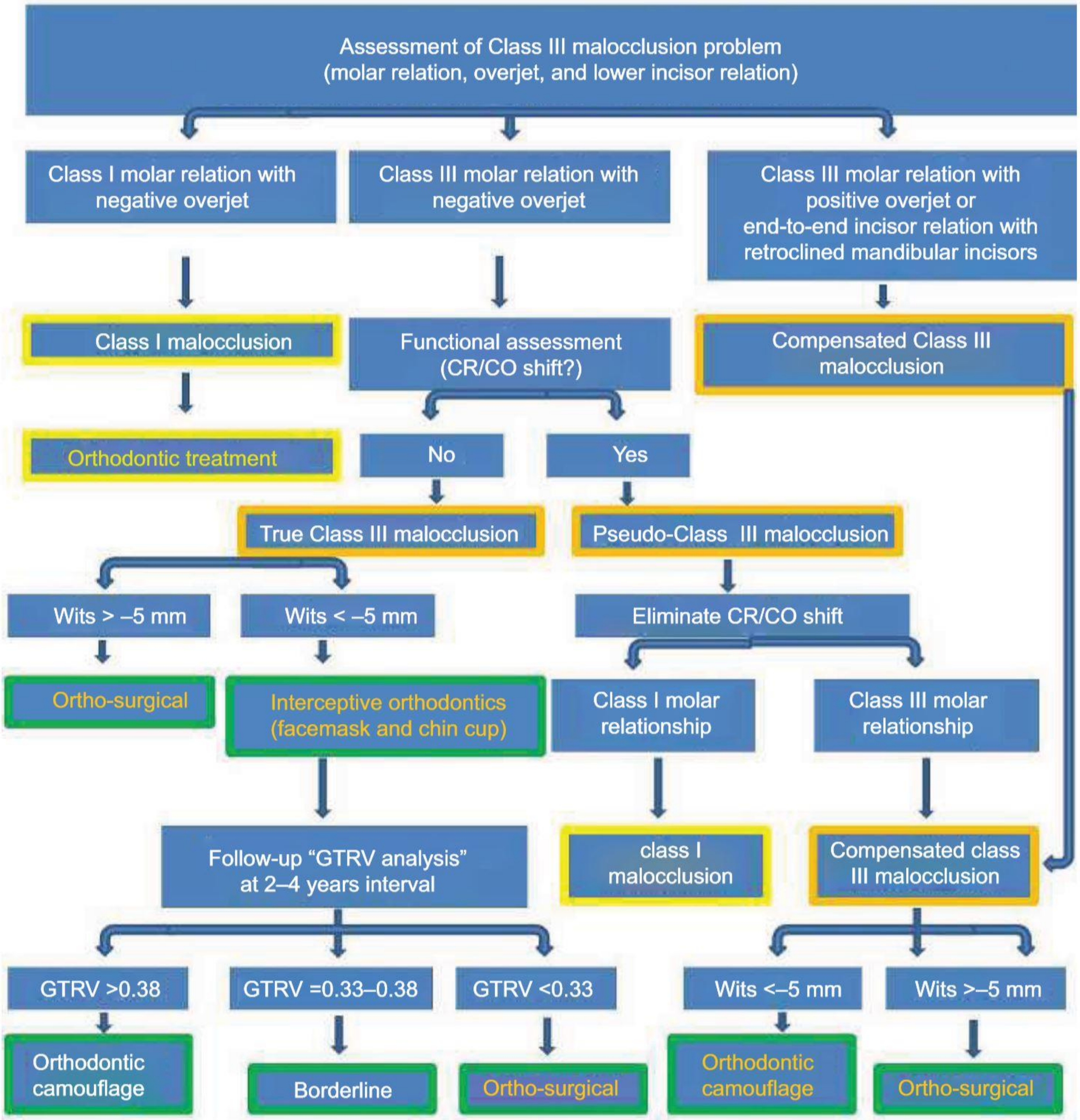

Figure 2.4: Summary of clinical practice guidelines for developing Class III malocclusion

2.7.1. Treatment of pseudo Class III

An anterior crossbite caused by a functional forward displacement or shift of the mandible is termed a pseudo-Class III malocclusion. In centric relation, the patients often have an edge-to-edge incisor relationship accompanied by a mandibular forward displacement to achieve maximum intercuspation that becomes a functional class III malocclusion. [52, 53] Often times, an excessive retroclination of the maxillary incisors causes the pseudo-Class III relationship. It is usually accompanied with a class I molar relationship, a normal mandibular appearance and a straight profile camouflaging the skeletal discrepancy.[36]

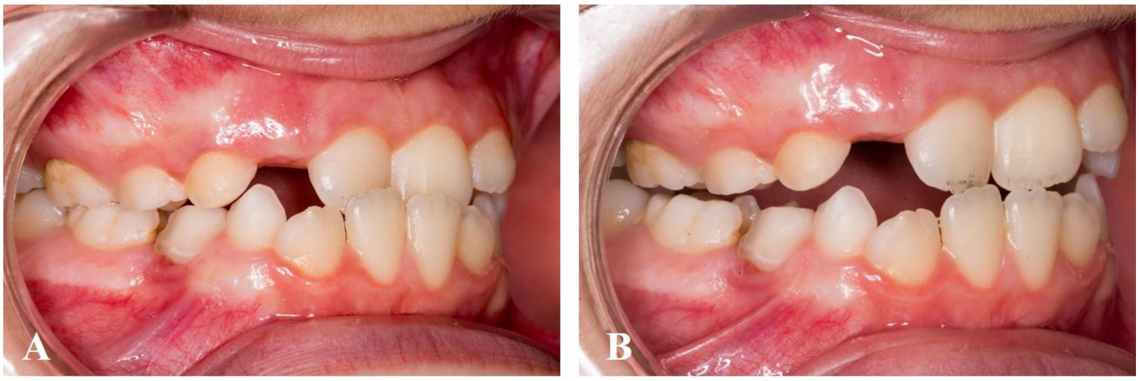

Figure 2.5: Intra-oral pictures illustrating a pseudo-class III malocclusion. A: in maximum intercuspation position with mandibular forward shift. B: in centric relation position.

A variety of treatment approaches can be employed for the correction of a mild skeletal class III with an anterior crossbite, including removable appliances, partial fixed appliances, or orthopedic devices (chin cup, facemask, mandibular headgear…) [54, 55]

Anterior crossbites should be corrected as soon as detected, to enhance the orthopedic effect, achieve more stable results and avoid detrimental side effects. If left untreated, anterior crossbites can lead to complications such as incisal wear, buccal gingival recessions on the mandibular incisors, and worsening of the growth pattern caused by the abnormal forward positioning of the mandible. [56, 57]

Anterior crossbite correction by proclination of the maxillary incisors increases the arch perimeter, yielding more space for the eruption of the maxillary canines and premolars. Early treatment of class III malocclusion with removable functional appliances such as Fränkel III appliance or Balters' Bionator works by preventing unfavorable growth particularly mandibular protrusion and habits such as bruxism and traumatic occlusion and anterior crossbite. [58] The reverse Bionator or Bionator III is a modified version of the traditional bionator that can be used in the early treatment of Class III malocclusion. It differs from the original appliance by having the lingual wire in a different position to control the position of the tongue up to the upper first molar. The labial arch is placed in the middle of the lower teeth, the acrylic should be as small as possible in order to occupy minimal space and should be concave in form to accommodate the tongue and obstruct its movement between the posterior segments by being of adequate thickness. The vertical occlusal height should be enough to correct the anterior crossbite, but should not exceed 3–4 mm. The construction bite is taken by positioning the mandible in centric relation. Finally, the acrylic vestibular lateral shields should be positioned to allow lateral alveolar growth in order to permit expansion of the maxillary arch.

Removable functional appliances such as Fränkel III regulators and activators to treat Class III malocclusions lead to an occlusal plane rotation that helps shift the molar relationship from Class III to Class I. On the other hand, maxillary protraction using a facemask creates a counterclockwise rotation of the maxilla and a clockwise rotation of the mandible, most often resulting in an increased anterior lower facial height. [58-61]

Consequently, it is preferable to avoid the maxillary protraction with the facemask in high angle patients.

In young patients with an anterior crossbite, the association of maxillary expansion and protraction was believed to yield more stable results and enhanced orthopedics due to the loosening of the circum-maxillary sutures, but more recent meta-analysis shows similarity in the results of protraction with or without maxillary expansion. [62, 63]

The association of maxillary expansion and 2 x 4 fixed appliances improves the arch perimeter, reducing the need for extractions in patients with mild crowding. The increase in arch perimeter has been quantified up to 6.0 mm in the maxillary arch. Other advantages of fixed appliances include better 3-dimensional (3D) control of tooth movement and the application of light continuous forces. [64, 65]

2.7.2. Orthopedic Class III treatment

2.7.2.1 Intraoral appliances

This type of appliances includes variations on a basic principle whereby the mandible is forced backwards and the condyles into a posterior centric relation. They include the Balters' bionator or bionator III [58], the Frankel III functional appliance [66], the Eschler appliance [67], the double plate appliance [42], the tandem appliance, Class III elastics with skeletal anchorage [68] and the Orthodontic Removable Traction Appliance (ORTA) [69] (Refer to figures 2.7 – 2.12).

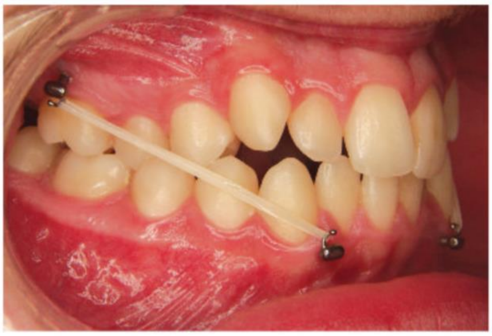

Figure 2.6: Class III correction achieved with the bone-anchored maxillary protraction (BAMP) orthopedic protocol and intraoral elastics.

(Cevidanes et al. 2010)

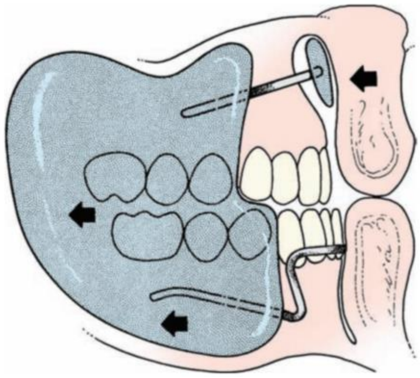

Figure 2.7: The FR-3 appliance of Fränkel. The vestibular shields and the upper labial pads shield the maxillary alveolus from the forces of the surrounding soft tissue. These forces are transmitted through the appliance to the mandible. (Adapted from Mcnamara and Brudon)

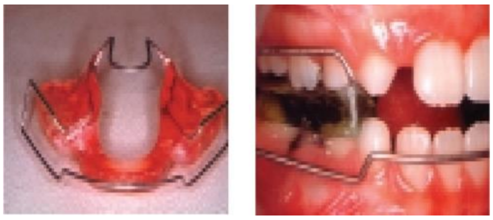

Figure 2.8: Balters' Bionator for Class III treatment. (Giancotti et al. 2003)

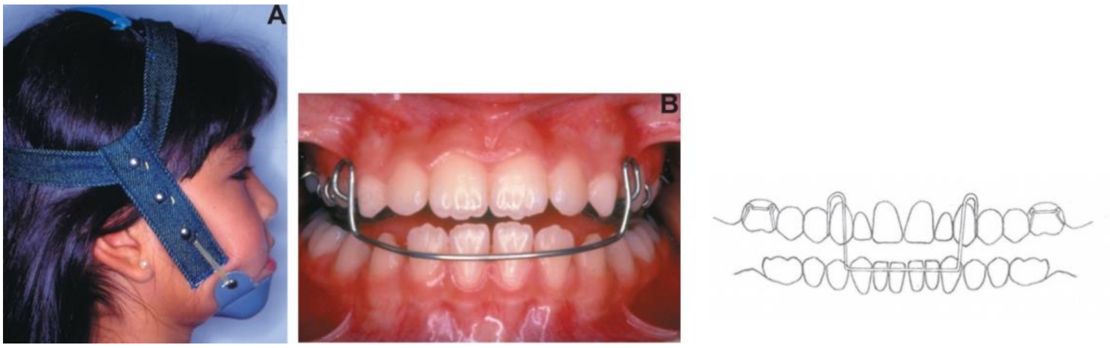

Figure 2.9: Extraoral, Intraoral and schemtic representation of the Eschler appliance. (Almeida et al. 2011)

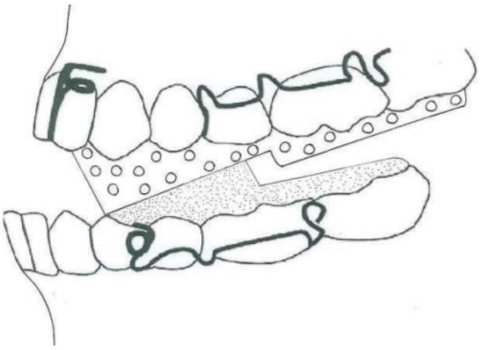

Figure 2.8: Double plate appliance (schematic representation adapted from Azamian et al. 2016)

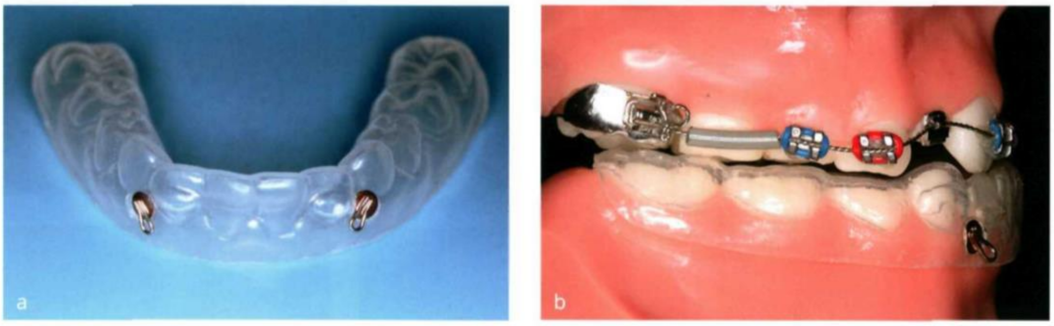

Figure 2.9: The Orthodontic Removable Traction Appliance (ORTA) is used in conjuction with Class III elastics to disarticulate the occlusion and facilitate Class III correction. It offers the advantages of being easy to manufacture and to adjust and being more accepted by the patients being less visible than extra-oral alternatives. (Musich et al., 2017)

2.7.2.2. Extraoral appliances

- Chin cap

The first reported use of a removable chin strap as a treatment modality for mandibular prognathism dates back to 1836, when Kneisel, a German dentist to Prince Charles of Prussia.[36] The chin-cup went into a long period of disuse during the 20th century because it was believe to "not work very well" [70] but Oppenheim reintroduced the concept of extraoral anchorage in 1944. [71]

The chincup, or chincap, was more widely used in the Southeast Asian countries because of the higher prevalence of Class III patients with mandibular prognathism and downward and backward growth directions in theses populations. Sugawara et al. [72] and Mitani et al. [73] reported that chincap forces can alter the mandibular form and condylar growth, but also admitted that although the mandibular position could be improved anteroposteriorly during the first 2 or 3 years of orthopedic treatment, the initial changes were not always maintained when chincap use was discontinued prior to facial growth completion. Residual growth may cause recurrence of the prognathic face and Class III malocclusion after discontinuation of chincap therapy. Deguchi et al. [74] reported that aggressive application of a chincup for 2 years resulted in effective orthopedic treatment, and the risk of skeletal relapse diminished by 0% to 40% judging by the ramus angle, gonial angle, ANB, and Wits appraisal. Therefore, chincap use must be continued until the completion of facial growth for more stable results and is not indicated for patients with a true skeletal Class III malocclusion and a large mandible.

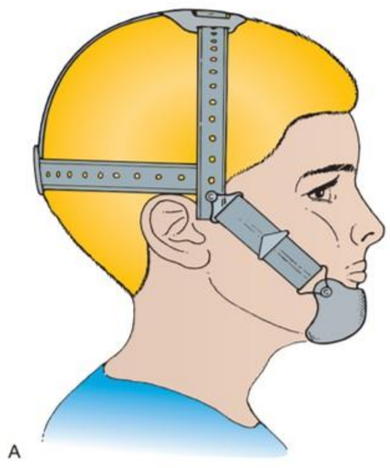

Figure 2.10: The occipital-pull chin cup.

- Headgear for mandibular arch

Baccetti et al. [75] and Rey et al. [76] used the mandibular cervical headgear in growing Class III patients exhibiting mandibular prognathism. This treatment option results in distalization of mandibular molars and redirection of mandibular growth.

- Face Mask

Class III malocclusion used to be synonymous with mandibular prognathism. However, since the 1970s, studies since then have found that in most patients, a hypoplastic maxilla is often the dominant factor in the etiology of a Class III malocclusion. Dietrich [77] reported maxillary retrusion in 40% of white children. Maxillary retrusion was due primarily to inadequate length of the maxillary base while mandibular prognathism was due in part to positional deviation of the mandible relative to the cranial base. Similarly, Guyer et al. [26] reported that most white children with either a normal or a prognathic mandible showed a deficiency in the maxilla.

While many orthopedic appliances for Class III correction have been described in the literature, the Orthodontic Face Mask popularized by Delaire and refined by Petit is the most widely used, for its dramatic results in a relatively short period of time. [50, 78] The Facial Mask Therapy comprises of 3 components: The face mask, a maxillary splint and rubber band elastics. The face mask comprises of a forehead and chin pads connected by a heavy steel support rod, to which a crossbow is attached and serves as attachment for rubber bands. Rapid maxillary expansion has been advocated as an adjunct to the face mask therapy under the hypothesis that the resulting loosening of the circummaxillary sutures will aid in the protraction of the maxilla. [79] The evidence however shows no skeletal differences between expansion and non-expansion groups of face mask treatment. [80, 81]

The treatment effects associated with the face mask therapy are: [50, 59, 79, 82]

1. Maxillary skeletal protraction, with forward movement of the maxilla reaching 2 to 4mm.
2. Downward and backward rotation of the mandible, resulting in an increase in lower anterior facial height.
3. Forward movement of the maxillary dentition
4. Lingual tipping of the lower incisors, particularly in patients with a preexisting anterior crossbite
5. Correction of an IC-RC relationship and elimination shifts and prematurities found in pseudo-Class III patients.

A routine protocol for face mask therapy is the application of force to a removable appliance bonded to the maxillary teeth. There is consensus over the application of the forces at 30∘ angulation to the occlusal plane to minimize unwanted counterclockwise rotation of the maxilla. Forces of 300–600 g on each side are applied through elastic rubber bands. The skeletal results obtained with different amounts of force (300–500 g) are similar, resulting in 3∘ increase in SNA. [83]

Some limitations arise in the use of a face mask, including patient compliance problems, dentoalveolar effect, limited protraction of maxilla (2-3 mm in 9–12 months), and the possibility of relapse as a result of mandibular growth. [79-81, 84]

Face masks can be used in various clinical applications. The clinician may choose a Petit face (one central connecting rod) mask or a Delaire type (two vertical side connecting rods) as an extraoral part of the appliance, opt for skeletal anchorage versus dental anchorage, or choose advancement with expansion in contrast to advancement without expansion.

Delaire face mask is commonly used for maxillary protraction. The chin and forehead are used as support for extraoral anchorage. This appliance might interfere with sleep or wearing eyeglasses. Petit modified the Delaire face mask in 1983, incorporating a forehead and a chin pad that are connected with a heavy steel rod. [42, 85]

Use of rapid maxillary expansion (RME) has been recommended in conjunction with protraction of the maxilla. Some authors believe that expansion will disarticulate maxillary bone and initiate exaggerated cellular response. [86-88] The appliance in the maxillary arch can be a bonded or banded maxillary expander. The patient activates the expander once or twice a day until the desired transverse relationship is achieved.

Another protocol is the use of alternate rapid maxillary expansions and constrictions (Alt-RAMEC). Activation of expansion/constriction is 0.5 mm daily to disarticulate the suture without overexpansion. [89, 90] However, two meta-analyses concluded that maxillary protraction was not affected with or without expansion. [80, 91]

Maxillary protraction has also been used in conjunction with an active chincup to produce a more efficient orthopedic treatment for Asian patients with combined maxillary deficiency and mandibular prognathism. [92, 93]

A shortcoming of using a tooth-borne appliance such as a rapid palatal expander for expansion and protraction is the loss of anchorage of the posterior molars and proclination of the maxillary incisors, resulting in less than optimal skeletal effect and inevitable dental effect.

Face Mask with Skeletal Anchorage: Bone Anchor Maxillary Protraction (BAMP)

To overcome the shortcomings of tooth borne protraction, the facemask can be used with Titanium Screws. These have been successfully used as skeletal anchorage, and do not require latency time for osseointegration, thus treatment can be instituted immediately after insertion. In a case report, a lag titanium screw was applied as skeletal anchorage for protraction of maxilla. 800 g force per side was applied at a 30∘ angle relative to the occlusal plane. The anterior nasal spine was advanced approximately 3 mm anteriorly, with stable improvement after one year. [94]

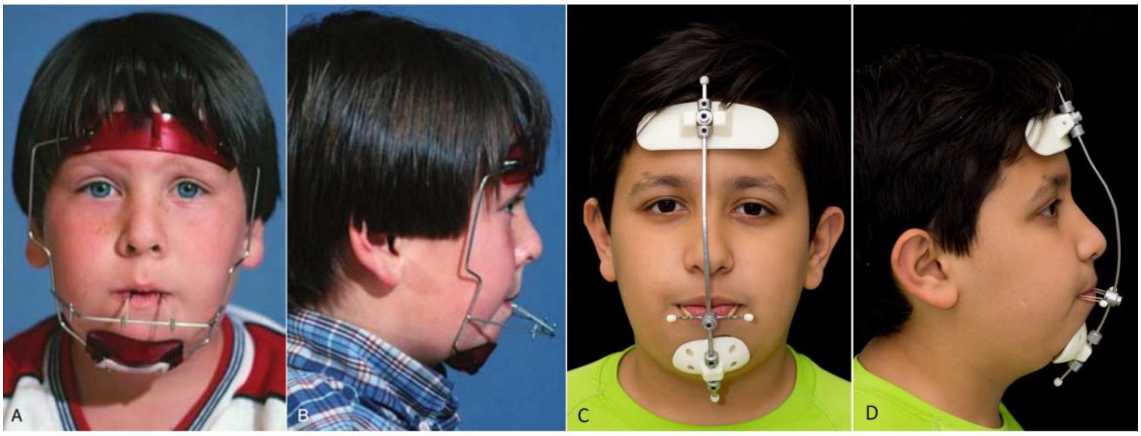

Figure 2.11: A&B: Delaire type facemask used to tract the maxilla forward. (Courtesy of Delaire) C&D: Petit type facemask with one central vertical heavy steel rod. (Courtesy of AUMBC)

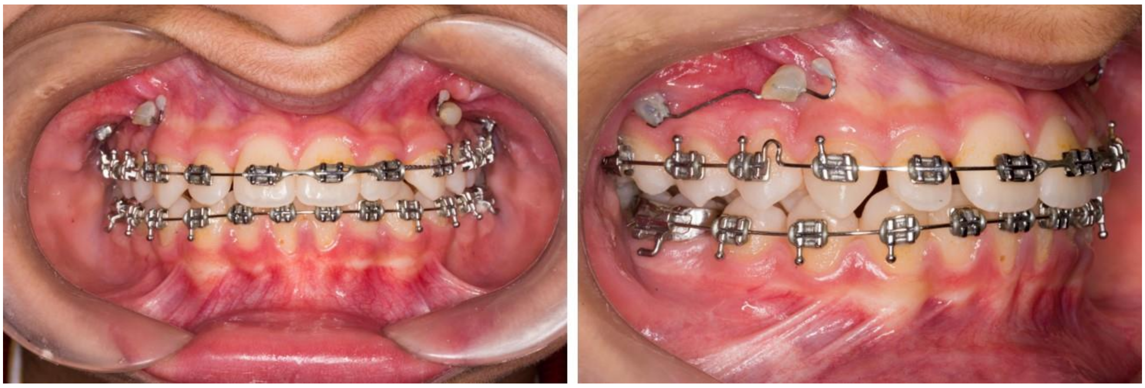

Figure 2.12: Bone Anchored Maxillary protraction. Two bracket head mini-implants were placed on each side and connected with a wire to serve as anchors for Face Mask

protraction. Mini-implants were covered with resin composite to alleviate soft tissue irritation.

2.7.3. Orthodontic camouflage in non-growing class III patient

Two ways are available to the practicing orthodontist to treat a non-growing Class III patient, and the choice between camouflage treatment and orthognathic surgery remains a challenge to the specialty. Camouflage treatment consists of displacing the teeth relative to their supporting bone to compensate for an underlying jaw discrepancy. It implies that growth modification to overcome the basic problem is not possible. The strategy to camouflage a Class III malocclusion usually involves proclination of the maxillary incisors and retroclination of the mandibular incisors to improve the dental occlusion, but it might not correct the underlying skeletal problem or facial profile.[95] Effects of Class III camouflage treatment include an increase in the ANB angle, little or no change in the vertical dimension, and decreased concavity of the facial profile. [96, 97]

Class III patients who decline orthognathic surgery have been aggressively treated using multibrackets with Class III elastics, extractions, and multiloop edgewise archwire therapy with varying degrees of success. Class III elastics or extraoral cervical anchorage applied to the mandibular teeth can be used to retract the mandibular teeth and achieve vertical control, but requires patient cooperation.[76] In addition, Class III elastics may have undesirable effects on the inclination of the occlusal plane, the interincisal relationship, and the temporomandibular joint resulting in a downward and backward rotation of the mandible, proclination of the maxillary incisors, and extrusion of the maxillary molars. These changes can lead to an unpleasing esthetic profile and instability during retention. The multiloop edgewise archwire technique has many loops with second-order bends to control the vertical movements of the posterior teeth. [98] It controls the movement of individual teeth and transmits the force produced by Class III elastics. The mandibular teeth can be distalized and uprighted by a combination of the multiloop edgewise archwire technique and intermaxillary elastics while inducing a counterclockwise rotation of the occlusal plane, without significant downward and backward rotation of the mandible. This technique is mostly indicated for patients with increased lower face height or an open-bite tendency. However, lack of patient cooperation with elastics can lead to worsening of the vertical dimension.

Extraction of mandibular teeth is sometimes indicated for patients with a moderate Class III skeletal malocclusion and may include extraction of premolars or mandibular incisors. Extraction of a mandibular incisor is occasionally indicated for patients with an anterior crossbite or an edge-to-edge incisor relationship. The decision is determined by factors such as the severity of anterior crowding in the mandibular arch, the Bolton discrepancy, the degrees of negative overjet and overbite, the facial profile and the age of the patient. A typical Class III camouflage extraction pattern requires removing the maxillary 2^{nd} and the mandibular 1^{st} bicuspids. [99]

In contrast to extraoral anchorage or intermaxillary elastics, the use of temporary anchorage devices as anchorage eliminates the need for patient cooperation; these devices simplify the treatment mechanics, reduce the amount of wire bending, and minimize the loss of anchorage, thus opening up a new variety of options for Class III camouflage treatment. [100] For retraction of the mandibular dentition, microimplants can be placed in the retromolar area or the inter-radicular space between the mandibular first molars and the second premolars, or between the first and second molars. The entire mandibular arch can be distalized or uprighted anchoring the forces on the microimplants, with no or minimal reaction forces on the maxillary dentition.

Microimplants can be placed more anteriorly in the maxillary arch for en-masse protraction when anterior movement of the maxillary dentition is possible. The relatively small interradicular space in this area may limit the amount of protraction, therefore it can be advantageous to position the microimplants as apically as possible to maximize the amount of movement before the interfere with the roots of the neighboring teeth. Protraction can be performed from the palatal side with the microimplants placed in the anterior palate. However, buccal protraction produces a moment in the outward direction, causing the arch expansion, while palatal protraction produces a moment in the opposite direction, causing arch constriction. Combining palatal and buccal protractions is most efficient, canceling the transverse side effects. Also, combining the use of mini-implants and the previously described traditional techniques (Multiloop edgewise, extractions) also proved effective in anchorage control and compliance elimination. [101] In addition, patients with severe Class III problems and/or facial asymmetry can be prepared for surgery using temporary anchorage devices to resolve dental problems followed by orthognathic surgery to resolve the remaining skeletal problems.

Camouflaging became more predictable with microimplants; consequently, more severe Class III problems can be treated non-surgically. The more difficult cases pose great challenges because treatment duration proportionally increases with the level of severity along with the risk of root resorption and enamel decalcification. Combining regional acceleratory phenomenon (RAP) and a microimplant anchor system may help in achieving satisfactory results with a shorter treatment time. RAP phenomenon can be created by extracting the mandibular third molars immediately before distalization and enhance the rate of distalization. Puncturing cortical bone in localized areas during microimplant-assisted retraction can also potentially create a regional acceleratory phenomenon, however, the risk of microimplant failure increases when a regional acceleratory phenomenon is created nearby. [102]

When microimplants are used as anchors during retraction and protraction of the mandibular and maxillary dentition respectively, biologic limitations should be considered not to displace the dentition beyond its alveolar housing. It is tempting to camouflage more severe patients with microimplants because of the mechanical advantages that this system provides; however, the biologic limitations are key in treatment planning and decision making, and the surgical treatment option remains a valid and optimal option in the more severe cases. [36, 100]

2.7.4. Surgical treatment of class III malocclusions

Surgery for mandibular prognathism began early in the 20th century, with occasional treatment that consisted of a body ostectomy, removing a posterior tooth and an accompanying block of bone. [36, 103] During the post-world war II years, the techniques and concepts of orthognathic surgery were refined for mandibular setback, with the introduction of the sagittal split ramus osteotomy (SSRO) in 1957 by Hugo Obwegesser [104] that marked the beginning of the modern era in orthognathic surgery [105]. The major advantage of this technique was the possibility for lengthening or shortening the mandible with the same bone cuts, thus allowing treatment of a mandibular deficiency or excess. Furthermore, SSRO used an intraoral approach, which avoided a prerequired potentially disfiguring skin incision.

In the 1990s, the advent of rigid internal fixation greatly improved patient comfort since jaw immobilization became unnecessary. A better understanding of the typical patterns of postsurgical changes made the outcomes of orthognathic surgery more stable and predictable. [106, 107]

The introduction of mandibular distraction osteogenesis by McCarthy et al. in 1992 [108] allowed greater jaw movements and treatment at an earlier age for patients with the most severe problems (usually related to syndromes) [109].

In addition, advances in imaging technology have enabled the use of a precise measuring tool based on a single-wave more imaging technique for multidimensional movement, stereophotogrammetry, 3D computed tomography, and a charge-coupled device camera for 3D analyses. Soft tissue changes to hard tissue movements can be predicted with a certain degree of precision [110].

A more predictable and precise surgical outcome can be achieved through the burgeoning cone-beam computed tomography-based treatment planning of orthognathic surgery [111]. It consists of the 8 following steps:

1. image acquisition for 3D virtual orthognathic surgery
2. processing of the image data towards a 3D virtual augmented model of the patient's head
3. 3D virtual diagnosis of the patient
4. 3D virtual treatment planning of orthognathic surgery
5. 3D virtual treatment planning communication
6. 3D splint manufacturing
7. 3D virtual treatment planning transfer to the operating room
8. 3D virtual treatment outcome evaluation.

2.7.4.1. Conventional surgical movement for Class III treatment

The surgical movements possible for the mandible are a forward or a backward movement, as well as rotations in the 3 planes of space; a pitch rotation to correct the divergence, yaw for transverse asymmetries or roll for correction of the occlusal plane canting [36].

In the treatment of Class III patients, the maxilla remains in the same postsurgical position in 80% of patients, and there is almost no tendency for major relapse (4 mm or more). After the advent of rigid fixation, the combination of maxillary advancement and mandibular setback is acceptably stable. In contrast, mandibular setback alone is often unstable. [112]

2.7.4.2. Distraction Osteogenesis

This technique is based the principle of “ tension stress” or manipulation of a healing bone, that allows its lengthening along with the surrounding soft tissues through progressively controlled fracture separation by means of a distraction device before calcification has occurred. [113]

For correction of facial deformities, distraction osteogenesis has 2 significant advantages:

1. Greater distances of movement are possible than with conventional orthognathic surgery.
2. Deficient jaws can be increased in size at an earlier age.

However, one great disadvantage remains the inaptitude to produce the precise movements required to establish ideal inter-jaw relationship and occlusion.

2.7.4.3. Surgically assisted rapid palatal expansion

Although "Class III" is a term representing the anteroposterior relationship between the maxilla and the mandible, the skeletal discrepancy is often a combination of a sagittal and transverse problem. Therefore, expansion is often a necessary step in Class III correction. Like distraction osteogenesis, a surgically assisted rapid palatal expansion can provide greater expansion movement and stability than a segmental osteotomy in adults. A segmental osteotomy detaches the maxilla and segments it into pieces. The normal LeFort 1 cuts are performed barring the down fracture: a lateral corticotomy, the maxillosphenoid junction disarticulation, cutting of the lateral nasal wall, and splitting of the midpalatal suture. A palatal jackscrew is used to rapidly expand the maxilla. This procedure is usually done during the presurgical decompensation phase of the treatment. [114, 115]

The major advantage of this type of expansion is eliminating incisor flare for non-extraction patients, as well as avoiding extreme dental expansion that can lead to gingival recessions in adults.

Despite surgically assisted rapid palatal expansion is a relatively minor surgical procedure, the patient will be subjected to 2 separate surgeries. [116]

2.7.4.4 Early maxillary advancement

Early advancement of a deficient maxilla in the sagittal plane remains relatively stable if there is careful attention to detail and grafts are used to combat relapse, but further forward growth of the maxilla is quite unlikely. Moreover, subsequent growth of the mandible is likely to result in reestablishing the Class III malocclusion and a concave profile. Surgical maxillary advancement should be delayed until growth cessation, unless earlier treatment is needed for psychosocial reasons. [36]

2.8. Prediction of long-term outcome of Face Mask Therapy

Post-pubertal growth is a major concern when treating Class III patients. A number of studies [117-120] have shown that face mask therapy does not normalize maxilla-mandibular growth, and the patients tend to resume their Class III pattern of growth characterized by mandibular outgrowth of the maxilla, which might lead in extreme cases to a relapse into a more severe Class III malocclusion.

The ability to classify a patient to an orthodontic or surgery group prior to treatment initiation would allow efficient triage according to patient treatment need, thus avoiding patient burn out when orthopedic treatment is predicted to fail. [121] Battagel [122] was one of the first investigators who employed discriminant function analysis to identify predictors of relapse in a group of children with treated with cervical headgear applied to the mandibular dentition. Subsequently many studies followed, trying to develop a model for Class III treatment prediction, of which 7 focused on predicting the long-term outcome of face mask therapy.

Baccetti et al. [123] found that successful orthopedic correction of Class III malocclusion might be unfavorable over the long term when the pretreatment cephalometric records exhibit an increased posterior facial height (long mandibular ramus) an acute cranial base angle, and a hyperdivergent pattern.

Ngan and Wei [124] used the GTRV (growth treatment response vector) to predict the outcome of face mask therapy. GTRV was defined as the ratio between the horizontal growth of the maxilla and the horizontal growth of the mandible. They found that the mean GTRV for a successful treatment was 0.49, while a ratio below 0.38 was highly indicative of a relapse patient.

Similarly to the first study, Ghiz et al. [125] investigated cephalometric predictors for successful face mask therapy but found dissimilar results. In this study, increased posterior facial height was predictive of favorable treatment response, as was a shorter mandibular length (Co-Pog), a more retruded position of the mandible to the cranial base and a decreased gonial angle.

Wells [126] investigated the long term efficacy of face mask therapy and found that the failure group was characterized with a higher position of the posterior nasal spine (PNS) and Gonion, greater mandibular length and increased overbite. Patients who responded to face mask therapy with more downward and backward rotation of the mandible were most likely to be classified in the failure group.

Lee et al. [127] studied cervical vertebral maturation, dento-alveolar, respiratory and head postural parameters to establish predictors for face mask treatment outcome. Patients with retroclined mandibular incisors showed more favorable outcomes of face mask treatment in the long term. They hypothesized that cephalometric measurements representing dentoalveolar adaptation, respiration, and head posture can be more closely related face-mask treatment stability than initial skeletal cephalometric components.

Auconi [128] used fuzzy clustering repartition and network analysis to establish that the Hypermandibular (macrognathic mandible) and the Hyperdivergent clusters have greater risk of unsuccessful treatment than the Balanced cluster. The risk of failure was 28.6%, 33.3% and 0% respectively in each group.

Nardoni et al. [129] found that orthopedic treatment of Class III malocclusion with face mask may have unfavorable prognosis at the end of pubertal growth whenever initial cephalometric assessment reveals an increased lower anterior facial height combined with reduced angle between the condylar axis and the mandibular plane.

Finally, Souki et al. [130] found that the best prediction model for their sample consisted of only one cephalometric variable: the condylar axis angle to the mandibular plane angle (CondAx–MP). Unsuccessful treatment was predicted for values of CondAx–MP greater than the cut-off value of 147.8 degrees. They tested their prediction model on a separate group of 28 treated Class III patients and found that their model was a reliable predictor of long-term Class III treatment with face mask treatment, predicting only 1 out the 28 cases incorrectly.

In a systematic review about the prediction of treatment outcome of orthodontic treatment of Class III malocclusion [121], the authors found 14 relevant articles, of which 5 were investigations where the treatment protocol was face mask therapy. Other treatment modalities in the other included investigations comprised chin cup therapy [131-133], facemask and chin cup combination [134], mandibular headgear [122], or various treatment modalities [135-137]. The total number of cephalometric predictors was 38, and only two studies shared more than one predictor [131, 132]. The accurate prediction of outcome of orthodontic/orthopedic treatment of Class III malocclusion seems questionable and a universal predictor, if ever existent, has yet to be found. To validate the discriminative power of the prediction models of those study, validation testing should be done on an independent sample from the one used to develop the model.

Table 2.2: Summary of facemask predictors for long term outcome in the literature.

Author – Year	Predictors	Sample Size	Age	Ethnicity	Outcome Measure
Baccetti et al. 2004	PFH Saddle Angle Divergence	42 SG (30) – USG (12)	8.6 y ± 2	White	Class III Molars Negative OJ
Ngan & Wei 2004	GTRV analysis	40 SG (20) – USG (20)	8.9 y ± 2.1	38% Caucasians 62% Asians	OJ >1mm
Ghiz et al. 2005	PFH Mandibular length Gonial angle AP position of condyle	64 SG (44) – USG (20)	9.2 y ± 1.8	30 Chinese 34 Whites	Class I molar OJ >1mm
Wells et al. 2006	Vertical position of PNS Vertical position of Go Overbite Mandibular length	41 SG (31) – USG (10)	ND	40 Caucasians 1 Asian	OJ < 0mm
Auconi et al. 2015	Hyperdivergence Mandibular length	54 SG (45) – USG (9)	8.2 y ± 1.6	Caucasians	Class III molars Negative OJ
Nardoni et al. 2015	Increased ALFH Small condylar axis to mandibular plane angle	26 SG (21) – USG (5)	8y 4m	Not mentioned	Subjective Fr. and Prof. assessment
Lee et al. 2015	Small L1 to NB was favorable Mandibular length unfavorable	46 - Stable (29) – Unstable (17)	9.8 y ± 1.9	Asian (South Korean)	Negative OJ Open bite
Souki et al. 2019	Condax-MP	73 SG (51) – USG (22)	7.1 y ± 1.6	Brazilian Italian	Occlusion and profile Classified into 4 groups from good to not acceptable

2.9. Research significance

Prediction has been used in the medical field to project treatment efficiency and prognosis to provide personalized treatment for the specific needs of the individual patient. Researchers have investigated extensively the possibility of affecting growth of the jaws in growing patients who have a Class III malocclusion with underlying skeletal dysmorphology. The main issue that remains is the unpredictability of treatment outcomes because of individual variation in responding to treatment, and late mandibular growth overcoming treatment correction. The variation in treatment modalities, timing of treatment, growth and compliance, further confound the predictability of treatment outcome. Yet, the very definition of patterns of response would indicate that pre-treatment skeletal and facial morphologic features can be defined, if properly determined, to help select malocclusions that would likely have a successful response to treatment.

Previous studies investigated the possibility of developing a prediction model for the long-term outcome of Class III treatment with the orthopedic face mask, but most of them lacked the proper sample size, adequate follow-up for meaningful conclusions, and stringent inclusion criteria to distinguish a real skeletal Class III from a dento-alveolar discrepancy. Furthermore, those predictive models were never tested on different samples from which they were derived to validate their accuracy.

Hence, this research will aim to build on previous trials of predicting the outcome of Class III treatment with facemask by applying strict inclusion criteria, investigating responses in gender and age brackets subgroups, and testing the available prediction models for accuracy and clinical reliability.

2.10. Hypotheses

- Predictive models of the long-term outcome of Class III orthopedic treatment based on cephalometric components can be used to accurately predict the outcome of individual patients.
- Age at the start of treatment and the severity of the initial malocclusion are reliable predictors for the long-term success or failure.

2.11. Specific aims

1. Investigate immediate and post-adolescent growth spurt changes induced by face mask treatment and growth on the maxillo-mandibular inter-relationship.
2. Investigate the response to face mask treatment between gender and between different ages of treatment onset.
3. Investigate the cephalometric, facial and dental predictors of successful and unsuccessful facemask therapy.
4. Check the validity and accuracy of the proposed predictive formulas in the literature.
5. Propose a new prediction model for long term facemask therapy outcome.

CHAPTER 3

MATERIALS AND METHODS

3.1. Materials

3.1.1. General characteristics

The parent sample consisted of the cephalometric records of 120 growing Class III patients who received a first phase of orthopedic treatment with facemask alone or with facemask and palatal expansion followed by comprehensive, preadjusted, edgewise therapy. The records were provided through the Dentofacial Clinic at the American University of Beirut-Medical Center and part-time faculty affiliated with the department. The radiographic images were part of the diagnostic records collected for orthodontic treatment. No patients were contacted nor were radiographs taken for the objective of the present research. The institutional review board (IRB) approval was granted before initiation of the study to evaluate the existing radiographs and photographs under specified conditions.

Records were collected at three different timepoints: Pre-treatment (T1), Post-facemask treatment (T2), Final evaluation (T3). The final sample of Class III patients who met the criteria consisted of 85 patients having records at T1 and T2, of which 52 had an additional T3 post-pubertal follow up as indicated by skeletal maturation evaluation (CVSM 5 or 6).

The sample was then divided into the following subgroups:

- A favorable and unfavorable response group, based on the Overjet at T3 being OJ>0 or OJ≤0 respectively. (Table 3.2)

- An early treatment and late treatment group based on the age at treatment initiation, with a cutoff point of 9 years for girls and 9.5 years for boys.

The age means and ranges for male and female subjects are listed in Table 3.1. Figure 3.1 shows the lateral cephalometric of a Class III patient.

Table 3.1: Class III sample distribution by sex

		Age T1	Age T2	Age T3	
Total Sample n=85	Mean	9.23	11.32	n=52	15.51
	STD	2.15	2.32		3.06
Males n=36	Mean	9.67	11.60	Males n=22	15.83
	STD	1.98	2.18		3.00
Females n=49	Mean	8.80	11.19	Females n=30	15.95
	STD	2.13	2.36		2.68

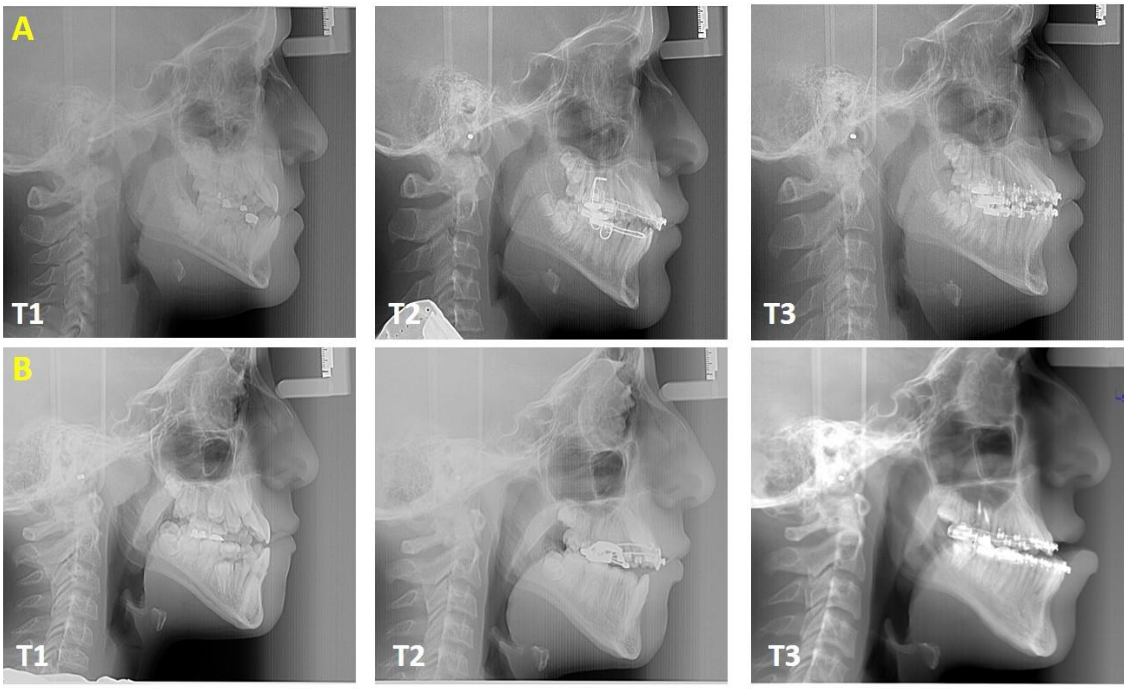

Figure 3.1: Lateral cephalometric radiographs of patients who underwent FaceMask treatment. A: Successful, B: Unsuccessful. Stages of measurements: T1: Initial, T2: end of Face Mask treatment, T3: Post pubertal follow-up.

3.1.2. Inclusion criteria

Patients who simultaneously met 2 of the following inclusion criteria, at the time of the first evaluation (Pre-treatment, T1), were included in the study:

- Edge to edge relationship or negative overjet, reflecting a Class III dental malocclusion
- ANB angle of 0^o or less, reflecting a maxillo-mandibular discrepancy in relation to the cranial base
- Wits appraisal (AoBo) of -2.5mm or less

3.1.3. Exclusion criteria

Excluded were the patients with:

1. Subjects with craniofacial anomalies (e.g. cleft lip/palate, hemifacial microsomia…)
2. Subjects of non-Caucasian ethnicity
3. Subjects who had previous orthodontic intervention
4. Subjects with incomplete records or radiographs of non-diagnostic quality

Table 3.2: Class III sample distribution by success

Success	N=42	Males N= 15
		Females N= 27
Failure	N=10	Males N= 7
		Females N= 3

3.2. Methods

3.2.1. Data entry and de-identification

Records collected fell into two types: conventional (film) radiographs and digital radiographs, depending on the timeframe during which the patients were treated. The conventional radiographs were converted to a digital format using the following process: a digital camera (Nikon 7200, 100mm f/2.8 Tokina Macro lens) on a steady tripod was placed at a fixed distance from a light box against which the conventional films were placed and shot. Leveling of the camera was assured using its built-in level meter and a level bubble embedded in the tripod's head. The settings were the same for all the shots (f/8, 1/20, iso100) and a remote camera was used to trigger the shutter to avoid camera shake during the shots. The radiographs were shot in dark room to ensure that the only source of light was coming from the light box and achieve optimal contrast. The photographs were shot in raw (NEF) format to maximize editing flexibility. The photographs were then imported to Adobe Lightroom (Lightroom version: CC 2015.14) enhanced and exported to JPEG format. The 2D digital radiographs were extracted from the x-ray storage software Cliniview (9.3). In this software, the identity of the patient is not a visible part of the image. The radiographs were exported to a digital folder and were assigned a serial number by the administrator (Dr. Christophe Zoughaib) starting from Patient 1, Patient 2, Patient 3, etc. The exported image could not be linked back to the subject. Accordingly, the "coding" of all radiographs was assured.

3.2.2. Cephalometric evaluation

The lateral cephalograms were digitized and analyzed using two imaging softwares: (Dolphin Imaging and Management Solutions, La Jolla, California, version 11.8) and Cliniview 9.3 (Instrumentarium, Finland).   Advantages of using a computer software include:

1- Ease of manipulation and accuracy of measurements and instant reading of distances and angles upon identification of corresponding landmarks.

2- Possibility of X-ray enhancement to allow adequate assessment of the bony and soft tissue landmarks.

3- The use of a standard ruler for digitization automatically compensates for the differences in magnification.

Linear and angular measurements will be performed to gauge relations among cranial base, maxilla, and mandible.

The lateral cephalometric radiographs were oriented to the natural head position prior to the digitization. The x-rays were taken in maximum intercuspation of the posterior teeth except when the presence of a shift was noted, in which case the x-rays were taken in centric relation. Landmarks and measurements are shown and defined in figures 3.2, 3.3 and tables 3.3 – 3.7.

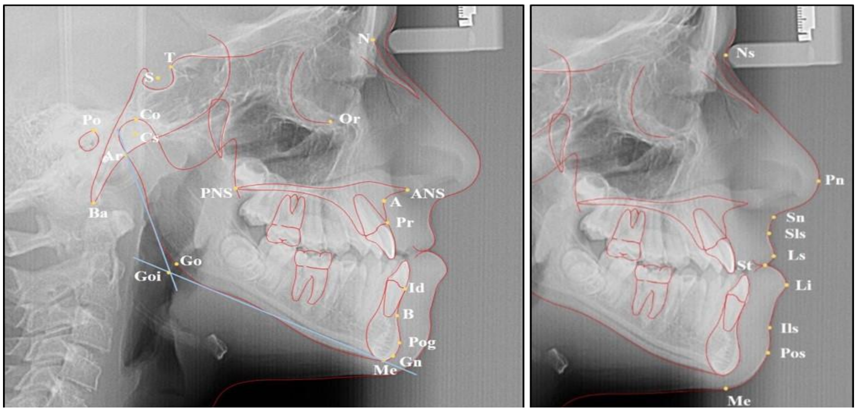

Figure 3.2: Hard and soft tissue cephalometric landmarks used during digitization and analysis.

Table 3.3: Soft tissue landmarks and definitions.

	Landmark	Definition
Ns	Soft tissue nasion	Point of intersection of the soft-tissue profile with a line drawn from the center of sella turcica through nasion
Pn	Pronasale	Most prominent or anterior point of the nose tip
Sn	Subnasale	Midpoint of the columella base at the apex of the angle where the lower border of the nasal septum and the surface of the upper lip meet
Sls	Soft tissue A point or Superior labial sulcus	Deepest point on the upper lip determined by an imaginary line joining subnasaale with the labrale superius
Ls	Labrale superior	Midpoint of the upper vermilion line
St	Stomion superior	Most inferior point located on the upper lip
St	Stomion inferior	Most superior point located on the lower lip
Li	Labrale inferior	Midpoint of the lower vermilion line
Ils	Soft tissue B or Inferior labial sulcus	Point at the deepest concavity between laberale inferius and soft tissue pogonion
Pos	Soft tissue pogonion	Most prominent or anterior point on the soft-tissue chin in the mid-sagittal plane
Ms	Soft tissue menton	Most inferior point on the soft-tissue chin

Table 3.4: Hard tissue landmarks and definitions.

	Landmark	Definition
N	Nasion	Intersection of the most anterior point of the nasofrontal suture
S	Sella	Center of Sella Turcica, located by inspection
T	Tuberculum Sella	Most superior point of the anterior wall of the sella turcica at the junction with tuberculum sellae
Po	Porion	Highest point on the roof of the external auditory meatus
Ba	Basion	Most inferior point on the anterior margin of the foramen magnum in the midsagittal plane
Or	Orbitale	Lowest point on the lower margin of the orbit.
Co	Condylion	Most posterior superior point on the condyle of the mandible
Ar	Articulare	Point of intersection of the dorsal contours of the process articularis mandibulae and temporal bone
Go	Gonion	External angle of the mandible, located by bisecting the angle formed by tangents to the posterior border of the ramus and the inferior border of the mandible
Me	Menton	Most inferior point on the symphysis of the mandible, in the median plane
Gn	Gnathion	Lowest point of the Mandibular symphysis
Pog	Pogonion	Most anterior point on the mid-sagittal symphysis
B	B point	Deepest midline point on the mandible between infradentale and pogonion
PNS	Posterior nasal spine	Most posterior point on the contour of the bony palate
ANS	Anterior nasal spine	Most anterior point of the nasal floor; tip of premaxilla on midsagittal plane
A	A point	Deepest point on the premaxilla between the anterior nasal spine and dental alveolus
Cs	Center of condyle	Point equidistant from the anterior, posterior, and superior borders of the condylar head
Goi	Gonial intersection	Intersection between the tangent to the lower mandibular border and the posterior border of the mandibular ramus
Id	Infradentale	The highest and most anterior point of the alveolar bone in the midline between the mandibular central incisors
Pr	Prosthion	The lowest and most anterior point of the alveolar bone in the midline between the maxillary central incisors
	U1	Most proclined maxillary incisor tip
	L1	Most proclined mandibular incisor tip
	U6	Maxillary first molar mesio buccal cusp
	L6	Mandibular first molar mesio buccal cusp

Table 3.5: Planes and lines used for cephalometric measurements.

Planes and Lines	
SBL	Line passing through the superior point of the anterior wall of the sella turcica at the junction with tuberculum sellae, point T, and tangent to the lamina cribrosa of the ethmoid
VertT	Line perpendicular to SBL and passing through point T
SH	Line parallel to Frankfort horizontal passing through sella
GD	Great Divide: vertical line passing through sella, perpendicular to sella horizontal
SN	Anterior cranial base
ANS-PNS	Palatal plane
Po-Or	Frankfort plane
Go-Me	Mandibular Plane
Co-Cs	Condylar Axis
OP	Functional occlusal plane

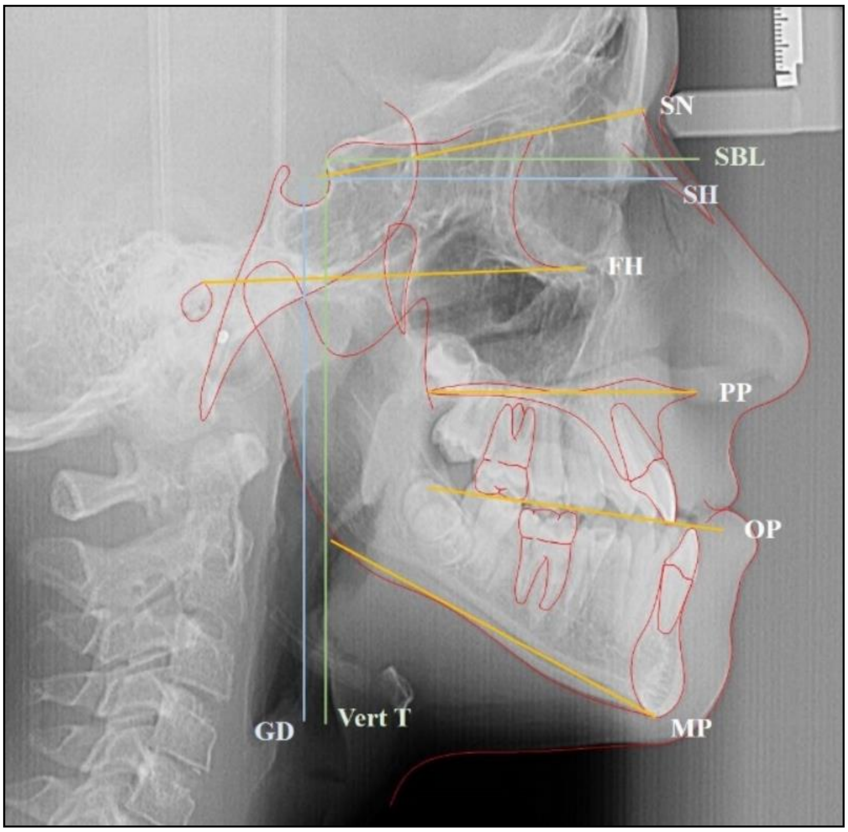

Figure 3.3: Cephalometric planes used for digitization and analysis.

Table 3.6: Cephalometric hard tissue measurements and their definitions.

Hard Tissue Measurements	
Skeletal Measurements	
S–N (mm)	Antero-posterior length of the anterior cranial base
S–Ar (mm)	Distance from point sella to point articulare
NSAr (degrees)	Saddle angle
S-Gn	Facial length on Y-axis (linear)
N-S-Gn	Y-axis to SN (angular)
Nasion–A point–pogonion	Facial convexity (angular)
Gonion–menton/nasion–sella	Mandibular body to anterior cranial base ratio
SNA (degrees)	Antero-posterior position of the maxilla to the anterior cranial plane
SNB (degrees)	Antero-posterior position of the mandible to the anterior cranial plane
ANB (degrees)	Antero-posterior relation of the maxilla to the mandible
Wits (mm)	Wits appraisal
SN–Pal. Pl. (degrees)	Inclination of the palatal plane in relation to anterior cranial base
SN–Mand. Pl. (degrees)	Inclination of the mandibular plane in relation to the anterior cranial base
PP-MP (degrees)	Inclination of the palatal plane in relation to the mandible plane
Ar-Go-Me (degrees)	Gonial angle
Ar-Goi-Me	Gonial angle
CondAx-MP (°)	Condylar axis angle to mandibular plane
N–Me (mm)	Anterior face height
ANS-PNS (mm)	Palatal Plane Length
Co–A (mm)	Midfacial length as distance from point condylion to point A
Co-Pog (mm)	Mandibular length as distance from point condylion to point pogonion
Co–Gn (mm)	Mandibular length as distance from point condylion to point gnathion
Co–Go (mm)	Mandibular ramus height, distance between point condylion and point gonion
Co-Goi (mm)	Mandibular ramus height, distance between point condylion and Gonial intersection
Go–Pog (mm)	Distance between point gonion and point pogonion
Goi-Pog (mm)	Distance between Gonial intersection and point pogonion
Dental Measurements	
U1 to NA (linear)	Distance from U1 tip from line nasion–A point
U1 to NA (angular)	Angle between U1 to Nasion-A point line
U1–Pal. Pl. (degrees)	Angle between the axis of the maxillary central incisor and the palatal plane
U1-SN	Angle between the axis of the maxillary central incisor and the anterior cranial base
L1 to NB (linear)	Distance from L1 tip to nasion–B point line

L1 to NB (angular)	Angle between L1 to Nasion-B point line
L1 to A-Pog (linear)	Distance from L1 tip to A-Pog line
L1 to A-Pog (angular)	Angle between L1 to A Pogonion line
IMPA (degrees)	Angle between the axis of the mandibular central incisor and the mandibular plane
FMIA (degrees)	Angle between Frankfort horizontal and the axis of the mandibular central incisor
FMA (angular)	Frankfort horizontal plane to mandibular plane angle; angle of line porion–orbitale and gonion–menton
Interincisal angle (degrees)	Angle between the axes of the maxillary and the mandibular central incisors
Overjet (mm)	Distance measured along the occlusal plane from the incisal edge of the maxillary central incisor to the most facial aspect in the incisal third of the mandibular central incisor
Overbite (mm)	Vertical distance between incisal edges of the maxillary and mandibular central incisors
	Measurements to SBL basicranial reference
A-VertT (mm)	Distance between Vertical T line and A point
B-VertT (mm)	Distance between Vertical T line and B point
Pog-VertT (mm)	Distance between Vertical T line and Pogonion
Co-VertT (mm)	Distance between Vertical T line and Co point
Ba-T-SBL (°)	Cranial Base Flexure
Ar-T-SBL (°)	Cranial Base Flexure
PP-SBL (°)	Palatal plane angle to SBL
MP-SBL (°)	Mandibular plane angle to SBL
CondAx-SBL (°)	Condylar axis angle to SBL
	Measurements to SH basicranial reference
A-GD (mm)	Distance between A point and Great Divide line
B-GD (mm)	Distance between B point and Great Divide line
Pr-GD (mm)	Distance between Pr point and Great Divide line
Id-GD (mm)	Distance between Id point and Great Divide line
Pog-GD (mm)	Distance between Pogonion and Great Divide line
Goi-GD (mm)	Distance between Gonial intersection and Great Divide line
Co-GD (mm)	Distance between Condylion and Great Divide line
Ba-S-GD (deg)	Cranial base flexure
Ar-S-GD (deg)	Cranial base flexure
PP-SH (deg)	Palatal plane angle to SH
MP-SH (deg)	Mandibular plane angle to SH
CondAx-SH	Condylar axis angle to SH

Table 3.7: Cephalometric soft tissue measurements and their definitions.

Soft Tissue Measurements	
Sagittal relationship of soft-tissue profile	
Ns-Pos/FH (deg)	Angle between soft tissue facial plane to Frankfort horizontal
Ns-Sls/Sls-Pos	Midfacial height to lower facial height ratio
Ls/Pn-Pos (mm)	Upper lip to E Line
Li/Pn-Pos (mm)	Lower lip to E Line
Pn/Ns (mm)	Nose protrusion
Ns/Sn (mm)	Distance between vertical through ST Nasion and Subnasale
Ns/Sls (mm)	Distance between vertical through ST Nasion and Superior Labial Sulcus
Ns/Ls (mm)	Distance between vertical through ST Nasion and Labrale Superior
Ns/St (mm)	Distance between vertical through ST Nasion and Stomion
Ns/Li (mm)	Distance between vertical through ST Nasion and Labrale Inferior
Ns/Ils (mm)	Distance between vertical through ST Nasion and Inferior Labial Sulcus
Ns/Pos (mm)	Distance between vertical through ST Nasion and Pogonion Soft Tissue
Vertical relationship of soft-tissue profile	
Sn-Ms (mm)	Soft tissue lower facial height
Sn-St (mm)	Upper lip length
St-Ms (mm)	Vertical distance between stomion and soft tissue menton
St-Ils (mm)	Lower lip length
Ns-Ms (mm)	Total facial height
Ns-Sn (mm)	Midfacial height
Soft tissue thickness	
Sn-A (mm)	Upper lip thickness
Ls-U1 (mm)	Upper vermillion thickness
Li-L1 (mm)	Lower vermillion thickness
Pos-Pog (mm)	Soft tissue thickness
Sls-A (mm)	Upper lip thickness
Ils-B (mm)	Lower lip thickness
Lip morphology	
Sn-Ls/FH (deg)	Upper lip inclination
Li-Ils/FH (deg)	Lower lip inclination
Ls-Ils-Pos	Labio-mental angle

3.2.3. Component analysis of the symphysis

This analysis is based on the geometric construction of a symphyseal angle formed by the intersection of the anterior and posterior slopes of the symphysis delineated through the methods adapted from Ghafari and Macari (2014). This angle is further bisected by a vertical (to normal head position) through the apex of the angle into 2 not necessarily equal posterior and anterior symphyseal angles. The anterior and posterior slopes of the symphysis helped determine the inclination of the symphysis. Definitions are shown in Table 3.8.

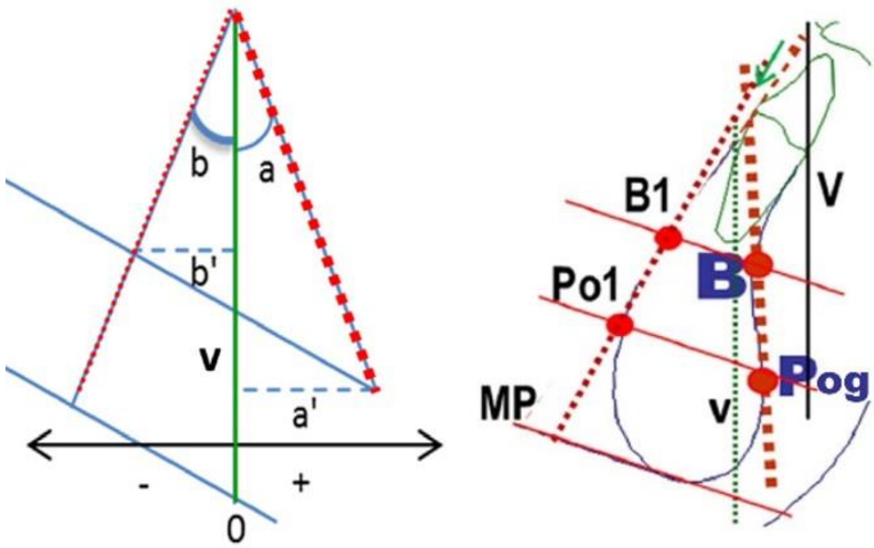

Figure 3.4: Component analysis of the chin.

Table 3.8: Definitions of cephalometric measurements relating to the chin components.

	Measurement	**Landmarks**
1	Anterior Symphyseal Angle **(ASA)**	Angle between Pog-B line and the vertical
2	Posterior Symphyseal Angle **(PSA)**	Angle between Po1-B1 and the vertical. Pogonion 1 (Po1: most convex point on the posterior symphyseal cortical); point B1 (intersection of the parallel to Po–Po1 through B and the posterior cortical of the symphysis)
3	Total Symphyseal Angle **(TSA)**	The sum of the two previous angles, or the angle formed by Pog-B and Pog1-B1

3.2.4. Response to treatment definition

Definition of “favorable” and “unfavorable” responder will be based on the following objective criteria:

1. The Overjet: evaluated on the T3 radiograph, a negative or null Overjet will indicate an unfavorable responder, while a positive overjet will characterize favorable responders.

3.2.5. Prediction formulas validation

Several formulas were proposed to predict at an early stage the long-term outcome of orthopedic intervention in Class III skeletal disharmony. But these were not validated on a different sample from which the data were derived.

The classification accuracy of the following formulas will be verified:

- **Score = 0.282(Co-Goi) + 0.205(Ba-T-SBL) + 0.12(ML-SBL) - 29.784 (Baccetti et al. 2003)**

The critical score of this formula is 0.406. Each new patient with Class III malocclusion that has a score lower than the critical score is predicted to be treated successfully with face mask therapy. On the other hand, patients with a score higher than the critical score can be predicted to respond poorly to orthopedic treatment.

- $\boldsymbol{P = \frac{1}{1+\exp(-L)}}$

L = 30.557 + 0.196 (Co-GD) – 0.129 (Co-Pog) + 0.162 (Co-Goi) – 0.206 (Ar-Goi-Me) (Ghiz et al. 2004)

P is the probability that early orthopedic treatment will be successful in a patient with Class III malocclusion.

- **Score = 0.232 x ALFH – 0.116 x CondAx.MP + 3.289 (Nardoni et al. 2015)**

The critical value is 0.595, which stands for the mean value for the centroid group of both groups. Each new Class III patient, whose value obtained for the discriminant function is below critical value, have a favorable prognosis. On the contrary, patients whose value is above the critical value shall be treated with prognosis of failure or unsatisfactory results.

- $P = \frac{1}{1+e^{-(-62.029+0.41973\ CondaxMP)}}$

The critical value of 147.8^{o} corresponded to a probability P of 50% of success. For CondaxMp values of more than 147.8^{o}, unsuccessful treatment was predicted as the values of P dropped below 50%, and successful treatment was predicted when the probability P rose above 50%, or values of CondaxMP were lower than the cutoff value.

3.2.6. Repeated measurements

To gauge intra-examiner reliability, 30 lateral cephalometric radiographs (10 pre-treatment 10 post-face mask, and 10 follow-ups lateral cephalograms) of 10 randomly selected patients (10% of the sample) were re-digitized by the same investigator (RK) 4 months after initial digitization. The two-way mixed effects intra-class Correlation Coefficient (ICC) was computed to test intra-examiner reliability of cephalometric measurements for absolute agreement on single measures.

3.2.7. Statistical Analysis

Descriptive statistics were computed for all the variables for each of the 3 time points both T1, T2 and T3. Frequency distribution was performed for the categorical variables (gender, success and time of treatment initiation). For the quantitative variables, means, standard deviations, minimums and maximums are presented in appendices.

A repeated measures analysis of variance (repeated measures ANOVA) was used to compare the changes in cephalometric variables due to growth and treatment.

A two-way mixed analysis of variance (ANOVA) was used to compare the mean differences in cephalometric variables between males and females, successful and unsuccessful, early and late initiation of treatment. The "within-subjects" factor is time (T1, T2 or T3) and the "between-subjects" factor consists of the sex (M or F), Success (S or U) or Treatment timing (Early or Late). After having established whether there is a statistically significant interaction between time and sex, subsequent adequate analyses were employed to check the effect of time and sex on the dependent variables. A repeated measures mixed models analysis was employed also to determine whether the changes between timepoints were significantly different between the different subgroups.

Multivariate discriminant analysis (DA) was applied to the 10 cephalometric measurements (those quantifying the components potentially contributing to treatment outcome) of the 52 subjects at T1 using the stepwise (statistical) method. It was applied also to variables previously reported in the litter This analysis allows identifying the variables that predict individual treatment response. The cross-validation approach was used for validation by classifying each case based on the discriminant function derived from all cases other than that case. The proportional by chance accuracy rate was further used to evaluate the classification accuracy.

SPSS and STATA statistical packages were used to perform all tests at a level of significance of 0.05.

CHAPTER 4

RESULTS

4.1. Intra-examiner reliability

The intra-class correlation coefficients (ICC) gauging intra-examiner reliability of repeated measurements ranged from 0.92 to 0.99 for the various cephalometric measurements, except for Condax to MP and Condax to H which were 0.85.

4.2. Sample characteristics

From the 120 patients' records that were reviewed, 85 met the inclusion criteria, 52 of whom had a post pubertal follow-up.

Table 4.1: Age distribution among the 3 Time points

	Initial (T1)		**Post-FMT (T2)**		**Post-Pubertal (T3)**	
N	85		85		52	
Age	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
	9.17 (2.10)	4.87 – 13.9	11.36 (2.28)	6.36 – 16.67	16.42 (2.62)	12.5 – 24.07

Table 4.2: Total sample, gender characteristics

SEX		N (%)	Mean	Std. Deviation	Duration
Age T1	Females	49 (57.6)	8.68	2.03	
	Males	36 (42.4)	9.73	2.02	
Age T2	Females	49 (57.6)	10.86	2.1	T2-T1=2.39±1.62
	Males	36 (42.4)	11.79	2.09	T2-T1=1.94±1.22
Age T3	Females	30 (57.6)	15.95	2.68	T3-T2=4.97±2.69
	Males	22 (42.4)	17.08	2.45	T3-T2=4.97±2.9
					T3-T1=7.22±2.6 T3-T1=7.05±3.12

Table 4.3: Sample characteristics based on long term success

		N (%)	Mean	Std. Deviation	Duration
Age T1	Successful	42 (80.7)	9.08	2.11	
	Unsuccessful	10 (19.3)	10.08	2.32	
Age T2	Successful	42 (80.7)	11.31	2.14	T2-T1=2.23±1.62
	Unsuccessful	10 (19.3)	12.04	2.37	T2-T1=1.96±0.98
Age T3	Successful	42 (80.7)	16.19	2.70	T3-T2=4.88±2.9
	Unsuccessful	10 (19.3)	17.40	2.09	T3-T2=5.36±2.08
					T3-T1=7.11±2.96 T3-T1=7.32±2.2

4.3. Treatment effects (Changes between T1 and T2) (Table 4.12)

4.3.1. Cranial base

The changes in the cranial base were mainly in size, with no major changes in cranial base flexure. The anterior (SN) and posterior (SAr) cranial bases increased in length by 1.36mm and 1.37mm respectively but no significant changes were observed in the saddle angle measurements.

4.3.2. Relationship between cranial base and jaws

The SNA angle significantly increased by 1.34^{o} while SNB decreased by 0.26^{o}. Consequently, the inter-jaw relationship was significantly improved as noted with an increase of 1.58^{o} in the ANB angle and 3mm increase in the Wits appraisal (Figure 4.1). Relative Nasion perpendicular, point A moved significantly forward by 1.35mm while point B remained relatively stable and went back only 0.28mm which was not statistically significant. A statistically significant clockwise rotation of the mandible of 1.29^{o} was noted relative to the palatal plane while the palatal plane tipped down posteriorly by 0.78^{o} relative to the horizontal. The condylar axis increased by 2.26^{o} relative to the horizontal.

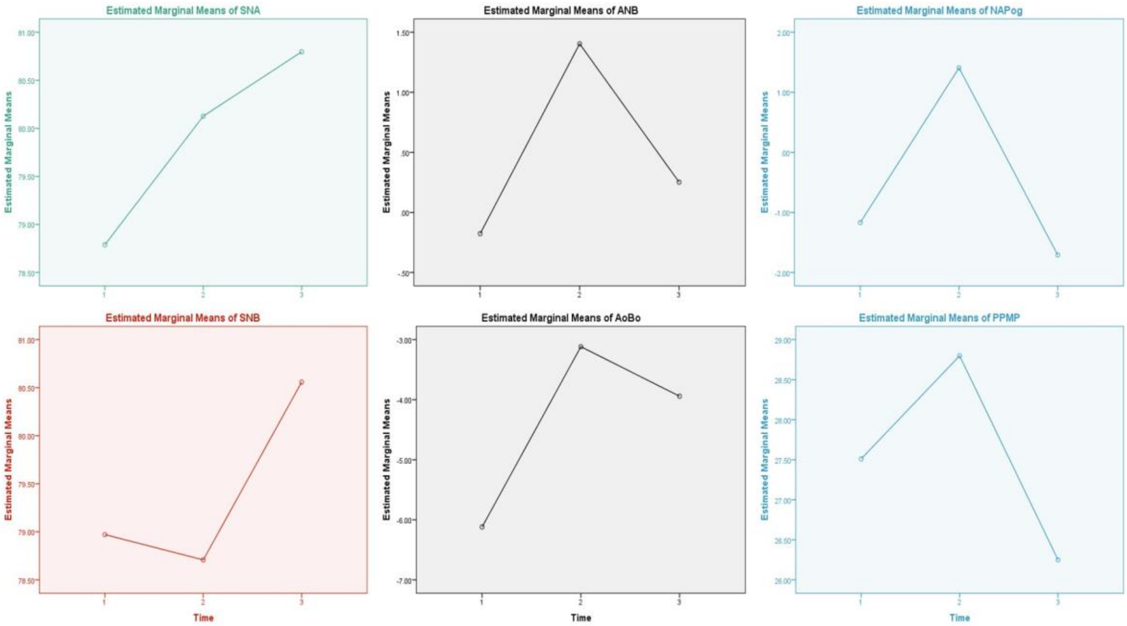

Figure 4.1: Changes in the relationship between the cranial base and the jaws across timepoints.

4.3.3. Jaw specific measurements

All mandibular linear measurements increased significantly. Overall mandibular length (Co-Pog) increased by 4.58mm, while the ramus increased in height (Co-Go) by 2.4mm while the corpus (Go-Me) grew 3.13mm on average.

Palatal plane length increased by 2.42mm while overall mandibular length (Co-Pog) increased by 4.58mm. The ramus increased in height by 2.4mm while the corpus grew 3.1mm on average.

The palatal plane rotated counterclockwise by 1^{o} relative to the horizontal and the gonial angle (Co-Go-Me) closed by 1^{o} on average. Changes in the condylar axis and mandibular divergence were not significant.

Symphyseal components: The anterior symphyseal angle increased by 2.75^{o} and the posterior symphyseal angle decreased by 2.25^{o} rendering the overall changes in the total symphyseal angle insignificant.

4.3.4. Relationship between teeth and jaws and dentoalveolar measurements

Changes in the dentition and occlusal relationship are evident, as shown by a significant proclination and protrusion of the maxillary incisors (6.15^{o} to PP and 2.52mm to NA) and to a lesser extent, some retroclination of the mandibular ones (2.44^{o} to MP).

The combination of the skeletal effects and dental compensation results in an improvement in the overjet averaging 4.74mm, and an average decrease of 5^{o} in the interincisal angle. The changes in overbite were not significant (Figure 4.2).

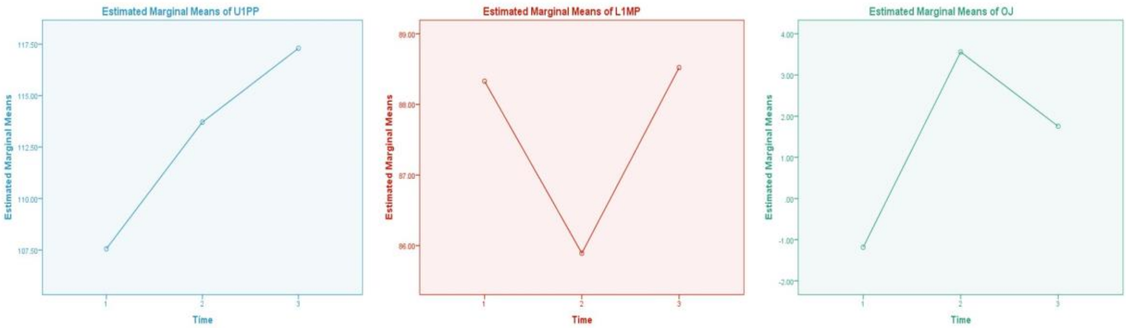

Figure 4.2: Changes in maxillary and mandibular incisors inclination and in overjet

4.3.5. Soft tissue measurements

In the sagittal, significant changes denoting improvement were observed and the level of the nose and upper lip. The nose tip, subnasale, the superior labial sulcus, labrale superior and stomion advanced between 2 and 3mm. Changes in the lower lip and soft tissue chin were not significant.

All the vertical soft tissue measurement changes between T1 and T2 were significant, namely the upper, lower and total facial heights as well as the upper and lower lip length, all of which increased significantly.

The upper lip thickness increased by about 1mm on average, while the lower lip and soft tissue chin thicknesses remained mainly unchanged. A significant proclination of the upper lip relative to Frankfort of 2.57^{o} was observed, while the lower lip inclination to Frankfort decreased by 4.16^{o}.

Relative to the E-line, the changes were minimal and not statiscally significant.

4.4. Post Face Mask Treatment changes (Changes between T2 and T3) (Table 4.4)

4.4.1. Cranial base

The anterior and posterior cranial base increased in length by 2.39mm and 1.69mm respectively but no significant changes were observed in the saddle angle measurements.

4.4.2. Relationship between cranial base and jaws

The improvement in the SNA angle was of 0.67^{o} while the SNB increased by 1.85^{o} yielding a decrease of 1.15^{o} in the ANB angle. The Wits appraisal decreased by 0.83mm (Figure 4.1).

While point A advanced 1mm relative Nasion perpendicular, point B advancement was almost threefold at 3.62mm. The convexity (N-A-Pog) decreased by 3.12^{o}.

A mandibular clockwise rotation was noted of the magnitude of 1.67^{o} relative to cranial base and 2^{o} relative to the horizontal. The condylar axis changes during this phase were not significant.

4.4.3. Jaw specific measurements

The palatal plane length increased as well as CoA by 3.17 and 4.29mm respectively. All mandibular linear measurements increased. The ramus, corpus and overall length increased by 6.45, 5.48 and 9.7mm respectively. The gonial angle decreased by 1.45^o. The changes in the condylar axis inclination to the mandibular plane were not significant.

Symphyseal components: In a similar fashion to the FMT effects on the symphyseal components, the anterior symphyseal angle increased by 4.52^o and the posterior symphyseal angle decreased by 5.05^o rendering the overall changes in the total symphyseal angle statistically and clinically insignificant.

4.4.4. Relationship between teeth and jaws and dentoalveolar measurements

Changes in the dentition and occlusal relationship were similar in both the maxilla and the mandible, in contrast to the previous phase where they moved in opposite directions. Proclination of the maxillary incisors was of 3.58^o relative to the palatal plane and 2.71^o to the cranial base. They also protruded by 1mm relative to NA.

The mandibular incisors also protruded by 1.43mm to NB and proclined by 2.80^o and 2.63^o to NA and the mandibular plane respectively. Consequently, the overjet reduced by 1.81mm and the interincisal angle decreased by 3.67^o (Figure 4.2).

4.4.5. Soft tissue measurements

In the sagittal plane, significant forward movement was observed across all the landmarks measured relating to the nose, upper and lower lip and the soft tissue chin.

Both lips saw significant proclination of 2.21^o and 4.15^o for the upper and lower lip respectively. Relative to the E-line, both lips moved back by 1.98 and 1.04mm respectively for the upper and lower lip.

Similarly, the total and lower soft tissue facial heights and the lip lengths all increased significantly, as well as both lips thicknesses.

4.5. Overall Treatment changes (Changes between T1 and T3) (Table 4.12)

4.5.1. Cranial base

The overall changes in the cranial base were in length, the anterior cranial base increasing by 3.75mm and posterior cranial base by 3.05mm, while the saddle angle NSAr remained virtually unchanged.

4.5.2. Relationship between cranial base and jaws

The improvement in the SNA angle of 2^o overall was counterbalanced with increase in the SNB by 1.59^o. Therefore, the slight 0.43^o improvement in the ANB angle overall was not statistically significant. On the other hand, the wits appraisal improved significantly by 2.18mm (Figure 4.1).

A point and B point both advanced forward relative to N perpendicular by 2.36 and 3.34mm, respectively.

The divergence pattern was slightly decreased on average, as indicated by a decrease of 1.53^o in the MP/H angle. Changes in the condylar axis to the horizontal were not significant.

4.5.3. Jaw specific measurements

The overall increase in length of the ramus, corpus and mandibular unit length were equal to 8.85, 8.97 and 14.28mm respectively. The gonial angle decreased significantly by 2.27^o. The condylar axis rotated anteriorly relative to the mandibular plane by 2.74^o.

In the maxilla, CoA increased by 7.36mm and the palatal plane length ANS-PNS increased by 5.59mm.

<u>*Symphyseal components*</u>: The overall changes in the symphyseal components follow the same pattern as before, the anterior slope increasing by 7.27^o and the posterior slope decreasing by 7.3^o ensuing in the conservation of the total symphyseal angle.

4.5.4. Relationship between teeth and jaws and dentoalveolar measurements

Overall changes of the maxillary teeth were more significant than the mandibular ones. Proclination of the maxillary incisors were of the order of 7.43^o to NA and around 9^o relative to the palatal plane and the anterior cranial base. They also protruded significantly by 3.57mm.

The mandibular incisors did not change in inclination significantly, but retruded relative to NB by 1.27mm. As a result, the interincisal angle decreased by 8.67^o overall. The net improvement in overjet was 2.94mm and the overbite increased by 0.69mm (Figure 4.2).

4.5.5. Soft tissue measurements

In the sagittal, significant forward movement was observed across all the landmarks measured relating to the nose, upper and lower lip and the soft tissue chin.

Similarly, the total and lower soft tissue facial heights and the lip lengths all increased significantly, as well as both lips thicknesses.

While the upper lip proclined significantly relative to Frankfort by 4.78^o, the lower lip inclination ended up almost identical to its original value. Relative to the E-line, both lips moved back by 1.32 and 1.33mm respectively for the upper and lower lip.

4.6. Comparison between Males and Females Class III patients undergoing FMT (Table 4.13)

4.6.1. Pre-treatment at T1 (Table 4.14)

- The cranial base measurements show a significantly longer anterior cranial base measurement SN by 2.67mm in males (64.43mm±3.39) than in females (61.76mm±2.90) ($p<0.05$).
- The angle of convexity NAPog was found to be significantly different between males(-2.69°±4.77) and females (-0.71°±4.41) by 1.98° ($p<0.05$).
- Jaw specific measurements tend to be larger in males, as shown the maxillary unit length (Co-A) was 2.57mm larger on average between males (77.03±3.56) and females (74.46±4.08), as well as the palatal plane length (ANS-PNS) which was 1.58mm larger in males (42.90±2.95) than in females (41.31±3.40) ($p<0.05$). Similarly, by the mandibular corpus (GoPog) which was 3.33mm larger in males (68.75±4.65) compared to females (65.41+4.99) and mandibular unit length (CoPog) which was 4.11mm larger ($p<0.05$). The ramus length (CoGo) was not significantly different between the two groups.
- Dento-alveolar measurements showed differences at the level of the maxillary incisors when measured to NA, where they were 1.20mm more protruded and 4.21° proclined in males than in females. Consequently, the interincisal angle was 4.71° smaller in males (134.41±11.42) than in females (139.12±10.23) ($p<0.05$).
- The anterior symphyseal angle was more anteriorly sloped in males (5.62±7.16) than in females (0.62±7.53) ($p<0.05$).
- The soft tissue lower and total facial heights were larger in males, as well as the upper lip thickness. SnMs in males (60.19±4.77mm) was 2.47mm larger than in

females (57.71±4.78mm). Similarly, NsMs was 3.76mm increased in males (109.33±7.09mm) than in females (105.57±8.41mm). The lip thickness differential measured at Sls-A was 1.37mm between the two groups. ($p<0.05$).

4.6.2. Post FMT at T2 (Table 4.15)

- The inclination of the cranial base to the horizontal SN/H is 1.42° increased in males compared to the females ($p<0.05$). The anterior cranial base measurement SN is longer by 3.01mm in males (66.00±3.47) than in females (62.99±2.84) ($p<0.05$).
- The angle of convexity NAPog was 1.86°±5.09 in females, and 0.6°±5.10 in males, a difference of 1.26° which was statistically significant.
- The same differences in the jaw specific measurements found at T1 are present at T2. The maxillary unit length (Co-A) was larger in males (79.96±4.00mm) and females (77.78 ±3.79mm), as well as the palatal plane length (ANS-PNS) which was again larger in males (46.20±3.44mm) than in females (43.56±3.49mm) ($p<0.05$). The mandibular corpus (GoPog) was significantly larger in males (72.05±5.2mm) compared to females (68.47±4.54mm) and mandibular unit length (CoPog) which was 106.80±7.87mm in males and 103.26±6.54mm in females ($p<0.05$). The ramus length (CoGo) was not significantly different between the two groups.
- Dental measurements were not statistically significant at T2 between the two gender groups.
- The same differences observed at T1 remained at T2 in the vertical soft tissue lower and total facial heights and the upper lip thickness.

4.6.3. Post pubertal follow-up at T3 Table (4.16)

- In the cranial base, both the anterior and posterior parts were 4.13mm and 2.47mm longer in males respectively for SN and SAr (p<0.05).
- A point was 2.55mm more anterior relative to Nperp in males than in females (p<0.05) and while point B was 4.55±8.10mm anterior to Nperp in males, it was -0.54±7.02mm posterior to Nperp in female with a significant difference of 5.08mm (p<0.01).
- Jaw specific measurements differences were similar to the previous timepoints, with the exception of the mandibular ramus that used to be equivalent in both genders but is now significantly larger in males (60.57±4.54) than females (56.59±3.99) (p<0.05).
- Dento-alveolar measurements showed no gender differences at T3.
- The anterior symphyseal angle was more anteriorly sloped in males (12.76±7.88) than in females (6.77±5.92) (p<0.05).
- The nose, the upper and lower lip as well as soft tissue chin were all more anteriorly positioned in males relative to females relative to soft tissue Nasion. The vertical soft tissue measurements reflected longer lower and total lower facial heights in males. The upper and lower lip were thicker in males. There were no significant differences in lip inclination or position relative to the E line.

4.6.4. Changes between T1 and T2 (Table 4.17)

1. The changes between T1 and T2 were similar in both males and females for cranial base measurements.

2. In the mandible, the condylar axis rotated 3.03^{o} forward in males and 0.52^{o} in females with a difference of 2.51^{o} which was significant ($p<0.05$), and the gonial angle reduced significantly more in the male group (-1.42 ± 2.69) than in the female group (-0.24 ± 2.25) ($p<0.05$). All other changes were similar in both groups.

4.6.5. Changes between T2 and T3 (Table 4.17)

- The changes between T1 and T2 were similar in both males and females for cranial base measurements.
- SNA increased 1.55^{o} in males compared to minimal 0.02^{o} increase in females, a difference of 1.53^{o} that is statistically significant. All other hard tissue measurement changes did not exhibit any statistical significance between both groups.
- Both pronasale and the upper lip (labrale superius) advanced more in the antero-posterior direction in males, 1.7mm and 2.06mm respectively. The soft tissue lower facial height increased 1.83mm more in males than in females. ($p<0.05$)

4.6.6. Changes between T1 and T3 (Table 4.17)

- In the cranial base, the saddle angle NSAr decreased by $-1.58^{o} \pm 3.62$ in males while in increased by $1.12^{o} \pm 5.17$ in females with a significant difference of 2.69^{o} ($p<0.05$).
- SNA increased 1.36^{o} more in males, and A to Nperp increased 1.63mm more in males ($p<0.05$).

- CoGo increased by 10.25mm in males compared to 7.83mm in females, with a significant difference of 2.42mm ($p<0.05$).
- The maxillary incisors proclined more in females than in males with a difference of 5.85^{o} to PP and 4.90^{o} to SN ($p<0.05$), and 6.91^{o} more decrease in the interincisal angle in females.
- The soft tissue measurements in the sagittal and vertical dimensions saw more increase in males. The changes that were not significantly different between genders are the sagittal position of Subnasale, Stomion and soft tissue Pogonion.

4.7. Comparison between Successful and Unsuccessful groups (Table 4.18)

4.7.1. Pre-treatment at T1 (Table 4.19)

- The cranial base measurements showed no statistically significant difference of any of the variables measured.
- The wits appraisal was more severe in the unsuccessful group (-8.21 ± 4.01mm) than in the successful group (-5.62 ± 2.86mm) with a difference of 2.59mm ($p<0.05$). The gonial angle (CoGoMe) was 5.10^{o} more obtuse in the unsuccessful group and MPSN showed a tendency toward a more hyperdivergent pattern with a difference of 4.62^{o} between both groups ($p<0.05$).
- The overjet that was -2.46 ± 3.04mm and -0.88 ± 1.99mm for the unsuccessful and the successful groups respectively ($p<0.05$).
- All the other measurements were not statistically significant between both groups.

4.7.2. Post FMT at T2 (Table 4.20)

- Both groups were largely similar at T2. The only significant differences in the hard tissue measurements were in the wits appraisal which was again -5.56 ± 2.75mm for the unsuccessful group and -2.54 ± 2.95mm for the successful group ($p<0.05$) and in the overbite which was -0.84 ± 2.36mm and 0.79 ± 2.19mm for the unsuccessful and successful groups respectively.
- In the soft tissue measurements, the lower facial height was increased in the unsuccessful group with a significant difference of 4.23mm ($p<0.05$).

4.7.3. Post pubertal follow-up at T3 (Table 4.21)

- The wits appraisal was again more severe in the unsuccessful group, the difference being 4.52mm ($p<0.05$).
- In the mandible, the unit length CoPog was 8.11mm longer and the gonial angle was 4.37^o more obtuse in the unsuccessful group compared to the successful group. The mandibular incisors in the unsuccessful group were on average 5.13^o more proclined and 2.63mm more protruded than in the successful group ($p<0.05$).
- The lower lip sagittal position relative to soft tissue Nasion was significantly more anterior in the unsuccessful group by 5.6mm. The vertical soft tissue measurements showed a tendency towards longer facial heights in the unsuccessful group. The lower and total facial heights were respectively 6.20mm and 8.86mm longer in the unsuccessful group.

4.7.4. Changes between T1 and T2 (Table 4.22)

- Both groups responded similarly to FMT as indicated by the similarity in the changes between T1 and T2. The only significant difference in the hard tissue measurement is more reduction in the gonial angle CoGoMe (-2.84 ^{o}±3.44) in the unsuccessful group when compared to the successful group (-0.34 ^{o}±2.28) ($p<0.05$).
- The upper lip inclination improved significantly more in the successful group (3.46^{o}±6.41) and worsened in the unsuccessful group (-1.13^{o}±4.24) ($p<0.05$).

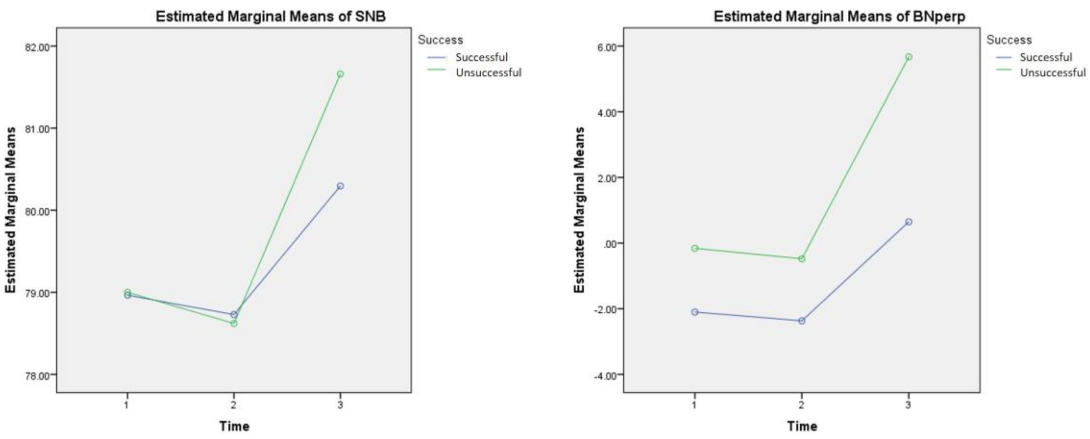

Figure 4.3: Changes in the relationship between the cranial base and the mandible between Successful and Unsuccessful groups.

4.7.5. Changes between T2 and T3 (Table 4.22)

- The changes in the cranial base were similar between both groups.
- The main differences between successful and unsuccessful groups was in the mandibular growth, as evident with the difference in the changes of SNB angle and the distance from B to N perp. SNB increased by 3.04 ^{o}±1.61 compared to 1.57 ^{o}±2.01 within the unsuccessful and successful groups respectively ($p<0.05$)

and point B advanced 6.15±3.95mm in the successful group compared to 3.02±3.67mm in the unsuccessful group (Figure 4.3).

- Mandibular incisor proclination was more pronounced in the unsuccessful group 6.36^{o}±6.74 compared to 1.96^{o}±5.15 in the successful group when measured to NB ($p<0.05$).
- The lower lip and inferior labial sulcus both came forward significantly more in the unsuccessful group, the difference being 3.69mm and 2.80mm respectively.

4.7.6. Changes between T1 and T3 (Table 4.22)

- Significant changes were observed in the mandibular growth where CoPog increased 13.54±5.01mm in the successful group compared to 17.38±5.67mm in the unsuccessful group, a difference of 3.84mm which was significant.
- While the successful group saw an increase of 0.96±1.55 in the overbite and an improvement of 3.32±2.01 in the overjet, the unsuccessful group had a -0.47±2.70mm change in overbite and limited overjet improvement of 1.34±3.68mm ($p<0.05$).
- In the soft tissue measurements, the lower lip came forward 3.69mm more relative to soft tissue Nasion in the unsuccessful group, who exhibited also greater changes in the soft tissue dimensions.

4.8. Comparison between Early and Late treatment initiation (Table 4.23)

4.8.1. Pre-treatment at T1 (Table 4.24)

- The cranial base length was significantly shorter in the early treatment group (61.88±2.29 mm) compared to the late treatment (64.54±3.39mm) ($p<0.05$).

- The wits appraisal was more severe in the late treatment group (-7.57$\pm$3.9mm) than in the early group (-4.67$\pm$1.32mm) with a difference of 2.9mm ($p<0.05$). B to Nperp was more forward in the late treatment group (-0.17$\pm$6.42mm) compared to -3.29$\pm$4.38mm in the early group, the difference of 3.12mm being significant ($p<0.05$).
- Linear jaw specific measurements were larger in the late treatment group, but the angular measurements were not statistically significantly different. Palatal plane length was 2.17mm longer in the late treatment group and CoA was 4.16mm longer. The ramus, corpus and total mandibular length were respectively 3.82mm, 5.96mm and 8.96mm larger in the late treatment group.
- The maxillary incisors were less protruded (1.98$\pm$2.18mm) in the early group than in the late group (3.47$\pm$2.45mm) relative to NA. Mandibular incisors measurements differed only when measured to NB, being more proclined (L1/NB=24.66$\pm$4.79^{o}) and protruded (L1-NB=4.49$\pm$1.98mm) in the late treatment group compared to the early treatment group (L1/NB=21.19$\pm$5.03^{o}) (L1-NB=2.94$\pm$1.28mm). The interincisal angle was 5.59^{o} smaller in the late treatment group which was significant ($p<0.05$).
- Soft tissue sagittal measurements were all increased significantly in the late treatment group, but the convexity was similar between both groups. Similarly, vertical measurements were increased in the same group, except for the upper lip length which was not significantly longer in the late treatment group. Thicker upper and lower lips were observed in the late treatment group by 1.76mm and 1.53mm respectively, a difference that was significant. The thickness of the soft tissue chin and lip morphology were similar in both groups.

4.8.2. Post FMT at T2 (Table 4.25)

- The anterior cranial base length was the only different measurement between both groups being 2.41mm longer in the late treatment group. The other cranial base measurements were not significantly different.
- Measurements relating jaws to each other, to the cranial base and to the horizontal were not significantly different, except for the condylar axis measured to the horizontal which was on average 3.24° more anteriorly rotated in the late treatment group.
- Comparably to the initial timepoint, linear jaw measurements were larger in the late treatment group, but the angular measurements were not statistically significantly different. Palatal plane length was not significantly different in both groups in the late treatment group, but CoA was 2.82mm longer. The ramus, corpus and total mandibular length were respectively 3.95mm, 3.7mm and 7.03mm larger in the late treatment group.
- Dentoalveolar measurements were not significantly different between both groups.
- Sagittal soft tissue measurements were increased in the late treatment group, except for the antero-posterior lower lip position and the facial convexity. Similarly, vertical measurements were increased in the same group, except for the upper lip length, and the thickness of both lips was increased by 1.63mm and 1.84mm for the upper and lower lip respectively. The lip morphology was not significantly different between both groups.

4.8.3. Post pubertal follow-up at T3 (Table 4.26)

- All hard tissue and dento-alveolar measurements were not significantly different between both groups.
- The sagittal soft tissue measurements were larger in the later treatment group except for the antero-posterior position of the labio-mental sulcus and soft tissue pogonion. The convexity is not significantly different between the two groups. Soft tissue thickness and lip morphology was not significantly different between the two groups.

4.8.4. Changes between T1 and T2 (Table 4.27)

- Cranial base measurement changes were not significantly different between both groups.
- SNA increased significantly more in the early treatment group (1.85^{o}) compared to the late treatment group (0.79^{o}), and point A came significantly more forward relative to N perpendicular in the early treatment group (1.89^{o}) compared to the late treatment group (1.03^{o}).
- The distance between the condyle and point A increased significantly more in the early treatment group (3.65mm) compared to the late treatment group (2.50mm) with a significant difference of 1.15mm ($p<0.05$).
- Dento-alveolar changes were similar in both groups.
- The upper labial sulcus and the upper lip moved forward 3.24mm and 3.62mm respectively in the early treatment group, which was significantly than in the late treatment group, where their position changed by 1.98mm and 2.09mm respectively.

4.8.5. Changes between T2 and T3 (Table 4.27)

- In contrast to the changes between T1 and T2, A point came more forward in the late treatment group (1.52mm) compared to the early treatment group (0.5mm) between T2 and T3, with the difference of 1.02mm being significant ($p<0.05$).
- Maxillary measurement changes were not significantly different between the two groups. Mandibular linear measurement increased significantly more in the early treatment group. The mandibular ramus, corpus and total length increased 7.6mm, 6.78mm and 11.33mm respectively in the early treatment group compared to 5.3mm, 4.9mm and 8.07mm respectively, a difference that was statistically significant ($p<0.05$).
- Dento-alveolar changes were not significantly different between the two groups.
- The difference in the soft tissue changes between T2 and T3 were limited to the position of the lips relative to the E-line. The upper and lower lips moved posteriorly 2.48mm and 1.51mm in the early treatment group which was significantly more than the late treatment group in which the lips moved 1.49mm and 0.57mm for the upper and lower lips respectively ($p<0.05$).

4.8.6. Changes between T1 and T3 (Table 4.27)

- Anterior and posterior cranial base length increased more in the early treatment group compared to the late treatment group.
- The palatal plane rotated 0.35^{o} clockwise in the early treatment group, and 0.91^{o} counterclockwise in the late treatment group. While the change within each group was not significant, the difference of 1.26^{o} of rotation between groups was statistically significant.

- The maxillary incisors proclined significantly more in the early treatment group compared to the late treatment group ($p<0.05$). When measured to the palatal plane, the incisors proclined 12.29^o in the early treatment group compared to 7.18^o in the late treatment group. Similarly, they proclined 11.45^o to SN compared to 7.46^o in the early and late treatment groups respectively, and they protruded 4.23mm to NA compared to 2.92mm, in the early and late treatment respectively.
- The lower lip to the E line went backwards 2.03mm in the early treatment group, and 0.63mm in the same direction in the late treatment group. The difference of 1.4mm was statistically significant. ($p<0.05$)

4.9. Prediction formulas validation

4.9.1. Bacetti et al., 2003

According to Bacetti et al.'s formula: DS= 0.282(Co-Goi) + 0.205(Ba-T-SBL) + 0.12(ML-SBL) - 29.784, the critical value is 0.4065, below which the treatment outcome is predicted to be successful. The reported accuracy of this model in predicting success in successful cases was 87.7% and it predicted correctly the unsuccessful group in 75% of the cases. When tested on our sample, accurate success prediction was 90.24%, but this model failed to predict any of the unsuccessful cases correctly.

Table 4.4: Classification results using Bacetti et al. formula.

Treated Patients	**Predicted group membership**			
	FR		**UFR**	
Original group	n	%	n	%
FR (n=42)	40	95.24	10	100
UFR (n=10)	2	4.76	0	0
Total accuracy 76.9%				

4.9.2. Ghiz et al., 2005

- L = 30.557 + 0.196 (Co-GD) – 0.129 (Co-Pg) + 0.162 (Co-Goi) – 0.206 (Ar-Goi-Me)
- $P=\frac{1}{1+EXP(-L)}$, Critical score 0.500

The model reportedly predicted correctly 95.5% of the successful cases and misclassified 4.5%. It correctly predicted 70% of the unsuccessful cases and missed 30%. When tested on our sample, the accuracy of success prediction was 90.5%, and correctly predicting unsuccessful patients was 30%.

Table 4.5: Classification results using Ghiz et al. formula.

Treated Patients	Predicted group membership			
	FR		UFR	
Original group	n	%	n	%
FR (n=42)	38	90.5	7	70
UFR (n=10)	4	9.5	3	30
Total accuracy 78.8%				

4.9.3. Nardoni et al., 2014

- DS = 0.232 x ALFH – 0.116 x CondAx.MP + 3.289

The critical value was 0.595, below which the case is predicted to be successfully treated. The reported accuracy of this model in predicting success in successful cases was 90.5% and it correctly predicted the unsuccessful group in 80% of the cases. When tested on our sample, accurate success prediction was 19.05%, yet was the most accurate in predicting failures at 80%.

Table 4.6: Classification results using Nardoni et al. formula.

Treated Patients	Predicted group membership			
	FR		UFR	
Original group	n	%	n	%
FR (n=42)	8	19.05	2	20
UFR (n=10)	34	80.95	8	80
Total accuracy 30.8%				

4.9.4. Choi et al., 2017

- L = -17.409 + 0.122 (AB to MP angle) + 0.254 (Wits) + 0.086 (articular angle)
- P=$\frac{EXP\ (L)}{1+EXP(L)}$, Critical score 0.725

The reported accuracy of this model in predicting success in successful cases was 86.5% and it predicted correctly the unsuccessful group in 22.7% of the cases. When tested on our sample, accurate success prediction was 16.7%, and correctly predicted failure in 60% of the cases.

Table 4.7: Classification results using Choi et al. formula.

Treated Patients	**Predicted group membership**			
	FR		**UFR**	
Original group	n	%	n	%
FR (n=42)	7	16.7	4	40
UFR (n=10)	35	83.3	6	60
Total accuracy 25%				

4.9.5. Souki et al., 2019

- $P = \frac{1}{1+e^{-(-62.029+0.41973\ CondaxMP)}}$
  - Critical value is 147.8^o or P=50%

The reported accuracy of this model in predicting success in successful cases was 86% and it predicted correctly the unsuccessful group in 98% of the cases. When tested on our sample, accurate success prediction was 95%, and correctly predicted failure in 10% of the cases.

Table 4.8: Classification results using Souki et al. formula.

Treated Patients	**Predicted group membership**			
	FR		**UFR**	
Original group	n	%	n	%
FR (n=42)	40	95	9	90
UFR (n=10)	2	5	1	10
Total accuracy 79%				

4.10. Predictors of long-term Face Mask therapy outcome in growing patients with Cl III malocclusion

4.10.1. Wits and Gonial angle as predictors

Based on this classification of favorable (FR, n=42) and unfavorable (UFR, n=10) responses, significant predictors of treatment outcome were found.

The stepwise variable selection resulted in a two-variable model that satisfied the level of significance of 0.05 and produced the best discrimination between the 2 groups: the wits appraisal (AoBo) and the gonial angle (CoGoMe), with a canonical correlation of -0.408. The cross-validation rate was 80.8%.

The following equation was generated using the unstandardized discriminant function coefficients of AoBo and CoGoMe:

DS = -0.2 AoBo + 0.117 CoGoMe – 15.981

This equation provides individual scores for assigning a new patient to either Successful or unsuccessful groups; the discriminant scores for group means (group centroids) were -0.214 for the FR group and 0.898 for the UFR group. The critical score was 0.342. A new growing Class III undergoing FMT patient who scores less than the critical score of 0.342 is more likely to have a long-term favorable response to treatment. Conversely, a new patient with the same malocclusion who has a score greater than the critical score is more likely to have an unfavorable response to treatment.

The computed cross-validated accuracy rate was 80.8%, a rate lower than the proportional by chance accuracy rate of 86.2%. Accordingly, the criterion for classification accuracy was not satisfied in this classification.

Table 4.9: Classification results for the stepwise discriminant analysis (classification 1)

Treated Patients	Predicted group membership			
	FR		UFR	
Original group	n	%	n	%
FR (n=42)	40	95.2	2	4.8
UFR (n=10)	7	70	3	30
82.7% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=55)	40	95.2	2	4.8
UFR (n=70)	8	80	2	20
80.8% of cross-validated grouped cases correctly classified				

4.10.2. Wits and Condylar axis as predictors

Based on this classification of favorable (FR, n=42) and unfavorable (UFR, n=10) responses, significant predictors of treatment outcome were found.

The stepwise variable selection resulted in a two-variable model that satisfied the level of significance of 0.05 and produced the best discrimination between the 2 groups: the wits appraisal (AoBo) and the Condylar Axis to the mandibular plane (CondaxMP) with a canonical correlation of 0.369. The cross-validation rate was 78.8%.

The following equation was generated using the unstandardized discriminant function coefficients of AoBo and CondaxMP:

DS = 0.249 AoBo - 0.78 CondaxMP – 11.944

This equation provides individual scores for assigning a new patient to either Successful or unsuccessful groups; the discriminant scores for group means (group centroids) were 0.19 for the FR group and -0.797 for the UFR group. The critical score was -0.3035. A new growing Class III undergoing FMT patient who scores more than the critical score of -0.3035 is more likely to have a long-term favorable response to treatment. Conversely, a new patient with the same malocclusion who has a score lower than the critical score is more likely to have an unfavorable response to treatment.

The computed cross-validated accuracy rate was 78.8%, lower than the proportional by chance accuracy rate of 86.2%. Accordingly, the criterion for classification accuracy was not satisfied in this classification.

Table 4.10: Classification results for the stepwise discriminant analysis (classification 2)

Treated Patients	**Predicted group membership**			
	FR		**UFR**	
Original group	n	%	n	%
FR (n=42)	40	95.2	2	4.8
UFR (n=10)	7	70	3	30
82.7% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=55)	39	92.9	7.1	4.8
UFR (n=70)	8	80	2	20
78.8% of cross-validated grouped cases correctly classified				

4.10.3. Predictors from the post face mask phase

Based on this classification of favorable (FR, n=42) and unfavorable (UFR, n=10) responses, significant predictors of treatment outcome were found.

The stepwise variable selection resulted in a three-variable model that satisfied the level of significance of 0.05 and produced the best discrimination between the 2 groups: the wits appraisal (AoBo) at T2, the gonial angle at T2 (CoGoMe) and the Overbite at T2(OB) with a canonical correlation of 0.452. The cross-validation rate was 78.8%.

The following equation was generated using the unstandardized discriminant function coefficients of AoBo and CoGoMe:

DS = 0.275 AoBo - 0.22 CoGoMe + 0.228 OB + 3.546

This equation provides individual scores for assigning a new patient to either Successful or unsuccessful groups; the discriminant scores for group means (group centroids) were 0.242 for the FR group and -1.018 for the UFR group. The critical score was -0.388. A new growing Class III undergoing FMT patient who scores more than the critical score of -0.388 is more likely to have a long-term favorable response to treatment. Conversely, a new patient with the same malocclusion who has a score lower than the critical score is more likely to have an unfavorable response to treatment.

The computed cross-validated accuracy rate was 78.8%, a rate lower than the proportional by chance accuracy rate of 86.2%. The criterion for classification accuracy was not satisfied in this classification.

Table 4.11: Classification results for the stepwise discriminant analysis (classification 3)

Treated Patients	**Predicted group membership**			
	FR		**UFR**	
Original group	n	%	n	%
FR (n=42)	40	95.2	2	4.8
UFR (n=10)	7	70	3	30
82.7% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=55)	39	92.9	7.1	4.8
UFR (n=70)	8	80	2	20
78.8% of cross-validated grouped cases correctly classified				

CHAPTER 5

DISCUSSION

5.1. Introduction

We investigated treatment outcome of Class III orthopedic treatment with face mask therapy using an approach based on the analysis of cephalometric components that reflected skeletal, dentoalveolar and soft tissue changes induced by growth and orthopedic/ orthodontic treatment in growing patients. We chose a combination of inclusion criteria to ensure patients included had a true skeletal Class III, not only a dental deformity leading to anterior shifting of the mandible, and to include heavily compensated skeletal Class III patients. Hence, patients chosen had to meet two of the three inclusion criteria set which were: an edge to edge or negative overjet, an ANB angle of 0^o or less and a Wits appraisal less than -2.5mm. Cephalometric analyses were the only means that were used in the literature to assess treatment outcome and explore predictors of Class III treatment outcome. [80, 121]

5.2. Cephalometric changes during facemask therapy

Most cephalometric variables were subject to significant changes with time due to face mask treatment and/or growth.

Cranial base: The changes observed in the length of the anterior cranial base SN were similar to those reported in control subjects by Baccetti et al. [43] and Alexander et al. [44] Between the ages of 9.2 and 11.5 years, the anterior cranial base SN grew 1.36mm in our treated sample, which is similar to the 1.5mm of growth during the same period of time reported in the untreated control Class III. Unlike the reports by the same authors that the cranial base flexure tends to decrease in the untreated growing class III patient, the value of the saddle angle SNAr remained mainly unchanged in our treated sample across all the timepoints evaluated.

Inter-jaw relations: The effects of facemask therapy on the jaws were favorable to the correction of the Class III malocclusion. Forward displacement of the maxilla, a backward rotation of the mandible combined with a counterclockwise rotation of the palatal plane were the major findings concerning inter-jaw relationships. These changes were concordant with those reported in the studies of Delaire, [138] Baccetti, [79] Turley, [81] Ngan [139] and the meta-analysis of Kim et al. [80] When compared with normal growth in the untreated Class III control, the observed favorable changes induced by face mask therapy were clinically significant. Baccetti et al. [43] reported that the SNA angle has a tendency to remain stable with growth, and the SNB increased with age, leading to a worsening in the ANB angle (sagittal jaw relationship). In our treated sample however, the average SNA angle increased by 1.34^{o} and the SNB decreased by 0.26^{o} leading to a significant improvement of the ANB by 1.58^{o}, and of 3mm in the Wits appraisal. The slight counterclockwise rotation of the palatal plane and clockwise rotation of the mandibular plane also contributed to an improvement in the sagittal jaw relationship but this increase in vertical divergence would worsen in a preexisting hyperdivergent pattern.

Jaw Specific measurements: The maxillary unit length CoA increased significantly during the phase of face mask treatment by 3.06mm, which is 1mm more than the change in control Class III during the same age interval shown in the study by Alexander et al. [44] The changes in mandibular ramus, corpus and total length were similar to growth changes in control groups, therefore, face mask treatment induced little or no change on mandibular growth and development, and only affected its rotation. The anterior symphyseal increased by 2.7º while the posterior symphyseal angle decreased by 2.25º rendering the total symphyseal angle practically unchanged. While never investigated in controls, the change in the anterior symphyseal angle was associated with bone remodeling induced by the mandibular rotation and possible neuromuscular adaptations.

Dento-alveolar measurements: The face mask treatment induced compensatory tooth movements favoring dental Class III correction (maxillary incisors proclination and mandibular incisors retroclination). These results are corroborated in the literature, with indicators that the maxillary incisor proclination is related to a mesial dental movement, and mandibular incisor uprighting results from pressures by the chincup and soft tissue. [80, 121] The combination of the aforementioned skeletal and dental effects led to a significant improvement in the overjet by more than 4.5mm, on average.

Soft tissue measurements: All soft tissue measurements changes denote an improvement in the soft tissue profile. The upper lip moved significantly forward (along with the growth of the nose) while the lower lip and chin remained relatively unchanged in the sagittal position. The thickness and proclination of the upper lip slightly increased. These findings are concordant with the studies of Ngan and Kilicoglu. [140, 141]

5.4. Cephalometric changes post-face mask therapy

Cranial base: The increased length of the anterior and posterior cranial bases is attributed to growth between the ages of 11 and 18 years.

Inter-jaw relations: The cephalometric changes during this period reflect a tendency toward relapse, with a considerable decrease of the maxillary forward displacement, and mandibular growth peaking concomitantly with the pubertal growth spurt. Thus Class III growth pattern recurred, as previously stated by Turley [81]. Accordingly, overcorrection is advocated during the face mask phase to anticipate this relapse tendency.

The rotational effect of the facemask on both jaws was also lost during this phase: the palatal plane rotated clockwise, and the mandible moved forward and upward. These results conflict with the findings of Wisth et al. [142] who investigated the posttreatment growth of 22 children treated with facemask and quad-helix, and compared them with Class I controls. They found that the changes in the maxilla, the mandible, and the overbite were not statistically different from the controls. However, other studies confirm our results that a Class III growth pattern resumes after stopping the face mask treatment. (Chong et al. [117], Shanker et al. [118], MacDonald et al. [119], Gallagher et al. [120] and Ngan et al. [60]) In these studies, follow up periods ranged from a little more than a year to up to 4 years, and with the greater follow up periods, not only greater relapse tendencies were observed, but also some patients reverted to having an anterior crossbite.

Jaw Specific measurements: The increase in size of both the maxilla and the mandible continued during this phase. The maxillary increments in size were similar to the previous phase over double the period of time. The mandibular growth in height and length were twice the growth amount during face mask treatment, denoting perpetuation of late mandibular growth in growing Class III patients.

Dento-alveolar measurements: During the post face mask phase, the maxillary teeth still proclined, but to a lesser extent than during the previous phase. The mandibular teeth proclined as well, either due to relapse after treatment cessation or the use of fixed appliance therapy in the later stages of treatment.

Soft tissue measurements: In contrast to the face mask period, the resumption of the Class III growth pattern affected the soft tissue profile negatively. All soft tissue landmarks moved anteriorly due to growth, but the lower lip moved anteriorly more than the upper lip, causing a worsening of the profile that was improved with the facemask. The lower lip also proclined forward almost double the amount of the upper lip (4.15^{o} and 2.21^{o} respectively).

5.5. Gender response during face mask therapy

Numerous studies addressed the effects of orthopedic face mask treatment on the growing Class III patients, but the treatment response was rarely analyzed with regard to gender differences. Vaughn et al. [143] did not find significant differences between males and females. Also, in a study of Japanese patients, no significant gender differences were found. [144, 145] Battagel [146] reported gender differences during protraction facemask treatment or mandibular headgear treatment, related to linear measurements indicating more growth in the male patient. These findings are concordant with ours. Initially, males exhibited longer anterior cranial base SN, a more concave profile, a longer mandibular corpus and total mandibular length, and a more prominent soft tissue profile relative to soft tissue Nasion. These differences were more evident post face mask treatment when the patients approached the growth spurt, the male individuals overgrowing their female counterparts. Similar findings were reported by Ursi et al. in normal growing patients [47] and by Baccetti et al. [6] in control Class III patients. They stated that male subjects with Class III malocclusion have significantly larger linear dimensions of the maxilla, mandible, and anterior facial heights when compared with female subjects during the circumpubertal and post-pubertal periods.

Both genders responded similarly to facemask treatment with no statistically significant differences across the variables studied, except for the maxillary incisors which tended to procline more in females. This result should be interpreted with caution, because some of the females were in the early mixed dentition prior to the start of the facemask therapy and therefore the recently erupted maxillary incisors might have been more retroclined than they normally would be independent of treatment.

During the post-facemask retention and orthodontic phase, more differences were evident between genders as would be expected particularly that males grow over a longer period of time.

5.6. Success and failure of facemask therapy

Maxillary protraction therapy can produce favorable effects on a short-term basis: however, relapse can be significant during the follow-up period, at times with a recurring anterior crossbite and Class III skeletal pattern because of mandibular overgrowth. Short term success approached 100% among our patients, 80.8% of whom maintained a positive overjet at the end of the follow-up period and 19.2% relapsed. Of the latter, 70% were male patients. The reported rates of long term success post face mask therapy ranges from 76% to 100% [147]. However, these numbers might not be generalized as the relapse is more likely to occur during and past the pubertal growth spurt. Studies with short follow up periods might project an inflated success percentage.

Our categorization of successful and unsuccessful subgroups was based on the overjet at T3. No statistically significant differences were observed in the response to facemask treatment between both groups, except for the gonial angle which was more acute in the unsuccessful group. During the follow-up period, the unsuccessful patients exhibited more mandibular growth. Therefore, excessive mandibular growth was mostly responsible for the relapse of orthopedic treatment. Thus, successful prediction of the outcome of face mask treatment would require an accurate forecasting of the mandibular growth, which is not yet possible with the conventional cephalometric methods available but might be in the future with the advancement in genetic testing. Yet, the initially successful and unsuccessful patients exhibited some cephalometric differences (Wits, MP/SN, gonial angle), indicating that at least these measurements may be significant to be evaluated by the orthodontist as potential signs for at least further overcorrection. The Wits appraisal, which improved equally in both groups, was still more severe in the unsuccessful group.

5.7. Early versus late face mask therapy

Many authors claimed that treatment should be started as early as possible to produce a more significant response from protraction therapy. [93, 138, 148] In a meta-analysis, Kim et al. [80] demonstrated that treatment changes in the younger group were greater than those in the older group but, the magnitude of the difference between the 2 groups was not significant. They concluded that protraction face mask therapy is still effective but to a lesser degree in growing patients older than 10 years of age. Our data agree partially with these findings. Our setting the cut-off between early and later intervention at ages 9 (girls) and 9.5 (boys) helped delineate such outcome.

Despite the apparent advantage of starting the treatment early due to more maxillary protraction, both groups ended up being cephalometrically similar at the end of the follow-up period. Accordingly, face mask treatment could be equally as effective even past the age of 10 years, at a minimum in the pre-pubertal period.

5.8. Outcome prediction

Many authors tried to develop prediction models to estimate Class III treatment outcome. Five of these models were based on treatment with the orthopedic face mask. However, many questions remain about the validation of these schemes because of the spectrum of variables assumed to have a predictive value, the dissimilarity of the sets of predictors established by different groups of researchers, and the potential low correlation between a particular predictor and treatment outcome. [121] Models for prediction of treatment outcome obtained from discriminant functions and regression analyses predict post hoc what has occurred previously. It is not uncommon to obtain a particularly good classification if a researcher uses the same cases from which the classification functions are computed. We tested the fit of our classification of successful and unsuccessful treatment with the prediction formulas proposed by various authors.

None of the proposed formulas delivered satisfying prediction accuracy, and none of them provided similar prediction odds to what was reported by its respective author. The main reasons for the lack of correspondence in predicting the outcome is that prediction formulas are likely related to the population from which they were derived, particularly that the inclusion criteria may not be uniform.

A registry encompassing large numbers of patients and data might be needed with sophisticated methodology (such as artificial intelligence) to sort out pathways of prediction for various groupings of class III malocclusion.

On the basis of previous formulas and trends within our population, we investigated additional prediction schemes taking into account the overjet at the end of the follow up period. To that end, used initial cephalometric variables and cephalometric variables from the post-face mask phase and applied a linear discriminant analysis.

The Wits appraisal, the gonial angle and the condylar axis were found to be the best predictors for treatment success with an overall accuracy of 82.7%. However, none of the different discriminant formulas we tested correctly predicted failure with more than 30% accuracy. This finding may be related to the small sample size of the unsuccessfully treated patients (n=10). Using predictors from T2 after the face mask phase yielded the same accuracy as before.

Also, the similarity in cephalometric characteristics between successful and unsuccessful patient's pretreatment may be misleading when the differences become apparent around and beyond the growth spurt. Therefore, a hypothetically more accurate prediction model would rely on data gathered at that age, after the completion of the face mask phase, as proposed by Ngan in his GTRV (growth treatment response vector) method. [149]

5.9. Research considerations

Our findings reinforce and expand existing knowledge of the treatment of growing Class III patients with the face mask protraction device. Although face mask changes were similar to what was previously reported, few reported on the gender differences and treatment timing considerations, of which none had an extensive follow up of 5 years.

Most studies investigating the long-term effects of face mask treatment set a follow up period for a number of years which did not cover the end of growth, especially in patients who started the face mask orthopedic treatment very early on. In this study, we used the CVM method to ascertain that all patients evaluated at the end of the follow-up period had little or no growth remaining, therefore minimizing the risk of additional relapse potential. Patients who did not reach a CVSM of 5 or 6 by the time of their latest radiograph were excluded from the study.

Because of the relative rarity of the Class III malocclusion, sample sizes are limited in the literature ($n<50$), and if larger, included multiethnic subjects. Our sample consisted of 85 treated patients with the orthopedic face mask with 52 patients having a follow-up beyond the growth spurt to determine the outcome of the treatment. However, the number of failures in our sample was relatively low ($n=10$) limiting the possibilities of extended analysis.

Scanning conventional film cephalograms would grants a distortion free digital image, but a digital single lens reflex camera was used for the better quality of the resulting image, thus easier and more consistent landmark identification. The standardization of the methodology used (described in Chapter 3.2) insured minimal distortion of the images, a consistent magnification which was accounted for in the digitization software, all while preserving a sharp image with good contrast. The Intraclass Correlation Coefficient was 0.99 between both digitization methods ($p<0.05$) (Appendix 2).

Methodological limitations of our study include the retrospective nature of the sample of patients who were treated by different residents under the supervision of different instructors, and by a private practitioner affiliated to the division of orthodontics and dentofacial orthopedics at AUBMC. While the methodology for the face mask treatment is largely similar, no reliable data regarding compliance or mechanotherapy used during fixed appliances treatment was readily available. On the other hand, while rising to higher research standards, prospective clinical trials would also imply more duration and more demanding IRB thresholds. Future research could be planned under stricter conditions of recruitment, treatment protocols, and compliance. A larger sample of unsuccessfully treated Class III patients will be also needed to reach more solid and generalizable conclusions.

5.10. Clinical implications

This research showed that early orthopedic and orthodontic interventions in growing Class III patients lead to a more favorable skeletal, dental and facial outcome on the short term, that is successfully maintained in 80% of the patients past the end of growth. However, the remaining 20% exhibited relapse into a Class III malocclusion that would require orthognathic surgery. Because the correction might still be associated with facial concavity and worsening with age, patients should be aware of the potential and limitations of the treatment prior to its initiation.

Males and females respond similarly to facemask treatment; however, males are more at risk of relapsing due to their increased growth residue over a longer period of time.

Similar characteristics between the early treated patients and late treated patients are revealed during and beyond the peak of growth. Therefore, face mask treatment can be as effective after the age of 10 on the long term.

In severe malocclusions, the ideal option involves orthognathic surgery commensurate with normal inclinations of maxillary and mandibular incisors that allow the optimal surgical approximation of the skeletal bases, leading to more pleasing facial esthetics and stable outcome. However, treatment with the face mask should not be overlooked because some of its effects are maintained despite the relapse tendencies, and therefore the surgical movements lessened. Often, early treatment is considered despite the possibility of later surgery because parents and/or patients are eager to see improvement, particularly if the problem affects function or psychology.

CONCLUSIONS

- Face mask therapy induced positive changes to the skeletal, dental and facial profile of the patient in the short term. However, relapse tendencies occurred in all patients, thus the need for overcorrection during the face mask phase in anticipation for late mandibular growth.
- Following the same pattern, remarkable improvement was observed in the facial profile. In time, the inter-labial improvement was maintained, but the initial facial concavity recurred.
- Males and females responded similarly to face mask treatment, but males were more at risk of relapse likely associated with their later growth spurt and longer period of growth.
- Differences between successfully and unsuccessfully treated patients with face mask therapy included a more severe Wits appraisal and a higher mandibular plane angle initially. Beyond the growth spurt, differences in mandibular size became more apparent.
- Early Class III correction before age 10 led to significant maxillary protraction, which was not maintained beyond the growth spurt. Treatment in later childhood (9 years in girls, 9.5 years in boys) can be as effective as treatment earlier ages.
- Cephalometric long-term prediction of face mask therapy was not validated clinically using various prediction models. Methods of prediction seem particular to the populations under study. Other methods, including genetic testing, should be explored.

- Future research should include larger samples with nearly equal distributions of successful and unsuccessful outcomes controlling for the variables tested in the and other studies.

TABLES

Table 4.12: Changes across timepoints. (Repeated measures ANOVA)

Variables	T1		T2		T3		p-value	T2-T1		T3-T2		T3-T1	
	Mean	SD	Mean	SD	Mean	SD		Mean Diff	p-value	Mean Diff	p-value	Mean Diff	p-value
Age	9.27	2.10	11.45	2.28	16.42	2.62	<0.001	2.18	<0.001	4.97	<0.001	7.15	<0.001
Cranial Base Measurements													
SN/H	9.88	2.90	10.07	2.91	10.44	3.37	0.001	0.19	0.179	0.37	0.023	0.57	0.005
SN	63.21	3.37	64.58	3.44	66.97	3.54	<0.001	1.36	<0.001	2.39	<0.001	3.75	<0.001
Sar	29.33	3.21	30.70	3.67	32.39	3.47	<0.001	1.37	<0.001	1.69	<0.001	3.05	<0.001
NSAr	123.20	5.02	123.48	4.71	123.17	5.56	0.825	0.29	1.000	-0.31	1.000	-0.02	1.000
Relationship between jaws, cranial base and horizontal													
SNA	78.79	3.23	80.13	3.52	80.80	4.08	<0.001	1.34	<0.001	0.67	0.037	2.01	<0.001
SNB	78.97	3.25	78.71	3.71	80.56	4.52	<0.001	-0.26	1.000	1.85	<0.001	1.59	<0.001
ANB	-0.18	1.70	1.40	2.05	0.25	2.25	<0.001	1.58	<0.001	-1.15	<0.001	0.43	0.376
AoBo	-6.12	2.86	-3.12	2.90	-3.94	3.55	<0.001	3.00	<0.001	-0.83	0.187	2.18	<0.001
A-Nperp	-1.13	2.83	0.22	3.32	1.23	4.12	<0.001	1.35	<0.001	1.01	0.001	2.36	<0.001
B-Nperp	-1.73	5.07	-2.01	6.09	1.61	7.84	<0.001	-0.28	1.000	3.62	<0.001	3.34	<0.001
NAPog	-1.17	4.65	1.41	5.10	-1.71	5.32	<0.001	2.58	<0.001	-3.12	<0.001	-0.54	1.000
ArGoMe	131.24	5.61	130.36	5.26	128.50	6.56	<0.001	-0.87	0.120	-1.86	0.001	-2.73	<0.001
PPMP	27.51	6.05	28.80	6.93	26.25	7.13	<0.001	1.29	0.012	-2.55	<0.001	-1.26	0.044
PPH	1.73	2.85	2.50	3.42	2.01	3.78	0.061	0.78	0.014	-0.49	0.456	0.28	1.000
MPSN	35.64	5.55	36.36	6.49	34.69	7.48	0.002	0.72	0.208	-1.67	<0.001	-0.95	0.203
MPH	25.77	5.18	26.29	6.07	24.25	6.66	<0.001	0.52	0.622	-2.04	<0.001	-1.53	0.014
Condylar Axis to H	70.88	4.67	73.13	4.79	71.70	4.76	0.030	2.26	0.028	-1.44	0.245	0.82	1.000
Jaw specific measurements													
CoGo	49.42	3.81	51.82	4.86	58.27	4.64	<0.001	2.40	<0.001	6.45	<0.001	8.85	<0.001
GoPog	66.68	5.10	69.81	5.14	75.65	5.38	<0.001	3.13	<0.001	5.84	<0.001	8.97	<0.001
CoPog	100.69	6.81	105.27	7.30	114.97	7.46	<0.001	4.58	<0.001	9.70	<0.001	14.28	<0.001
CoGoMe	126.58	5.43	125.77	5.26	124.31	6.27	<0.001	-0.82	0.099	-1.45	0.007	-2.27	<0.001
Condylar Axis To MP	133.30	6.59	131.71	8.02	130.56	7.41	0.013	-1.59	0.289	-1.15	0.593	-2.74	0.013
CoA	75.67	4.05	78.73	4.01	83.03	3.67	<0.001	3.06	<0.001	4.29	<0.001	7.36	<0.001
ANSPNS	42.47	3.30	44.89	3.69	48.06	2.83	<0.001	2.42	<0.001	3.17	<0.001	5.59	<0.001
Relationship between teeth and jaws													
U1PP	107.56	8.76	113.71	7.69	117.29	6.99	<0.001	6.15	<0.001	3.58	0.003	9.74	<0.001
U1-NA	2.73	2.44	5.24	2.36	6.30	2.36	<0.001	2.52	<0.001	1.06	0.017	3.57	<0.001
U1/NA	20.63	8.10	26.03	6.60	28.06	6.30	<0.001	5.40	<0.001	2.03	0.120	7.43	<0.001
U1SN	99.41	8.19	106.15	7.06	108.86	7.39	<0.001	6.74	<0.001	2.71	0.016	9.45	<0.001
L1-NB	3.72	1.97	3.56	2.63	4.99	2.84	<0.001	-0.16	1.000	1.43	<0.001	1.27	<0.001
L1/NB	22.93	6.08	20.96	7.09	23.77	6.53	0.005	-1.96	0.124	2.80	0.002	0.84	0.955
L1MP	88.33	7.41	85.89	8.31	88.52	7.95	0.006	-2.44	0.034	2.63	0.009	0.19	1.000

Relationship between teeth												
U1L1	136.61	10.94	131.61	10.01	127.94	9.03	<0.001	-5.00	0.009	-3.67	0.008	-8.67	0.009
OB	0.12	1.99	0.47	2.13	0.80	1.26	0.067	0.36	0.787	0.33	0.813	0.69	0.033
OJ	-1.18	2.15	3.56	2.24	1.75	1.96	<0.001	4.74	<0.001	-1.81	<0.001	2.94	<0.001
Symphyseal Components												
ASA	2.03	7.74	4.78	6.97	9.31	7.38	<0.001	2.75	<0.001	4.52	<0.001	7.27	<0.001
PSA	30.16	8.29	27.91	7.39	22.86	7.57	<0.001	-2.25	0.003	-5.05	<0.001	-7.30	<0.001
TSA	32.20	7.67	32.70	6.12	32.16	6.42	0.670	0.50	1.000	-0.53	1.000	-0.04	1.000
Soft Tissue Measurements												
Sagittal												
NsMsFH	94.58	3.02	94.54	3.06	92.22	3.52	<0.001	-0.04	1.000	-2.32	<0.001	-2.37	<0.001
NsSls/ SlsPos	146.44	15.71	143.22	15.28	142.89	15.72	0.112	-3.22	0.242	-0.33	1.000	-3.55	0.139
PnNs	19.59	3.54	22.61	4.00	26.47	4.17	<0.001	3.02	<0.001	3.85	<0.001	6.88	<0.001
NsSn	48.49	4.50	50.88	4.65	54.01	5.19	<0.001	2.40	<0.001	3.13	<0.001	5.52	<0.001
NsSls	7.05	3.59	9.69	4.01	11.49	5.44	<0.001	2.64	<0.001	1.80	<0.001	4.44	<0.001
NsLs	9.33	4.13	12.21	4.37	14.65	5.88	<0.001	2.88	<0.001	2.45	<0.001	5.32	<0.001
NsSt	4.70	4.27	6.69	4.86	9.18	6.42	<0.001	1.99	<0.001	2.49	<0.001	4.48	<0.001
NsLi	9.45	4.87	10.47	5.42	14.48	7.20	<0.001	1.02	0.109	4.01	<0.001	5.03	<0.001
NsIls	3.23	5.14	3.24	6.16	7.32	7.56	<0.001	0.02	1.000	4.08	<0.001	4.09	<0.001
NsPos	3.97	5.99	4.53	7.34	9.71	9.05	<0.001	0.56	1.000	5.18	<0.001	5.74	<0.001
Vertical												
SnMs (StLFH)	58.88	4.91	62.60	5.61	67.64	5.91	<0.001	3.73	<0.001	5.04	<0.001	8.77	<0.001
SnSt	17.77	2.72	19.01	2.84	20.16	2.45	<0.001	1.24	0.003	1.15	0.003	2.39	<0.001
StMs	42.87	3.79	45.46	4.18	49.64	4.54	<0.001	2.60	<0.001	4.18	<0.001	6.78	<0.001
NsMs	107.36	8.06	113.49	8.82	121.69	9.32	<0.001	6.13	<0.001	8.20	<0.001	14.33	<0.001
NsSn vert	48.49	4.50	50.88	4.65	54.01	5.19	<0.001	2.40	<0.001	3.13	<0.001	5.52	<0.001
Thickness												
SnA	13.83	1.78	14.91	1.99	16.18	2.06	<0.001	1.08	<0.001	1.27	0.001	2.34	<0.001
PosPog	10.57	1.99	10.90	2.05	11.77	2.12	<0.001	0.34	0.256	0.87	<0.001	1.21	<0.001
SlsA	15.08	1.99	16.33	2.16	17.51	2.47	<0.001	1.24	0.001	1.18	0.006	2.43	<0.001
IlsB	10.35	1.84	10.99	2.29	11.66	1.78	<0.001	0.64	0.070	0.67	0.030	1.31	<0.001
Lip Morphology												
SnLsFH	98.38	9.39	100.95	8.68	103.16	9.01	0.010	2.57	0.014	2.21	0.025	4.78	<0.001
LiIlsFH	55.33	10.83	51.18	8.78	55.33	7.60	0.010	-4.16	0.060	4.15	0.002	-0.01	1.000
UEline	-3.70	2.13	-3.03	2.32	-5.02	2.23	<0.001	0.66	0.213	-1.98	<0.001	-1.32	<0.001
LEline	0.06	2.60	-0.23	2.55	-1.27	2.51	<0.001	-0.29	1.000	-1.04	0.003	-1.33	<0.001

Table 4.13: Two-way mixed ANOVA tests of between-subjects effects (Gender)

Variables	Type III Sum of Squares	df	Mean Square	F	Sig.	Variables	Type III Sum of Squares	df	Mean Square	F	Sig.
Age	53.90	1.00	53.90	5.66	0.021	**Relationship between teeth**					
Cranial Base Measurements						U1L1	349.56	1.00	349.56	2.37	0.130
SN/H	96.99	1.00	96.99	3.22	0.079	OB	5.32	1.00	5.32	0.84	0.363
SN	556.43	1.00	556.43	26.58	<0.001	OJ	0.96	1.00	0.96	0.12	0.730
Sar	165.23	1.00	165.23	5.98	0.018	**Symphyseal Components**					
NSAr	15.84	1.00	15.84	0.25	0.618	ASA	1395.25	1.00	1395.25	12.82	0.001
Relationship between jaws, cranial base and horizontal						PSA	424.98	1.00	424.98	3.08	0.085
SNA	0.31	1.00	0.31	0.01	0.930	TSA	280.50	1.00	280.50	2.51	0.119
SNB	23.47	1.00	23.47	0.50	0.482	**Soft Tissue Measurements**					
ANB	18.63	1.00	18.63	2.25	0.140	***Sagittal***					
AoBo	36.28	1.00	36.28	1.61	0.210	NsMsFH	105.24	1.00	105.24	3.97	0.052
A-Nperp	94.02	1.00	94.02	2.77	0.102	NsSls/SlsPos	76.91	1.00	76.91	0.14	0.714
B-Nperp	568.79	1.00	568.79	4.88	0.032	PnNs	228.71	1.00	228.71	5.99	0.018
NAPog	262.59	1.00	262.59	5.23	0.027	NsSn	238.71	1.00	238.71	4.30	0.043
ArGoMe	28.28	1.00	28.28	0.28	0.600	NsSls	455.79	1.00	455.79	9.22	0.004
PPMP	52.27	1.00	52.27	0.39	0.535	NsLs	561.11	1.00	561.11	9.66	0.003
PPH	24.41	1.00	24.41	0.91	0.344	NsSt	629.14	1.00	629.14	8.89	0.004
MPSN	5.62	1.00	5.62	0.04	0.841	NsLi	829.30	1.00	829.30	9.27	0.004
MPH	148.56	1.00	148.56	1.44	0.236	NsIls	856.30	1.00	856.30	8.32	0.006
Condylar Axis to H	62.51	1.00	62.51	1.72	0.195	NsPos	1280.24	1.00	1280.24	8.89	0.004
Jaw specific measurements						***Vertical***					
CoGo	257.86	1.00	257.86	6.16	0.016	SnMsStLFH	653.42	1.00	653.42	9.69	0.003
GoPog	1288.50	1.00	1288.50	29.91	<0.001	SnSt	73.96	1.00	73.96	5.18	0.027
CoPog	2210.15	1.00	2210.15	22.02	<0.001	StMs	279.27	1.00	279.27	6.64	0.013
CoGoMe	0.41	1.00	0.41	0.00	0.949	NsMs	1694.51	1.00	1694.51	9.47	0.003
Condylar Axis To MP	209.86	1.00	209.86	1.46	0.233	NsSn vert	238.71	1.00	238.71	4.30	0.043
CoA	740.56	1.00	740.56	32.13	<0.001	***Thickness***					
ANSPNS	213.31	1.00	213.31	12.79	0.001	SnA	107.02	1.00	107.02	16.19	<0.001
Relationship between teeth and jaws						PosPog	8.24	1.00	8.24	0.75	0.390
U1PP	503.80	1.00	503.80	4.33	0.043	SlsA	142.89	1.00	142.89	18.99	<0.001
U1-NA	44.44	1.00	44.44	4.28	0.044	IlsB	41.01	1.00	41.01	4.06	0.049
U1/NA	290.90	1.00	290.90	3.41	0.071	***Lip Morphology***					
U1SN	308.32	1.00	308.32	2.47	0.122	SnLsFH	189.99	1.00	189.99	0.97	0.330
L1-NB	6.88	1.00	6.88	0.46	0.503	LiIlsFH	57.02	1.00	57.02	0.47	0.494
L1/NB	36.40	1.00	36.40	0.44	0.511	UEline	0.38	1.00	0.38	0.05	0.818
L1MP	12.11	1.00	12.11	0.09	0.771	LEline	2.34	1.00	2.34	0.20	0.657

Table 4.14: Comparison between males and females at T1 (Mixed ANOVA)

Variables at T1	Females		Males		F-M		Variables at T1	Females		Males		F-M	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value		**Mean**	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	8.80	2.13	9.67	1.98	-0.87	0.031	**Relationship between teeth**						
Cranial Base Measurements							U1L1	139.12	10.23	134.41	11.42	4.71	0.021
SN/H	9.64	2.59	11.02	3.14	-1.38	0.104	OB	0.11	1.82	0.44	2.22	-0.33	0.262
SN	61.76	2.90	64.43	3.39	-2.67	<0.001	OJ	-1.22	2.01	-0.99	2.35	-0.23	0.264
Sar	29.27	3.14	30.37	3.24	-1.10	0.070	**Symphyseal Components**						
NSAr	123.04	4.81	124.60	5.23	-1.56	0.209	ASA	0.62	7.53	5.62	7.16	-5.00	0.001
Relationship between jaws, cranial base and horizontal							PSA	31.26	8.37	28.77	8.07	2.49	0.098
SNA	79.30	3.45	78.24	2.84	1.06	0.756	TSA	31.89	7.48	34.38	7.80	-2.49	0.157
SNB	79.44	3.28	78.85	3.21	0.59	0.727	**Soft Tissue Measurements**						
ANB	-0.14	1.68	-0.59	1.72	0.45	0.177	***Sagittal***						
AoBo	-5.75	2.77	-6.15	3.00	0.40	0.689	NsMsFH	94.67	3.22	94.20	2.74	0.47	0.121
A-Nperp	-0.89	3.04	-0.66	2.55	-0.23	0.275	NsSls/SlsPos	147.61	14.18	148.05	17.80	-0.44	0.326
B-Nperp	-1.40	5.37	-0.27	4.64	-1.13	0.092	PnNs	19.76	3.80	20.43	3.17	-0.66	0.231
NAPog	-0.71	4.41	-2.69	4.77	1.98	0.031	NsSn	47.86	4.59	49.14	4.33	-1.29	0.165
ArGoMe	130.23	5.47	131.22	5.81	-0.99	0.478	NsSls	6.92	3.69	8.10	3.38	-1.19	0.030
PPMP	26.33	5.93	26.73	6.29	-0.40	0.523	NsLs	9.14	4.20	10.64	3.91	-1.50	0.022
PPH	1.39	2.44	2.43	3.26	-1.04	0.600	NsSt	4.47	4.59	6.10	3.65	-1.63	0.015
MPSN	34.56	5.75	35.31	5.31	-0.74	0.991	NsLi	9.28	4.95	10.91	4.65	-1.63	0.063
MPH	24.93	5.18	24.29	5.22	0.64	0.321	NsIls	3.31	5.48	4.74	4.57	-1.43	0.035
Condylar Axis to H	71.31	5.24	71.35	3.85	-0.03	0.878	NsPos	4.10	6.33	6.13	5.36	-2.02	0.019
Jaw specific measurements							***Vertical***						
CoGo	49.09	4.37	49.79	2.88	-0.70	0.169	SnMsStLFH	57.71	4.78	60.19	4.77	-2.47	0.058
GoPog	65.41	4.99	68.75	4.65	-3.33	<0.001	SnSt	17.33	2.76	17.96	2.65	-0.63	0.321
CoPog	98.75	6.88	102.86	6.04	-4.11	0.001	StMs	42.12	3.68	43.71	3.78	-1.59	0.059
CoGoMe	125.50	5.44	126.27	5.46	-0.77	0.585	NsMs	105.57	8.41	109.33	7.09	-3.76	0.062
Condylar Axis To MP	132.27	6.69	132.18	6.55	0.09	0.747	NsSn vert	47.86	4.59	49.14	4.33	-1.29	0.165
CoA	74.46	4.08	77.03	3.56	-2.57	<0.001	***Thickness***						
ANSPNS	41.31	3.40	42.90	2.95	-1.58	0.038	SnA	13.43	1.80	14.36	1.63	-0.93	0.024
Relationship between teeth and jaws							PosPog	10.55	1.87	10.72	2.17	-0.17	0.354
U1PP	106.46	9.08	109.94	8.00	-3.49	0.007	SlsA	14.43	1.97	15.79	1.77	-1.37	0.001
U1-NA	2.27	2.31	3.48	2.47	-1.20	0.005	IlsB	9.96	1.68	10.57	2.01	-0.61	0.054
U1/NA	18.91	7.98	23.12	7.73	-4.21	0.006	***Lip Morphology***						
U1SN	98.21	8.00	101.36	8.22	-3.14	0.016	SnLsFH	97.72	9.19	99.72	9.67	-2.00	0.102
L1-NB	3.36	1.83	3.81	2.15	-0.45	0.433	LiIlsFH	56.05	11.08	55.75	10.64	0.31	0.380
L1/NB	22.09	6.00	23.07	6.24	-0.98	0.577	UEline	-4.09	2.12	-3.77	2.16	-0.32	0.427
L1MP	88.09	7.01	88.93	7.99	-0.84	0.799	LEline	-0.22	2.52	-0.30	2.74	0.08	0.363

Table 4.15: Mi Comparison between males and females at T2 (Mixed ANOVA)

Variables at T2	Females		Males		F-M	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	11.19	2.36	11.60	2.18	-0.41	0.062
Cranial Base Measurements						
SN/H	9.92	2.68	11.34	3.03	-1.42	0.045
SN	62.99	2.84	66.00	3.47	-3.01	<0.001
Sar	30.34	3.57	31.91	3.67	-1.56	0.034
NSAr	123.38	4.43	124.44	5.07	-1.07	0.429
Relationship between jaws, cranial base and horizontal						
SNA	80.74	3.62	79.56	3.30	1.17	0.660
SNB	79.11	3.74	78.25	3.68	0.86	0.637
ANB	1.62	2.05	1.30	2.07	0.32	0.060
AoBo	-2.70	2.80	-2.87	3.07	0.17	0.069
A-Nperp	0.61	3.34	0.88	3.35	-0.27	0.225
B-Nperp	-1.63	6.28	-0.67	5.86	-0.97	0.049
NAPog	1.86	5.09	0.60	5.10	1.26	0.010
ArGoMe	129.52	5.69	129.88	4.68	-0.36	0.516
PPMP	27.75	7.06	28.32	6.84	-0.57	0.577
PPH	2.38	2.91	3.53	3.96	-1.15	0.475
MPSN	35.29	6.71	36.13	6.24	-0.84	0.986
MPH	25.37	6.26	24.79	5.89	0.58	0.307
Condylar Axis to H	71.83	4.99	74.38	4.12	-2.55	0.245
Jaw specific measurements						
CoGo	51.25	5.11	51.66	4.57	-0.41	0.113
GoPog	68.47	4.54	72.05	5.25	-3.59	<0.001
CoPog	103.26	6.54	106.80	7.87	-3.54	<0.001
CoGoMe	125.27	5.66	124.85	4.74	0.42	0.923
Condylar Axis To MP	132.32	8.55	129.68	7.09	2.64	0.238
CoA	77.78	3.79	79.96	4.00	-2.19	<0.001
ANSPNS	43.56	3.49	46.20	3.44	-2.64	0.005
Relationship between teeth and jaws						
U1PP	113.34	7.01	113.08	8.63	0.26	0.216
U1-NA	4.78	2.18	5.15	2.59	-0.38	0.063
U1/NA	25.08	6.38	25.71	6.96	-0.63	0.275
U1SN	105.81	6.26	105.27	8.12	0.54	0.459
L1-NB	3.24	2.56	3.89	2.72	-0.65	0.330
L1/NB	19.89	7.19	21.98	6.87	-2.09	0.268
L1MP	85.50	8.40	87.59	8.13	-2.09	0.487

Variables at T2	Females		Males		F-M	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value
Relationship between teeth						
U1L1	133.41	9.84	131.02	10.21	2.39	0.210
OB	0.55	2.39	0.73	1.76	-0.18	0.239
OJ	3.64	2.33	3.04	2.10	0.59	0.388
Symphyseal Components						
ASA	5.09	7.28	7.63	6.33	-2.55	0.002
PSA	28.16	7.36	25.83	7.32	2.34	0.053
TSA	33.26	5.71	33.47	6.72	-0.21	0.361
Soft Tissue Measurements						
Sagittal						
NsMsFH	94.47	3.15	94.27	2.96	0.20	0.057
NsSls/SlsPos	144.37	14.18	143.98	16.87	0.39	0.924
PnNs	22.67	3.83	23.51	4.24	-0.84	0.074
NsSn	49.57	4.18	51.46	5.10	-1.88	0.049
NsSls	9.50	3.98	10.94	3.95	-1.44	0.019
NsLs	12.07	4.28	13.64	4.37	-1.57	0.014
NsSt	6.57	4.85	8.04	4.80	-1.47	0.008
NsLi	10.21	5.35	12.39	5.32	-2.19	0.005
NsIls	3.45	6.31	5.00	5.91	-1.55	0.012
NsPos	4.82	7.31	6.74	7.34	-1.91	0.009
Vertical						
SnMsStLFH	60.90	5.25	64.26	5.58	-3.37	0.010
SnSt	18.32	2.83	19.63	2.72	-1.30	0.185
StMs	44.49	3.59	46.75	4.61	-2.27	0.036
NsMs	110.47	8.06	115.72	9.01	-5.25	0.009
NsSn vert	49.57	4.18	51.46	5.10	-1.88	0.049
Thickness						
SnA	14.33	1.89	15.18	2.06	-0.85	0.031
PosPog	10.81	2.05	11.11	2.07	-0.31	0.379
SlsA	15.60	1.94	16.77	2.30	-1.17	0.019
IlsB	10.89	2.54	11.14	1.93	-0.25	0.383
Lip Morphology						
SnLsFH	100.63	8.31	102.15	9.21	-1.52	0.263
LiIlsFH	52.16	8.97	50.11	8.49	2.05	0.794
UEline	-3.37	2.35	-2.99	2.30	-0.37	0.583
LEline	-0.78	2.63	-0.09	2.43	-0.69	0.938

Table 4.16: Comparison between males and females at T3 (Mixed ANOVA)

Variables at T3	Females		Males		F-M		Variables at T3	Females		Males		F-M	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value		**Mean**	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	15.95	2.68	17.08	2.45	-1.13	0.125	**Relationship between teeth**						
Cranial Base Measurements							U1L1	127.72	8.80	128.24	9.54	-0.51	0.842
SN/H	9.82	3.23	11.30	3.44	-1.48	0.118	OB	0.92	0.88	0.65	1.66	0.27	0.458
SN	65.22	2.68	69.35	3.20	-4.13	<0.001	OJ	2.00	1.11	1.42	2.73	0.57	0.302
Sar	31.34	3.12	33.81	3.46	-2.47	0.010	**Symphyseal Components**						
NSAr	123.55	6.10	122.65	4.80	0.90	0.570	ASA	6.77	5.92	12.76	7.88	-5.99	0.003
Relationship between jaws, cranial base and horizontal							PSA	23.92	6.63	21.41	8.64	2.51	0.241
SNA	80.35	4.33	81.40	3.72	-1.05	0.362	TSA	30.69	4.18	34.18	8.28	-3.49	0.052
SNB	79.95	4.16	81.39	4.95	-1.44	0.262	**Soft Tissue Measurements**						
ANB	0.42	2.10	0.02	2.47	0.40	0.535	***Sagittal***						
AoBo	-3.53	3.24	-4.50	3.94	0.97	0.337	NsMsFH	92.97	3.12	91.19	3.85	1.78	0.072
A-Nperp	0.15	4.04	2.70	3.84	-2.55	0.026	NsSls/SlsPos	143.10	13.96	142.60	18.19	0.50	0.911
B-Nperp	-0.54	7.02	4.55	8.10	-5.08	0.019	PnNs	24.82	3.94	28.71	3.41	-3.90	<0.001
NAPog	-0.93	5.00	-2.78	5.65	1.85	0.218	NsSn	52.79	4.28	55.68	5.91	-2.90	0.046
ArGoMe	128.37	6.04	128.69	7.36	-0.32	0.866	NsSls	9.34	4.97	14.42	4.70	-5.07	0.001
PPMP	26.77	6.24	25.55	8.28	1.22	0.547	NsLs	12.37	5.30	17.77	5.27	-5.40	0.001
PPH	1.45	3.02	2.79	4.57	-1.34	0.209	NsSt	7.08	5.79	12.04	6.24	-4.96	0.005
MPSN	35.16	6.69	34.06	8.56	1.10	0.606	NsLi	11.80	6.29	18.13	6.86	-6.33	0.001
MPH	25.33	5.97	22.76	7.39	2.57	0.172	NsIls	4.71	6.79	10.88	7.24	-6.17	0.003
Condylar Axis to H	70.72	4.67	73.03	4.65	-2.31	0.083	NsPos	6.63	7.75	13.91	9.17	-7.28	0.003
Jaw specific measurements							***Vertical***						
CoGo	56.59	3.99	60.57	4.54	-3.98	0.002	SnMsStLFH	65.17	4.63	71.02	5.89	-5.85	<0.001
GoPog	73.02	3.74	79.25	5.25	-6.23	<0.001	SnSt	19.16	2.36	21.53	1.87	-2.37	<0.001
CoPog	111.30	5.41	119.98	7.00	-8.68	<0.001	StMs	48.17	3.63	51.65	4.95	-3.48	0.005
CoGoMe	124.51	5.75	124.04	7.05	0.48	0.789	NsMs	117.96	7.15	126.78	9.66	-8.83	<0.001
Condylar Axis To MP	131.98	7.83	128.64	6.48	3.34	0.109	NsSn vert	52.79	4.28	55.68	5.91	-2.90	0.046
CoA	81.04	2.54	85.74	3.24	-4.70	<0.001	***Thickness***						
ANSPNS	46.99	2.75	49.53	2.26	-2.55	0.001	SnA	15.13	1.73	17.60	1.58	-2.47	<0.001
Relationship between teeth and jaws							PosPog	11.63	1.84	11.97	2.48	-0.34	0.575
U1PP	116.79	5.65	117.98	8.58	-1.19	0.549	SlsA	16.49	1.89	18.90	2.53	-2.41	<0.001
U1-NA	6.27	1.77	6.34	3.03	-0.06	0.925	IlsB	11.08	1.42	12.45	1.95	-1.37	0.005
U1/NA	28.06	5.69	28.05	7.19	0.00	0.999	***Lip Morphology***						
U1SN	108.42	5.31	109.47	9.65	-1.05	0.618	SnLsFH	103.29	8.48	102.98	9.88	0.32	0.902
L1-NB	4.94	2.43	5.05	3.39	-0.12	0.884	LiIlsFH	55.13	8.17	55.59	6.93	-0.46	0.833
L1/NB	23.82	6.57	23.70	6.62	0.12	0.947	UEline	-5.07	2.44	-4.94	1.95	-0.13	0.835
L1MP	88.73	8.28	88.24	7.66	0.49	0.830	LEline	-1.20	2.39	-1.37	2.72	0.17	0.809

Table 4.17: Pairwise comparison between males and females across timepoints.

Measure	Time	Females		Males		Mixed models regression	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
Age	1-2	2.246*	<0.001	2.085*	<0.001	-0.42	0.487
	2-3	4.975*	<0.001	4.967*	<0.001	0.32	0.582
	1-3	7.221*	<0.001	7.051*	<0.001	-0.13	0.816
Cranial Base Measurements							
SNH	1-2	.043	1.000	.400*	0.034	0.04	0.843
	2-3	.520*	0.014	.173	1.000	-0.18	0.472
	1-3	.563*	0.049	.573	0.105	-0.14	0.578
SN	1-2	1.070*	<0.001	1.764*	<0.001	0.34	0.276
	2-3	2.340*	<0.001	2.459*	<0.001	0.34	0.368
	1-3	3.410*	<0.001	4.223*	<0.001	0.68	0.072
SAr	1-2	1.127*	0.018	1.691*	0.002	0.47	0.325
	2-3	1.560*	0.002	1.864*	0.001	0.42	0.466
	1-3	2.687*	<0.001	3.555*	<0.001	0.88	0.122
NSAr	1-2	.607	0.927	-.150	1.000	-0.49	0.531
	2-3	.510	1.000	-1.427	0.257	-2.05	0.030
	1-3	1.117	0.565	-1.577	0.339	-2.55	0.007
Relationship between jaws, cranial base and horizontal							
SNA	1-2	1.413*	<0.001	1.236*	0.002	-0.11	0.788
	2-3	.020	1.000	1.555*	<0.001	1.56	0.002
	1-3	1.433*	<0.001	2.791*	<0.001	1.45	0.004
SNB	1-2	-.357	0.999	-.136	1.000	-0.26	0.557
	2-3	1.483*	<0.001	2.350*	<0.001	1.21	0.025
	1-3	1.127*	0.041	2.214*	<0.001	0.95	0.079
ANB	1-2	1.753*	<0.001	1.345*	0.003	0.13	0.764
	2-3	-1.430*	<0.001	-.773	0.144	0.24	0.634
	1-3	.323	1.000	.573	0.556	0.37	0.466
AoBo	1-2	3.520*	<0.001	2.295*	0.005	0.22	0.743
	2-3	-1.090	0.188	-.464	1.000	-0.36	0.660
	1-3	2.430*	<0.001	1.832*	0.025	-0.13	0.869
ANperp	1-2	1.223*	<0.001	1.527*	<0.001	0.05	0.917
	2-3	.450	0.500	1.773*	<0.001	1.54	0.003
	1-3	1.673*	<0.001	3.300*	<0.001	1.58	0.002
BNperp	1-2	-.763	0.707	.386	1.000	-0.16	0.841
	2-3	3.090*	<0.001	4.341*	<0.001	2.15	0.028
	1-3	2.327*	0.023	4.727*	<0.001	1.98	0.042
NAPog	1-2	2.867*	0.001	2.177*	0.037	0.72	0.431
	2-3	-3.753*	<0.001	-2.245*	0.029	0.50	0.651
	1-3	-.887	0.733	-.068	1.000	1.22	0.268

Measure	Time	Females		Males		Mixed models regression	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
ArGoMe	1-2	-.760	0.520	-1.027	0.348	-0.63	0.355
	2-3	-1.570	0.053	-2.255*	0.012	-0.47	0.570
	1-3	-2.330*	0.003	-3.282*	<0.001	-1.09	0.183
PPMP	1-2	1.300	0.078	1.268	0.182	0.17	0.807
	2-3	-2.523*	0.001	-2.582*	0.002	-0.27	0.756
	1-3	-1.223	0.215	-1.314	0.290	-0.09	0.913
PPH	1-2	.643	0.207	.955	0.067	0.11	0.820
	2-3	-.767	0.272	-.114	1.000	0.68	0.255
	1-3	-.123	1.000	.841	0.384	0.79	0.184
MPSN	1-2	.730	0.495	.714	0.731	0.10	0.877
	2-3	-1.220*	0.046	-2.282*	0.001	-1.16	0.124
	1-3	-.490	1.000	-1.568	0.148	-1.07	0.159
MPH	1-2	.670	0.655	.309	1.000	0.06	0.930
	2-3	-1.743*	0.004	-2.455*	0.001	-0.99	0.202
	1-3	-1.073	0.361	-2.145*	0.028	-0.94	0.229
CondaxSH	1-2	1.430	0.596	3.386*	0.033	2.51	0.045
	2-3	-1.677	0.375	-1.109	1.000	-0.04	0.976
	1-3	-.247	1.000	2.277	0.303	2.47	0.093
Jaw specific measurements							
CoGo	1-2	2.107*	0.006	2.809*	0.002	-0.29	0.731
	2-3	5.723*	<0.001	7.441*	<0.001	2.55	0.011
	1-3	7.830*	<0.001	10.250*	<0.001	2.26	0.025
GoPog	1-2	2.910*	<0.001	3.432*	<0.001	0.25	0.752
	2-3	5.687*	<0.001	6.050*	<0.001	0.86	0.370
	1-3	8.597*	<0.001	9.482*	<0.001	1.11	0.246
CoPog	1-2	4.327*	<0.001	4.918*	<0.001	-0.56	0.605
	2-3	9.153*	<0.001	10.445*	<0.001	2.39	0.067
	1-3	13.480*	<0.001	15.364*	<0.001	1.83	0.161
CoGoMe	1-2	-.357	1.000	-1.450*	0.042	-1.19	0.058
	2-3	-1.317	0.097	-1.641	0.068	-0.26	0.729
	1-3	-1.673*	0.027	-3.091*	<0.001	-1.45	0.056
CondaxMP	1-2	-.567	1.000	-2.977	0.128	-2.55	0.056
	2-3	-1.030	1.000	-1.314	1.000	-0.32	0.841
	1-3	-1.597	0.558	-4.291*	0.010	-2.87	0.073
CoA	1-2	3.180*	<0.001	2.900*	<0.001	-0.38	0.531
	2-3	4.053*	<0.001	4.623*	<0.001	0.93	0.206
	1-3	7.233*	<0.001	7.523*	<0.001	0.55	0.457
ANSPNS	1-2	2.127*	0.005	2.823*	0.001	1.06	0.112
	2-3	3.203*	<0.001	3.123*	<0.001	-0.21	0.789
	1-3	5.330*	<0.001	5.945*	<0.001	0.85	0.288

Measure	Time	Females		Males		Mixed models regression	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
Relationship between teeth and jaws							
U1PP	1-2	7.997*	<0.001	3.641	0.102	-3.75	0.029
	2-3	4.213*	0.010	2.723	0.280	-0.72	0.725
	1-3	12.210*	<0.001	6.364*	0.009	-4.47	0.030
U1NAmm	1-2	2.760*	<0.001	2.186*	<0.001	-0.83	0.120
	2-3	1.580*	0.005	.341	1.000	-0.82	0.194
	1-3	4.340*	<0.001	2.527*	<0.001	-1.65	0.009
U1NA	1-2	7.200*	<0.001	2.941	0.219	-3.59	0.030
	2-3	2.883	0.082	.864	1.000	-1.65	0.399
	1-3	10.083*	<0.001	3.805	0.123	-5.24	0.008
U1SN	1-2	8.600*	<0.001	4.200*	0.040	-3.68	0.019
	2-3	2.923	0.068	2.427	0.302	-0.12	0.947
	1-3	11.523*	<0.001	6.627*	0.001	-3.81	0.042
L1NBmm	1-2	-.303	1.000	.041	1.000	0.20	0.631
	2-3	1.697*	<0.001	1.064*	0.026	-0.55	0.264
	1-3	1.393*	0.002	1.105	0.051	-0.36	0.473
L1NB	1-2	-2.563	0.132	-1.145	1.000	1.11	0.383
	2-3	3.803*	0.002	1.441	0.705	-2.21	0.148
	1-3	1.240	0.802	.295	1.000	-1.10	0.471
L1MP	1-2	-2.947	0.061	-1.741	0.692	1.25	0.341
	2-3	3.550*	0.007	1.373	0.884	-2.26	0.153
	1-3	.603	1.000	-.368	1.000	-1.01	0.523
Relationship between teeth							
U1L1	1-2	-6.347*	0.012	-3.159	0.611	2.32	0.284
	2-3	-5.243*	0.003	-1.523	1.000	3.77	0.146
	1-3	-11.590*	<0.001	-4.682	0.163	6.09	0.019
OB	1-2	.297	1.000	.436	1.000	-0.15	0.761
	2-3	.767	0.153	-.264	1.000	-0.67	0.238
	1-3	1.063*	0.008	.173	1.000	-0.81	0.151
OJ	1-2	5.313*	<0.001	3.968*	<0.001	-0.82	0.163
	2-3	-1.827*	0.003	-1.777*	0.017	-0.05	0.937
	1-3	3.487*	<0.001	2.191*	<0.001	-0.88	0.203
Symphyseal Components							
ASA	1-2	3.137*	0.002	2.218	0.092	-2.45	0.025
	2-3	4.367*	<0.001	4.736*	<0.001	1.47	0.267
	1-3	7.503*	<0.001	6.955*	<0.001	-0.99	0.455
PSA	1-2	-2.043	0.060	-2.532*	0.042	0.16	0.901
	2-3	-5.680*	<0.001	-4.191*	0.001	0.95	0.527
	1-3	-7.723*	<0.001	-6.723*	<0.001	1.11	0.461
TSA	1-2	1.083	0.653	-.300	1.000	-2.28	0.059
	2-3	-1.320	0.275	.536	1.000	2.51	0.084
	1-3	-.237	1.000	.236	1.000	0.22	0.877

Measure	Time	Females		Males		Mixed models regression	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
Soft Tissue Measurements							
Sagittal							
NsMsFH	1-2	.133	1.000	-.286	1.000	0.27	0.607
	2-3	-2.340*	<0.001	-2.300*	<0.001	2.51	0.084
	1-3	-2.207*	<0.001	-2.586*	<0.001	-0.26	0.679
NsSlsSlsPos	1-2	-1.567	1.000	-5.477	0.162	-0.83	0.784
	2-3	.063	1.000	-.868	1.000	-1.87	0.610
	1-3	-1.503	1.000	-6.345	0.061	-2.70	0.460
PnNs	1-2	2.620*	<0.001	3.568*	<0.001	0.17	0.763
	2-3	3.137*	<0.001	4.832*	<0.001	2.22	0.001
	1-3	5.757*	<0.001	8.400*	<0.001	2.40	0.001
NsSn	1-2	2.067*	0.010	2.845*	0.002	0.60	0.460
	2-3	3.043*	<0.001	3.241*	0.001	0.43	0.659
	1-3	5.110*	<0.001	6.086*	<0.001	1.03	0.291
NsSls	1-2	2.360*	<0.001	3.032*	<0.001	0.25	0.651
	2-3	.913	0.182	3.000*	<0.001	2.45	<0.001
	1-3	3.273*	<0.001	6.032*	<0.001	2.71	<0.001
NsLs	1-2	2.643*	<0.001	3.195*	<0.001	0.07	0.916
	2-3	1.573*	0.016	3.636*	<0.001	2.51	0.002
	1-3	4.217*	<0.001	6.832*	<0.001	2.58	0.001
NsSt	1-2	1.647*	0.007	2.455*	<0.001	-0.16	0.826
	2-3	2.097*	0.006	3.032*	0.001	1.71	0.053
	1-3	3.743*	<0.001	5.486*	<0.001	1.55	0.080
NsLi	1-2	.167	1.000	2.182*	0.009	0.56	0.499
	2-3	3.383*	<0.001	4.868*	<0.001	2.49	0.012
	1-3	3.550*	<0.001	7.050*	<0.001	3.05	0.002
NsIls	1-2	-.610	1.000	.868	0.936	0.12	0.889
	2-3	3.483*	<0.001	4.882*	<0.001	2.40	0.021
	1-3	2.873*	0.006	5.750*	<0.001	2.52	0.015
NsPos	1-2	-.160	1.000	1.550	0.371	-0.11	0.910
	2-3	4.600*	<0.001	5.973*	<0.001	2.65	0.027
	1-3	4.440*	<0.001	7.523*	<0.001	2.54	0.034
Vertical							
SnMs	1-2	3.107*	<0.001	4.573*	<0.001	0.89	0.168
	2-3	4.270*	<0.001	6.095*	<0.001	2.15	0.006
	1-3	7.377*	<0.001	10.668*	<0.001	3.04	<0.001
SnSt	1-2	1.110	0.075	1.427*	0.042	0.67	0.175
	2-3	.593	0.482	1.900*	0.001	1.11	0.062
	1-3	1.703*	<0.001	3.327*	<0.001	1.79	0.003
StMs	1-2	2.323*	<0.001	2.968*	<0.001	0.67	0.275
	2-3	3.823*	<0.001	4.664*	<0.001	0.88	0.233
	1-3	6.147*	<0.001	7.632*	<0.001	1.56	0.036

Measure	Time	Females		Males		Mixed models regression	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
NsMs	1-2	5.183*	<0.001	7.423*	<0.001	1.49	0.214
	2-3	7.307*	<0.001	9.418*	<0.001	2.63	0.069
	1-3	12.490*	<0.001	16.841*	<0.001	4.12	0.004
NsSnvert	1-2	2.067*	0.010	2.845*	0.002	0.60	0.460
	2-3	3.043*	<0.001	3.241*	0.001	0.43	0.659
	1-3	5.110*	<0.001	6.086*	<0.001	1.03	0.291
Thickness							
SnA	1-2	1.020*	0.012	1.159*	0.015	-0.09	0.832
	2-3	.793	0.224	1.909*	0.001	1.38	0.005
	1-3	1.813*	<0.001	3.068*	<0.001	1.30	0.009
PosPog	1-2	.340	0.565	.332	0.811	0.14	0.679
	2-3	.950*	0.003	.764	0.055	-0.21	0.590
	1-3	1.290*	<0.001	1.095*	0.004	-0.08	0.845
SlsA	1-2	1.413*	0.003	1.009	0.117	-0.19	0.697
	2-3	.800	0.289	1.705*	0.010	1.00	0.089
	1-3	2.213*	<0.001	2.714*	<0.001	0.81	0.170
IlsB	1-2	.860	0.064	.345	1.000	-0.36	0.354
	2-3	.347	0.875	1.109*	0.016	0.80	0.086
	1-3	1.207*	<0.001	1.455*	<0.001	0.44	0.345
Lip Morphology							
SnLsFH	1-2	3.200*	0.023	1.723	0.619	-0.48	0.756
	2-3	3.513*	0.004	.427	1.000	-3.27	0.078
	1-3	6.713*	<0.001	2.150	0.646	-3.75	0.043
LiIlsFH	1-2	-3.290	0.474	-5.336	0.156	-1.74	0.474
	2-3	4.203*	0.023	4.077	0.076	1.24	0.666
	1-3	.913	1.000	-1.259	1.000	-0.50	0.861
UEline	1-2	.987	0.127	.223	1.000	0.06	0.911
	2-3	-2.167*	<0.001	-1.736*	0.008	-0.08	0.893
	1-3	-1.180*	0.009	-1.514*	0.004	-0.02	0.968
LEline	1-2	-.573	0.633	.095	1.000	0.77	0.125
	2-3	-.947	0.062	-1.168*	0.045	-0.42	0.487
	1-3	-1.520*	0.002	-1.073	0.106	0.35	0.559

Table 4.18: Success vs Failure, test of between subjects effects. (mixed ANOVA)

Variables	Type III Sum of Squares	df	Mean Square	F	Sig.	Variables	Type III Sum of Squares	df	Mean Square	F	Sig.
Age	23.15	1.00	23.15	2.28	0.137	**Relationship between teeth**					
Cranial Base Measurements						U1L1	1.73	1.00	1.73	0.01	0.916
SN/H	54.01	1.00	54.01	1.74	0.193	OB	54.81	1.00	54.81	10.29	0.002
SN	3.25	1.00	3.25	0.10	0.751	OJ	103.54	1.00	103.54	17.62	<0.001
Sar	18.77	1.00	18.77	0.61	0.437	**Symphyseal Components**					
NSAr	16.71	1.00	16.71	0.27	0.608	ASA	0.67	1.00	0.67	0.00	0.944
Relationship between jaws, cranial base and horizontal						PSA	131.60	1.00	131.60	0.92	0.343
SNA	0.87	1.00	0.87	0.02	0.884	TSA	114.55	1.00	114.55	1.00	0.323
SNB	4.49	1.00	4.49	0.10	0.759	**Soft Tissue Measurements**					
ANB	1.34	1.00	1.34	0.15	0.696	***Sagittal***					
AoBo	276.22	1.00	276.22	15.57	<0.001	NsMsFH	1.87	1.00	1.87	0.07	0.799
A-Nperp	57.08	1.00	57.08	1.65	0.205	NsSls/SlsPos	680.81	1.00	680.81	1.23	0.274
B-Nperp	211.05	1.00	211.05	1.71	0.198	PnNs	77.83	1.00	77.83	1.89	0.175
NAPog	1.17	1.00	1.17	0.02	0.885	NsSn	53.05	1.00	53.05	0.90	0.348
ArGoMe	390.40	1.00	390.40	4.13	0.047	NsSls	80.46	1.00	80.46	1.41	0.240
PPMP	408.61	1.00	408.61	3.23	0.078	NsLs	116.26	1.00	116.26	1.74	0.194
PPH	12.41	1.00	12.41	0.46	0.501	NsSt	105.70	1.00	105.70	1.30	0.259
MPSN	575.39	1.00	575.39	4.56	0.038	NsLi	238.37	1.00	238.37	2.35	0.131
MPH	277.52	1.00	277.52	2.76	0.103	NsIls	193.52	1.00	193.52	1.67	0.203
Condylar Axis to H	49.13	1.00	49.13	1.35	0.252	NsPos	176.00	1.00	176.00	1.06	0.308
Jaw specific measurements						***Vertical***					
CoGo	12.21	1.00	12.21	0.26	0.612	SnMsStLFH	442.85	1.00	442.85	6.18	0.016
GoPog	191.39	1.00	191.39	2.94	0.092	SnSt	48.77	1.00	48.77	3.30	0.075
CoPog	762.59	1.00	762.59	5.90	0.019	StMs	326.36	1.00	326.36	7.93	0.007
CoGoMe	391.39	1.00	391.39	4.28	0.044	NsMs	820.44	1.00	820.44	4.18	0.046
Condylar Axis To MP	236.06	1.00	236.06	1.65	0.205	NsSn vert	53.05	1.00	53.05	0.90	0.348
CoA	29.85	1.00	29.85	0.80	0.375	***Thickness***					
ANSPNS	0.87	1.00	0.87	0.04	0.839	SnA	16.65	1.00	16.65	1.98	0.166
Relationship between teeth and jaws						PosPog	7.74	1.00	7.74	0.70	0.405
U1PP	28.19	1.00	28.19	0.22	0.638	SlsA	36.52	1.00	36.52	3.78	0.057
U1-NA	0.00	1.00	0.00	0.00	0.991	IlsB	16.12	1.00	16.12	1.52	0.223
U1/NA	101.18	1.00	101.18	1.13	0.292	***Lip Morphology***					
U1SN	83.02	1.00	83.02	0.64	0.427	SnLsFH	0.92	1.00	0.92	0.00	0.946
L1-NB	67.04	1.00	67.04	4.82	0.033	LiIlsFH	455.30	1.00	455.30	4.05	0.049
L1/NB	155.20	1.00	155.20	1.93	0.171	UEline	0.31	1.00	0.31	0.04	0.836
L1MP	183.18	1.00	183.18	1.32	0.256	LEline	2.07	1.00	2.07	0.18	0.677

Table 4.19: Comparison between Successful and Unsuccessful outcomes at T1 (repeated measures ANOVA)

Variables at T1	**Successful**		**Unsuccessful**		**S-U**		Variables at T1	**Successful**		**Unsuccessful**		**S-U**	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value		**Mean**	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	9.08	2.11	10.08	2.32	-1.00	0.194	**Relationship between teeth**						
Cranial Base Measurements							U1L1	136.95	10.22	135.16	9.50	1.79	0.616
SN/H	9.61	3.13	10.99	3.57	-1.38	0.228	OB	0.26	1.62	-0.47	3.09	0.73	0.298
SN	63.17	3.28	63.37	2.76	-0.20	0.862	OJ	-0.88	1.99	-2.46	3.04	1.58	0.048
Sar	29.18	3.26	29.99	2.74	-0.81	0.470	**Symphyseal Components**						
NSAr	123.18	4.79	123.25	6.35	-0.07	0.971	ASA	1.85	7.34	2.81	7.38	-0.96	0.712
Relationship between jaws, cranial base and horizontal							PSA	29.76	7.96	31.81	5.49	-2.05	0.446
SNA	78.73	3.35	79.02	3.92	-0.29	0.815	TSA	31.62	7.75	34.62	6.49	-3.00	0.264
SNB	78.96	3.16	79.00	4.96	-0.04	0.977	**Soft Tissue Measurements**						
ANB	-0.22	1.48	0.02	2.50	-0.24	0.687	***Sagittal***						
AoBo	-5.62	2.86	-8.21	4.01	2.59	0.021	NsMsFH	94.45	3.03	95.13	3.95	-0.68	0.552
A-Nperp	-1.40	2.93	0.00	3.19	-1.40	0.187	NsSls/SlsPos	147.76	13.85	140.92	21.42	6.84	0.216
B-Nperp	-2.10	5.28	-0.16	7.16	-1.94	0.335	PnNs	19.38	3.75	20.48	3.53	-1.10	0.403
NAPog	-1.33	4.04	-0.49	6.06	-0.84	0.595	NsSn	48.46	4.80	48.62	5.56	-0.16	0.926
ArGoMe	130.23	5.72	135.45	7.10	-5.22	0.017	NsSls	6.86	3.95	7.84	3.42	-0.98	0.475
PPMP	26.87	5.83	30.21	7.38	-3.34	0.128	NsLs	9.02	4.53	10.63	3.59	-1.61	0.301
PPH	1.71	2.41	1.82	3.06	-0.11	0.900	NsSt	4.44	4.69	5.81	5.12	-1.37	0.417
MPSN	34.75	5.52	39.37	7.21	-4.62	0.030	NsLi	9.08	5.25	10.99	6.24	-1.91	0.324
MPH	25.15	5.15	28.38	5.53	-3.23	0.085	NsIls	2.91	5.44	4.56	6.42	-1.65	0.410
Condylar Axis to H	70.79	4.81	71.24	5.21	-0.45	0.795	NsPos	3.58	6.42	5.60	6.80	-2.02	0.380
Jaw specific measurements							***Vertical***						
CoGo	49.47	4.30	49.20	2.67	0.27	0.851	SnMsStLFH	58.41	4.95	60.81	3.82	-2.40	0.159
GoPog	66.33	5.24	68.17	5.30	-1.84	0.323	SnSt	17.75	2.77	17.87	2.20	-0.12	0.895
CoPog	99.87	7.28	104.14	6.99	-4.27	0.100	StMs	42.41	3.80	44.78	3.26	-2.37	0.075
CoGoMe	125.60	5.75	130.70	5.87	-5.10	0.015	NsMs	106.87	8.86	109.43	7.10	-2.56	0.399
Condylar Axis To MP	132.46	7.05	136.84	6.02	-4.38	0.076	NsSn vert	48.46	4.80	48.62	5.56	-0.16	0.926
CoA	75.34	3.97	77.08	3.81	-1.74	0.215	***Thickness***						
ANSPNS	42.30	3.64	43.22	1.46	-0.92	0.437	SnA	13.84	2.08	13.81	1.27	0.03	0.968
Relationship between teeth and jaws							PosPog	10.39	2.02	11.29	1.99	-0.90	0.211
U1PP	107.30	10.01	108.64	6.73	-1.34	0.690	SlsA	15.06	2.26	15.16	1.66	-0.10	0.901
U1-NA	2.86	2.29	2.16	2.95	0.70	0.415	IlsB	10.19	1.73	11.03	3.24	-0.84	0.257
U1/NA	20.67	8.67	20.45	7.47	0.22	0.941	***Lip Morphology***						
U1SN	99.40	9.02	99.46	8.83	-0.06	0.985	SnLsFH	97.84	9.75	100.63	6.70	-2.79	0.397
L1-NB	3.49	1.66	4.68	2.26	-1.19	0.063	LiIlsFH	54.73	11.30	57.88	6.48	-3.15	0.402
L1/NB	22.59	5.38	24.33	4.10	-1.74	0.344	UEline	-3.69	2.10	-3.72	2.02	0.03	0.968
L1MP	88.88	6.98	86.02	5.07	2.86	0.229	LEline	0.07	2.49	-0.01	2.13	0.08	0.922

Table 4.20: Comparison between Successful and Unsuccessful outcomes at T2 (repeated measures ANOVA)

Variables at T2	Successful		Unsuccessful		S-U		Variables at T2	Successful		Unsuccessful		S-U	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value		**Mean**	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	11.31	2.14	12.04	2.37	-0.73	0.349	**Relationship between teeth**						
Cranial Base Measurements							U1L1	131.25	9.19	133.11	8.75	-1.86	0.565
SN/H	9.76	3.17	11.36	3.50	-1.60	0.167	OB	0.79	2.19	-0.84	2.36	1.63	0.043
SN	64.52	3.29	64.82	3.76	-0.30	0.800	OJ	3.76	2.22	2.70	3.63	1.06	0.238
Sar	30.60	3.91	31.09	2.57	-0.49	0.711	**Symphyseal Components**						
NSAr	123.49	4.25	123.45	6.23	0.04	0.980	ASA	4.97	6.79	4.00	7.20	0.97	0.690
Relationship between jaws, cranial base and horizontal							PSA	27.29	7.89	30.50	3.96	-3.21	0.220
SNA	80.20	3.62	79.82	4.85	0.38	0.781	TSA	32.26	6.43	34.53	5.66	-2.27	0.311
SNB	78.73	3.88	78.62	5.79	0.11	0.943	**Soft Tissue Measurements**						
ANB	1.45	1.83	1.19	2.73	0.26	0.711	***Sagittal***						
AoBo	-2.54	2.95	-5.56	2.75	3.02	0.005	NsMsFH	94.50	3.50	94.71	3.16	-0.21	0.861
A-Nperp	0.03	3.41	1.04	4.34	-1.01	0.427	NsSls/SlsPos	143.69	15.37	141.27	17.85	2.42	0.667
B-Nperp	-2.37	6.68	-0.48	8.23	-1.89	0.446	PnNs	22.32	4.49	23.84	3.97	-1.52	0.330
NAPog	1.39	4.27	1.49	6.62	-0.10	0.951	NsSn	50.54	4.50	52.34	6.40	-1.80	0.301
ArGoMe	129.83	5.53	132.59	4.48	-2.76	0.150	NsSls	9.38	4.47	11.02	5.05	-1.64	0.313
PPMP	28.00	7.12	32.15	7.64	-4.15	0.109	NsLs	11.88	4.77	13.58	5.62	-1.70	0.332
PPH	2.35	3.20	3.14	4.20	-0.79	0.514	NsSt	6.38	5.25	7.97	6.60	-1.59	0.417
MPSN	35.41	6.46	40.34	8.96	-4.93	0.050	NsLi	10.10	6.20	12.01	6.81	-1.91	0.395
MPH	25.65	6.21	28.99	6.93	-3.34	0.141	NsIls	2.86	6.85	4.87	7.26	-2.01	0.413
Condylar Axis to H	72.62	5.42	75.30	4.33	-2.68	0.152	NsPos	4.20	8.02	5.90	9.24	-1.70	0.562
Jaw specific measurements							***Vertical***						
CoGo	51.81	5.41	51.86	3.56	-0.05	0.979	SnMsStLFH	61.79	5.53	66.02	4.95	-4.23	0.031
GoPog	69.25	4.83	72.20	5.62	-2.95	0.098	SnSt	18.59	2.92	20.81	1.52	-2.22	0.024
CoPog	104.41	7.44	108.87	8.22	-4.46	0.101	StMs	44.69	4.01	48.69	5.36	-4.00	0.011
CoGoMe	125.27	5.68	127.86	4.77	-2.59	0.188	NsMs	112.33	8.94	118.36	9.70	-6.03	0.065
Condylar Axis To MP	131.40	9.39	133.04	8.40	-1.64	0.615	NsSn vert	50.54	4.50	52.34	6.40	-1.80	0.301
CoA	78.71	3.93	78.84	4.61	-0.13	0.926	***Thickness***						
ANSPNS	45.06	3.63	44.20	2.03	0.86	0.476	SnA	14.65	2.07	15.99	2.73	-1.34	0.091
Relationship between teeth and jaws							PosPog	10.73	2.26	11.63	1.06	-0.90	0.227
U1PP	114.08	7.44	112.17	8.86	1.91	0.485	SlsA	15.92	2.05	18.02	2.65	-2.10	0.008
U1-NA	5.16	2.12	5.59	3.87	-0.43	0.632	IlsB	10.78	2.30	11.90	3.08	-1.12	0.200
U1/NA	26.47	5.92	24.15	8.74	2.32	0.316	***Lip Morphology***						
U1SN	106.66	6.38	103.99	10.69	2.67	0.306	SnLsFH	101.30	8.79	99.50	8.85	1.80	0.564
L1-NB	3.34	2.33	4.47	4.02	-1.13	0.242	LiIlsFH	50.05	7.64	55.89	7.22	-5.84	0.033
L1/NB	20.82	6.70	21.55	9.11	-0.73	0.775	UEline	-3.07	1.99	-2.88	1.59	-0.19	0.781
L1MP	86.68	8.32	82.59	9.23	4.09	0.177	LEline	-0.17	2.08	-0.48	2.80	0.31	0.698

Table 4.21: Comparison between Successful and Unsuccessful outcomes at T3 (repeated measures ANOVA)

Variables at T3	Successful		Unsuccessful		S-U	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	16.19	2.70	17.40	2.09	-1.21	0.192
Cranial Base Measurements						
SN/H	10.15	3.16	11.66	4.09	-1.51	0.208
SN	66.85	3.54	67.45	3.71	-0.60	0.635
Sar	32.13	3.51	33.47	3.19	-1.34	0.276
NSAr	123.66	5.12	121.14	7.04	2.52	0.201
Relationship between jaws, cranial base and horizontal						
SNA	80.67	3.81	81.33	5.26	-0.66	0.649
SNB	80.30	3.99	81.66	6.45	-1.36	0.396
ANB	0.38	2.15	-0.30	2.68	0.68	0.393
AoBo	-3.07	3.05	-7.59	3.26	4.52	<0.001
A-Nperp	0.81	3.86	3.00	4.91	-2.19	0.132
B-Nperp	0.65	7.06	5.67	9.96	-5.02	0.068
NAPog	-1.65	5.34	-1.94	5.47	0.29	0.881
ArGoMe	127.72	6.18	131.79	7.42	-4.07	0.078
PPMP	25.32	6.51	30.15	8.57	-4.83	0.053
PPH	1.77	3.50	3.02	4.86	-1.25	0.353
MPSN	33.72	6.62	38.79	9.70	-5.07	0.053
MPH	23.56	6.43	27.14	7.19	-3.58	0.128
Condylar Axis to H	71.48	5.02	72.62	3.54	-1.14	0.501
Jaw specific measurements						
CoGo	57.82	4.76	60.17	3.69	-2.35	0.151
GoPog	74.95	4.80	78.59	6.86	-3.64	0.054
CoPog	113.41	6.47	121.52	8.09	-8.11	0.001
CoGoMe	123.47	5.90	127.84	6.83	-4.37	0.047
Condylar Axis To MP	129.92	7.37	133.26	7.34	-3.34	0.204
CoA	82.75	3.56	84.20	4.11	-1.45	0.265
ANSPNS	47.97	3.11	48.47	1.06	-0.50	0.618
Relationship between teeth and jaws						
U1PP	117.81	6.28	115.14	9.52	2.67	0.282
U1-NA	6.24	1.81	6.54	4.07	-0.30	0.724
U1/NA	28.75	5.84	25.16	7.61	3.59	0.106
U1SN	109.43	6.10	106.49	11.51	2.94	0.263
L1-NB	4.47	2.41	7.14	3.60	-2.67	0.006
L1/NB	22.78	6.21	27.91	6.51	-5.13	0.024
L1MP	88.77	8.20	87.47	7.10	1.30	0.646

Variables at T3	Successful		Unsuccessful		S-U	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value
Relationship between teeth						
U1L1	128.11	8.38	127.24	11.90	0.87	0.788
OB	1.22	0.83	-0.94	1.32	2.16	<0.001
OJ	2.44	0.76	-1.12	2.79	3.56	<0.001
Symphyseal Components						
ASA	9.40	7.51	8.91	7.17	0.49	0.852
PSA	22.52	7.68	24.26	7.30	-1.74	0.520
TSA	31.92	6.50	33.18	6.28	-1.26	0.582
Soft Tissue Measurements						
Sagittal						
NsMsFH	92.23	3.30	92.17	4.55	0.06	0.964
NsSls/SlsPos	144.17	15.85	137.52	14.69	6.65	0.233
PnNs	25.94	3.83	28.69	4.98	-2.75	0.060
NsSn	53.54	4.66	56.01	6.93	-2.47	0.178
NsSls	10.94	5.24	13.79	5.94	-2.85	0.138
NsLs	14.03	5.62	17.29	6.52	-3.26	0.116
NsSt	8.55	6.03	11.85	7.62	-3.30	0.145
NsLi	13.40	6.59	19.00	8.25	-5.60	0.026
NsIls	6.39	7.15	11.21	8.41	-4.82	0.070
NsPos	8.87	8.49	13.24	10.91	-4.37	0.173
Vertical						
SnMsStLFH	66.45	5.39	72.65	5.58	-6.20	0.002
SnSt	19.79	2.45	21.70	1.89	-1.91	0.026
StMs	48.75	4.18	53.39	4.23	-4.64	0.003
NsMs	119.99	8.47	128.85	9.77	-8.86	0.006
NsSn vert	53.54	4.66	56.01	6.93	-2.47	0.178
Thickness						
SnA	15.95	1.94	17.13	2.37	-1.18	0.104
PosPog	11.79	2.13	11.69	2.21	0.10	0.892
SlsA	17.22	2.28	18.71	3.00	-1.49	0.087
IlsB	11.57	1.50	12.05	2.75	-0.48	0.449
Lip Morphology						
SnLsFH	103.24	9.17	102.83	8.72	0.41	0.899
LiIlsFH	54.55	7.95	58.57	4.97	-4.02	0.135
UEline	-4.92	2.27	-5.42	2.10	0.50	0.530
LEline	-1.52	2.29	-0.25	3.22	-1.27	0.153

Table 4.22: Pairwise comparison between Successful and Unsuccessful outcomes across timepoints.

Measure	Time	Successful		Unsuccessful		Mixed models regression	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
Age	1-2	2.230*	<0.001	1.960*	0.001	-0.27	0.750
	2-3	4.878*	<0.001	5.362*	<0.001	0.48	0.567
	1-3	7.108*	<0.001	7.322*	<0.001	0.21	0.800
Cranial Base Measurements							
SNH	1-2	0.15	0.546	0.37	0.345	0.22	0.530
	2-3	.390*	0.039	0.30	1.000	-0.09	0.794
	1-3	.543*	0.020	0.67	0.281	0.13	0.714
SN	1-2	1.343*	<0.001	1.450*	0.009	0.11	0.840
	2-3	2.333*	<0.001	2.630*	<0.001	0.30	0.576
	1-3	3.676*	<0.001	4.080*	<0.001	0.40	0.447
SAr	1-2	1.429*	<0.001	1.10	0.342	-0.33	0.676
	2-3	1.524*	<0.001	2.380*	0.006	0.86	0.276
	1-3	2.952*	<0.001	3.480*	<0.001	0.53	0.502
NSAr	1-2	0.31	1.000	0.20	1.000	-0.11	0.937
	2-3	0.17	1.000	-2.31	0.183	-2.48	0.069
	1-3	0.47	1.000	-2.11	0.477	-2.58	0.058
Relationship between jaws, cranial base and horizontal							
SNA	1-2	1.467*	<0.001	0.80	0.326	-0.67	0.286
	2-3	0.47	0.309	1.510*	0.036	1.04	0.095
	1-3	1.936*	<0.001	2.310*	0.002	0.37	0.549
SNB	1-2	-0.24	1.000	-0.38	1.000	-0.14	0.844
	2-3	1.567*	<0.001	3.040*	<0.001	1.47	0.045
	1-3	1.331*	0.002	2.660*	0.003	1.33	0.071
ANB	1-2	1.679*	<0.001	1.17	0.130	-0.51	0.427
	2-3	-1.071*	0.001	-1.490*	0.036	-0.42	0.513
	1-3	0.61	0.154	-0.32	1.000	-0.93	0.148
AoBo	1-2	3.086*	<0.001	2.650*	0.043	-0.44	0.688
	2-3	-0.54	0.795	-2.03	0.130	-1.49	0.170
	1-3	2.548*	<0.001	0.62	1.000	-1.93	0.076
ANperp	1-2	1.426*	<0.001	1.04	0.125	-0.39	0.561
	2-3	.783*	0.022	1.960*	0.004	1.18	0.076
	1-3	2.210*	<0.001	3.000*	<0.001	0.79	0.233
BNperp	1-2	-0.27	1.000	-0.32	1.000	-0.05	0.969
	2-3	3.017*	<0.001	6.150*	<0.001	3.13	0.022
	1-3	2.750*	0.001	5.830*	0.001	3.08	0.024
NAPog	1-2	2.717*	<0.001	1.98	0.355	-0.74	0.595
	2-3	-3.040*	<0.001	-3.430*	0.027	-0.39	0.779
	1-3	-0.32	1.000	-1.45	0.812	-1.13	0.416

Measure	Time	Successful		Unsuccessful		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
ArGoMe	1-2	-0.40	1.000	-2.860*	0.008	-2.46	0.033
	2-3	-2.112*	0.001	-0.80	1.000	1.31	0.257
	1-3	-2.512*	<0.001	-3.660*	0.008	-1.15	0.321
PPMP	1-2	1.13	0.064	1.94	0.157	0.81	0.486
	2-3	-2.679*	<0.001	-2.00	0.205	0.68	0.559
	1-3	-1.548*	0.022	-0.06	1.000	1.49	0.200
PPH	1-2	0.65	0.093	1.32	0.094	0.67	0.398
	2-3	-0.58	0.396	-0.12	1.000	0.46	0.566
	1-3	0.07	1.000	1.20	0.431	1.13	0.156
MPSN	1-2	0.66	0.405	0.97	0.853	0.31	0.776
	2-3	-1.698*	0.001	-1.55	0.231	0.15	0.891
	1-3	-1.03	0.226	-0.58	1.000	0.45	0.673
MPH	1-2	0.50	0.845	0.61	1.000	0.11	0.918
	2-3	-2.090*	<0.001	-1.85	0.137	0.24	0.828
	1-3	-1.595*	0.025	-1.24	0.905	0.36	0.749
CondaxSH	1-2	1.83	0.165	4.06	0.114	2.23	0.292
	2-3	-1.14	0.639	-2.68	0.463	-1.54	0.467
	1-3	0.69	1.000	1.38	1.000	0.69	0.744
Jaw specific measurements							
CoGo	1-2	2.343*	<0.001	2.66	0.068	0.32	0.824
	2-3	6.007*	<0.001	8.310*	<0.001	2.30	0.106
	1-3	8.350*	<0.001	10.970*	<0.001	2.62	0.066
GoPog	1-2	2.917*	<0.001	4.030*	0.003	1.11	0.400
	2-3	5.710*	<0.001	6.390*	<0.001	0.68	0.607
	1-3	8.626*	<0.001	10.420*	<0.001	1.79	0.175
CoPog	1-2	4.540*	<0.001	4.730*	0.009	0.19	0.915
	2-3	8.998*	<0.001	12.650*	<0.001	3.65	0.040
	1-3	13.538*	<0.001	17.380*	<0.001	3.84	0.031
CoGoMe	1-2	-0.34	1.000	-2.840*	0.003	-2.50	0.018
	2-3	-1.795*	0.002	-0.02	1.000	1.78	0.094
	1-3	-2.133*	0.001	-2.860*	0.033	-0.73	0.494
CondaxMP	1-2	-1.06	0.937	-3.80	0.240	-2.74	0.228
	2-3	-1.48	0.420	0.22	1.000	1.70	0.455
	1-3	-2.54	0.051	-3.58	0.284	-1.04	0.646
CoA	1-2	3.371*	<0.001	1.76	0.160	-1.61	0.103
	2-3	4.040*	<0.001	5.360*	<0.001	1.32	0.182
	1-3	7.412*	<0.001	7.120*	<0.001	-0.29	0.768
ANSPNS	1-2	2.764*	<0.001	0.98	1.000	-1.78	0.102
	2-3	2.907*	<0.001	4.270*	<0.001	1.36	0.211
	1-3	5.671*	<0.001	5.250*	<0.001	-0.42	0.699

Measure	Time	Successful		Unsuccessful		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
Relationship between teeth and jaws							
U1PP	1-2	6.779*	<0.001	3.53	0.512	-3.25	0.269
	2-3	3.729*	0.007	2.97	0.648	-0.76	0.796
	1-3	10.507*	<0.001	6.50	0.126	-4.01	0.173
U1NAmm	1-2	2.300*	<0.001	3.430*	<0.001	1.13	0.203
	2-3	1.081*	0.034	0.95	0.792	-0.13	0.883
	1-3	3.381*	<0.001	4.380*	<0.001	1.00	0.261
U1NA	1-2	5.802*	<0.001	3.70	0.417	-2.10	0.444
	2-3	2.27	0.121	1.01	1.000	-1.26	0.646
	1-3	8.074*	<0.001	4.71	0.310	-3.36	0.221
U1SN	1-2	7.264*	<0.001	4.53	0.229	-2.73	0.305
	2-3	2.764*	0.034	2.50	0.753	-0.26	0.921
	1-3	10.029*	<0.001	7.030*	0.032	-3.00	0.261
L1NBmm	1-2	-0.15	1.000	-0.21	1.000	-0.06	0.922
	2-3	1.133*	<0.001	2.670*	<0.001	1.54	0.021
	1-3	.988*	0.008	2.460*	0.001	1.47	0.027
L1NB	1-2	-1.77	0.297	-2.78	0.610	-1.01	0.631
	2-3	1.96	0.073	6.360*	0.002	4.40	0.036
	1-3	0.19	1.000	3.58	0.185	3.39	0.107
L1MP	1-2	-2.20	0.118	-3.43	0.342	-1.23	0.584
	2-3	2.09	0.090	4.880*	0.043	2.79	0.214
	1-3	-0.11	1.000	1.45	1.000	1.56	0.488
Relationship between teeth							
U1L1	1-2	-5.700*	0.007	-2.05	1.000	3.65	0.320
	2-3	-3.15	0.058	-5.87	0.097	-2.72	0.458
	1-3	-8.845*	<0.001	-7.92	0.110	0.93	0.801
OB	1-2	0.53	0.406	-0.37	1.000	-0.90	0.211
	2-3	0.43	0.595	-0.10	1.000	-0.53	0.458
	1-3	.962*	0.003	-0.47	1.000	-1.43	0.046
OJ	1-2	4.645*	<0.001	5.160*	<0.001	0.51	0.582
	2-3	-1.326*	0.007	-3.820*	<0.001	-2.49	0.008
	1-3	3.319*	<0.001	1.34	0.251	-1.98	0.034
Symphyseal Components							
ASA	1-2	3.119*	<0.001	1.19	1.000	-1.93	0.210
	2-3	4.431*	<0.001	4.910*	0.001	0.48	0.755
	1-3	7.550*	<0.001	6.100*	<0.001	-1.45	0.346
PSA	1-2	-2.474*	0.003	-1.31	1.000	1.16	0.503
	2-3	-4.767*	<0.001	-6.240*	0.001	-1.47	0.397
	1-3	-7.240*	<0.001	-7.550*	<0.001	-0.31	0.859
TSA	1-2	0.64	1.000	-0.09	1.000	-0.73	0.662
	2-3	-0.34	1.000	-1.35	0.972	-1.01	0.545
	1-3	0.30	1.000	-1.44	1.000	-1.74	0.297

Measure	Time	Successful		Unsuccessful		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
Soft Tissue Measurements							
Sagittal							
NsMsFH	1-2	0.05	1.000	-0.42	1.000	-0.47	0.591
	2-3	-2.271*	<0.001	-2.540*	0.002	-0.27	0.756
	1-3	-2.226*	<0.001	-2.960*	0.004	-0.73	0.397
NsSlsSlsPos	1-2	-4.07	0.145	0.35	1.000	4.42	0.340
	2-3	0.48	1.000	-3.75	1.000	-4.23	0.361
	1-3	-3.59	0.217	-3.40	1.000	0.19	0.968
PnNs	1-2	2.940*	<0.001	3.360*	0.001	0.42	0.675
	2-3	3.617*	<0.001	4.850*	<0.001	1.23	0.218
	1-3	6.557*	<0.001	8.210*	<0.001	1.65	0.099
NsSn	1-2	2.081*	0.002	3.720*	0.006	1.64	0.230
	2-3	2.998*	<0.001	3.670*	0.014	0.67	0.623
	1-3	5.079*	<0.001	7.390*	<0.001	2.31	0.091
NsSls	1-2	2.517*	<0.001	3.180*	<0.001	0.66	0.492
	2-3	1.564*	0.002	2.770*	0.008	1.21	0.211
	1-3	4.081*	<0.001	5.950*	<0.001	1.87	0.053
NsLs	1-2	2.860*	<0.001	2.950*	0.002	0.09	0.934
	2-3	2.145*	<0.001	3.710*	0.001	1.56	0.154
	1-3	5.005*	<0.001	6.660*	<0.001	1.66	0.131
NsSt	1-2	1.948*	<0.001	2.16	0.061	0.21	0.860
	2-3	2.162*	0.001	3.880*	0.003	1.72	0.155
	1-3	4.110*	<0.001	6.040*	<0.001	1.93	0.110
NsLi	1-2	1.02	0.184	1.02	1.000	0.00	0.999
	2-3	3.302*	<0.001	6.990*	<0.001	3.69	0.008
	1-3	4.321*	<0.001	8.010*	<0.001	3.69	0.008
NsIls	1-2	-0.05	1.000	0.31	1.000	0.36	0.804
	2-3	3.536*	<0.001	6.340*	<0.001	2.80	0.056
	1-3	3.481*	<0.001	6.650*	<0.001	3.17	0.031
NsPos	1-2	0.63	1.000	0.30	1.000	-0.33	0.849
	2-3	4.667*	<0.001	7.340*	<0.001	2.67	0.119
	1-3	5.293*	<0.001	7.640*	<0.001	2.35	0.171
Vertical							
SnMs	1-2	3.374*	<0.001	5.210*	<0.001	1.84	0.093
	2-3	4.664*	<0.001	6.630*	<0.001	1.97	0.072
	1-3	8.038*	<0.001	11.840*	<0.001	3.80	0.001
SnSt	1-2	0.84	0.101	2.940*	0.001	2.10	0.009
	2-3	1.207*	0.005	0.89	0.723	-0.32	0.692
	1-3	2.048*	<0.001	3.830*	<0.001	1.78	0.026
StMs	1-2	2.283*	<0.001	3.910*	<0.001	1.63	0.106
	2-3	4.055*	<0.001	4.700*	<0.001	0.65	0.521
	1-3	6.338*	<0.001	8.610*	<0.001	2.27	0.024

Measure	Time	Successful		Unsuccessful		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (M-F)	P>|z|
NsMs	1-2	5.464*	<0.001	8.930*	<0.001	3.47	0.092
	2-3	7.655*	<0.001	10.490*	<0.001	2.84	0.168
	1-3	13.119*	<0.001	19.420*	<0.001	6.30	0.002
NsSnvert	1-2	2.081*	0.002	3.720*	0.006	1.64	0.230
	2-3	2.998*	<0.001	3.670*	0.014	0.67	0.623
	1-3	5.079*	<0.001	7.390*	<0.001	2.31	0.091
Thickness							
SnA	1-2	.817*	0.013	2.180*	0.001	1.36	0.059
	2-3	1.295*	0.004	1.14	0.443	-0.16	0.830
	1-3	2.112*	<0.001	3.320*	<0.001	1.21	0.094
PosPog	1-2	0.34	0.376	0.34	1.000	0.00	0.993
	2-3	1.064*	<0.001	0.06	1.000	-1.00	0.041
	1-3	1.400*	<0.001	0.40	1.000	-1.00	0.042
SlsA	1-2	.857*	0.032	2.860*	<0.001	2.00	0.014
	2-3	1.300*	0.007	0.69	1.000	-0.61	0.456
	1-3	2.157*	<0.001	3.550*	<0.001	1.39	0.089
IlsB	1-2	0.59	0.186	0.87	0.524	0.28	0.636
	2-3	.793*	0.019	0.15	1.000	-0.64	0.281
	1-3	1.381*	<0.001	1.02	0.052	-0.36	0.545
Lip Morphology							
SnLsFH	1-2	3.457*	0.002	-1.13	1.000	-4.59	0.051
	2-3	1.94	0.109	3.33	0.233	1.39	0.555
	1-3	5.398*	<0.001	2.20	1.000	-3.20	0.174
LiIlsFH	1-2	-4.67	0.059	-1.99	1.000	2.68	0.466
	2-3	4.500*	0.003	2.68	0.931	-1.82	0.620
	1-3	-0.17	1.000	0.69	1.000	0.86	0.815
UEline	1-2	0.62	0.391	0.84	0.946	0.22	0.795
	2-3	-1.852*	<0.001	-2.540*	0.009	-0.69	0.413
	1-3	-1.231*	0.001	-1.700*	0.038	-0.47	0.576
LEline	1-2	-0.25	1.000	-0.47	1.000	-0.22	0.778
	2-3	-1.343*	<0.001	0.23	1.000	1.57	0.047
	1-3	-1.590*	<0.001	-0.24	1.000	1.35	0.088

Table 4.23: Early versus late treatment initiation. Between subjects effect. (mixed ANOVA)

Variables	Type III Sum of Squares	df	Mean Square	F	Sig.	Variables	Type III Sum of Squares	df	Mean Square	F	Sig.
Age	240.79	1.00	240.79	41.60	<0.001	**Relationship between teeth**					
Cranial Base Measurements						U1L1	235.82	1.00	235.82	1.57	0.216
SN/H	83.31	1.00	83.31	2.74	0.104	OB	9.70	1.00	9.70	1.56	0.218
SN	187.66	1.00	187.66	6.63	0.013	OJ	0.06	1.00	0.06	0.01	0.930
Sar	23.46	1.00	23.46	0.77	0.385	**Symphyseal Components**					
NSAr	22.54	1.00	22.54	0.36	0.551	ASA	136.64	1.00	136.64	1.02	0.318
Relationship between jaws, cranial base and horizontal						PSA	1100.82	1.00	1100.82	8.85	0.005
SNA	0.16	1.00	0.16	0.00	0.950	TSA	462.47	1.00	462.47	4.28	0.044
SNB	0.03	1.00	0.03	0.00	0.981	**Soft Tissue Measurements**					
ANB	0.31	1.00	0.31	0.04	0.852	***Sagittal***					
AoBo	125.10	1.00	125.10	6.03	0.018	NsMsFH	5.50	1.00	5.50	0.19	0.662
A-Nperp	76.58	1.00	76.58	2.24	0.141	NsSls/SlsPos	148.88	1.00	148.88	0.26	0.610
B-Nperp	179.42	1.00	179.42	1.44	0.235	PnNs	421.75	1.00	421.75	12.30	0.001
NAPog	0.31	1.00	0.31	0.01	0.940	NsSn	610.47	1.00	610.47	12.71	0.001
ArGoMe	52.15	1.00	52.15	0.51	0.476	NsSls	389.19	1.00	389.19	7.66	0.008
PPMP	4.78	1.00	4.78	0.04	0.851	NsLs	470.08	1.00	470.08	7.85	0.007
PPH	9.06	1.00	9.06	0.34	0.565	NsSt	442.72	1.00	442.72	5.94	0.018
MPSN	205.85	1.00	205.85	1.54	0.220	NsLi	641.72	1.00	641.72	6.89	0.011
MPH	27.00	1.00	27.00	0.26	0.615	NsIls	548.06	1.00	548.06	5.02	0.029
Condylar Axis to H	124.03	1.00	124.03	3.54	0.066	NsPos	400.32	1.00	400.32	2.48	0.122
Jaw specific measurements						***Vertical***					
CoGo	385.09	1.00	385.09	9.79	0.003	SnMsStLFH	506.52	1.00	506.52	7.20	0.010
GoPog	569.26	1.00	569.26	9.91	0.003	SnSt	4.60	1.00	4.60	0.29	0.590
CoPog	1691.59	1.00	1691.59	15.28	<0.001	StMs	506.52	1.00	506.52	13.49	0.001
CoGoMe	62.83	1.00	62.83	0.64	0.427	NsMs	2244.29	1.00	2244.29	13.36	0.001
Condylar Axis To MP	0.02	1.00	0.02	0.00	0.992	NsSn vert	610.47	1.00	610.47	12.71	0.001
CoA	316.49	1.00	316.49	10.04	0.003	***Thickness***					
ANSPNS	74.49	1.00	74.49	3.83	0.056	SnA	73.53	1.00	73.53	10.10	0.003
Relationship between teeth and jaws						PosPog	7.37	1.00	7.37	0.67	0.417
U1PP	236.55	1.00	236.55	1.94	0.169	SlsA	88.65	1.00	88.65	10.30	0.002
U1-NA	35.58	1.00	35.58	3.37	0.072	IlsB	80.99	1.00	80.99	8.71	0.005
U1/NA	8.40	1.00	8.40	0.09	0.763	***Lip Morphology***					
U1SN	10.51	1.00	10.51	0.08	0.778	SnLsFH	12.75	1.00	12.75	0.06	0.801
L1-NB	56.28	1.00	56.28	3.98	0.051	LiIlsFH	1.10	1.00	1.10	0.01	0.925
L1/NB	140.79	1.00	140.79	1.74	0.193	UEline	0.14	1.00	0.14	0.02	0.891
L1MP	5.03	1.00	5.03	0.04	0.852	LEline	14.83	1.00	14.83	1.29	0.261

Table 4.24: Comparison between Early and Late treatment at T1. (repeated measures ANOVA)

Variables at T1	Early		Late		L-E		Variables at T1	Early		Late		L-E	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value		**Mean**	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	7.48	1.04	11.07	1.33	3.59	<0.001	**Relationship between teeth**						
Cranial Base Measurements							U1L1	139.40	10.79	133.81	8.48	-5.59	0.043
SN/H	9.17	2.96	10.58	3.38	1.41	0.117	OB	-0.49	2.24	0.72	1.44	1.21	0.025
SN	61.88	2.29	64.54	3.39	2.66	0.002	OJ	-1.05	2.04	-1.32	2.54	-0.26	0.684
Sar	28.54	3.06	30.12	3.12	1.58	0.071	**Symphyseal Components**						
NSAr	123.35	5.46	123.04	4.73	-0.31	0.829	ASA	0.80	7.04	3.27	7.45	2.48	0.224
Relationship between jaws, cranial base and horizontal							PSA	33.76	7.08	26.56	6.24	-7.20	<0.001
SNA	78.53	3.05	79.04	3.81	0.51	0.598	TSA	34.57	7.10	29.83	7.39	-4.73	0.023
SNB	78.60	2.60	79.35	4.27	0.75	0.448	**Soft Tissue Measurements**						
ANB	-0.06	1.26	-0.30	2.06	-0.24	0.617	***Sagittal***						
AoBo	-4.67	1.32	-7.57	3.90	-2.90	0.001	NsMsFH	95.04	2.05	94.13	4.03	-0.91	0.309
A-Nperp	-1.93	2.89	-0.33	2.94	1.60	0.054	NsSls/SlsPos	145.74	16.71	147.15	14.65	1.41	0.748
B-Nperp	-3.29	4.38	-0.17	6.42	3.12	0.046	PnNs	17.55	2.39	21.63	3.68	4.08	<0.001
NAPog	-0.76	3.54	-1.58	5.22	-0.82	0.509	NsSn	46.17	4.15	50.81	4.53	4.64	<0.001
ArGoMe	130.68	6.15	131.79	6.49	1.10	0.532	NsSls	5.34	3.00	8.76	3.88	3.42	0.001
PPMP	27.62	5.74	27.40	6.79	-0.22	0.899	NsLs	7.42	3.37	11.25	4.50	3.83	0.001
PPH	2.09	2.15	1.37	2.83	-0.72	0.307	NsSt	3.03	3.71	6.37	5.16	3.34	0.010
MPSN	34.69	5.53	36.59	6.57	1.90	0.265	NsLi	7.15	3.79	11.75	5.93	4.59	0.002
MPH	25.53	4.88	26.02	5.83	0.48	0.746	NsIls	0.97	4.29	5.48	5.95	4.51	0.003
Condylar Axis to H	70.05	4.87	71.71	4.74	1.66	0.219	NsPos	1.79	5.31	6.14	6.90	4.35	0.014
Jaw specific measurements							***Vertical***						
CoGo	47.51	3.19	51.33	3.90	3.82	<0.001	SnMsStLFH	56.63	4.53	61.12	4.03	4.49	<0.001
GoPog	63.70	4.02	69.66	4.64	5.96	<0.001	SnSt	17.51	2.63	18.03	2.70	0.52	0.483
CoPog	96.22	5.64	105.17	6.06	8.96	<0.001	StMs	40.97	3.57	44.76	3.02	3.78	<0.001
CoGoMe	126.07	5.77	127.10	6.41	1.02	0.548	NsMs	102.79	7.44	111.93	7.09	9.14	<0.001
Condylar Axis To MP	133.25	6.94	133.35	7.25	0.10	0.960	NsSn vert	46.17	4.15	50.81	4.53	4.64	<0.001
CoA	73.59	3.37	77.75	3.42	4.16	<0.001	***Thickness***						
ANSPNS	41.39	3.70	43.56	2.58	2.17	0.018	SnA	12.95	1.56	14.71	1.90	1.76	0.001
Relationship between teeth and jaws							PosPog	10.18	1.71	10.95	2.27	0.76	0.178
U1PP	105.06	8.39	110.05	9.89	4.99	0.055	SlsA	14.20	1.92	15.96	2.02	1.76	0.002
U1-NA	1.98	2.18	3.47	2.45	1.48	0.025	IlsB	9.58	1.49	11.12	2.34	1.53	0.007
U1/NA	19.44	8.30	21.82	8.46	2.37	0.312	***Lip Morphology***						
U1SN	97.98	7.85	100.84	9.78	2.86	0.250	SnLsFH	98.07	8.35	98.69	10.23	0.62	0.811
L1-NB	2.94	1.28	4.49	1.98	1.55	0.001	LiIlsFH	54.39	11.34	56.28	9.87	1.89	0.525
L1/NB	21.19	5.03	24.66	4.79	3.47	0.014	UEline	-3.42	2.25	-3.97	1.87	-0.55	0.346
L1MP	87.91	6.97	88.75	6.54	0.84	0.655	LEline	0.06	2.20	0.06	2.63	0.00	1.000

Table 4.25: Comparison between Early and Late treatment at T2. (repeated measures ANOVA)

Variables at T2	Early		Late		L-E		Variables at T2	Early		Late		L-E	
	Mean	SD	Mean	SD	Mean Diff	p-value		Mean	SD	Mean	SD	Mean Diff	p-value
Age	10.15	1.91	12.76	1.58	2.61	<0.001	**Relationship between teeth**						
Cranial Base Measurements							U1L1	131.87	8.89	131.35	9.38	-0.52	0.838
SN/H	9.36	3.12	10.78	3.31	1.43	0.116	OB	0.35	2.42	0.60	2.20	0.25	0.703
SN	63.37	2.60	65.78	3.61	2.41	0.008	OJ	3.29	2.47	3.83	2.63	0.54	0.447
Sar	30.09	3.53	31.31	3.78	1.22	0.235	**Symphyseal Components**						
NSAr	123.46	4.22	123.50	5.07	0.04	0.974	ASA	3.85	6.81	5.72	6.82	1.87	0.326
Relationship between jaws, cranial base and horizontal							PSA	30.50	6.80	25.32	7.14	-5.18	0.010
SNA	80.42	3.66	79.83	4.05	-0.58	0.588	TSA	34.35	6.27	31.05	6.01	-3.30	0.058
SNB	79.07	3.90	78.34	4.61	-0.73	0.540	**Soft Tissue Measurements**						
ANB	1.33	1.90	1.48	2.13	0.15	0.795	***Sagittal***						
AoBo	-2.58	2.43	-3.66	3.67	-1.08	0.216	NsMsFH	94.72	3.11	94.35	3.73	-0.37	0.700
A-Nperp	-0.18	3.60	0.62	3.60	0.80	0.429	NsSls/SlsPos	142.27	15.62	144.18	16.07	1.91	0.665
B-Nperp	-2.42	6.22	-1.60	7.72	0.82	0.675	PnNs	20.93	4.13	24.29	4.06	3.36	0.005
NAPog	1.48	4.50	1.33	5.03	-0.15	0.910	NsSn	48.75	3.95	53.02	4.89	4.28	0.001
ArGoMe	129.77	6.10	130.96	4.68	1.19	0.434	NsSls	8.37	4.11	11.02	4.73	2.64	0.036
PPMP	28.55	7.02	29.04	7.77	0.49	0.813	NsLs	10.77	4.23	13.64	5.24	2.87	0.035
PPH	3.13	3.28	1.88	3.43	-1.25	0.184	NsSt	5.24	4.61	8.13	6.00	2.89	0.057
MPSN	34.77	6.57	37.95	7.53	3.18	0.111	NsLi	8.83	5.53	12.10	6.69	3.27	0.061
MPH	25.42	5.80	27.17	7.00	1.75	0.331	NsIls	1.82	6.39	4.67	7.22	2.84	0.139
Condylar Axis to H	71.52	5.50	74.75	4.64	3.24	0.026	NsPos	3.48	7.31	5.58	9.03	2.11	0.359
Jaw specific measurements							***Vertical***						
CoGo	49.85	4.57	53.80	4.86	3.95	0.004	SnMsStLFH	60.52	5.75	64.68	4.77	4.16	0.007
GoPog	67.97	4.62	71.66	4.90	3.70	0.007	SnSt	18.78	2.70	19.24	3.01	0.46	0.566
CoPog	101.75	7.27	108.79	6.55	7.03	0.001	StMs	43.33	4.17	47.59	3.89	4.25	<0.001
CoGoMe	125.29	6.16	126.24	4.99	0.95	0.545	NsMs	109.28	8.39	117.70	8.33	8.43	0.001
Condylar Axis To MP	132.28	9.46	131.15	8.99	-1.13	0.662	NsSn vert	48.75	3.95	53.02	4.89	4.28	0.001
CoA	77.32	3.95	80.14	3.65	2.82	0.010	***Thickness***						
ANSPNS	44.11	3.14	45.68	3.50	1.57	0.095	SnA	14.18	1.83	15.64	2.42	1.46	0.017
Relationship between teeth and jaws							PosPog	10.60	1.90	11.21	2.28	0.61	0.299
U1PP	112.46	6.61	114.97	8.55	2.51	0.242	SlsA	15.51	1.97	17.14	2.36	1.63	0.009
U1-NA	4.64	2.28	5.85	2.61	1.21	0.081	IlsB	10.07	1.76	11.91	2.76	1.84	0.006
U1/NA	25.83	6.47	26.23	6.70	0.40	0.828	***Lip Morphology***						
U1SN	106.24	6.36	106.06	8.34	-0.18	0.932	SnLsFH	100.82	7.68	101.09	9.85	0.27	0.912
L1-NB	3.02	2.02	4.09	3.23	1.07	0.158	LiIlsFH	51.43	8.71	50.92	7.02	-0.52	0.815
L1/NB	20.99	6.51	20.94	7.83	-0.05	0.980	UEline	-2.97	1.92	-3.10	1.93	-0.13	0.802
L1MP	87.13	7.69	84.65	9.33	-2.48	0.300	LEline	-0.46	1.60	0.00	2.70	0.46	0.460

Table 4.26: Comparison between Early and Late treatment at T3. (repeated measures ANOVA)

Variables at T3	Early		Late		L-E	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value
Age	15.80	2.32	17.05	2.80	1.25	0.086
Cranial Base Measurements						
SN/H	9.67	3.18	11.22	3.44	1.55	0.098
SN	66.21	2.87	67.72	4.02	1.51	0.126
Sar	32.62	3.40	32.15	3.58	-0.47	0.627
NSAr	124.18	4.75	122.17	6.19	-2.02	0.194
Relationship between jaws, cranial base and horizontal						
SNA	80.66	3.79	80.93	4.41	0.27	0.814
SNB	80.61	4.24	80.51	4.87	-0.10	0.937
ANB	0.07	2.64	0.43	1.82	0.36	0.572
AoBo	-3.25	3.04	-4.64	3.93	-1.39	0.159
A-Nperp	0.33	3.83	2.13	4.27	1.81	0.114
B-Nperp	0.37	6.39	2.86	9.02	2.50	0.255
NAPog	-2.06	6.04	-1.36	4.57	0.70	0.638
ArGoMe	127.92	7.26	129.09	5.86	1.18	0.523
PPMP	25.86	6.59	26.64	7.73	0.78	0.695
PPH	1.75	3.89	2.28	3.72	0.53	0.620
MPSN	33.78	6.53	35.60	8.35	1.82	0.387
MPH	24.12	5.59	24.38	7.70	0.26	0.889
Condylar Axis to H	71.47	5.34	71.92	4.19	0.45	0.737
Jaw specific measurements						
CoGo	57.44	4.69	59.10	4.52	1.66	0.200
GoPog	74.75	4.96	76.56	5.72	1.81	0.229
CoPog	113.09	7.15	116.85	7.41	3.77	0.068
CoGoMe	123.39	6.52	125.23	5.99	1.84	0.295
Condylar Axis To MP	130.02	6.98	131.11	7.92	1.09	0.602
CoA	82.24	2.66	83.81	4.38	1.57	0.125
ANSPNS	47.86	3.28	48.27	2.34	0.41	0.605
Relationship between teeth and jaws						
U1PP	117.35	6.77	117.24	7.33	-0.11	0.955
U1-NA	6.22	2.22	6.38	2.53	0.17	0.799
U1/NA	28.75	6.60	27.37	6.03	-1.38	0.435
U1SN	109.43	6.64	108.30	8.17	-1.13	0.588
L1-NB	4.50	2.48	5.48	3.14	0.98	0.217
L1/NB	22.63	5.91	24.91	7.02	2.28	0.211
L1MP	88.24	7.50	88.80	8.52	0.57	0.801

Variables at T3	Early		Late		L-E	
	Mean	**SD**	**Mean**	**SD**	Mean Diff	p-value
Relationship between teeth						
U1L1	128.57	7.19	127.31	10.68	-1.27	0.618
OB	0.78	1.33	0.82	1.22	0.04	0.914
OJ	1.95	1.37	1.55	2.42	-0.40	0.467
Symphyseal Components						
ASA	8.67	7.44	9.94	7.41	1.27	0.542
PSA	24.63	6.75	21.08	8.05	-3.55	0.091
TSA	33.31	6.88	31.02	5.83	-2.30	0.200
Soft Tissue Measurements						
Sagittal						
NsMsFH	92.14	3.13	92.29	3.94	0.15	0.877
NsSls/SlsPos	141.62	16.24	144.16	15.39	2.54	0.565
PnNs	25.25	3.47	27.68	4.51	2.42	0.035
NsSn	52.53	4.34	55.49	5.61	2.95	0.039
NsSls	9.78	4.80	13.20	5.58	3.42	0.022
NsLs	12.80	5.14	16.51	6.08	3.72	0.021
NsSt	7.24	5.40	11.12	6.86	3.88	0.028
NsLi	12.33	6.26	16.63	7.55	4.31	0.030
NsIls	5.37	6.43	9.27	8.22	3.89	0.063
NsPos	8.13	7.92	11.29	9.96	3.15	0.212
Vertical						
SnMsStLFH	66.56	6.60	68.73	5.03	2.17	0.189
SnSt	20.13	2.59	20.18	2.37	0.05	0.942
StMs	48.25	5.19	51.03	3.33	2.77	0.026
NsMs	119.10	9.10	124.28	8.97	5.19	0.044
NsSn vert	52.53	4.34	55.49	5.61	2.95	0.039
Thickness						
SnA	15.73	1.88	16.63	2.17	0.90	0.116
PosPog	11.81	2.02	11.74	2.25	-0.07	0.908
SlsA	16.94	2.62	18.07	2.22	1.13	0.100
IlsB	11.18	1.43	12.14	1.99	0.95	0.053
Lip Morphology						
SnLsFH	102.75	9.83	103.57	8.27	0.82	0.746
LiIlsFH	55.76	6.64	54.89	8.56	-0.87	0.684
UEline	-5.45	2.52	-4.59	1.84	0.86	0.167
LEline	-1.97	1.88	-0.58	2.87	1.39	0.044

Table 4.27: Pairwise comparison between early and late treatment. (Repeated measures ANOVA)

		Early		Late		Mixed models analysis	
Measure	**Time**	Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (L-E)	p value
Age	1-2	2.43	<0.001	1.90	<0.001	-0.53	0.246
	2-3	5.65	<0.001	4.29	<0.001	5.75	<0.001
	1-3	8.32	<0.001	5.98	<0.001	-2.18	<0.001
Cranial Base Measurements							
SNH	1-2	0.31	0.618	0.29	0.490	-0.01	0.955
	2-3	0.31	0.333	0.43	0.084	0.15	0.551
	1-3	0.50	0.139	0.64	0.034	0.14	0.582
SN	1-2	1.49	<0.001	1.22	<0.001	-0.27	0.377
	2-3	2.84	<0.001	1.94	<0.001	-0.89	0.014
	1-3	4.33	<0.001	3.18	<0.001	-1.16	0.001
SAr	1-2	1.36	0.002	1.16	0.022	-0.19	0.672
	2-3	2.53	<0.001	0.84	0.158	-1.76	0.001
	1-3	4.08	<0.001	2.03	<0.001	-1.95	<0.001
NSAr	1-2	-0.03	1.000	0.33	1.000	0.36	0.650
	2-3	0.72	1.000	-1.34	0.235	-2.19	0.020
	1-3	0.83	1.000	-0.88	1.000	-1.84	0.052
Relationship between jaws, cranial base and horizontal							
SNA	1-2	1.85	<0.001	0.79	0.025	-1.05	0.012
	2-3	0.24	1.000	1.10	0.011	0.86	0.088
	1-3	2.13	<0.001	1.89	<0.001	-0.19	0.703
SNB	1-2	-0.15	0.587	-0.83	0.024	-0.67	0.132
	2-3	1.53	0.001	2.17	<0.001	0.22	0.680
	1-3	2.01	<0.001	1.16	0.056	-0.45	0.401
ANB	1-2	1.99	0.001	1.60	<0.001	-0.39	0.351
	2-3	-1.26	0.003	-1.05	0.015	0.72	0.146
	1-3	0.13	1.000	0.73	0.202	0.33	0.504
AoBo	1-2	2.91	0.004	3.46	<0.001	0.55	0.417
	2-3	-0.67	0.851	-0.98	0.355	0.11	0.887
	1-3	1.42	0.064	2.93	<0.001	0.66	0.407
ANperp	1-2	1.89	<0.001	1.03	0.008	-0.86	0.049
	2-3	0.50	0.483	1.52	<0.001	1.10	0.035
	1-3	2.26	<0.001	2.47	<0.001	0.24	0.646
BNperp	1-2	0.18	0.562	-0.94	0.101	-1.12	0.168
	2-3	2.78	0.002	4.46	<0.001	1.12	0.248
	1-3	3.65	0.001	3.03	0.006	0.01	0.995
NAPog	1-2	29.23	0.017	21.08	0.001	-0.72	0.427
	2-3	-3.54	<0.001	-2.69	0.003	1.80	0.098
	1-3	-1.30	0.326	0.22	1.000	1.08	0.322

Measure	Time	Early		Late		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (L-E)	p value
ArGoMe	1-2	-0.98	0.384	-0.96	0.499	0.01	0.986
	2-3	-1.85	0.029	-1.87	0.028	0.11	0.890
	1-3	-2.77	0.001	-2.70	0.002	0.13	0.878
PPMP	1-2	1.52	0.389	1.45	0.027	-0.06	0.929
	2-3	-2.70	0.001	-2.40	0.002	0.77	0.361
	1-3	-1.77	0.048	-0.76	0.867	0.71	0.402
PPH	1-2	1.21	0.020	0.80	0.526	-0.41	0.390
	2-3	-1.38	0.010	0.40	1.000	1.76	0.002
	1-3	-0.34	1.000	0.91	0.215	1.35	0.019
MPSN	1-2	0.62	1.000	0.97	0.046	0.35	0.580
	2-3	-0.99	0.182	-2.35	<0.001	-0.82	0.279
	1-3	-0.90	0.652	-0.99	0.534	-0.47	0.533
MPH	1-2	0.31	1.000	0.66	0.141	0.35	0.580
	2-3	-1.30	0.060	-2.79	<0.001	-0.96	0.212
	1-3	-1.42	0.181	-1.64	0.092	-0.61	0.430
CondaxSH	1-2	1.38	0.662	1.85	0.039	0.47	0.712
	2-3	-0.04	1.000	-2.83	0.044	-1.48	0.318
	1-3	1.43	0.802	0.22	1.000	-1.01	0.495
Jaw specific measurements							
CoGo	1-2	1.88	0.005	2.24	0.003	0.36	0.666
	2-3	7.60	<0.001	5.30	<0.001	-2.19	0.027
	1-3	9.93	<0.001	7.77	<0.001	-1.83	0.066
GoPog	1-2	3.73	<0.001	2.43	0.015	-1.30	0.082
	2-3	6.78	<0.001	4.90	<0.001	-2.43	0.006
	1-3	11.05	<0.001	6.90	<0.001	-3.73	<0.001
CoPog	1-2	4.65	<0.001	3.78	0.001	-0.87	0.401
	2-3	11.33	<0.001	8.07	<0.001	-3.69	0.003
	1-3	16.87	<0.001	11.68	<0.001	-4.55	<0.001
CoGoMe	1-2	-0.74	0.450	-0.74	0.344	0.01	0.992
	2-3	-1.90	0.013	-1.01	0.359	0.92	0.226
	1-3	-2.68	0.001	-1.87	0.023	0.93	0.223
CondaxMP	1-2	-0.86	1.000	-1.24	0.314	-0.37	0.781
	2-3	-2.26	0.223	-0.04	1.000	1.79	0.265
	1-3	-3.23	0.050	-2.24	0.274	1.41	0.378
CoA	1-2	3.65	<0.001	2.50	<0.001	-1.15	0.048
	2-3	4.92	<0.001	3.67	<0.001	-1.34	0.054
	1-3	8.65	<0.001	6.06	<0.001	-2.48	<0.001
ANSPNS	1-2	2.71	0.001	2.66	0.009	-0.06	0.930
	2-3	3.75	<0.001	2.59	<0.001	-1.48	0.059
	1-3	6.47	<0.001	4.71	<0.001	-1.54	0.050

Measure	Time	Early		Late		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (L-E)	p value
Relationship between teeth and jaws							
U1PP	1-2	6.14	<0.001	4.21	0.009	-1.93	0.265
	2-3	4.89	0.004	2.27	0.368	-3.13	0.126
	1-3	12.29	<0.001	7.18	0.001	-5.06	0.013
U1NAmm	1-2	2.32	<0.001	1.93	<0.001	-0.39	0.463
	2-3	1.58	0.010	0.53	0.902	-1.07	0.091
	1-3	4.23	<0.001	2.92	<0.001	-1.46	0.021
U1NA	1-2	5.21	<0.001	3.93	0.017	-1.28	0.447
	2-3	2.92	0.112	1.14	1.000	-2.58	0.193
	1-3	9.30	<0.001	5.55	0.007	-3.86	0.052
U1SN	1-2	7.05	<0.001	4.73	0.004	-2.32	0.143
	2-3	3.19	0.061	2.24	0.297	-1.54	0.413
	1-3	11.45	<0.001	7.46	<0.001	-3.85	0.040
L1NBmm	1-2	0.12	1.000	-0.24	0.925	-0.36	0.379
	2-3	1.47	0.001	1.38	0.001	-0.06	0.910
	1-3	1.56	0.001	0.98	0.058	-0.42	0.396
L1NB	1-2	-0.99	1.000	-2.69	0.018	-1.70	0.181
	2-3	1.64	0.431	3.97	0.002	1.70	0.260
	1-3	1.43	0.696	0.25	1.000	0.00	0.998
L1MP	1-2	-1.46	1.000	-2.84	0.007	-1.38	0.293
	2-3	1.10	1.000	4.15	0.003	2.04	0.193
	1-3	0.33	1.000	0.05	1.000	0.66	0.672
Relationship between teeth							
U1L1	1-2	-6.18	0.004	-2.84	0.818	3.34	0.126
	2-3	-3.30	0.161	-4.04	0.057	-0.05	0.986
	1-3	-10.83	<0.001	-6.50	0.017	3.30	0.203
OB	1-2	0.70	0.184	-0.04	1.000	-0.74	0.118
	2-3	0.43	0.931	0.23	1.000	-0.35	0.532
	1-3	1.27	0.002	0.10	1.000	-1.09	0.050
OJ	1-2	4.69	<0.001	4.27	<0.001	-0.42	0.477
	2-3	-1.33	0.060	-2.28	<0.001	-0.51	0.461
	1-3	3.01	<0.001	2.87	<0.001	-0.92	0.177
Symphyseal Components							
ASA	1-2	3.91	0.005	2.81	0.031	-1.10	0.320
	2-3	4.83	<0.001	4.22	<0.001	-0.47	0.721
	1-3	7.88	<0.001	6.67	<0.001	-1.57	0.235
PSA	1-2	-4.49	0.002	-1.15	0.509	3.34	0.005
	2-3	-5.87	<0.001	-4.23	<0.001	0.98	0.494
	1-3	-9.12	<0.001	-5.48	<0.001	4.32	0.003
TSA	1-2	-0.58	1.000	1.67	0.598	2.24	0.061
	2-3	-1.04	0.664	-0.03	1.000	0.44	0.756
	1-3	-1.25	0.687	1.18	0.770	2.69	0.060

Measure	Time	Early		Late		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (L-E)	p value
Soft Tissue Measurements							
Sagittal							
NsMsFH	1-2	-0.25	1.000	0.13	1.000	0.38	0.462
	2-3	-2.58	<0.001	-2.06	<0.001	0.60	0.330
	1-3	-2.90	<0.001	-1.83	0.004	0.99	0.112
NsSlsSlsPos	1-2	-3.65	0.553	-3.53	0.766	0.12	0.969
	2-3	-0.65	1.000	-0.02	1.000	1.00	0.783
	1-3	-4.12	0.310	-2.98	0.705	1.11	0.759
PnNs	1-2	3.22	<0.001	2.66	<0.001	-0.55	0.346
	2-3	4.32	<0.001	3.38	<0.001	-0.93	0.188
	1-3	7.70	<0.001	6.05	<0.001	-1.48	0.035
NsSn	1-2	2.06	0.002	1.85	0.010	-0.21	0.794
	2-3	3.79	<0.001	2.47	0.006	-1.23	0.199
	1-3	6.37	<0.001	4.68	<0.001	-1.44	0.133
NsSls	1-2	3.24	<0.001	1.98	<0.001	-1.26	0.029
	2-3	1.41	0.039	2.18	0.001	1.09	0.113
	1-3	4.44	<0.001	4.44	<0.001	-0.17	0.809
NsLs	1-2	3.62	<0.001	2.09	<0.001	-1.53	0.023
	2-3	2.02	0.005	2.87	<0.001	1.20	0.134
	1-3	5.38	<0.001	5.27	<0.001	-0.33	0.684
NsSt	1-2	2.38	0.001	1.59	0.008	-0.79	0.282
	2-3	2.00	0.017	2.98	<0.001	1.21	0.168
	1-3	4.21	<0.001	4.75	<0.001	0.42	0.632
NsLi	1-2	1.71	0.044	0.44	1.000	-1.27	0.129
	2-3	3.49	<0.001	4.53	<0.001	1.11	0.267
	1-3	5.17	<0.001	4.89	<0.001	-0.16	0.874
NsIls	1-2	0.70	0.839	-0.49	0.892	-1.19	0.169
	2-3	3.55	<0.001	4.60	<0.001	0.89	0.394
	1-3	4.40	<0.001	3.78	0.001	-0.31	0.768
NsPos	1-2	1.31	0.200	-0.15	1.000	-1.45	0.144
	2-3	4.66	<0.001	5.70	<0.001	0.68	0.567
	1-3	6.34	<0.001	5.15	<0.001	-0.77	0.518
Vertical							
SnMs	1-2	3.65	<0.001	3.44	<0.001	-0.21	0.749
	2-3	6.04	<0.001	4.05	<0.001	-1.95	0.014
	1-3	9.93	<0.001	7.61	<0.001	-2.16	0.006
SnSt	1-2	1.52	0.051	0.98	0.069	-0.54	0.291
	2-3	1.35	0.016	0.94	0.143	-0.14	0.822
	1-3	2.63	<0.001	2.15	<0.001	-0.67	0.266
StMs	1-2	2.73	<0.001	2.55	<0.001	-0.18	0.768
	2-3	4.92	<0.001	3.44	<0.001	-0.98	0.184
	1-3	7.28	<0.001	6.27	<0.001	-1.16	0.115

Measure	Time	Early		Late		Mixed models analysis	
		Mean Diff	Sig.[b]	Mean Diff	Sig.[b]	Coef. (L-E)	p value
NsMs	1-2	5.72	<0.001	5.28	<0.001	-0.44	0.711
	2-3	9.82	<0.001	6.58	<0.001	-3.11	0.030
	1-3	16.31	<0.001	12.35	<0.001	-3.56	0.013
NsSnvert	1-2	2.06	0.002	1.85	0.010	-0.21	0.794
	2-3	6.37	<0.001	4.68	0.006	-1.23	0.199
	1-3	3.79	<0.001	2.47	<0.001	-1.44	0.133
Thickness							
SnA	1-2	0.95	0.004	0.75	0.039	-0.20	0.640
	2-3	1.55	0.006	0.98	0.133	-0.60	0.222
	1-3	2.77	<0.001	1.92	<0.001	-0.80	0.105
PosPog	1-2	0.50	0.416	0.08	1.000	-0.42	0.187
	2-3	1.21	<0.001	0.53	0.193	-0.50	0.187
	1-3	1.62	<0.001	0.79	0.023	-0.93	0.015
SlsA	1-2	1.24	0.014	0.90	0.029	-0.33	0.497
	2-3	1.43	0.022	0.93	0.226	-0.38	0.512
	1-3	2.74	<0.001	2.11	<0.001	-0.72	0.217
IlsB	1-2	0.87	0.653	0.66	0.141	-0.21	0.589
	2-3	1.11	0.007	0.23	1.000	-0.52	0.257
	1-3	1.60	<0.001	1.02	0.001	-0.73	0.112
Lip Morphology							
SnLsFH	1-2	3.96	0.096	1.09	0.179	-2.87	0.063
	2-3	1.93	0.296	2.48	0.107	1.65	0.371
	1-3	4.68	0.019	4.88	0.013	-1.22	0.507
LiIlsFH	1-2	-4.63	0.708	-4.64	0.103	-0.02	0.994
	2-3	4.33	0.032	3.97	0.055	-1.46	0.607
	1-3	1.37	1.000	-1.38	1.000	-1.48	0.603
UEline	1-2	1.00	1.000	0.42	0.288	-0.58	0.251
	2-3	-2.48	<0.001	-1.49	0.013	1.49	0.013
	1-3	-2.02	<0.001	-0.62	0.341	0.91	0.129
LEline	1-2	-0.22	0.879	-0.25	1.000	-0.03	0.954
	2-3	-1.51	0.002	-0.57	0.524	1.23	0.038
	1-3	-2.03	<0.001	-0.63	0.456	1.20	0.042

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APPENDIX 1

Intra-class coefficient of all variables for repeated measurements in 10% of the sample

Intra Class Coefficient Table									
		95% Confidence Interval					95% Confidence Interval		
	Intraclass Correlation	Lower Bound	Upper Bound	Sig		Intraclass Correlation	Lower Bound	Upper Bound	Sig
Hard Tissue					Soft Tissue				
SN/H	.992[a]	.983	.996	.000	NsMsFH	.920[a]	.841	.961	.000
S-N	.993[a]	.986	.997	.000	NsSlsSlsPos	.949[a]	.894	.976	.000
S-Ar	.984[a]	.966	.992	.000	PnNs	.997[a]	.995	.999	.000
N/S/Ar	.984[a]	.966	.992	.000	NsSn	.984[a]	.958	.993	.000
SNA	.993[a]	.986	.997	.000	NsSls	.994[a]	.987	.997	.000
SNB	.991[a]	.981	.996	.000	NsLs	.997[a]	.992	.999	.000
ANB	.993[a]	.986	.997	.000	NsSt	.993[a]	.984	.997	.000
AoBo	.920[a]	.841	.961	.000	NsLi	.998[a]	.995	.999	.000
A-Nperp	.997[a]	.993	.998	.000	NsIls	.997[a]	.994	.999	.000
B-Nperp	.998[a]	.996	.999	.000	NsPos	.997[a]	.993	.999	.000
N/A/Pog	.931[a]	.861	.966	.000	SnMs	.999[a]	.996	1.000	.000
Ar/Go/Me	.994[a]	.988	.997	.000	SnSt	.947[c]	.850	.978	.000
PP/MP	.997[a]	.994	.999	.000	StMs	.998[a]	.994	.999	.000
PP/H	.998[a]	.995	.999	.000	NsMs	.997[a]	.992	.999	.000
MP/SN	.997[a]	.995	.999	.000	NsSnvert	.984[a]	.958	.993	.000
MP/H	.996[a]	.991	.998	.000	SnA	.966[a]	.925	.984	.000
Condax/H	.854[c]	.626	.937	.000	PosPog	.966[a]	.777	.989	.000
Co-Go	.942[a]	.838	.976	.000	SlsA	.934[a]	.866	.968	.000
Go-Pog	.957[a]	.896	.981	.000	IlsB	.957[a]	.911	.979	.000
Co-Pog	.997[a]	.994	.999	.000	SnLsFH	.955[a]	.905	.979	.000
Co/Go/Me	.997[a]	.993	.998	.000	LiIlsFH	.977[a]	.953	.989	.000
Condax/MP	.854[a]	.653	.935	.000	UEline	.979[a]	.956	.990	.000
Co-A	.954[a]	.906	.978	.000	LEline	.992[a]	.984	.996	.000
ANS-PNS	.921[c]	.790	.966	.000					
U1/PP	.993[a]	.984	.997	.000					
U1-NA	.996[a]	.992	.998	.000					
U1/NA	.992[a]	.983	.996	.000					
U1/SN	.993[a]	.986	.997	.000					
U1/L1	.990[a]	.886	.997	.000					
OB	.995[a]	.982	.998	.000					
OJ	.997[a]	.976	.999	.000					
ASA	.950[a]	.898	.976	.000					
PSA	.929[a]	.858	.966	.000					
TSA	.959[a]	.917	.980	.000					

APPENDIX 2

Intra-class coefficient for digitization comparison between scanner and camera methods

	Intraclass Correlation	95% Confidence Interval		Sig
		Lower Bound	Upper Bound	
Single Measures	.999[a]	.998	.999	.000
Average Measures	.999[c]	.999	1.000	.000