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DOMINANCE OF FACIAL COMPONENTS IN PREDICTING TREATMENT OUTCOME OF CLASS II, DIVISION 1 MALOCCLUSION

By

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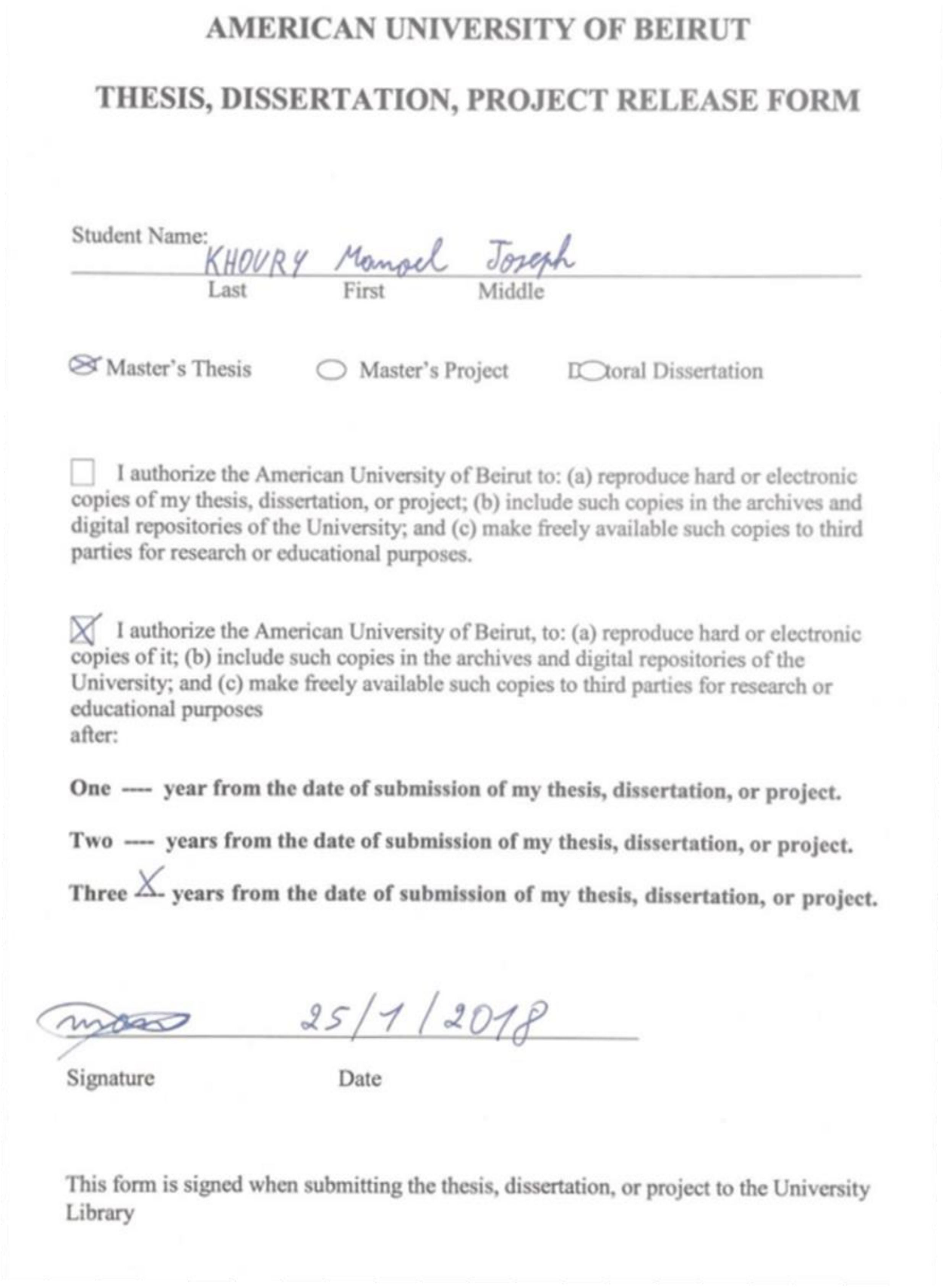

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First and foremost, I praise the almighty god for his endless blessings and to whom we owe our very existence!

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AN ABSTRACT OF THE THESIS OF

Manoel Joseph Khoury for Master of Science
Major: Orthodontics

Title: Dominance of facial components in predicting treatment outcome of Class II, division 1 malocclusion.

Introduction

Treatment outcome of Class II, division 1 (Class II/1) malocclusion associated with retrognathic mandible depends on several constitutional components rather than a prominent change in one of them. In a prior study, the cant of the anterior contour of the symphysis along with the ANB angle were shown to be good predictors of forward chin projection following Class II/1 orthopedic treatment started in prepubertal children.

Aims

1. Evaluate Class II treatment effect on the various facial components among growing and adult age groups, and between malocclusion severity subgroups; 2. Develop predictive models of treatment response (favorable vs unfavorable) based on objective cephalometric classifications and on the judgments of a panel of experts; 3. Explore the correspondence between the panel assessment of improvement of treated Class II/1 patients and different cephalometric outcome predictors.

Design

The research comprised 2 main parts; a cephalometric evaluation of the major facial components including variations in age groupings (growing and adult) and severity of malocclusion, and a panel assessment of the soft tissue facial profile in conjunction with the nature of treatment outcome.

Methods

A total of 179 patients recruited under strict inclusion criteria of Class II/1, and treated in the Division of Orthodontics and Dentofacial Orthopedics at AUBMC, were classified into 2 age groups (growing and adults) based on superimposition of T1 and T2 lateral cephalograms. The growing group was further divided into pre-pubertal and post-pubertal subjects based on the time of initiation of treatment (T1). Each age group was also stratified based on the ANB angle into severity categories (high: ANB between 4.5^0 and 6.5^o; low: ANB $\geq 6.6^o$) of the malocclusion. All patients must have reached Class I occlusion at the end of treatment (T2). Linear and angular measurements gauging relations among cranial base and both jaws were taken on pre- and post-treatment lateral cephalograms. Treatment responses were defined as “favorable” or “unfavorable” following two separate approaches: 1- Specific pre and post-treatment cephalometric classifiers related to facial/jaw sagittal relations (NA/Apog, ANB), mandibular position (SNB), chin projection (Pog-N perpendicular), upper lip position (Ulip-Eline) and inclination of the mandibular incisor (L1/MP) and, 2- Expert panel evaluating pre and post-treatment profile pictures of a subsample of 50 patients from among the total sample. Various appropriate statistical analyses were applied, including multivariate analyses to both the cephalometric data and to the panel data to determine pretreatment predictors of a favorable Class II/1 treatment outcome.

Results

Treatment effects on the various age categories resulted in more decrease in the skeletal discrepancy (ANB) in the pre- pubertal (-2°) than the post- pubertal (-1°) groups. Among adults, no change in this angle was observed (0.05°), but the maxillary incisors were significantly retroclined (-7.5°), more than in the post-pubertal group (≈-4°), while almost no retroclination occurred in the pre-pubertal group (-0.5°). The initially proclined mandibular incisors remained relatively stable after treatment. In only the growing group, the high severity subgroup the Class II phenotype was maintained (ANB = 5.56°), whereas the low severity subgroup demonstrated a move towards Class I phenotype (ANB = 3.95°). Correlations between overjet and ANB across severity and age categories at T1 were low ($0.006<r<0.206$). Based on the multivariate analyses in which different cephalometric classifiers were used, the significant predictors of treatment outcome involved mostly mandibular components. More specifically, the anterior chin slope angle and the chin extension were significantly associated with treatment response. Both components also emerged as predictors upon panel assessment. The only significant yet low correlation was found between the panel-determined profile improvement and change in ANB angle ($r\approx-0.28$; $p=0.049$).

Conclusion

In 2 novel approaches to the study of Class II/1 treatment outcome, the categorization on various cephalometric measurements and the panel assessments, the results indicated post-treatment maintenance of the Class II phenotype, particularly in the most severe malocclusion. The panel judgments indicated that the ANB angle is a prime classifier of Class II/1 treatment response. Various predictive equations pointed to mandibular components as predictors of outcome. Among these components, chin characteristics were dominant, including post-treatment increases in chin extension and the anterior chin slope angle. The overjet is not a reliable classifier of the severity of Class II/1 malocclusion, which is camouflaged by compensatory inclinations of the incisors. Most of the overjet correction resulted from the retraction of the maxillary incisors. The avoidance of further proclination of the originally proclined mandibular incisors reflected premeditated plans by the orthodontists, likely for periodontal and facial esthetic reasons. Future research should expand the boundaries of the methodology used in this study, by including larger samples, particularly in the set-up of panels to judge facial characteristics in relation to the underlying skeletal structures.

CONTENTS

Appendix

ILLUSTRATIONS

TABLES

ABBREVIATIONS

Class II/1	Class II, division 1
TMJ	Temporomandibular joint
NHP	Natural Head Position
FH	Frankfort Horizontal
mm	Millimeter
Niti	Nickel Titanium
Cl	Class
Coef.	Coefficient
Conf. Interval	Confidence. Interval
Tx	Treatment

CHAPTER 1

INTRODUCTION

With scientific developments and advanced clinical applications of new technologies, the objectives of orthodontic treatment have gradually departed from the beliefs that “excellent occlusion dictates proper facial esthetics” (Proffit et al, 2014), specifically when achieved at the expense of profile harmony.

The 3 main goals of orthodontic treatment are function, esthetics (dental and facial), and stability. Facial esthetics has risen to a higher ranking because of personal and societal demands. Accordingly, the main focus in treatment planning in contemporary orthodontics is on the enhancement of appearance, traditionally focusing on the facial profile in addition to the face, rather than targeting only dental alignment and occlusion. As in all medical specialties, the personalization of treatment remains a challenge, particularly in malocclusions combining skeletal dysmorphology underlying the dental/occlusal irregularities. Treatment of such problems is guided by central tendencies gathered from research, including investigations at the highest level on the evidence hierarchy. The assessment of treatment outcomes has redirected research into associating modalities and timing of treatment with successful outcome in the individual patient. Dentofacial orthopedics or growth modification aims to correct or reduce the severity of dentoskeletal discrepancies in growing children. Limitations to this modality are inherent to the growth potential of each individual patient determined by his genome.

Class II, division 1 malocclusion is characterized mainly by a retruded position of the mandible relative to the maxilla; its treatment outcome depends on the configuration and therapeutic response of constitutional components. Every malocclusion should be diagnosed on the basis of its multiple components instead of focusing on a major one, because the outcome of treatment encompasses the cumulative response of a number of components rather than a singular effect of one component (Efstratiadis et al, 2005; Ghafari and Macari, 2014). Growth modification, usually by enhancement of mandibular growth relative to the maxilla (differential growth) may avoid future orthognathic surgery after cessation of growth. Accordingly, prediction of craniofacial growth is a key element to a successful orthopedic treatment.

Unfortunately, despite contemporary attempts to anticipate growth, clinicians are still unable to accurately forecast the remaining amount of growth for individual malocclusions. The focus of the present research is to study the main craniofacial components of Class II, division 1 malocclusion that discriminate between favorable and unfavorable treatment responses, based on the post-treatment changes in these components. The scope of the research includes variations in age groupings (growing and adult), severity of malocclusion, and assessment of the soft tissue facial profile in conjunction with the nature of treatment outcome.

CHAPTER 2

LITERATURE REVIEW

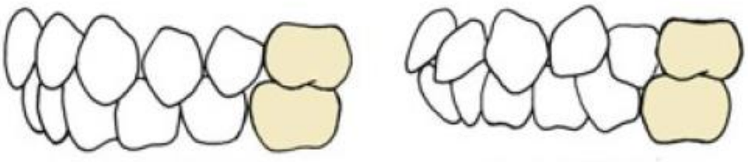
2.1. Concept of occlusion and malocclusion

As early as the 18th century, a concept of normal occlusion and irregularities between teeth and jaws were described by the anatomist John Hunter (Hunter, 1839). Later on, in the middle of the 19th century, a classification system describing abnormal relationships between dental arches including the terms "edge to edge ", "open occlusion", "protruding and retruding occlusion" and "zig-zag occlusion" was introduced by Georg Carabelli.

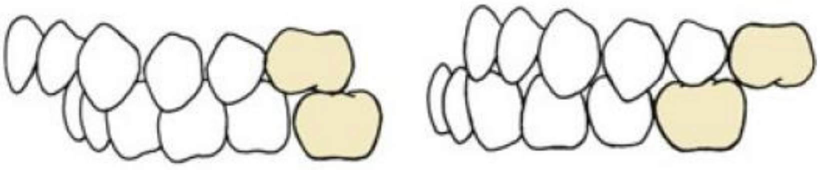
In the late 1800s, the concept of occlusion started to develop because of the need for prosthetic replacement of teeth. This interest in treating natural teeth to a normal occlusion happened at a time when a pioneer of that era, "Edward H. Angle", introduced a definition of malocclusion and of orthodontics as a specialty, for which he was considered as the "father of modern orthodontics" (Proffit et al, 2014).

Angle's three classes of malocclusion were based on the antero-posterior relationship of the first permanent molars in occlusion (Fig. 2.1). This classification was quickly and widely adopted early in the twentieth century. It is incorporated within all contemporary descriptive and classification schemes.

While commonly used to this day, the Angle classification was considered incomplete because it did not represent the myriad of encountered problems. Reported deficiencies included the lack of correlation between dentition and face or profile, the prevalence of sagittal rather than 3-dimensional analysis, the absence of differentiation between dentoalveolar and skeletal discrepancies, as well as the incorporation of arch deficiencies and the complexity of the problem. 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.



Normal occlusion Class I malocclusion



Class II malocclusion Class III malocclusion

Fig. 2.1: Normal occlusion and malocclusion classes as specified by Angle. The normal Class I neutroclusion is characterized by normal antero-posterior relation of the dental arches and jaws whereby the mesio-buccal cusp of the maxillary 1st permanent molar occlude in the central groove of the mandibular 1st permanent molar.
In Class I malocclusion, a normal relationship of the molars coexists with disharmony in the line of occlusion of the other teeth for a variety of conditions. The Class II malocclusion is defined by distally positioned mandibular first molar relative to the maxillary first molar and includes 2 divisions determined by the position of the maxillary incisors, which are protruded in the first and retruded in the second. In addition, Angle described a 'subdivision", based on the asymmetry of neutroclusion (molars being in Class I on one side and Class II on the other. 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, p. 7).

To overcome the major drawbacks of Angle's classification, Ackerman and Proffit (1969) described a system of diagnosis encompassing five major characteristics of malocclusion that account for skeletal deviations in the three planes of space, crowding, protrusion, asymmetry within dental arches, and most importantly profile consideration (Fig. 2.2). The classification succeeded in dissecting the complexities of malocclusions but was not practical for wide use in clinical practice.

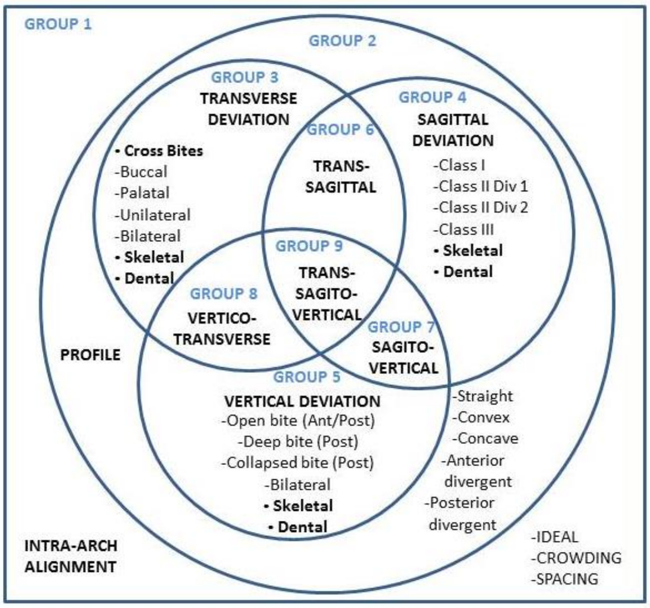


Fig. 2.2: Venn diagram of Ackermann and Proffit classification System.

Rather than establishing a simple and comprehensive classification of malocclusion, Andrews defined 6 keys to normal occlusion, in essence defining targets for the correction of malocclusion. These components 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.

2.2. Description and prevalence of the Class II, division 1 malocclusion

The Class II malocclusion is the most encountered clinical situation in any orthodontic practice in the U.S (Proffit et al, 1997). According to NHANES III, the prevalence of malocclusion of the U.S. population is the following: 50% to 55% of the population have Class I malocclusion, which constitute the largest group, followed by the Class II malocclusion encompassing around 15% of the population and finally the Class III malocclusion which represents less than 1% of the total population **(Fig. 2.3)** (Proffit et al, 1997). However, the classification was based on the amount of overjet, thus Class II prevalence would be greater than 15% because dentoalveolar compensation (proclined mandibular incisors and/or retroclined maxillary incisors) might camouflage the severity of the distoclusion.

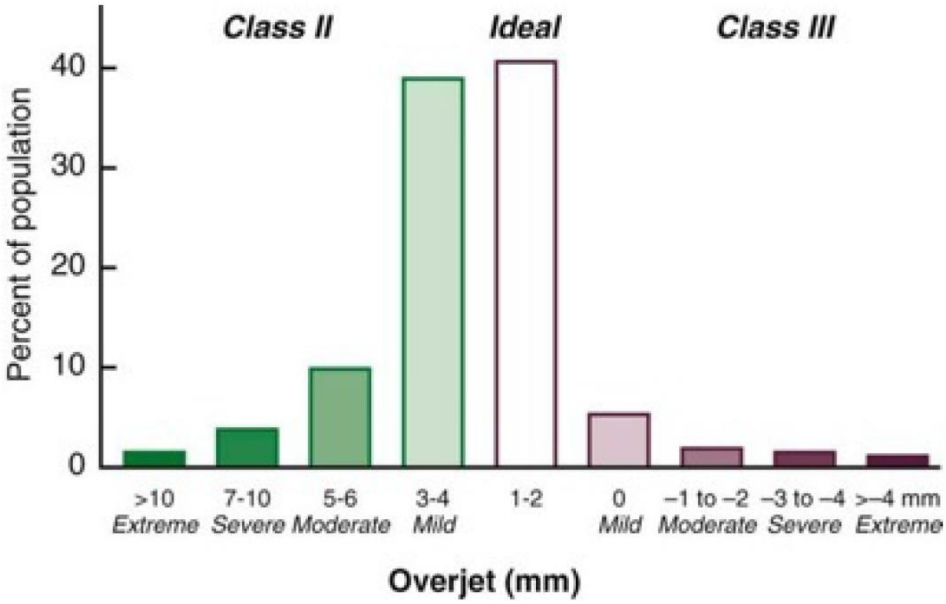


Fig. 2.3: Overjet (Class II) and reverse overjet (Class III) in the U.S. population, 1989-1994. Only one-third of the population has ideal anteroposterior incisor relationships, but overjet is only moderately increased in another one-third. Increased overjet accompanying Class II malocclusion is much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

This classification scheme has facilitated scientific and clinical communication and diagnosis. Because of the possibility of the sagittal malocclusion falling between a fully interdigitated Class I or Class II malocclusion, some authors have attempted to gauge the severity in various ways: measuring half and quarter cusps in quantifying the malocclusion for research purposes and assessment of treatment results (Snyder & Jerrold, 2007); creating comprehensive indices that encompass all the occlusal anomalies possibly present in a malocclusion including the amount of overjet and overbite (Richmond et al, 1992).

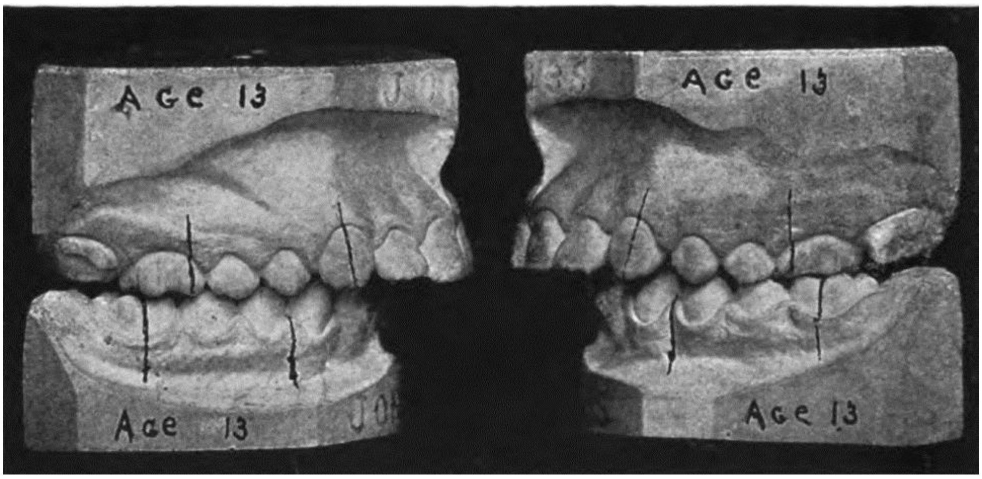
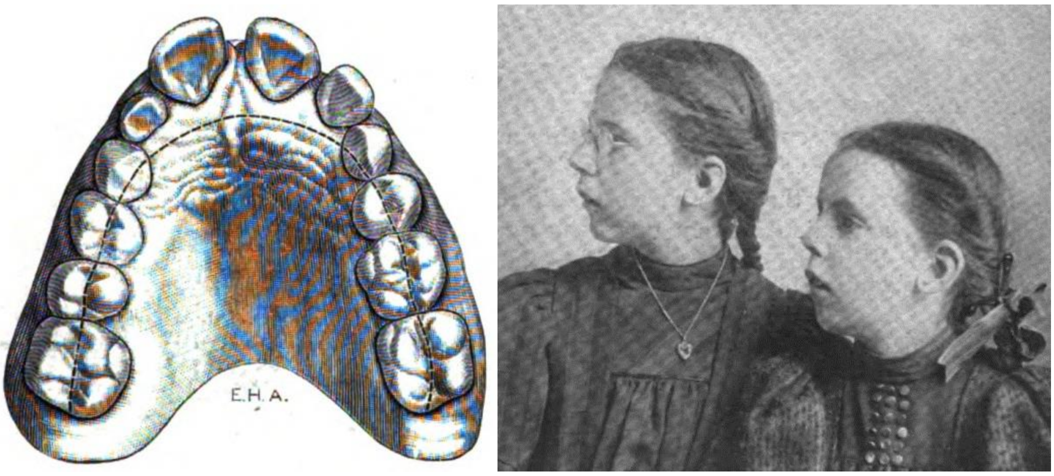


Fig. 2.4: Occlusion of a fully developed Class II, division 1 case showing the distoclusion of mandibular teeth in addition to the small and distally positioned mandible in relation to the maxilla. (Adapted from Angle, 1907, p. 46).

In Angle’s definition, the Class II malocclusion includes distally positioned mandibular teeth, and a distal position of the mandible itself (usually lesser than the normal size) relative to the maxilla (Fig. 2.4). He further underlined the major constituents of Class II division 1 malocclusion: 1- abnormally lengthened and narrowed maxillary arch, 2- lengthened and protruded maxillary incisors (Fig. 2.5A),



A **B**

Fig. 2.5: A, Abnormally lengthened and narrowed maxillary arch in Class II, division 1 malocclusion. Note the protruding incisors away from the normal curve of alignment. **B,** Profile outlines typical to Class II/1 malocclusion. Notice the convexity of the face and the lip incompetency associated with mouth breathing. (From Angle, 1907, p. 47, 48).

3- deep curve of spee due to greater compensation, mainly from the overeruption of mandibular incisors, 4- lengthened lower incisors, 5- short and functionless upper lip, 6- thickened and interposed lower lip (Angle, 1907). Angle pointed out the lack of facial harmony and impairment of the profile outline associated with the Class II/1 malocclusion (Fig. 2.5B). In almost a century following these descriptions, hundreds of studies confirmed the presence of these findings.

2.3. Cephalometric characteristics of Class II malocclusion

Radiographic cephalometry, introduced independently by Hofrath in Germany and Broadbent in the United States in 1931 when each, independently, designed for the first time an accurate cephalostat machine that permitted precise registration of the radiographic images (Fig. 2.6) (Johnson & Eid, 1979). This innovation provided more scientific solutions to orthodontic malocclusions and their underlying skeletal discrepancies and expanded our understanding of growth patterns in the craniofacial complex through research (Broadbent, 1981).

Cephalometric radiography has allowed orthodontists to identify the relationship between the major facial components (cranial base, jaws, and teeth) for diagnostic purposes with great precision. In addition, serial cephalometric radiographs taken throughout treatment can be thoroughly evaluated using superimposition methods that identify structural changes resulting from growth and treatment mechanics (except in non-growing patients) (Proffit et al, 2014). Accordingly, the skeletal and dentoalveolar components of the Class II, division 1 malocclusion have been delineated in much detail in major cephalometric studies. Five principal components were described: mandibular skeletal position, maxillary skeletal position, maxillary dentoalveolar position, mandibular dentoalveolar position, and vertical development (anterior facial height) (McNamara, 1981). More specifically, multiple morphological variations in the dentofacial complex are responsible for the development of the Class II, division 1 malocclusion:

1- Prognathic maxilla along with anteriorly positioned maxillary dentition relative to the cranium,

2- Orthognathic maxilla along with anteriorly positioned maxillary dentition,

3- Small orthognathic mandible,

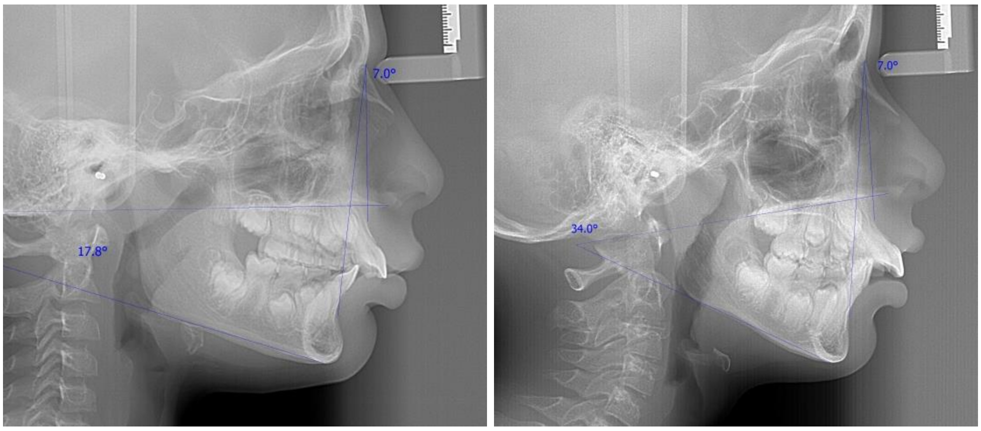
4- Retrognathic mandible of normal size,

5- Orthognathic mandible along with posteriorly positioned mandibular dentition.

Many other combinations could be present, entailing dentoalveolar compensation for the underlying skeletal discrepancies, which can be therapeutically challenging insofar as their severity (Fisk et al, 1953).

Controversial results were reported in the literature but common findings were that mandibular skeletal retrognathism along with maxillary dental protrusion are significant factors behind the development of Class II profiles. Despite wide variations in the vertical dimension, nearly half of Class II profiles presented excessive vertical development (Fig. 2.7) (McNamara, 1981).

Therefore, a Class II malocclusion is the result of multiple anatomical variations in skeletal and dentoalveolar components; however, mandibular skeletal retrusion was shown to be the most prevalent characteristic (McNamara, 1981, Anderson, 1983; Kerr, 1987; Varella 1998). In addition, some studies associated the retruded mandibular position with short mandibular length (Baccetti et al, 1997). The sum of these features define a specific phenotype where, during the diagnosis, it is important to evaluate its components to end up with a targeted treatment plan that achieves the best functional, esthetic and stable results (Ghafari & Macari, 2014).



A B

Fig. 2.6: A, Lateral cephalogram of a patient having Class II/1 with an ANB angle of 7˚ and a hypodivergent skeletal pattern. **B,** Lateral cephalogram of a patient having Class II/1 with an ANB angle of 7˚ and a hyperdivergent skeletal pattern.

2.4. Etiology of Class II, division 1 malocclusion

In his brief description of Class II division 1, Angle did not miss the importance of the etiology when he stated: it is “primarily, at least, associated with mouth-breathing”. Malocclusion results from a mild to moderate deviation of normal development. It is the sum of multifactorial interactions between hereditary and environmental influences that affect growth and development of the jaws. Sometimes, past events or a systemic condition can lead to the development of a malocclusion, such as mandibular underdevelopment secondary to a previous fracture during childhood or to growth deficiency related to some genetic syndromes (Proffit et al, 2014). Congenital syndromes characterized by a Class II malocclusion include hemifacial macrosomia, Treacher Collins, achondroplasia, Mobius and many other widely known syndromes (Shaughnessy & Shire, 1988).

Mandibular deficiency plays a major role in the establishment of distocclusion. Approximately 5 to 10% of severe mandibular growth deficit and/or asymmetry were closely related to previous trauma to the temporomandibular complex and fracture of the mandibular condyle (Proffit, 1980). In some instances, condylar fracture in childhood may be overlooked, leading limited mandibular motion. Partial ankylosis of the mandible impedes translational movements and restricts normal growth.

Many authors evaluated the association between cranial base length and angulation with the sagittal relationship of the jaws, based on the assumption that the cant of the anterior cranial base affects the maxillary position whereas the posterior cranial base affects the position of the mandible (Dhopatkar et al, 2002). A long anterior cranial base would lead to the midface protrusion, whereas a long posterior cranial base would position the TMJ more posteriorly and lead to mandibular retrognathia (Shaughnessy & Shire, 1988). The Class II, division 1 malocclusion was also accompanied with higher linear and angular measurements of the cranial base compared to other malocclusions, which would also place the mandible in a more retruded position compared to the maxilla (Fig.2.7) (Hopkin et al, 1968; Ghafari et al, 2011; Ghafari and Macari, 2014). The cranial base angle was found to be the best discriminating variable between Class I and Class II malocclusions. In almost 73% of cases, cranial base angle at age of 5 years was a good predictor of the patient's occlusion at age of 15 years old (Kerr & Hirst, 1987).

In contrast, other authors found similarity in the growth pattern of the cranial base among both skeletal Class I and Class II subjects and no association between the cranial base angle and the type of malocclusion, contradicting the previous description of more obtuse angulation of the cranial base in skeletal Class II subjects (Wilhelm et al, 2001; Guyer et al, 1986).

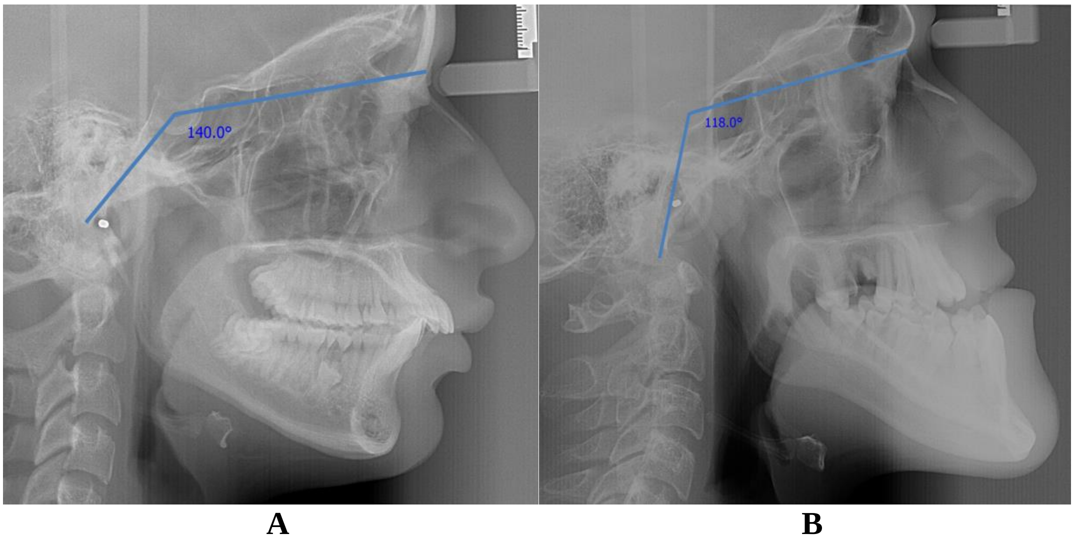


Fig. 2.7: Lateral cephalograms of two patients showing higher cranial base angle in the Class II/1 patient (**A**) than the Class III patient (**B**).

Based on genetic studies, 40% of common dentofacial variations in tooth malposition and malocclusion between dental arches were related to genetic factors that dictate variability between individuals (Lundstrom, 1984). However, other studies in which twin models were used to estimate genetic variability have indicated that a significant amount of concealed environmental influences might induce the development of malocclusions. The same studies failed to demonstrate significant heritability for dental overjet, indirectly eliminating the dominance of genetic over environmental factors in the establishment of some features of the Class II division 1 malocclusion (Corruccini & Potter, 1980). Therefore, it seems that a dental Class II is more likely to be the result of local environmental factors, whereas a skeletal Class II with underlying skeletal dysplasia is less likely to be influenced by these factors. In other words, inter-arch problems are due to genetic predisposition and intra-arch problems are mostly shaped by environmental factors (Shaughnessy & Shire, 1988). Among these, oral habits can be associated with any type of malocclusion, predominantly the Class II malocclusion (Ferreira, 2012). Also, Angle stated without much of evidence that mouth breathing related to blockage of the adenoids at an early age, leads to the development of the Class II division 1 malocclusion (Angle, 1907).

Mouth breathing is known to cause a cascade of events that alters the myofunctional equilibrium and leads to an increased overjet, anterior open bite and posterior crossbite without necessary inducing a Class II malocclusion. This conclusion was confirmed by Harvold's experiment of inducing obligatory mouth breathing in monkeys, which resulted in different malocclusions, comprising Class III (Harvold et al, 1981). At least two environmental factors have been recognized in the development and worsening of Class II, division 1 malocclusion. Sustained digit sucking would lead to protrusion of maxillary incisors and retrusion of mandibular incisors, producing an increased overjet which is the most important expression of the malocclusion (Ghafari and Macari, 2014). On the other hand, sustained mouth breathing would lead to changes in some skeletal and soft tissue components of the face (head, mandible and tongue posture), causing a steep mandibular plane, large gonial angles and increased anterior lower facial height (Harvold et al, 1981). In extreme situations, these manifestations will lead to the development of the long face syndrome (also known as adenoid facies) (Fig. 2.8), which will aggravate the phenotypic expression of a present Class II, division 1 malocclusion (Ghafari and Macari, 2014).

Fig. 2.8: Morphological characteristics of the ‘long face’ syndrome in a 10 years and 10 months old girl with chronic mouth breathing. Extraoral photographs (a–d) reveal lip incompetency, increased lower facial height, narrow nose base width and shadows under the eyes from chronic venous congestion. (e) Lateral cephalograph of the same patient shows characteristic findings of adenoid facies: palatal plane (ANS-PNS) tipped postero-inferiorly, steep mandibular plane (MP: menton-gonion), angular notching, reduced inclination of anterior slope of chin, increased lower face height. (Adapted from Ghafari and Macari, 2012, p. 200).

2.5. Pattern of growth in Class II patients

To optimize treatment timing and achieve satisfactory profile outcomes, targeting the appropriate time to initiate dentofacial growth modification in Class II patients has revealed the association between treatment outcome and growth pattern. In fact, untreated growing Class II and Class I patients have been found to have a similar craniofacial growth pattern, except for a lesser increase in mandibular length in Class II patients during the adolescent growth spurt. In addition, a skeletal Class II malocclusion usually persists if left untreated; sometimes the mandibular deficiency worsens, presenting with greater profile convexity (Stahl et al, 2008). Patients in whom the Class II malocclusion is associated with maxillary protrusion have been shown to have similar transverse growth trends during puberty as patients having normal occlusion (Vásquez et al, 2009).

Despite the similarity in growth pattern with normal Class I patients, it is likely that mandibular retrognathism existed in the early developmental stages, inferring either the prevalence of genetic factors, or the possibility of more growth expression in the Class II, division 1 subjects at later stages of development (Bishara, 1997).

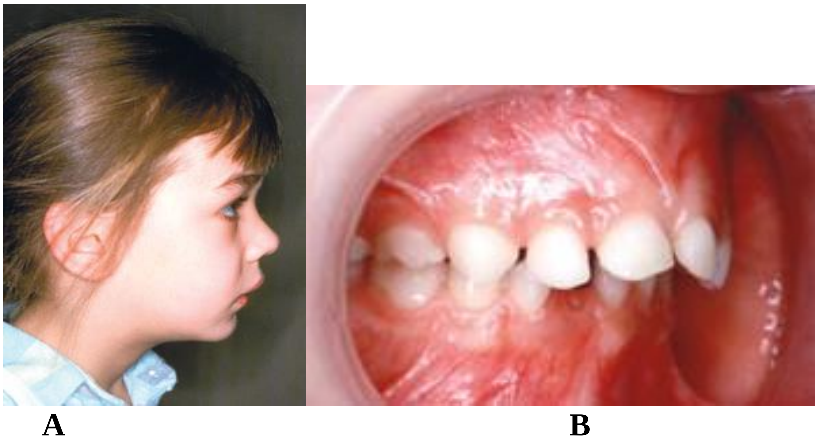


Fig. 2.9: A, Young girl in the deciduous dentition phase presented with early signs of Class II/1 malocclusion. **B,** An increased overjet and overbite and distal step of mandibular primary second molar. (Adapted from Bergersen, 2013).

Unlike the mixed dentition stage, comparison between untreated Class II and Class I subjects in the deciduous dentition revealed that early features of Class II malocclusion (distal step, primary canines in Class II occlusion, increased overjet and transverse discrepancy due to maxillary constriction) appear during early childhood and persist during the mixed dentition phase (Fig. 2.9). In the latter phase, these features tend to worsen with lesser increments in mandibular length and constant increase in maxillary protrusion (Baccetti et al, 1997).

Concerning soft tissue profile, sagittal growth and anterior nasal projection continued in both genders even after the end of skeletal growth. The main difference was in the age at which most of the soft tissue development is achieved: 12 years for girls but until 17 years in males, a difference possibly explaining the greater soft tissue dimensions in males. There was a constant trend throughout the development of the nose, lips and chin, unrelated to the underlying skeletal base where the development of the nose was not related to the gender or skeletal pattern (Genecow et al, 1989).

2.6. Treatment modalities and outcome of Class II, division 1 malocclusion

Treatment of distoclusion through various modalities aims at achieving neutroclusion within the surrounding soft tissue envelope. The ideal goal is to approach or achieve an orthognathic profile, entailing normalization of cephalometric measurements away from compensatory compromises (Ghafari & Macari, 2014).

In the following review, treatment modalities of Class II, division 1 malocclusion are shown in growing and adult patients (Fig. 2.10). A priori, whenever a Class II malocclusion is associated with deleterious oral habits, they should be controlled and eliminated prior or during the beginning of treatment (Salzmann, 1950).

2.6.1. Orthopedic treatment

Previous reports showed that the Class II malocclusion does not tend to self-resolve solely with growth, thus the emphasis on orthopedic intervention to diminish or if possible normalize the underlying skeletal disharmony (Stahl et al, 2008, Ghafari and Macari, 2014). "Growth modification" aims to correct the skeletal discrepancy underlying the Class II, division 1 malocclusion during the active period of growth (Fisk et al, 1953). The rationale is to enhance the differential growth that normally occurs between the jaws by restraining the maxilla in its position and favoring the forward growth of the mandible which is basically determined by the growth potential of the patient at the time of treatment (Proffit et al, 2014). If the maxilla is prognathic, its growth is usually targeted by the use of direct distal extra-oral force provided by the headgear (Lima et al, 2013; Ghafari & Macari, 2014). As often is the condition, mandibular retrognathism is treated by functional appliances are favored under the assumption of stimulating mandibular growth.

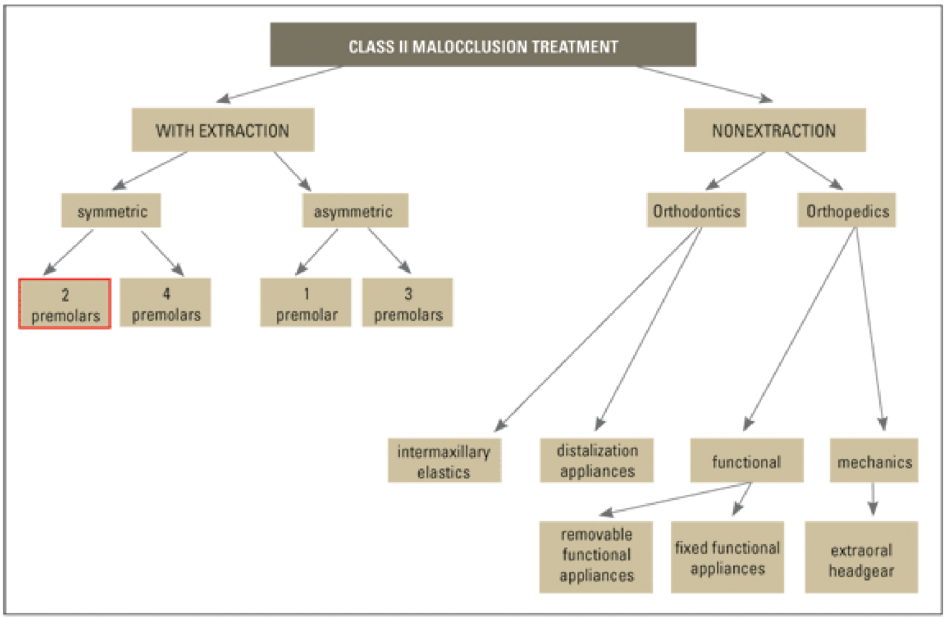


Fig. 2.10: Treatment protocols and clinical resources frequently employed to correct Class II malocclusion. (Adapted from Janson et al, 2009).

Researchers have shown that in either diagnosis, these appliances result in similar outcomes, likely due to the fact that the Class II phenotype is difficult to be transformed into a Class I phenotype, particularly in severe malocclusions with skeletal dysplasia (Efstratiadis et al, 2005; Ghafari and Macari, 2014). In essence, treatment modalities include a combination of extra-oral forces and a variety of removable or fixed functional appliances designed to modify the mandibular position resulting in a maximum advantage of vertical and sagittal growth (Proffit et al, 2014).

2.6.1.1 Extra-oral traction:

Most commonly used to correct maxillary prognathism, the headgear has 3 basic components: the facebow transfers traction forces to the molars and sets the direction of the traction forces, the neckstrap or headcap provides the anchorage, and the modules that attach the facebow to the neckstrap or headcap and provide the traction forces.

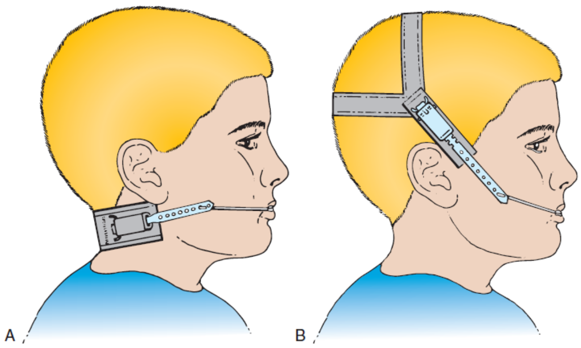


Fig. 2.11: Extraoral traction. Commonly used directions of forces are low-pull, straight-pull and high pull. **A,** Low-pull (cervical) face bow is mostly used in patients with decreased lower vertical facial heights. The direction of traction prevents the forward movement of the maxilla and allows for the extrusion of posterior teeth, leading to increased lower vertical facial height. **B,** High-pull facebow, used in patients with increased lower vertical facial dimensions to minimize or avoid the worsening of the vertical problem. It generates vertically directed forces that control the downward growth of the maxilla, favoring counterclockwise mandibular rotation that favors more horizontal mandibular growth. (From McNamara et al, 2001). The straight-pull headgear is a combination of both aforementioned directions of traction and is used in patients with no vertical problems. It delivers pure translation forces to the maxillary molars (Graber et al, 2011).

2.6.1.2 Functional appliances:

Functional appliances modify the posture of the mandible in a forward and downward position; therefore, a reactive backward and upward force generated by the muscles is transmitted to the maxillary complex (Headgear effect), restraining its growth while mandibular growth continues (Ghafari et al, 1998). The stretch of the soft tissues and muscles resulting from mandibular repositioning is thought to spread over the dentition and jaws, affecting growth and moving the teeth. Functional appliances are classified into four categories (Proffit et al, 2014, Graber et al, 2011):

-*Passive tooth-borne appliances* depend solely on forces generated from soft tissue stretch and contraction of muscles to generate treatment effects. Commonly used appliances of this type are the activator, bionator (always removable), twin-blocks (usually removable but can be made to be fixed), Herbst appliance (usually fixed but can be removable) and the MARA appliance (fixed) (Figs. 2.12-2.16).

A B

Fig. 2.12: The first commonly used functional appliance for Class II orthopedic correction, the activator induces mandibular advancement during contact between the lingual flanges and lingual mucosa. Selective grinding of the interposed acrylic shelf usually blocks the eruption of maxillary posterior teeth and allows mandibular posterior teeth to erupt, producing a rotation of the occlusal plane. (Proffit et al, 2014). **A,** original Andersen Activator with angled flutes in the acrylic used to guide the path of eruption of the posterior teeth, usually allowing maxillary molars to move distally and mandibular molars mesially. **B,** acrylic shelf is trimmed to allow eruption of mandibular posterior teeth. (Image from Proffit et al, 2014, p. 370, 372).

A **B**

Fig. 2.13: The bionator positions the mandible forward with the same mechanism as the activator. A buccal wire separates the lips away from the teeth and a tongue shield prevents abnormal posture of the tongue. A palatal connector stabilizes the posterior segments (**A**). Eruption guidance of posterior teeth is achieved by the acrylic occlusal stops similar to the effect of the acrylic shelf in the activator (**B**) (Image from Francisconi et al, 2013).

Fig. 2.14: The Twin-Block (TB) is composed of two complementary removable acrylic inclines that fit tightly against the teeth and supporting structures, inducing mandibular advancement upon closure. The main sources of retention are Adams and ball clasps, but the TB can be made to be cemented and fixed in place. The acrylic blocks can be adjusted to allow posterior eruption of teeth as desire. (Image after Allesee Orthodontic Appliances (AOA), Sturtevant, WI).

Fig. 2.15: The "fixed" Herbst appliance is mostly used in the permanent dentition and anchored on maxillary and mandibular molars through bands (original design) or stainless steel crowns connected by a lingual arch for stability. The sliding of a mandibular plunger inside a maxillary tube induces passive mandibular advancement upon closure. (Image from Allesee Orthodontic Appliances (AOA), Sturtevant, WI).

Fig. 2.16: The MARA appliance (Mandibular Anterior Repositioning Appliance) is a fixed appliance anchored on the maxillary and mandibular first molars through stainless steel crowns. It is less bulky and thus patients prefer it over the Herbst appliance. Upon closure, passive mandibular advancement occurs to avoid interference between the upper and lower extension arms of the appliance. (Image from Allesee Orthodontic Appliances (AOA), Sturtevant, WI).

-*Active tooth-Borne appliances* are modifications of bionator, activator (Fig. 2.17), Herbst and Twin-Blocs designs that are capable of producing active tooth movement. Their designs include expansion screws and/or finger springs that can be largely useful in camouflaging slight posterior or anterior cross bites (Proffit et al, 2014).

Fig. 2.17: Active tooth-Borne activator incorporating an expansion screw to increase transverse and sagittal dimensions in addition to posterior Adams clasps to aid in retention. (After Proffit et al, 2014, p. 523).

-*Tissue-Borne appliance* is represented by the Frankel functional regulator appliance (Fig. 2.18).

Fig. 2.18: Frankel's function regulator (FR) lies mostly in the vestibule and holds the cheeks and lips without touching the dentition, simulating an arch expansion appliance. The mandible is advanced through the contact between a lingual pad placed behind mandibular incisors and the mucosa in that area. Illustrated is an FR II appliance. (Image courtesy Allesee Orthodontic Appliances (AOA), Sturtevant, WI).

-*Hybrid functional appliances* are fabricated from a combination of components belonging to different appliances. These individualized appliances are made to meet specific treatment needs.

2.6.1.3 Outcome of orthopedic treatment modalities:

Regardless of the appliance used, response to orthopedic treatment depends on the patient's cooperation and growth potential. There is no evidence regarding the minimal time of wear required to achieve treatment goals, but usual instructions indicate at least 14 hours per day (Barton & Cook, 1997), close to reported findings of 12-13 hours (headgear) or 14-16 hours (functional regulator) (Ghafari et al, 1997). Treatment success is compromised by poor compliance, favoring the use of fixed functional appliances that are assumed to be more predictable than removable appliances (O'Brien et al, 2003).

Functional appliances presumably produce additional condylar growth mediated by the muscle tension exerted on the condyle after its movement out of the glenoid fossa (Fig. 2.19) (Proffit et al, 2014). Most appliances correct the Class II by a combination of dentoalveolar and skeletal changes summarized by key outcomes: 1- restriction of maxillary forward translation, 2- retroclination of maxillary incisors along with distal movement of maxillary buccal segments, 3- proclination of mandibular incisors along with mesial movement of mandibular buccal segments and 4- clockwise rotation of the occlusal plane (Ruf & Pancherz, 1999; Heinig & Goz, 2001; Franchi, 2011). Other investigators have shown unfavorable clockwise rotation of the mandible after treatment with headgear (Baumrind et al, 1983).

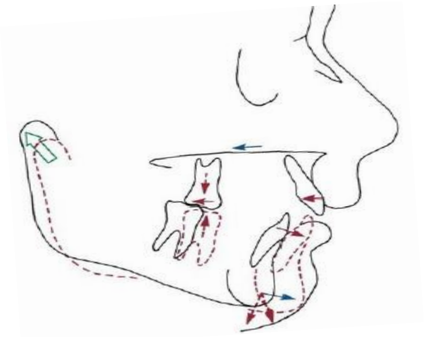


Fig. 2.19: Representation of the potential orthopedic effect of a functional appliance for correction of a skeletal Class II malocclusion. (Adapted from Proffit et al, 2014, p. 514).

Individual differences exist in the amount of skeletal and dentoalveolar response to treatment inherent to each jaw, whereby mandibular growth is reported to be unpredictable and most of the correction related to maxillary changes (West, 1957). It has been suggested that mandibular growth can be accelerated with functional appliances but its predetermined final size cannot be increased (Ghafari et al, 1998; Tulloch, 2004).

In summary, while adult comprehensive orthodontic treatment focuses on resolving the Class II malocclusion by dentoalveolar movements, early treatment aims to redirect growth of the jaws using either headgear or functional appliances. Modalities of orthopedic treatment have been assessed through multiple randomized clinical trials and comparable results were found (Ghafari et al, 1998; Keeling et al, 1998; O’Brien et al, 2003; Tulloch et al, 2004). All the various modalities could yield optimal overjet and overbite; however, not all corrections were related to favorable differential growth (Ghafari et al, 1998). Comparisons between the headgear and function regulator showed similar results of enhancing differential growth. The headgear targets mainly the maxilla by restraining its forward growth and functional appliances target the mandible by repositioning it in a forward direction; however, each appliance has an indirect effect on the other jaw (Ghafari et al, 1998). Moreover, no significant differences were shown in the treatment outcome of Class II, division 1, whether treated with fixed or removable functional appliances followed by a second phase of fixed appliances (Lima, 2013).

2.6.2. Combined orthodontic-surgical treatment

In patients having severe dentoskeletal dysplasia, orthognatic surgery is the ideal approach to restore a proper skeletal relationship when orthopedic and orthodontic camouflage treatments fail to resolve the problem. Indeed, with the movement of underlying bony structures, the envelope of change is expanded (Fig. 2.20). Orthodontic treatment remains essential in these conditions to normalize (decompensate) the relationship of the teeth to their underlying basal bones, followed by the surgical procedure that realigns the jaws into a proper Class I relationship.

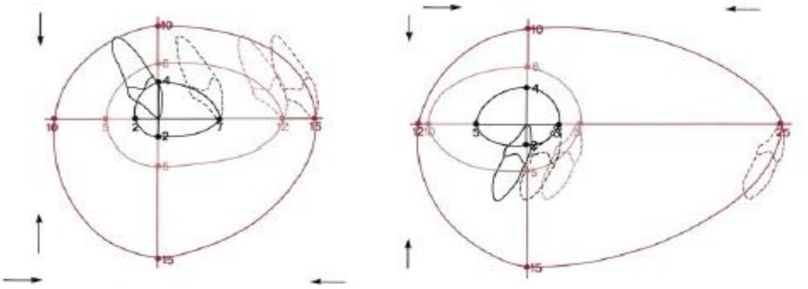


Fig. 2.20: diagrammatic representation of the amount of change that could be produced by orthodontic tooth movement alone (inner envelope of each diagram); combined orthodontic-orthopedic approach (middle envelope); and orthognathic surgery (outer envelope). (Adapted from Proffit et al, 2014, p. 702).

Coordination between the orthodontist and the orthognathic surgeon is a key factor responsible for treatment success. In the past century, remarkable improvement has been made in this combined treatment approach resulting in better planning, outcomes and prognosis.

2.6.3. Orthodontic treatment

When the surgical option is discarded in non-growing patients with severe Class II skeletal discrepancies, treatment alternatives to camouflage the skeletal discrepancy encompass the following:

1- Extraction of two maxillary premolars (in addition to mandibular premolars in the presence of severe crowding) to camouflage the skeletal dysplasia and reduce the overjet. In some instances, this dentoalveolar compensation might result in undesirable effects on facial esthetics (Ghafari & Macari, 2014). Moreover, the extraction protocol of two maxillary premolars has yielded better occlusal success than the four premolars extraction protocol, regardless of the severity of the skeletal dysplasia (Janson et al, 2004). When a “high angle” vertical pattern is present, there is an inherent limitation of the conventional non-surgical orthodontic treatment (whether extraction is considered or not) to modify the vertical skeletal pattern (Sivakumar et al, 2008). Moreover, the concept of premolars extraction in hyperdivergent conditions to favor the mesial movement of the molars and therefore increase bite depth through the “wedge effect” has been discredited (Kim et al, 2005) and would require further research.

2- Non-extraction treatment with a combination of retraction of maxillary teeth and protraction of mandibular teeth. When Class II elastics are used in this alternative, they produce more proclination of the mandibular teeth because of decreased resistance to movement. The elastics also tend to extrude the mandibular molars and maxillary anterior teeth, potentially resulting in a clockwise rotation of the occlusal plane. These vertical effects are usually undesirable because they can result in increased gingival display. A concomitant resultant downward and backward rotation of the mandible would also decrease the chin extension. However, using the elastics for a limited duration to support anchorage and obtain good posterior interdigitation at the end of treatment is often acceptable (Proffit et al, 2014). Focused research on this mechanical aspect also is needed.

3- Distalization of the maxillary arch by means of mini-screws, intraoral fixed distalizing appliances or conventional extra-oral traction. Depending on the severity of the discrepancy, mandibular incisor compensation is considered acceptable (Ghafari & Macari, 2014). The concept of maxillary teeth distalization was recognized with the early cephalometric studies (1940s) when Class II elastics were found to produce little or no “distal driving” of maxillary molars; thus, headgear (Fig. 2.11) and appliances with palatal anchorage were used as means of distalization (Proffit et al, 2014). Multiple ways have been used to generate molar distalizing forces once the palatal anchorage has been set, such as the compression of nickel-titanium or stainless steel coil springs from the anterior anchorage unit against the molars, repulsive magnets (fig. 2.21), or pendulum appliance with beta-titanium springs. The advent of temporary skeletal (absolute) anchorage devices brought a more drastic solution to complicated tooth movements that were difficult or impossible to accomplish with traditional appliances. Temporary anchorage devices (TADs) encompass a variety of miniscrews, miniplates and palatal onplants (Fig. 2.23).

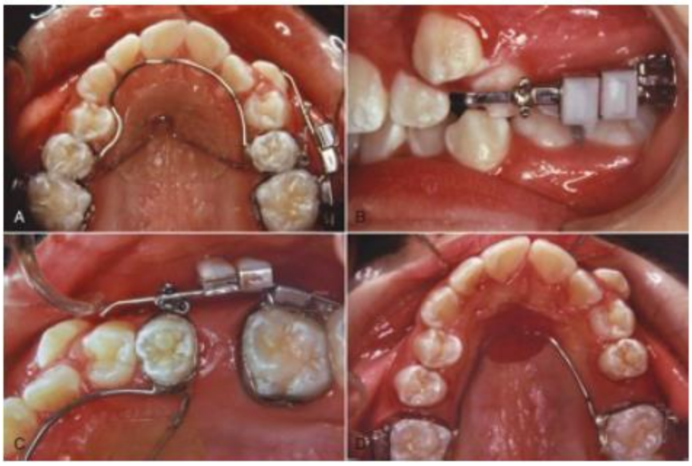


Fig. 2.21: Distalization of maxillary right molars using repulsive magnets. **A**, Transpalatal bar and lingual arch were placed on second molars for anchorage. **B**, Lateral view of the magnet assembly. The assembly was designed to allow repositioning of the premolar magnet as the molar moved back, to sustain same force. **C**, Progress: space opened at the rate of about 1 mm/month. **D**, Placement of a Nance arch to maintain the molar in place. The system was generally cumbersome and was not successful enough for routine usage (Photos from Proffit et al, 2014, p. 579).

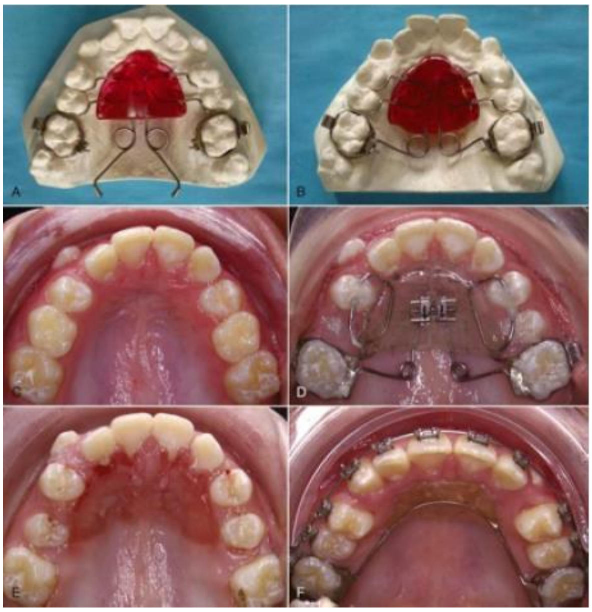


Fig. 2.22: Pendulum appliance for molar distalization. A, B, Appliance on cast before and after activation of the springs. C, Occlusal view of a patient with blocked out maxillary canine. D, Pendulum appliance with both a jackscrew for transverse expansion and molar distalizing springs (this modification is called the T-Rex appliance). E, Increase in space in the arch and the irritation of the palatal tissue beneath the appliance. Both are typical responses. F, Placement of a Nance arch to maintain the molars in place. Anchorage could still be lost with these appliances through forward movement of the anterior teeth. (Photos from Proffit et al, 2014, p. 580).

Fig. 2.23: A, Indirect anchorage modality applied for the distalization of the mandibular molars against mini-implants. Note the compressed Niti open coil between first molar and second premolar while the anterior anchorage unit is ligated to the miniscrew. **B**, Direct anchorage modality for "*en-masse*" retraction of the maxillary arch into the extraction space of maxillary first molars. Same anchorage modality as in A is being applied for the retraction of mandibular incisors.

2.7. Treatment timing of Class II, division 1 malocclusion

Success of treatment depends mainly on eliminating the particularly the known etiology if controllable, and enhancing growth opportunities (skeletal and dental). Thus emerges the concept and practice of early treatment in the primary but mostly mixed dentition to normalize the natural forces and if possible rectify alterations with muscle equilibrium (Ghafari, 1997). Delaying treatment until the permanent dentition may shorten active treatment duration but earlier intervention may help avoid the extraction of permanent teeth and better benefit from growth, particularly in girls whose growth spurt coincides with the late mixed dentition (about age 11.5 years) (Ghafari & Macari, 2014).

Several randomized clinical trials have shown that early treatment followed by a second phase has no advantages over a 1 phase of orthodontic treatment (Tulloch, 2004; O'Brien, 2009). On the contrary, treatment duration is lengthened and the burden of treatment weighs more on the patient (O'Brien, 2009). Also, comparison of Class II treatment outcomes between pre- and post-pubertal interventions showed no difference in the overall dentoskeletal components at the completion of growth (Chhibber et al, 2013). From the various prospective and retrospective studies in the past 20 years, an evidence-supported consensus emerged regarding the optimal timing of early or phase 1 treatment: during the late childhood or late mixed dentition phase (Gianelly, 1994), running into phase 2 without a retention period. This working hypothesis would cover nearly 60% of malocclusions (Ghafari et al, 1995). However, in some specific conditions, the Class II, division 1 malocclusion would need intervention in the early or mid- mixed dentition when one of the following conditions is present: severe overjet that would also expose the maxillary incisors to serious risks of trauma, psychological problems (also related to increased overjet), functional posterior crossbite, risk of developing a skeletal deviation, other developmental conditions such as early dental development relative to normal skeletal development. When an earlier intervention is needed the two phases of treatment are necessarily distant, and retention of phase 1 results may be needed (Ghafari, 1998).

2.8. Facial esthetics in Class II, division 1 malocclusion

The two common reasons for seeking orthodontic treatment are facial disharmony related to a discrepancy between the jaws, and crowding of teeth. Orthodontics can induce significant changes in the lower third of the face, whereas the middle and upper thirds are mainly affected by maxillofacial and plastic surgery (Herzberg, 1952). A balanced face has been related to an average chin size that is neither in protrusion nor in recession, both lips with average thickness and not protruded, and a mental sulcus that is not deep nor absent, unaffected by a strain of the mentalis muscles (Herzberg, 1952).

Perception of facial beauty is indirectly affected by the morphology of the teeth and their underlying skeletal tissues (Kerns et al, 1997). In general, Caucasians have a preference for straight profiles (Peck & Peck, 1970). In adult treatment, correcting a severe dentoskeletal deviation by orthodontic compensation might worsen facial esthetics; therefore, adjunctive orthognathic surgery is the ideal treatment option if facial esthetics needs improvement (Proffit et al, 2014). Otherwise, if camouflage treatment is implemented, dental compensation should be limited, maintaining a residual overjet but an acceptable facial appearance (Ghafari & Macari, 2014). In addition, differential thickness between the lips may represent a constitutional limitation that might dictate compromised treatment outcome. A thin upper lip can be affected by the retroclination of maxillary incisors that would create a reverse step between both upper and lower lips, impairing facial harmony (Ghafari & Macari, 2014).

Despite the increasing interest in facial esthetics, the routine assessment is still limited to the description of profile outline and subnasal profile. Thicknesses of soft tissue components of the face are not conventionally required measurements, although their variation may aggravate or compensate for a dentoskeletal discrepancy (Ghafari & Macari, 2014). In this context, the component analysis represents an important tool that facilitates a thorough diagnosis to generate a comprehensive treatment plan that targets all the components of a malocclusion, but also sorts out the predictive elements that may favor or disfavor a successful outcome (Ghafari & Macari, 2013).

2.9. Prediction of treatment outcome of Class II, division 1 malocclusion

2.9.1. Centrality of growth components for potential prediction

Understanding growth of the human head and more specifically that of the jaws will help recognize the underpinnings of orthodontic treatment outcome. In fact, a clockwise or counterclockwise rotation of the mandible reflects a discrepancy between the vertical and horizontal growth patterns. Excessive vertical growth will rotate the mandible backward, cause the chin to move vertically and produce a skeletal hyperdivergency. On the other hand, excessive horizontal growth will rotate the mandible forward, increase the forward extension of the chin and produce a skeletal hypodivergency. Therefore, the resultant of both vectors of growth will determine the extension of the chin in the profile (Schudy, 1965). For instance, the vertical growth is determined by:

1- Maxillary growth and its downward translation,

2- Growth of the maxillary posterior alveolar processes, and

3- Growth of the mandibular posterior alveolar processes. When this growth outweighs the condylar horizontal growth, the correction of a Class II malocclusion becomes more challenging (Schudy, 1965).

The anatomical structures that contribute to a Class II, division 1 malocclusion encompass both jaws and the cranial base. Based on the literature, selected components consist of:

1- Flexure of the cranial base (Saddle angle).
2- Sagittal and vertical jaw relations.
3- Total mandibular length and position relative to the cranial base.
4- Mandibular dentoalveolar/skeletal relation.
5- Chin projection and its soft tissue thickness (Ghafari & Macari, 2014).

It has been demonstrated that the initial anteroposterior discrepancy between the jaws, chin projection, and cant of the posterior cranial base are dominant components that affect orthopedic treatment outcome with a wide range of individual variability (Ghafari et al, 2009). Moreover, major constitutional limitations acting against achieving normal craniofacial anatomy were revealed by a descriptive component analysis of Class II therapy (Ghafari et al, 2009).

2.9.2. Challenging outcome prediction: the unknown growth potential

Contemporary orthodontic literature is rich with studies involving assessment of treatment outcome, especially in growing patients in whom improvement of the skeletal discrepancy is possible. Prediction studies focused more on the challenging Class III malocclusion because of the high frequency of unsatisfactory orthopedic outcome and greater possibility for relapse (Fudalej et al, 2010). Yet, given the potential of negatively affecting facial esthetics (with possible side effects on teeth and periodontium), prediction of the Class II/1 treatment outcome warrants thorough investigations as well.

Orthopedic treatment outcome of Class II/1 malocclusion, using a variety of appliances that target either the maxilla (e.g. headgear) or the mandible (functional appliances), remains unpredictable. Accordingly, the selection of specific treatment modalities and appliances to “suitable malocclusions” becomes more difficult when the intended outcome is unknown (Barton and Cook, 1997). Early intervention with “orthopedic” appliances is mostly successful during the period of rapid facial growth in growing patients as supported by human and animal studies (Barton and Cook, 1997).

Orthopedic treatment in adolescents has shown that successful responders presented more facial growth during active period of treatment (Hagg and Taranger, 1982). Moreover, functional appliance therapy specifically might result in an increased condylar growth activity when implemented during the period of peak height velocity (Pancherz and Hagg, 1985). Such effects would not be expected in the non-growing adults, as demonstrated in clinical and animal studies (McNamara et al, 1982).

While the general tendency of successful outcome is linked to growth potential is acceptable, “prediction” of a precise outcome in the individual patient is the needed target. Confounding this premise are findings that treating similar malocclusions can have different outcomes because of the wide range of individual variation in treatment response (Vargervik and Harvold, 1985). Morphological differences between individuals with the same malocclusion would account for the success or shortcoming of treatment (Bondevik, 1991). Such findings point in the direction of studying the responses of the various components of the malocclusions rather than a general assessment of selected general measurements of inter-jaw relations.

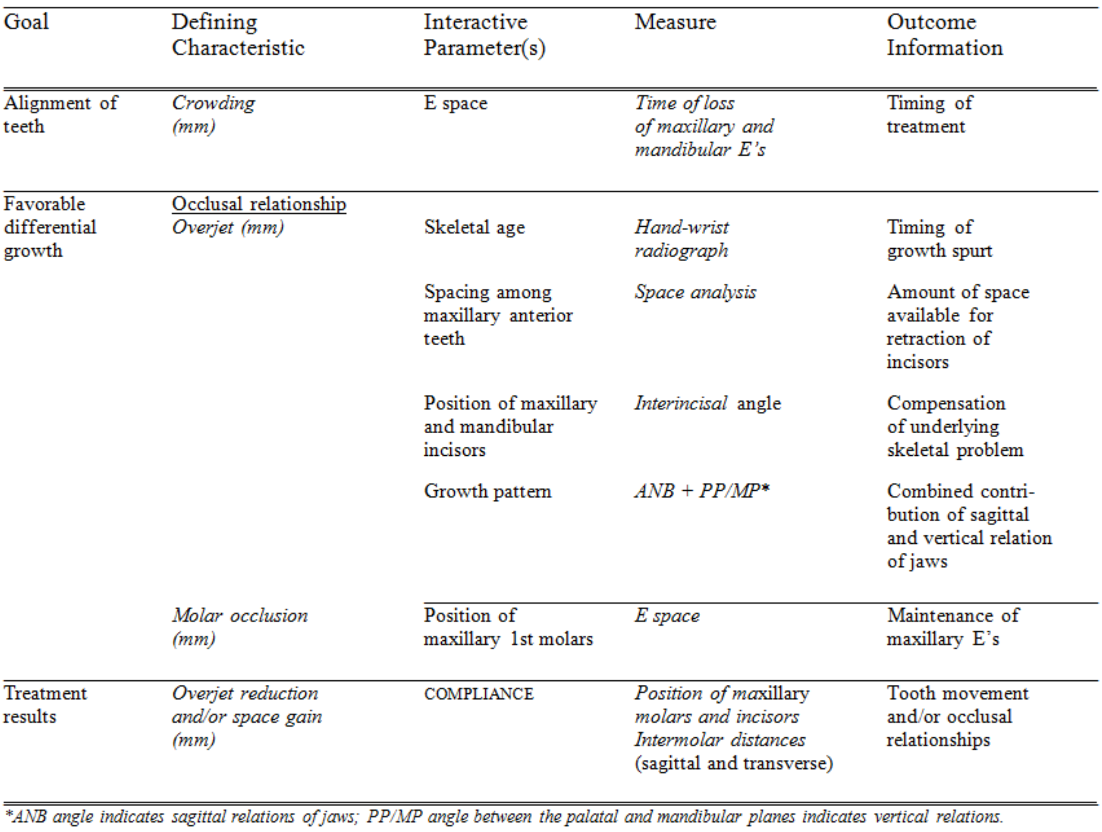
2.9.3. The search for predictors

The ability to predict treatment outcome improves treatment planning based on advanced scientific evidence. However, the documented individual variability in growth and development of orthodontic patients adds remarkable difficulties to the prediction process (Baumrind, 1991).

While he observed that on average, there is a slight mandibular forward rotation during adolescence, Björk (1969) reported that the pre-pubertal mandibular size and inclination cannot serve as predictors for the size and rotation during the adolescent phase. He described seven mandibular anatomical variations help predict mandibular growth rotation: 1- inclination of the condyle, 2- curvature of the mandibular canal, 3- symphyseal inclination, 4- shape of mandibular lower border, 5- intermolar angle, 6- interincisal angle and 7- anterior lower facial height.

Ghafari (1998) enumerated component variables essential for the prediction of Class II, division 1 treatment outcome usage (Table 2.1). The model proposed included cephalometric and non-cephalometric measures, such as overjet, molar occlusion, timing of loss of the space of the second primary molar (E space), and progress results (which would strengthen the predictive equation on the basis of already achieved results). Sagittal and vertical cephalometric components were grouped in possible “field” effects (e.g. combining the interactive sagittal and vertical measurements of corresponding skeletal discrepancy ANB and PP/MP angles to account for growth pattern). Research must be invested in this and other models to determine their accuracy.

Table 2.1: Probable parameters interacting in the individual prediction model for optimal correction of the Class II, division 1 malocclusion *(After Ghafari, 1998)*



Goal	Defining Characteristic	Interactive Parameter(s)	Measure	Outcome Information
Alignment of teeth	*Crowding (mm)*	E space	*Time of loss of maxillary and mandibular E's*	Timing of treatment
Favorable differential growth	Occlusal relationship *Overjet (mm)*	Skeletal age	*Hand-wrist radiograph*	Timing of growth spurt
		Spacing among maxillary anterior teeth	*Space analysis*	Amount of space available for retraction of incisors
		Position of maxillary and mandibular incisors	*Interincisal* angle	Compensation of underlying skeletal problem
		Growth pattern	ANB + PP/MP*	Combined contribution of sagittal and vertical relation of jaws
	Molar occlusion (mm)	Position of maxillary 1st molars	*E space*	Maintenance of maxillary E's
Treatment results	*Overjet reduction and/or space gain (mm)*	COMPLIANCE	*Position of maxillary molars and incisors* *Intermolar distances* (sagittal and transverse)	Tooth movement and/or occlusal relationships

*ANB angle indicates sagittal relations of jaws; PP/MP angle between the palatal and mandibular planes indicates vertical relations.

2.9.4. Prediction schemes

Several attempts have been made to find predictors that define individual responsiveness to Class II treatment. The main tools of predicting treatment outcome were cephalometric measurements, but few orthodontic studies focused on pinpointing the relevant variables that predict treatment results. The focus in this section is on the results of these attempts.

The visualized treatment objective (VTO) of Ricketts (1957) is one of the oldest prediction methods of craniofacial growth pattern and orthodontic treatment outcome that used cephalometric radiography. This method helped forecast the soft tissue profile outcome based on the attainment of the ideal skeletal and dental relationship. Johnston (1975) used a computerized scheme for growth and treatment outcome prediction. While helpful, these schemes have not yielded dependable results or routine.

In a retrospective study of treatment outcome, conducted on 212 patients with Class II, division 1 (overjet > 6 mm) and treated in the permanent dentition with fixed appliances, patients with large overjet and more upright incisors were found to be less likely to achieve successful treatment outcome. Multivariate logistic and linear regressions identified these dental parameters as valid predictors with a reasonable degree of certainty. The results suggested that only patients with substantial amount of maxillary incisors proclination prior to treatment are expected to show excellent treatment results. The pretreatment anteroposterior and vertical skeletal relationships were not significant predictors of good outcome (Burden et al, 1999).

In another retrospective study of Class II malocclusions treated with functional appliances, good responders were categorized as having their post-treatment ANB angle reduced by at least 3 degrees. The results showed that the defined good responders started treatment with smaller size of some components compared with bad responders, suggesting the presence of more growth potential at baseline (Patel et al, 2002).

A third study of predicting favorable Class II treatment in term of increase in total mandibular length was applied using three types of functional appliances. Discriminant analysis revealed that the condylion-gonion-gnathion angle (mandibular angle) was the main predictor of outcome (Franchi & Baccetti, 2006).

Finally, in a preliminary study of outcome predictors of the early treatment of Class II, division 1 malocclusion using a sample derived from an RCT comparing headgear vs function regulator, patients with severe Class II, division 1 (ANB>6.5) were likely to maintain a Class II phenotype at the end of treatment. The cant of the anterior slope of the symphysis was a critical predictor of forward chin projection following Class II orthopedic treatment (Ghafari & Macari, 2014).

Outcome prediction of particularly Class II, division 1 may remain elusive because of two seemingly contradictory premises:

1- The transformation through orthodontic treatment (an environmental factor) of a Class II phenotype with skeletal dysplasia into a phenotype that has adequate skeletal relations. Thus, “idealized” success would depend on the relative repositioning of the skeletal bases. In this context, only sufficient forward growth of the mandible or orthognathic surgery may be successful.

2- The limitation in affecting or stimulating mandibular growth beyond its growth potential, which is by and large genetically paced if not entirely dependent.

In this context, the intelligent mind might wonder about the value of re-attempting to explore predictive models for treatment outcome of Class II, division 1 treatment. The answer lies in the cause of difficult forecasting: individual variation. Further exploration is needed because anticipating the individual outcome would dictate different interventions in different patients, more personalized and less heroic treatment.

However, individual variation would also dictate approaching the prediction process through multiple components defining the malocclusion, not only simplified describers such as the dental (interincisal) or skeletal (ANB angle) “overjet.”

2.10. Research significance

Prediction has been used in the medical field to project treatment efficiency and prognosis for the purpose of providing personalized treatment. Researchers have investigated extensively the possibility of affecting growth of the jaws in growing patients who have a Class II malocclusion with underlying skeletal dysmorphology. The main issue still remains in the unpredictability of treatment outcomes because of individual variation in responding to treatment. 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.

Constitutional limitations related to severity of the sagittal skeletal discrepancy and symphyseal morphology have affected treatment outcome of the Class II, division 1 malocclusion. While such limitations may prevent the transfer of a Class II phenotype to a Class I facial morphology (Ghafari and Macari, 2014), previous studies have concentrated only on a specific qualifier of good or bad response to treatment, rather than exploring different classifiers of response to generate predictive models under different scenarios. Also, some of these previous studies lacked the proper sample size, or age brackets for meaningful conclusions.

Accordingly, the major thrust of this research is to build on prior trials of predicting the outcome of Class II/1 treatment, taking into account:

1. Various components that alone (dominant component) or in combination define the individual character of the malocclusion and its response to treatment;
2. The severity of the malocclusion, whereby past research have demonstrated the impact of severity on the potential for a Class II/1 to shift towards a Class I phenotype or remain in the Class II domain.
3. The consideration of various ages of treatment, rather than either growing or adult patients.
4. The associated facial esthetics, abandoning the common approach to the evaluation of treatment outcome by relying mainly on the response of hard tissues (bone and teeth), through cephalometric and cast analyses, when an inherent goal to orthodontic treatment is also dental and facial esthetics. Accordingly, assessment of pre and post-treatment facial photographs would reflect more directly the human perception of improvement. In fact, treatment decisions are mainly dictated by the perception of facial and profile attractiveness whereby treatment outcome is the result of small to moderate changes in the different facial components rather than a single change in one of them (Efstratiadis et al, 2005). Accordingly, an optimal way to judge such changes through the judgment of an expert panel would amount in epidemiological studies to a bench mark or gold standard that could also be used to test a predictive model for success or shortcoming in orthodontic treatment.

2.11. Hypotheses

Predictive models of response to Class II, division 1 treatment are related to component analysis of the malocclusion:

1. Constitutional differences in chin anatomy and mandibular position (specifically chin extension relative to a true vertical through nasion) are major factors that influence Class II treatment profile outcome.
2. Categorization on measurements related to the discrepancy between the jaws rather than a single jaw-specific component would yield more accurate prediction of treatment outcome.

Subsidiary hypotheses:

1. High severity malocclusion remains in the Class II phenotype domain, regardless of treatment modality.
2. Judgment of faces by panel discriminates between a- type of underlying malocclusion, b- severity of malocclusion (favorable profile in low severity group of malocclusions).

2.12. Specific aims

1. Evaluate Class II treatment effect on the various facial components among growing and adult age groups.
2. Evaluate the differences between severity subgroups in sagittal skeletal discrepancy and the treatment effects on the various cephalometric components.
3. Determine the facial components that contribute to favorable or unfavorable treatment outcome with respect to facial profile enhancement in Class II treatment.

4. Develop predictive models of treatment outcome (favorable vs unfavorable) based on objective celphalometric classification and on the judgments of a panel of experts.
5. Explore the correspondence between the panel assessment of improvement of treated Class II/1 patients and different cephalometric outcome predictors.

CHAPTER 3

MATERIALS AND METHODS

3.1. Materials

3.1.1. General characteristics

The sample consisted of pre- and post-treatment lateral cephalometric radiographs and profile photographs of patients screened and treated at the division of Orthodontics and Dentofacial Orthopedics of the American University of Beirut Medical Center (AUBMC). The radiographic images and profile photographs were part of the diagnostic records collected for orthodontic treatment. All patients were diagnosed with Class II, division 1 malocclusion and treated to a Class I occlusion with a non-surgical approach that consisted of either an orthodontic treatment with fixed appliances alone or a combined orthopedic-orthodontic treatment for the growing patients. None of the patients were contacted nor were photos or 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.

A total of 179 subjects were recruited and divided into two age groups (Growing/Adults) based on growth potential evaluated through superimposition of pre- and post-treatment lateral cephalograms. More specifically, when an increase of more than 1 mm in anterior cranial base length (SN), maxillary length (ANS-PNS) and mandibular length (Co-Gn) was present between pre- and post-treatment lateral cephalograms, the patient was considered as growing.

The growing group consisted of 125 subjects. Based on the documented age of the adolescent's peak of growth spurt (11.5 years for girls and 13.5 years for boys), the growing sample was further divided into two age groups; pre-pubertal (n=88) and post-pubertal (n=37) (Berkey et al, 1993). The adult group consisted of 54 subjects (Table 1).

To study the effect of malocclusion severity on treatment outcomes, the growing and adult groups were stratified into low severity and high severity subgroups based on the pre-treatment (T1) ANB angle being $4.5<\text{ANB}\leq 6.5$ and $\text{ANB}\geq 6.5$, respectively. The growing (125 subjects) and adult (54 subjects) groups consisted of 84 and 34 subjects in the low severity subgroup, and 41 and 20 subjects in the high severity subgroups, respectively (Table 3.1).

Table 3.1: Distribution of subjects (N) in growing and adult groups and subgroups

	Growing		Adult
	Pre-pubertal	Post-pubertal	
	88	37	54
High severity	84		34
Low severity	41		20

3.1.2. Inclusion criteria

-Subject diagnosed with a Class II division 1 malocclusion that was treated non-surgically.

- Overjet (OJ) greater than 3 mm. Although this minimal value is close to normal, it accounts for malocclusions with severe dentoalveolar compensation (particularly proclination of mandibular incisors) camouflaging a severe Class II, division 1 malocclusion.

-ANB angle equal to or greater than 4.5 degrees (over one standard deviation from the normal ANB = $2^{o} + 1.5^{o}$), reflecting definite maxillo-mandibular discrepancy.

3.1.3. Exclusion criteria

-Subjects who underwent orthognathic surgery to correct the Class II/1 malocclusion.

-Subjects who had previous orthodontic treatment.

-Subjects with craniofacial anomalies (e.g. cleft lip/palate, hemifacial microsomia).

-Subjects whose cephalograms were not available at T2 or were of non-diagnostic quality.

3.2. Methods

Pre- and post-treatment lateral cephalograms were taken at the AUBMC Division of Orthodontics and Dentofacial Orthopedics using the same digital machine (GE, Instrumentarium, Tuusula, Finland).

All lateral cephalometric radiographs were taken in natural head position (Moorrees and Kean, 1958) with posterior teeth in maximum intercuspation, lips touching gently and the midsagittal plane-film distance standardized at 13 cm. The patient's body was covered with lead apron. The 2D digital radiographs were automatically saved and stored in a dedicated computer within the available software (Cliniview 9.3). In this software, the identity of the patient is not a visible part of the image. Accordingly, the radiographs were located and exported from the software to a digital folder. The radiographs were assigned a serial number by the administrator (Dr. Mohannad Khandakji) 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.

Upon this process, the administrator provided the investigator (MJK) with the following coded records for data collection:

- The digital folders containing the radiographs.
- A list that contains the serial number, gender, and chronological age of the subjects when the records were taken. This list did not contain the patients' names.

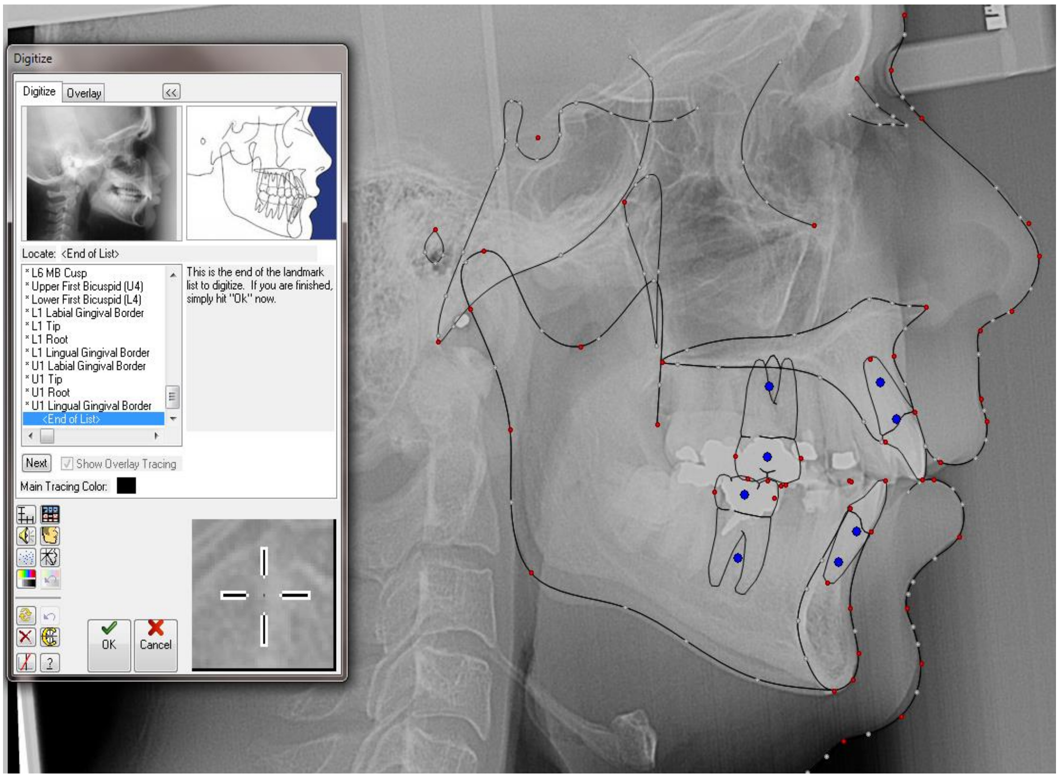
The radiographs were digitized by one investigator (MJK) using the imaging program (Dolphin Imaging and Management Solutions, version 11.5, La Jolla, California). The screen view during digitization in the Dolphin Imaging software is illustrated in figure 3.1.

3.2.1. Cephalometric landmarks

The definition of soft and hard tissue landmarks was adopted from the glossary of the American Association of Orthodontists (Table 3.1 and 3.2) and their corresponding locations are identified in figure 3.2.

3.2.2. Cephalometric measurements

Linear and angular measurements were performed to gauge the characteristics of the cranial base and each jaw, as well as the relationships of the jaws to the cranial base and to each other. Each component that would potentially contribute to treatment outcome was quantified by its corresponding cephalometric measurement. All landmarks and angles used to describe the relationship among cranial base, jaws, and teeth are presented in figures 3.2 and 3.3. The definitions of cephalometric measurements are listed in Table 3.3.



Locate: <End of List>

- * L6 MB Cusp
- * Upper First Bicuspid (U4)
- * Lower First Bicuspid (L4)
- * L1 Labial Gingival Border
- * L1 Tip
- * L1 Root
- * L1 Lingual Gingival Border
- * U1 Labial Gingival Border
- * U1 Tip
- * U1 Root
- * U1 Lingual Gingival Border
- <End of List>

This is the end of the landmark list to digitize. If you are finished, simply hit "Ok" now.

☑ Show Overlay Tracing

Main Tracing Color: ■

Fig. 3.1: Representative illustration of the computer view while digitizing a lateral cephalometric radiograph using Dolphin Imaging software.

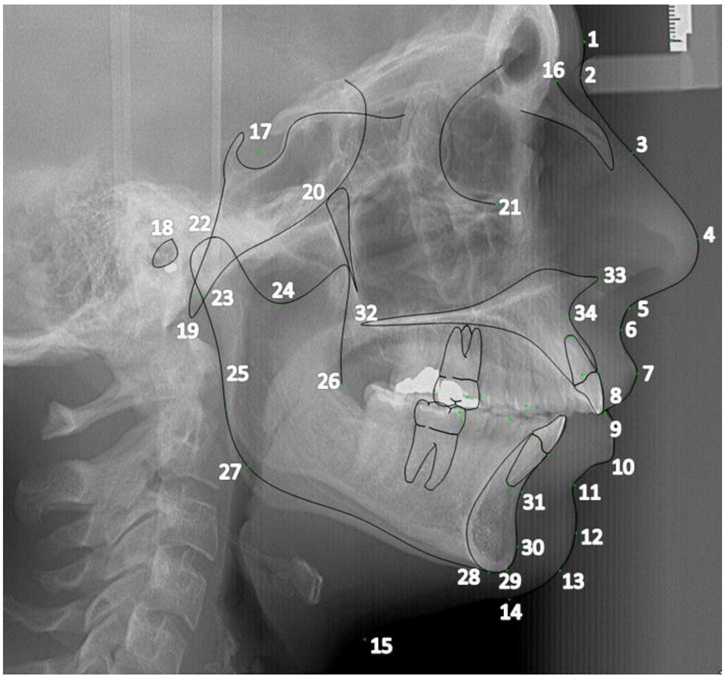


Fig. 3.2: Soft and hard tissue landmarks digitized on a lateral cephalometric radiograph.

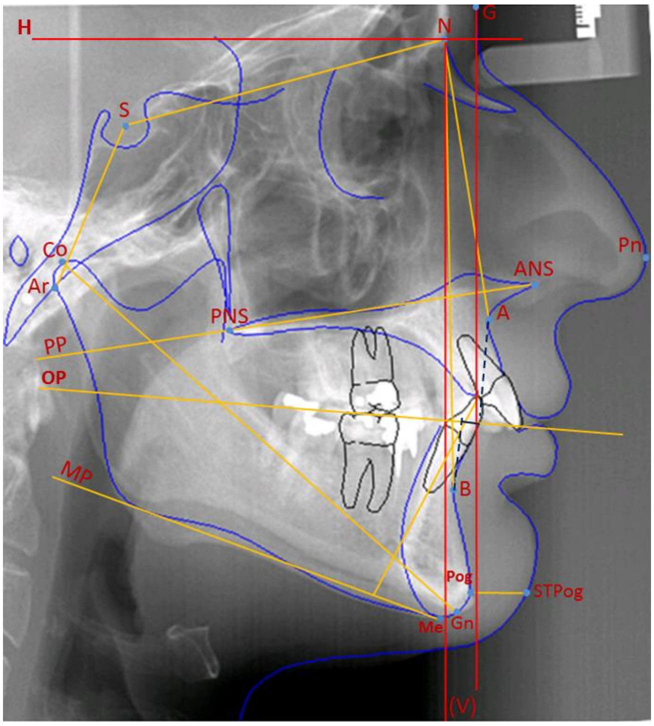


Fig. 3.3: A lateral cephalometric tracing showing some landmarks and measurements used to describe the relationship between jaws, cranial base, and horizontal.

Table 3.2: Soft tissue landmarks definition

#	Landmark	Definition
1	Glabella (G)	Most prominent or anterior point in the mid-sagittal plane of the forehead at the level of the superior orbital ridges
2	Soft tissue Nasion	Point of intersection of the soft-tissue profile with a line drawn from the center of Sella turcica through Nasion
3	Bridge of nose	Mid-way between the soft tissue N and tip of nose
4	Tip of nose/Pronasale Pn	Most prominent or anterior point of the nose
5	Subnasale (Sn)	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
6	Soft tissue A point	Deepest point on the upper lip determined by an imaginary line joining subnasale with laberale superius
7	Superior lip	Midpoint of the upper vermilion line
8	Stomion superior	Most inferior point located on the upper lip
9	Stomion inferior	Most superior point located on the lower lip
10	Lower lip	Midpoint of the lower vermilion line
11	Soft tissue B point	Point at the deepest concavity between laberale inferius and soft-tissue pogonion
12	Soft tissue pogonion	Most prominent or anterior point on the soft-tissue chin in the mid-sagittal plane
13	Soft tissue gnathion	Midpoint between soft-tissue pogonion and soft-tissue menton
14	Soft tissue menton	Most inferior point on the soft-tissue chin
15	Throat point	Intersection of lines tangent to the neck and throat

Table 3.3: Hard tissue landmarks definition

#	Landmark	Definition
16	Nasion (N)	The junction of the frontal and nasal bones
17	Sella (S)	The pituitary fossa. The center is used as a cephalometric landmark
18	Porion (Po)	Highest point on the roof of the external auditory meatus
19	Basion (Ba)	Most inferior point of the anterior margin of the foramen magnum in the midsagittal plane
20	Pterygoid point	Most posterior point on the outline of the pterygopalatine fossa
21	Orbitale (Or)	Lowest point on the lower margin of the orbit
22	Condylion (Co)	The highest point on the superior outline of the mandibular condyle
23	Articulare (Ar)	A constructed point representing the intersection of three radiographic images: the inferior surface of the cranial base and the posterior outlines of the ascending rami or dorsal contour of the mandibular condyles bilaterally
24	Sigmoid notch	Deepest point on the sigmoid notch of the mandible
25	Ramus point	Most posterior point up the border of the ramus
26	Mid ramus	Most concave point of the inferior of the ramus
27	Gonion	The most posterior inferior point on the outline of the angle of the mandible. It is identified by bisecting the angle formed by the tangents to the mandibular corpus (mandibular plane) and posterior border of the mandible (dorsal ramal plane)
28	Menton (Me)	The most inferior point on the chin in the lateral view
29	Gnathion	The lowest point of the mandibular symphysis
30	Pogonion (Pog)	The most anterior point on the contour of the bony chin in the midsagittal plane
31	B point	The deepest (most posterior) midline point on the bony curvature of the anterior mandible, between infradentale and pogonion. Also called supramentale. (Downs)
32	Posterior nasal spine (PNS)	The most posterior point on the bony hard palate in the midsagittal plane; the meeting point between the inferior and the superior surfaces of the bony hard palate (nasal floor) at its posterior aspect
33	Anterior nasal spine (ANS)	The tip of the bony anterior nasal spine at the inferior margin of the piriform aperture, in the midsagittal plane
34	A point	Subspinale, the deepest (most posterior) midline point on the curvature between the ANS and prosthion (dental alveolus) (Downs)

Table 3.4: Definition of cephalometric measurements

Cranial base measurements	
SN	Anterior cranial base length: reference line connecting the center of sella turcica with nasion
SN/H	Inclination of anterior cranial base in reference to the NHP
S-Ar	Posterior cranial base length
SN/Ar	Saddle angle: Evaluates cant of the anterior cranial base
Relationship between jaws, cranial base and horizontal	
SNA (maxilla)	Angle between anterior cranial base cant (SN) and point A (most posterior point on anterior contour of the maxilla)
SNB (mandible)	Angle between anterior cranial base cant (SN) and point B (most posterior point on anterior contour of the mandible)
ANB	Sagittal skeletal relationship: Angle between points A and B
Witts (Ao-Bo)	Sagittal skeletal relationship: Distance between the projections from points A and B to the occlusal plane.
NA/Apog	Angle of convexity: Formed by the intersection of lines NA and Apog
N-ANS	Upper facial height
ANS-Me (AFH)	Anterior facial height
Ar-Go (PFH)	Posterior facial height
LFH/TFH (%)	Lower to total facial height: depicts the relationship between anterior facial height (ANS-Me) and total facial height (N-Me)
PP/MP	Palatal plane to mandibular plane: represents the vertical divergence
MP/SN	Represents vertical inclination of the mandible relative to SN
PP/H	Represents vertical inclination of PP to the true Horizontal in (NHP)
MP/H	Vertical inclination of the mandible relative to the true Horizontal
Pog Proj	Pogonion projection to the true vertical passing through Nasion
Jaw specific measurements	
Co-Gn	Length of the mandible
Co-Go, Go-Gn	Length of mandibular components (ramus and body)
Co/Go/Me	Mandibular angle between ramus and body
ANS-PNS	Length of the maxilla
Relationship between teeth and jaws	
U1-NA, U1/NA	Distance and inclination of maxillary incisors to NA
U1/SN	Inclination of maxillary incisors to anterior cranial base SN
U1/PP	Inclination of maxillary incisors to PP
L1-NB, L1/NB	Distance and inclination of mandibular incisors to NB
L1/MP	Inclination of mandibular incisors to MP
Relationship between teeth	
U1/L1	Inter-incisal angle
Overbite (OB)	Percentage of overlap of mandibular incisors by maxillary incisors
Overjet (OJ)	Horizontal projection of maxillary incisors tip to mandibular incisors
Soft tissue measurments	
UL- E line	Distance between point superior lip and Esthetic line (Nose tip - Me)
LL- E line	Distance between point lower lip and Esthetic line (Nose tip - Me)
Naso labial angle	Angle formed by the points upper lip, subnasale and columella (c')
Mento labial angle	Angle formed by the points Lower lip, St B-point and St Pogonion
U lip length	Distance between subnasale and stomion superius
U lip thickness @ A	Distance between St A-point and A point
U lip inclination	Angle formed by the intersection of subnasale-Upper lip/ N perp(FH)
L lip length	Distance between ST B-point and stomion inferius
L lip thickness @ B	Distance between ST B-point and B point
St Chin thickness	Distance between ST Pogonion and Pogonion
Pn-D	Pronasale distance to vertical through glabella G

3.2.3. Symphyseal components

These components consisted of measurements within the symphysis (height, depth and slope inclinations), involving the use of point D (symphyseal center) as a reference point (Steiner, 1959) (Fig. 3.4, Table 3.4). Chin anatomy was further delineated through the methods adapted from Ghafari and Macari (2014) (Fig. 3.5) along with cephalometric measurements in Table 3.4. The anterior and posterior slopes of the symphysis helped determine the inclination of the symphysis.

Fig. 3.4: Cephalometric tracing indicating the measurements used to evaluate some components of the symphysis (centered at point D).

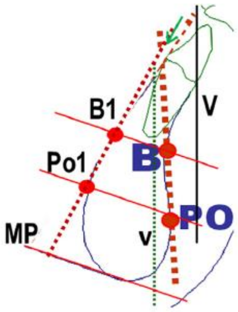


Fig. 3.5: Chin drawing from cephalometric radiograph indicating the component analysis of the symphysis (Adapted from Ghafari and Macari, 2014).

Table 3.5: Definition of symphyseal cephalometric measurements

	Measurement	Landmarks
1	Distance between point D and incisor apex **(D-Apex)**	Point D to Apex
2	Distance between point D and menton **(D-Me)**	Point D to Menton
3	Chin width at the level of the incisor apex **(CW-Apex)**	Line through A parallel to the horizontal, intersecting anterior and posterior contours of symphysis
4	Chin width at the level of point D **(CW-D)**	Line through D parallel to the horizontal, intersecting anterior and posterior contours of symphysis
5	Anterior Symphyseal Angle **(ASA)**	Angle between Pog-B line and the vertical
6	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)

3.2.4. Definition of response to treatment based on cephalometric outcome predictors

Definition of “favorable” (FR) and “unfavorable” (UFR) responses to treatment measured between pre (T1) and post (T2) treatment cephalograms, was based on objective criteria determined by treatment changes in specific cephalometric measurements in the growing and adult groups. Individual responsiveness to Class II treatment was defined on the basis of the following criteria:

1- Decrease in the angle of convexity (NA/APog) between time points T2 and T1. This angle was first defined by Down’s (1948), and it is frequently used to assess the convexity of the skeletal profile. Treatment outcome was considered a “favorable response” (FR) when the T2-T1 NA/APog difference in a treated subject was equal to or smaller than the mean NA/APog change of the corresponding group, whereas the outcome was considered an “unfavorable response” (UFR) when The T2-T1 NA/APog difference was higher than the mean change of NA/APog in the corresponding group.

2- The relation of the upper lip to Rickets’s esthetic line (E-line). Corresponding Z scores for U-lip/ E-line measurements at T1 and T2 time points were computed; whenever the upper lip moved closer to the norm (-4mm) at T2, the response to treatment was considered favorable (FR), whereas the response was deemed unfavorable (UFR) if the upper lip displaced farther from the norm at T2.

3- Increase in projection of pogonion to the true vertical passing through nasion (N) between T1 and T2. A “favorable response” (FR) corresponded to a (T2-T1) Pog proj in a treated subject that was equal or higher than the mean Pog proj change in the corresponding group; an “unfavorable response” (UFR) was assigned when (T2-T1) Pog proj was less than the mean Pog proj change of the corresponding group.

4- The change in the SNB angle reflecting the position of the mandible relative to the cranial base (SN) between T1 and T2 time points. Similar to the computation for the change in pogonion projection to the true vertical, treatment that led to no change or an increase in SNB reflected a favorable response; a decrease in SNB reflected an unfavorable response.

5- The alteration in the ANB angle reflecting the maxillo-mandibular relation relative to the cranial base between T1 and T2. No change or decrease in the angle was a favorable outcome; an increase was unfavorable.

6- The change in the L1/MP angle reflecting mandibular incisors compensation of the skeletal discrepancy. Favorable outcome accompanied no change or decreased angulation between T1 and T2; proclination was the unfavorable response.

Table 3.6: Components potentially contributing to treatment outcome and their corresponding cephalometric measurements

Components	**Means of measurement**
CRANIAL BASE	
1- Flexure (Saddle angle)	SN/Ar
JAW RELATIONS	
2- Sagittal relations	ANB
3- Vertical relations	PP/MP
MANDIBLE	
4- Length	Co-Gn
5- Position	SNB
ALVEOLAR/SKELETAL RELATIONS	
6- Mandibular incisors to mandibular plane	I/MP angle
CHIN	
7- Pog- (Projection)	Pog proj to vertical through Nasion
8- St Chin thickness	Proj Pog'-Pog
9- Symphyseal angle	anterior symphyseal angle
NOSE	
10- Nose tip projection (Pn-D)	Pn proj to vertical through Glabella

3.2.5. Panel examination

In an attempt to forego bias derived from the above-defined cephalometric outcome predictors of treatment responses, pre and post-treatment profile photographs (mainly profile outline) was evaluated by a panel of 15 orthodontists (instructors at and graduates of the AUB Department of Orthodontics and Dentofacial Orthopedics) and 19 dentists (applicants for post-graduate study at the same program) to determine correspondence between subjective and objective assessments. A 5-score Likert scale was used (Fig. 3.6; 3.7) to rate a subsample of 50 patients, randomly selected for the panel study based on the following criteria:

- Availability of pre and post-treatment profile photograph.
- Good quality of the photographs
- Head posture in the natural position
- Eyes fixed horizontally
- Face clearly visible
- Non-smiling photographs
- Pre and post-treatment pictures having approximately similar lighting conditions.

The following grading set up and conditions were adopted:

1. One hundred photographs of individual profiles were shown to the graders, one photograph at a time in a random order.
2. All raters examined the photographs in the presence of the project coordinator.
3. Photographs were shown on the same monitor, in the same room, under the same conditions of seating and lighting, with no interruption.
4. Photographs were shown in the same sequence for all raters.

5. The examiners were given adequate time to complete the rating; however, they could not return to an already rated photograph.

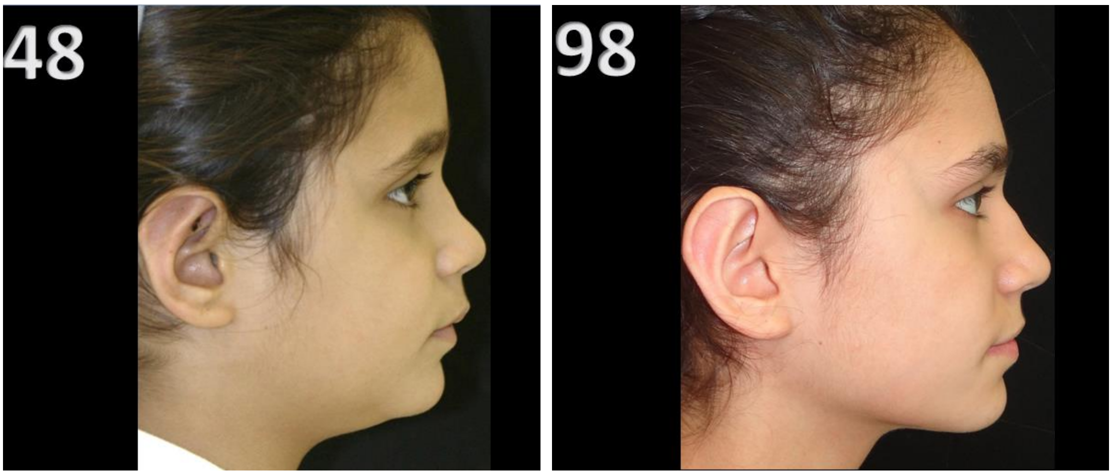
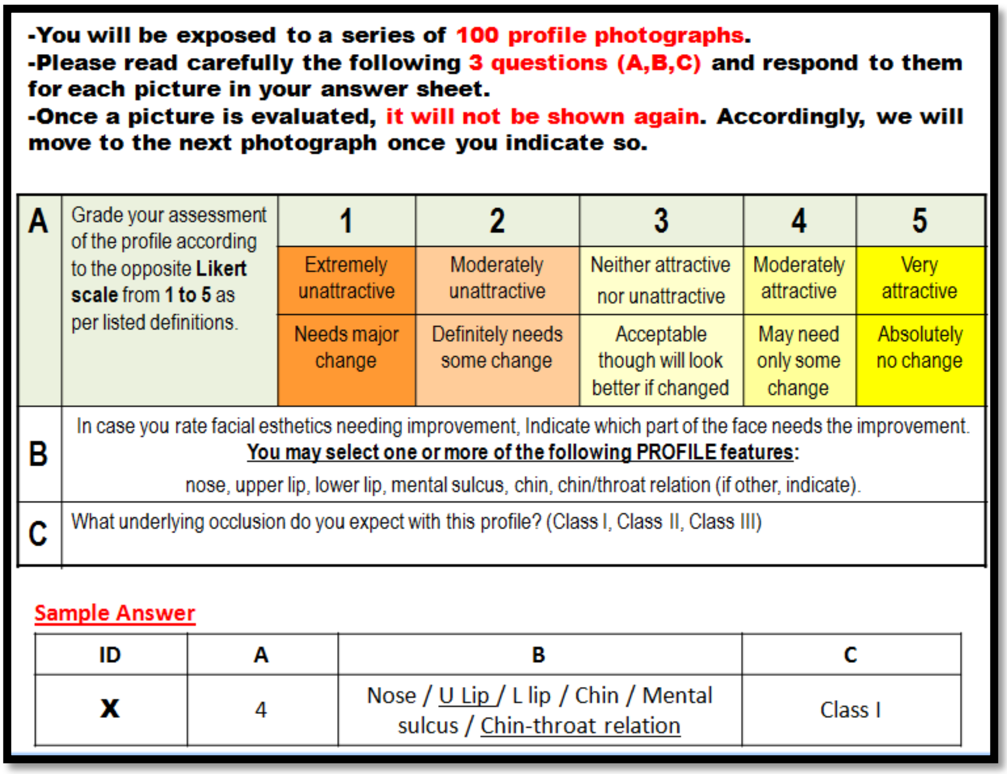


Fig. 3.6: Pre and post-treatment profile photographs of a patient as shown to the panel. The different numbers reflect the fact that pre- and post- treatment profiles were mixed among patients in a random sequence. Only one face was shown at any given time to the panel.



-You will be exposed to a series of 100 profile photographs.
-Please read carefully the following 3 questions (A,B,C) and respond to them for each picture in your answer sheet.
-Once a picture is evaluated, it will not be shown again. Accordingly, we will move to the next photograph once you indicate so.

A	Grade your assessment of the profile according to the opposite **Likert scale** from **1 to 5** as per listed definitions.	**1**	**2**	**3**	**4**	**5**
		Extremely unattractive	Moderately unattractive	Neither attractive nor unattractive	Moderately attractive	Very attractive
		Needs major change	Definitely needs some change	Acceptable though will look better if changed	May need only some change	Absolutely no change
B	In case you rate facial esthetics needing improvement, Indicate which part of the face needs the improvement. **You may select one or more of the following PROFILE features:** nose, upper lip, lower lip, mental sulcus, chin, chin/throat relation (if other, indicate).					
C	What underlying occlusion do you expect with this profile? (Class I, Class II, Class III)					

Sample Answer

ID	A	B	C
X	4	Nose / U Lip / L lip / Chin / Mental sulcus / Chin-throat relation	Class I

Fig. 3.7: Instructions form and definitions of the Likert scale categories as presented to the panel during the assessment session.

3.2.6. Definition of response to treatment based on the panel assessment

The definition of “favorable” (FR) and “unfavorable” (UFR) responses was based on the third panel question regarding the underlying malocclusion expected with the shown profile. Individual responsiveness to Class II treatment was defined on the basis of the following: when more than half of the panel of orthodontists (≥8 orthodontists) perceived a patient profile reflecting a Class II at the pre-treatment time point, the patient was considered as having a Class II profile phenotype; 38 out of 50 patients were perceived as such. From among the 38 patients, a favorable response was defined when less than half of the orthodontists (<8 orthodontists) perceived the patient’s profile being Class II at post-treatment. Accordingly, 15 subjects were classified as favorable responders FR, and 23 as unfavorable responders UFR. Moreover, to quantify the amount of Class II improvement for each patient, a rate of improvement (T2-T1) was computed based on the number of panelists who perceived the patient’s profile as reflecting a Class II malocclusion at T2 and T1. Given a total number of panelists of 15 for any assessment, the percentage of Class II assessment was computed at T1 (e.g. 10/15=0.67) and at T2 (e.g. 5/15=0.33). Subsequently, the rate of improvement between T2 and T1 was calculated (e.g. 0.33-0.67=-0.33). A negative T2-T1 difference in Class II perception reflected an improvement of the Class II phenotype toward a Class I profile.

3.2.7. Chin extension assessment based on the throat line (T-line)

The throat line or T-line was determined as a practical tool to evaluate the relation between throat inclination and chin extension, providing an easy and individualized interpretation that takes into account the facial proportions (Haddad and

Ghafari, 2017). The pre- and post-treatment radiographs of the 50 patients included in the panel study were superimposed on their corresponding pre- and post-treatment profile photograph to determine the landmarks with greater accuracy (Fig. 3.8). Measurements of the percentage of anterior and posterior portions at pre-treatment (T1) and post-treatment (T2) time points were computed.

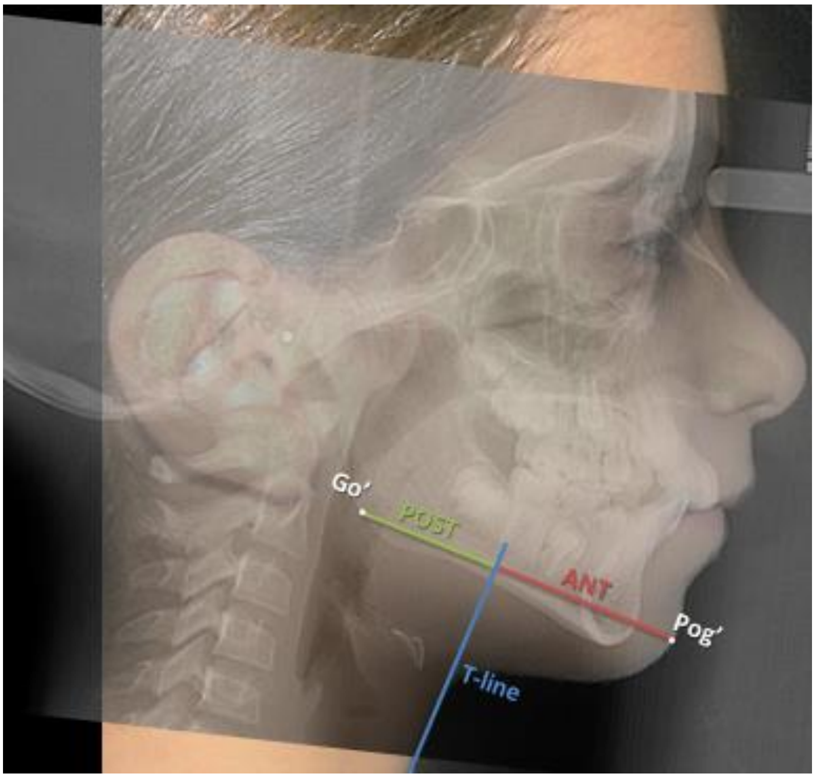


Fig. 3.8: Landmarks and lines used for assessing the chin extension. Go': soft tissue gonion determined by superimposing hard tissue gonion on the photograph; Pog': soft tissue pogonion; throat line (T-line) tangent to the throat; ANT/POST: anterior and posterior portions of the mandibular border determined by the intersection of T-line with Go'-Pog' line.

3.2.8. Repeated measurements

For the purpose of gauging intra-examiner reliability, 40 lateral cephalometric radiographs (20 pre- and 20 post-treatment lateral cephalograms) of 20 randomly selected patients (10% of the sample) were re-digitized by the same investigator (MJK) 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.

3.2.8. Statistical Analysis

Descriptive statistics were computed for all the variables for each of the 3 age groups (pre-pubertal, post-pubertal and adults) at both T1 and T2 time points. Frequency distribution was performed for the categorical variables (age groups and gender). For the quantitative variables, means, standard deviations, minimums and maximums are presented in appendices 2 and 3.

A two-way mixed analysis of variance (ANOVA) was used to compare the mean differences in cephalometric variables between the three groups. The “within-subjects” factor is time (T1 and T2) and the “between-subjects” factor consists of the age groups (pre-pubertal, post-pubertal and adult). After having established whether there is a statistically significant interaction between time and age groups, subsequent adequate analyses were employed to check the effect of time and age group on the dependent variables: one-way ANOVA followed by multiple comparison tests (Tukey) to evaluate the effect of age group and paired t-tests to assess the effect of time.

Multivariate discriminant analysis (DA) was applied to the 10 cephalometric measurements (those quantifying the components potentially contributing to treatment outcome) (Table 3.5) of the 179 subjects at T1 using the stepwise (statistical) method. 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.

Mann Whitney U test was employed to assess the differences between severity subgroups within the adult sample and the Wilcoxon signed-rank test was used to assess treatment changes within each severity subgroup.

Independent t-test was used to assess differences between severity subgroups within the growing sample and paired t-test was used to assess treatment changes within each severity subgroup.

Kruskal-Wallis test was employed to assess differences between response groups as classified by the expert panel. Post hoc for non-parametric test (Dunn's multiple comparison test) was employed to evaluate pairwise comparisons between response groups.

Pearson product-moment correlation coefficient was applied to check the correlation between the change in each of the 6 cephalometric outcome measures and the amount of Class II improvement as perceived by the expert panel.

Multiple linear regressions using clinically significant variables based on the panel assessment were performed to predict the improvement of Class II after treatment.

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 measurement ranged from 0.88 to 0.99 for the various cephalometric measurements.

4.2. Sample characteristics

The majority of the recruited 179 subjects, stratified into pre-pubertal, post-pubertal and adults age groups, were in their pre-pubertal period (group 1, n=88) and constituted almost half of the total sample (49.16%), followed by the adults (group 3, n=54), then the post-pubertal patients (group 2, n=37) (Table 4.1).

Table 4.1: Age distribution among the 3 age groups

	Pre-pubertal (1)		**Post-pubertal (2)**		**Adults (3)**	
N (%)	88 (49.16)		37 (20.67)		54 (30.17)	
Age	Mean(SD)	Range	Mean (SD)	Range	Mean(SD)	Range
	10.75(1.32)	7.41-13.33	13.39(1.27)	11.75-16.83	25.75(8.8)	15-52.53

The sample consisted of almost 60% females and 40% males. Consistent with the total sample distribution, the number of female participants was greater in the pre-pubertal (n=40) than the adult (n=38) and post-pubertal (n=28) groups. The male participants were also represented more in the prepubertal group (n=48), but less in the post-pubertal (n=9) than the adult (n=16) periods (Table 4.2).

Table 4.2: Total sample, gender characteristics

	Males	**Females**	**TOTAL**
Age (Mean ± SD)	14.53±5.7	16.7±9.56	15.82±8.26
Age groups N (%)			
Adults	16 (21.92%)	38 (35.85%)	54 (30.55%)
Pre-pubertal	48 (65.75%)	40 (37.74%)	88 (48.9%)
Post-pubertal	9 (12.33%)	28 (26.41%)	37 (20.55%)

4.3. Differences among age groups and time points

This section includes the findings of the two-way mixed ANOVA presented in Table 4.3, followed by the “simple effects” of group (Tables 4.4, 4.5) and time (Tables 4.6 - 4.8) for the variables that showed a significant group x time interaction. The “main effects” of group (regardless of time) and time (regardless of group) are presented for the variables that did not show a significant group x time interaction (Tables 4.9, 4.10).

4.3.1. Cranial base measurements

Significant group x time interactions (p<0.001) were observed in the anterior (SN) and posterior (S-Ar) cranial base lengths (Table 4.3).

- SN at T1 was the largest in group 3 (67.22 mm ± 3.82) compared to groups 2 (66.45 mm ± 3.27) and 1 (64.5 mm ± 2.9). The differences were statistically significant between group 1 and each of groups 2 (p=0.007) and 3 (p<0.001) (Table 4.4). At T2, there was no statistically significant difference in SN among all age groups (Table 4.5). Comparison of SN between T1 and T2 within each age group showed a statistically significant difference in all age groups (p<0.001). SN increased by 3.2 mm, 1.55 mm, and 0.18 mm in groups 1, 2, and 3 respectively (Tables 4.6 - 4.8).
- The posterior base S-Ar at T1 was the largest in group 3 (34.77 mm ± 3.81) compared to group 2 (34.12 mm ± 3.44) and group 1 (32.16 mm ± 3.02). The

differences were statistically significant between groups 1 and 2 ($p=0.009$) and between groups 1 and 3 ($p<0.001$) (Table 4.4). No statistically significant differences were noted at T2 among all age groups (table 4.5). Between T1 and T2 statistically significant differences were noted within each age group ($p<0.001$). S-Ar increased by 2.53 mm in group 1, almost 1mm in group 2 and 0.3 mm in group 3 (Tables 4.6 - 4.8).

- Differences in the inclination of the anterior cranial base to the true horizontal (SN/H) were not statistically significant between age groups regardless of time (Table 4.9). Between T1 and T2 time points the mean difference (0.037º) was statistically significant regardless of age ($p<0.001$) (Table 4.10).
- The saddle angle SN/Ar was the greatest in group 1 and lowest in group 3. A statistically significant difference ($p=0.042$) was present only between group 1 (126.25 º) and group 3 (124.06 º) whereby this angle was more obtuse in the growing groups (Table 4.9). No statistically significant difference was present between T1 and T2 (Table 4.10).

4.3.2. Relationship among jaws, cranial base and horizontal

All variables showed significant group x time interactions ($P<0.001$) except the Witts appraisal (Ao-Bo) (Table 4.3).

4.3.2.1 Antero-posterior jaw relationship

- Among the variables reflecting the antero-posterior relationship of the jaws, only the angle of convexity (NA/Apog) and the pogonion projection to vertical through nasion (Pog proj) showed statistically significant differences among age groups at

T1. The difference was statistically significant for NA/Apog only between groups 1 (12.49º ± 4.06) and 2 (10.51 º ± 3.49) [p=0.022], whereas the difference for pog proj was statistically significant only between groups 1 (-1.45 mm ± 3.82) and 3 (0.25 mm ± 4.66) [p=0.041] (Table 4.4).

- At T2, and among the same category of variables involving the maxilla, only SNA, ANB and NA/APog angles showed statistically significant difference between age groups; all 3 variables tended to be greater moving from pre-pubertal through post-pubertal to adult groups. For SNA, the difference was statistically significant only between groups 1 (80.47 º ± 3.21) and 3 (82.38 º ± 4.19) [p=0.008]; for ANB and NA/APog, the differences were statistically significant between groups 1 (4.35 º ± 1.49 and 7.43 º ± 4.52, respectively) and 3 (6.37 º ± 1.65 and 11.58 º ±3.94, respectively), and between groups 2 (4.79 º ± 1.58 and 7.78 º ± 4.59, respectively) and 3 [p<0.001] (Table 4.5). Comparisons among these variables between T1 and T2 within each age group showed a statistically significant difference in all age groups, except for SNB in group 2 and ANB, NA/APog and Pog proj in group 3 (tables 4.6 - 4.8).
- The Witts appraisal (Ao-Bo) was highest in group 3 and lowest in group 1. Statistically significant differences were present between groups 1 (1.66 mm) and 3 (4.27 mm) and between groups 2 (1.92 mm) and 3 (p<0.001), regardless of time (Table 4.9). In addition, a statistically significant difference was present between T1 and T2, regardless of age groupings (p=0.011) (Table 4.10).

4.3.2.2 Facial heights

- The upper (N-ANS), anterior lower (ANS-Me). and posterior facial (Ar-Go) heights, as well as the ratio between lower and total facial heights (LFH/TFH) all showed statistically significant differences among age groups at T1. The means of these variables were highest in group 3 and lowest in group 1. Pairwise comparisons between age groups revealed statistically significant differences in all combinations except between groups 2 and 3 for N-ANS, Ar-Go, LFH/TFH and between groups 1 and 2 for LFH/TFH (Table 4.4).
- At T2, only ANS-Me and LFH/TFH showed statistically significant differences between groups 1 (66 mm ± 5.53 and 55.85 % ± 1.72 respectively) and 3 (68.56 mm ± 5.02 and 56.76 % ± 2.41 respectively) (table 4.5).
- Comparisons of these variables between T1 and T2 within each age group showed a statistically significant difference in all age groups ($p<0.001$). All means were higher at T2 than at T1 in all age groups (Tables 4.6 - 4.8).

4.3.2.3 Vertical relationship between the jaws

- None of the variables reflecting the vertical divergence of the jaws showed a statistically significant difference between age groups at T1 and T2, except for the angle PP/MP between groups 1 (25.18° ± 4.62) and 3 (27.46° ± 6.02) at T2 (Tables 4.4 and 4.5).
- Comparisons between T1 and T2 within each age group showed statistically significant differences in groups 1 for all variables and 3 for MP/SN and MP/H only (Tables 4.6 and 4.8).

4.3.3. Jaw specific measurements

Significant group x time interactions were found for all variables, at $p<0.001$ for all linear measurements and $p=0.006$ for the gonial angle (Co/Go/Me) (Table 4.3).

- All mandibular linear measurements were highest in group 3 and lowest in group 1 at T1. All pairwise comparisons between age groups were statistically significantly different except for the mandibular body length (Go-Gn) between groups 2 and 3. Maxillary length (ANS-PNS) was statistically significantly different between groups 1 (51.95 mm ± 3.23) and 2 (54 mm ± 2.53) [$p=0.002$] and between groups 1 and 3 (53.56 mm ± 3.1) [$p=0.007$] (Table 4.4).
- At T2, and among the mandibular linear measurements, only Co-Gn and Go-Gn showed statistically significant differences between groups 1 (112.78 mm ± 6.63 and 74.32 mm ± 4.62, respectively) and 2 (115.7 mm ± 5.6 and 77.82 mm ± 4.03, respectively) [$p<0.05$]. Except between groups 1 and 2, ANS-PNS showed statistically significant differences in all pairwise comparisons at T2 (Table 4.5).
- The mandibular angle Co/Go/Me did not show any statistically significant difference between age groups, neither at T1 nor at T2 (Tables 4.4 and 4.5).
- Comparisons between T1 and T2 within each age group showed statistically significant differences in all age groups for all variables ($p<0.001$) except for the mandibular angle in groups 2 and 3. All linear measurements increased at T2 in all age groups (Tables 4.6 - 4.8).

4.3.4. Relationship among teeth and jaws

Statistically significant group x time interactions ($P<0.001$) were observed for all variables except the inclination of mandibular incisors to the mandibular plane (L1/MP) and to the profile line (L1/NB) (Table 4.3).

4.3.4.1 Inclination and position of maxillary incisors

- None of the variables related to the maxillary incisors showed a statistically significant difference between age groups at T1. In contrast, the same variables showed statistically significant differences between all age groups at T2 ($p<0.05$), except for U1-NA and U1/SN between groups 1 and 2 (Tables 4.4 and 4.5).
- Comparisons of all the variables between T1 and T2 within each age group showed statistically significant differences in groups 2 and 3 in which the inclination and protrusion of the maxillary incisors had decreased at T2 (Tables 4.6 - 4.8).

4.3.4.2 Inclination and position of mandibular incisors

- The mandibular incisors position relative to the profile L1-NB was statistically significantly different between groups 1 (6.08 mm ± 1.77) and 3 (7.73 mm ± 2.23) and between groups 2 (6.09 mm ± 2.22) and 3 [$P<0.001$] at T1 (Table 4.4) but not at T2 (Table 4.5). Comparisons between T1 and T2 within each age group showed statistically significant difference only in group 1 ($p=0.011$) (Table 4.6).
- While no statistically significant difference emerged from comparisons of L1/MP and L1/NB between age groups (Table 4.9), statistical significance was found

between T1 and T2 irrespective of age groups ($P<0.05$) with an average increase of nearly 1° at T2 (Table 4.10).

4.3.5. Relationship between teeth

Only the inter-incisal angle U1/L1 showed significant group x time interactions ($P=0.012$) (Table 4.3), although not statistically significantly different between age groups at T1 (table 4.4). At T2, only comparison between groups 1 (122.53º ± 8.48) and 3 (127.64 º ± 10.45) showed a statistically significant difference ($p=0.004$) (Table 4.5).

- Comparisons of U1/L1 between T1 and T2 within each age group showed a tendency for an increase in this angle at T2 but a statistically significant difference was present only in group 3 ($p<0.001$) (Table 4.8).
- Differences in overjet and overbite were not statistically significant between age groups regardless of time, but they were between T1 and T2 regardless of age groups ($P<0.001$); overbite decreased by 1.3 mm and overjet by 3.2 mm at T2 (Table 4.10).

4.3.6. Soft tissue measurements

Significant group x time interactions ($P<0.05$) were found for all variables except the mentolabial angle and both the length and inclination of the upper lip (Table 4.3).

- The relation of upper and lower lips to the Rickets Esthetic line showed statistically significant differences between age groups at T1. For UL-E line, statistically significant differences were present between groups 1 (-0.1 mm ± 1.9) and 2 (-1.44 mm ± 1.8) [$p=0.001$] and between groups 1 and 3 (-2.25 mm ± 2.11) [p<0.001]. LL-E line showed statistically significant differences only between groups 1 (1.7 mm ± 2.24) and 2 (0.42 mm ± 2.71) [0.029] (table 4.4).

- The nasolabial angle was more obtuse in group 1 at T1 and showed a statistically significant difference only between groups 1 (113.68º ± 10.33) and 3 (108.96 º ± 10.45) [p=0.025] (Table 4.4).
- The upper lip thickness and lower lip length were highest in group 3 and lowest in group 1 at T1. A statistically significant difference in upper lip thickness was present only between groups 1(14.73 mm ± 1.7) and 3 (16.07 mm ± 2.2) [<0.001]. Statistically significant differences in lower lip length were present between groups 1 (16.36 mm ± 2.35) and 2 (17.9 mm ± 2.36) [p=0.007] and between groups 1 and 3 (18.38 mm ± 2.96) [p<0.001] (table 4.4).
- The thicknesses of the lower lip and soft tissue chin did not show any statistically significant differences between age groups at T1. The average nose projection was highest in group 3 and lowest in group 1, with statistically significant differences between all age groups at T1 (p<0.001) (Table 4.4). None of soft tissue variables showed statistically significant differences between age groups (Table 4.5).
- When compared between T1 and T2, soft tissue measurements were statistically significantly different within group 1 (P<0.001). At T2, decreases were observed in the upper and lower lip distances to E line, and in the nasolabial angle; all other measurements increased (Table 4.6). In groups 2 and 3, the same pattern of change was noted at T2 for all soft tissue measurements except the nasolabial angle, which increased at T2 in group 3. Comparisons between T1 and T2 within groups 2 and 3 showed statistically significant differences in all soft tissue variables

(p<0.05) except for the nasolabial angle and upper lip thickness in group 2, and lower lip thickness in groups 2 and 3 (Tables 4.7 and 4.8).

- In comparisons of the mentolabial angle, UL length and UL inclination between age groups regardless of time, only UL length showed a statistically significant difference between groups 1 (21 mm) and 3 (22.56 mm) [p<0.001] (Table 4.9). Statistically significant differences were present between T1 and T2 regardless of age groupings (p<0.001); the mentolabial angle and UL length increased, and UL inclination decreased, at T2 (Table 4.10).

4.3.7. Symphyseal components

All variables showed significant group x time interactions (p<0.001) (Table 4.3).

- Among these variables, only D-apex, D-Menton, and chin width (CW) at the level of lower incisor apex showed statistically significant differences between age groups at T1. D-Apex was highest in group 3 (10.1 mm ± 1.95) and lowest in group 1 (6.04 mm ± 1.92), with a statistically significant difference between all age groups (p<0.001) at T1. D-Me was borderline significant between groups 1 (11 mm ± 0.92) and 3 (11.48 mm ± 1.38) [0.048]. CW-apex was highest in group 1 and lowest in group 3, with a statistically significant difference between groups 1 (10.28 mm ± 1.65) and 2 (9.35 mm ± 2.17) [p=0.033] and between groups 1 and 3 (8.51 mm ± 2) [p<0.001] at T1 (table 4.4).
- At T2, D-Apex was also highest in group 3 (10.6 mm ± 2.25) and lowest in group 1 (8.69 mm ± 2.07); statistically significant differences were between groups 1 and 2 (9.82 mm ± 2.49) [p=0.027] and between groups 1 and 3 [p<0.001].

- CW-Apex differences were statistically significant only between groups 1 (9.18 mm ± 1.79) and 3 (8.04 mm ± 2.21) [p=0.004] at T2. No statistically significant differences were observed for all other variables between age groups at T2 (table 4.5).
- Comparisons of symphyseal variables between T1 and T2 within groups 1 and 2 revealed statistically significant differences for all variables except the posterior slope (PSA) in group 2. In both groups 1 and 2, all measurements increased at T2 except for the chin width at lower incisor apex. In group 3, only D-Apex and CW-apex showed statistically significant differences between T1 and T2 (p=0.034 and p<0.001 respectively) (Tables 4.6 - 4.8).

4.4. Predictors of Class II, division 1 treatment outcome

This section includes the results of 6 different discriminant analyses that were applied for the growing (combined pre- and post- pubertal) and adult groups. The analyses were conducted using 6 different methods of classification of treatment outcome into “favorable” and “unfavorable” responses. The classifications were based on the treatment changes between T1 and T2 in 6 cephalometric outcome measures: the angle of convexity (NA/APog), the projection of pogonion to the true vertical passing through nasion (Pog proj), ANB angle, SNB angle, Upper lip relation to E-Line, and mandibular incisor inclination to mandibular plane (L1/MP).

4.4.1. Classification 1 based on treatment change in Pog proj

Based on this classification of favorable (FR, n=55) and unfavorable (UFR, n=70) responses, significant predictors of treatment outcome were found only in the growing group. Descriptive statistics for the 10 cephalometric variables at baseline (T1) are listed in Table 4.11.

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: St Chin thickness (p=0.009) and nose projection (Pn-D) (p=0.002), with a canonical correlation of 0.308. The cross validation rate was 63.2% (Table 4.12).

The following equation was generated using the unstandardized discriminant function coefficients of St Chin thickness, Pn-D, and a constant:

DS = -9.757 + 0.424 Chin Th + 0.231 Pn-D.

This equation provides individual scores for assigning a new patient to either FR or UFR groups; the discriminant scores for group means (group centroids) were -0.362 for the FR group and 0.284 for the UFR group. The critical score was -0.039. A new growing Class II/1 patient who scores less than the critical score of -0.039 is more likely to have a favorable response to treatment, with a more forward position of the chin. 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 63.2%, a rate lower than the proportional by chance accuracy rate of 63.4%. Accordingly, the criterion for classification accuracy was not satisfied in this classification.

4.4.2. Classification 2 based on treatment change in angle of convexity

Under this classification, significant predictors of treatment outcome were also found only in the growing group. Descriptive statistics for the 10 cephalometric variables at baseline (T1) for the FR (n=59) and UFR (n=66) are listed in Table 4.13.

The stepwise variable selection resulted in a one-variable model that satisfied the level of significance of 0.05 and produced the best discrimination between the 2 groups: the mandibular length (Co-Gn) (p=0.006) with a canonical correlation of 0.247. The cross validation rate was 60% (table 4.14).

The equation generated by using the unstandardized discriminant function coefficients of Co-Gn and a constant was:

$$\mathbf{DS = -15.827 + 0.151\ Co\text{-}Gn.}$$

The equation provides individual scores for assigning a new patient to either FR or UFR groups; the discriminant scores for group means (group centroids) were -0.267 for the FR group and 0.239 for the UFR group. The critical score was -0.014. A new growing Class II/1 patient who gets less than the critical score of -0.014 is more likely to have a favorable response to treatment, with decrease profile convexity. Conversely, a new patient with the same malocclusion whose score is greater than the critical score is more likely to have an unfavorable treatment outcome.

The cross-validated accuracy rate of 60% was less than the proportional by chance accuracy rate of 62.696%, thus not satisfying the criterion for classification accuracy.

4.4.3. Classification 3 based on treatment change in ANB angle

In this scheme, significant predictors of treatment outcome were found in both growing and adult groups.

4.4.3.1 Classification 3 for the growing sample

Descriptive statistics for the 10 cephalometric variables at baseline for the FR (n=58) and UFR (n=67) are displayed in Table 4.15.

The 2-variable model yielded by the stepwise variable selection satisfied the level of significance (0.05) and produced the best discrimination between the 2 groups: the saddle angle (SN/Ar) (p=0.017) and Pogonion projection (Pog proj), with a canonical correlation of 0.299. The cross validation rate was 59.2% (table 4.16).

The unstandardized discriminant function coefficients of SN/Ar, Pog proj and a constant determined the following equation:

$$\mathbf{DS = -18.152 + 0.142\ SN/Ar - 0.194\ Pog\ proj.}$$

The equation presents individual scores for assigning a new patient to either FR or UFR groups, whereby the discriminant scores for group means (group centroids) were 0.334 for the FR group and -0.289 for the UFR group, and the critical score was 0.0225. A new growing Class II/1 child whose score is greater than the critical 0.0225 is more likely to respond favorably to treatment with a straighter profile. Another patient with a score lower than the critical score is more likely to have respond unfavorably.

The cross-validated accuracy rate of 59.2% was less than the proportional by chance accuracy rate of 62.824%; the criterion for classification accuracy was not satisfied.

4.4.3.2 Classification 3 for the adult sample

The FR (n=26) and UFR (n=28) were nearly equal under the ANB classification; their corresponding cephalometric variables at baseline are shown in Table 4.17. A one-variable model resulted from the stepwise variable selection at the 0.05 level of significance, and produced the best discrimination between the 2 groups, including the soft tissue chin thickness (St chin thickness) (p=0.014) with a canonical correlation of 0.333. The cross validation rate was 63% (Table 4.18).

The following equation was generated using the unstandardized discriminant function coefficients of St Chin thickness and a constant:

$$\mathbf{DS = -6.115 + 0.549\ St\ Chin\ thickness,}$$

providing individual scores to assign a new patient to either FR or UFR groups; the discriminant scores for group means (group centroids) were 0.36 for the FR group and -0.334 for the UFR group. The critical score was 0.013. A new adult patient having a Class II, division 1 malocclusion and who has a score higher than the critical score of 0.013, is more likely to have a favorable response to treatment with a less convex profile. Another patient with a similar malocclusion who has a score lesser than the critical score is more likely to respond unfavorably.

The cross-validated accuracy rate of 63% was higher than the proportional by chance accuracy rate of 62.59%. The criterion for classification accuracy was satisfied.

4.4.4. Classification 4 based on treatment change in SNB angle

Significant predictors of treatment outcome were found in both growing and adult groups.

4.4.4.1 Classification 4 for the growing sample

The UFR (n=67) were more than the FR (n=58) under the SNB classification; the corresponding cephalometric components at baseline are shown in Table 4.19.

A one-variable model emerged from the stepwise variable selection at the 0.05 level of significance, producing the best discrimination between the 2 groups: pogonion projection (Pog proj) (p=0.028) with a canonical correlation of 0.197. The cross validation rate was 59.2% (Table 4.20).

The following equation was generated using the unstandardized discriminant function coefficients of Pog proj and a constant:

$$\mathbf{DS = 0.326 + 0.269\ Pog\ proj.}$$

This equation provides individual scores for assigning a new patient to either FR or UFR groups; the discriminant scores for group means (group centroids) were -0.214 for the FR group and 0.186 for the UFR group. The critical score was -0.014. A new growing Class II/1 patient whose score is less than the critical score of -0.014 is more likely to have a favorable treatment outcome with reduced mandibular retrognathism. In contrast, a new patient with a score higher than the critical score is more likely to have an unfavorable outcome.

The cross-validated accuracy rate of 59.2% was lower than the proportional by chance accuracy rate of 62.824%. The criterion for classification accuracy was not satisfied in this classification.

4.4.4.2 Classification 4 for the adult sample

More adult FR (n=30) than UFR (n=24) were observed under the SNB classification; their cephalometric components at baseline are shown in Table 4.21.

The stepwise variable selection resulted in a one-variable model satisfying the 0.05 level of significance and producing the best discrimination between the 2 groups: the mandibular length (Co-Gn) (p=0.034) with a canonical correlation of 0.289. The cross validation rate was 63% (Table 4.22).

The following equation was generated using the unstandardized discriminant function coefficients of Co-Gn and a constant:

$$\mathbf{DS = -19.425 + 0.171\ Co\text{-}Gn.}$$

This equation provides individual scores for assigning a new patient to either FR or UFR groups; the discriminant scores for group means (group centroids) were 0.265 for the FR group and -0.331 for the UFR group. The critical score was -0.033. A new adult patient with Class II/1 whose score is higher than the critical score of -0.033 is more likely to respond favorably to treatment with reduced retrognathic mandible. A new patient with the same malocclusion who has a score that is lesser than the critical score is more likely to have an unfavorable response to treatment.

The cross-validated accuracy rate computed by SPSS was 63%, which was less than the proportional by chance accuracy rate of 63.284%. The criterion for classification accuracy was not satisfied in this classification.

4.4.5. Classification 5 based on treatment change in UL-E line

Significant predictors of treatment outcome were found in both growing and adult groups.

4.4.5.1 Classification 5 for the growing sample

Nearly 5 times more FR (n=104) than UFR (n=21) were observed under the UL-E line; their cephalometric components at baseline are shown in Table 4.23.

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: St Chin thickness ($p<0.001$) and the anterior symphyseal slope ($p=0.001$) with a canonical correlation of 0.363. The cross validation rate was 69.6% (Table 4.24).

The following equation was generated using the unstandardized discriminant function coefficients of St Chin thickness, anterior slope and a constant:

$$\mathbf{DS = -4.597 + 0.157\ Ant\ SL + 0.358\ Chin\ th,}$$

providing individual scores for assigning a new patient to either FR or UFR groups: The discriminant scores for group means (group centroids) were -0.173 for the FR group and 0.859 for the UFR group. The critical score was 0.343. A new growing Class II patient who has a score that is lesser than the critical score of 0.343 is more likely to have a favorable response to treatment, with a more harmonious subnasal profile. Conversely, a new patient with the same malocclusion who has a score that is higher than the critical score is more likely to have an unfavorable response to treatment.

The cross-validated accuracy rate of 69.6% was greater than the proportional by chance accuracy rate of 62.5%. The criterion for classification accuracy was satisfied.

4.4.5.2 Classification 5 for the adult sample

Descriptive statistics for the 10 cephalometric variables at baseline for the adult FR (n=33) and UFR (n=21) are listed in Table 4.25.

The stepwise variable selection resulted in a two-variable model at the 0.05 level of significance that produced the best discrimination between the 2 groups: the mandibular incisors compensatory inclination (L1/MP) ($p=0.002$) and the angle between maxillary and mandibular planes (PP/MP) ($p<0.001$), with a canonical correlation of 0.537. The cross validation rate was 68.5% (Table 4.26).

The following equation was generated using the unstandardized discriminant function coefficients of L1/MP, PP/MP and a constant:

$$\mathbf{DS = -23.671 + 0.197\ L1/MP + 0.152\ PP/MP.}$$

The equation provides individual scores for assigning a new patient to either FR or UFR groups: the discriminant scores for group means (group centroids) were 0.498 for the FR group and -0.783 for the UFR group. The critical score was -0.1425. An adult patient presenting with Class II/1 and who has a score higher than the critical score of -0.1425 is more likely to have a favorable outcome, with a more harmonious subnasal profile. A new patient with a similar malocclusion but a score lower than the critical score is more likely to respond unfavorably to treatment.

The cross-validated accuracy rate of 68.5% was greater than the proportional by chance accuracy rate of 62.5%. The criterion for classification accuracy was satisfied.

4.4.6. Classification 6 based on treatment change in L1/MP

Both growing and adult groups had significant predictors of treatment outcome.

4.4.6.1 Classification 6 for the growing sample

More FR (n=69) than UFR (n=56) were observed under the L1/MP classification; their cephalometric components at baseline are shown in Table 4.27.

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: L1/MP ($p<0.001$) and PP/MP ($p<0.001$) with a canonical correlation of 0.473. The cross validation rate was 71.2% (table 4.28).

The equation generated using the unstandardized discriminant function coefficients of L1/MP, PP/MP and a constant was:

$$\mathbf{DS = -24.731 + 0.167\ PP/MP + 0.206\ L1/MP.}$$

This equation provides individual scores for assigning a new patient to either FR or UFR groups: the discriminant scores for group means (group centroids) were 0.48 for the FR group and -0.592 for the UFR group. The critical score was -0.056. A growing Class II/1 patient whose score is higher than the critical score of -0.056 is more likely to respond favorably with less mandibular incisors compensation for the skeletal discrepancy. For a similar malocclusion, a new patient with a score lower than the critical score is more likely to have an unfavorable response to treatment.

The cross-validated accuracy rate of 71.2% was greater than the proportional by chance accuracy rate of 62.5%. The criterion for classification accuracy was satisfied.

4.4.6.2 Classification 6 for the adult sample

Classification on the inclination of the mandibular incisor yielded a higher number of UFR (n=32) than the FR (n=22). Descriptive statistics for the 10 cephalometric components in both groups are shown in Table 4.29.

The one-variable model that resulted from the stepwise variable selection at the 0.05 level of significance produced the best discrimination between the 2 groups: the saddle angle (SN/Ar) (p=0.033) with a canonical correlation of 0.291. The cross validation rate was 68.5% (Table 4.30).

The equation **DS = -27.718 + 0.223 SN/Ar** was generated using the unstandardized discriminant function coefficients of SN/Ar and a constant. The equation provides individual scores for assigning a new patient to either FR or UFR groups: the discriminant scores for group means (group centroids) were 0.36 for the FR group and -0.247 for the UFR group. The critical score was 0.0565. Accordingly, an adult patient presenting for the correction of Class II/1 and whose score is higher than the critical score of 0.0565 is more likely to respond favorably to treatment, with less mandibular incisors compensation for the skeletal discrepancy. The response to treatment of a similar malocclusion with a corresponding score that is lesser than the critical score is more likely to be unfavorable.

The cross-validated accuracy rate of 68.5% was greater than the proportional by chance accuracy rate of 62.5%. The criterion for classification accuracy was satisfied.

4.5. Differences between Severity Subgroups

The group of 125 growing patients included 84 in the low severity (GLS) and 41 in the high severity (GHS) subgroups. No age difference was found between these subgroups at both T1 and T2 ($p=0.14$ and $p=0.76$ respectively). Of the 54 adults, 34 were in the low severity subgroup (ALS) and 20 in the high severity subgroup (AHS). Age was not different between these subgroups at both T1 and T2 ($p=0.8$ and $p=0.95$ respectively). The following analysis was limited to selected cephalometric variables considered of meaningful significance to treatment definition and outcome.

4.5.1. Severity within the growing group

Comparisons between T1 and T2 within each growing severity subgroup showed statistically significant differences ($p<0.001$) for all variables except the saddle angle (SN/Ar) and the inclination of both maxillary and mandibular incisors to their skeletal bases (U1/PP and L1/MP respectively) (Tables 4.31, 4.32).

Comparison between GLS and GHS subgroups at each time point disclosed the following (Tables 4.33, 4.34):

- The ANB angle was higher in the GHS subgroup with a mean difference of 2.45° at T1 and 1.61° at T2 ($p<0.001$).
- The SNA angle was greater in the GHS subgroup with a mean difference of 1.7 ° at T1 and 1.4 ° at T2 ($p=0.002$ and $p=0.027$ respectively).

- The mandibular length (Co-Gn) was greater in the GLS subgroup with a mean difference of 3 mm at T1 (p=0.019) that decreased to 2mm at T2, but the difference was not statistically significant (p=0.107).
- The inclination of mandibular incisors to mandibular plane (L1/MP) was higher in the GHS subgroup (mean difference of almost 3º at T1; p=0.015), decreasing to a non-statistically significant difference at T2 (2.3 º ; p=0.066).
- The chin projection to vertical through nasion (Pog proj) was larger in the GLS subgroup with a mean difference of 1.5 mm at T1 (p=0.029) that diminished to 0.8mm at T2, a difference that was no longer statistically significant (p=0.35).
- The anterior slope of the chin (ANT slope) was higher in the GLS subgroup with a mean difference of 4.7º at both T1 and T2 time points (P<0.001).
- All other variables (SN, SN/Ar, PP/MP, SNB, U1/PP, St Chin thickness and Pn-D) did not show statistically significant differences between severity subgroups.

4.5.2. Severity within the adult group

Comparisons between T1 and T2 within each adult severity subgroup showed statistically significant differences (p<0.05) for the following variables: anterior cranial base SN, mandibular length Co-Gn, maxillary incisors inclination to the palatal planeU1/PP, soft tissue chin thickness and extension of the nose (Tables 4.35 and 4.36).

Comparison between ALS and AHS subgroups at each time point revealed the following (Tables 4.37, 4.38):

- The ANB angle was greater in the AHS subgroup with a mean difference of 2.56º at T1 and 2.65º at T2 (p<0.001).

- The SNA angle was higher in the AHS subgroup with mean differences of 2.44º at T1 and 2.5º at T2 that were not statistically significant ($p=0.07$ and $p=0.095$, respectively).
- Mandibular length (Co-Gn) was greater in the ALS subgroup with mean differences of 3.47 mm at T1 and 3.33 mm at T2 that were not statistically significant ($p=0.062$ and $p=0.056$, respectively).
- The vertical divergence between the jaws PP/MP was higher in AHS subgroup with a mean difference of 2.14º at T1 and 2.8º at T2 ($p<0.001$).
- The inclination of the mandibular incisors to mandibular plane (L1/MP) was higher in the AHS subgroup with mean differences of nearly 3.45º at T1 and 2.53º at T2 ($p<0.001$).
- All other variables (SN, SN/Ar, SNB, U1/PP, St Chin thickness, Pog proj, Ant slope and Pn-D) did not show statistically significant differences between the ALS and AHS subgroups.

4.5.3. Relation between overjet and severity of the skeletal discrepancy

The correlations between overjet and ANB at T1 were low ($0.006<r<0.206$) (Table 4.39).

4.6. Panel assessment

This section includes descriptive statistics of the panel assessment of profile attractiveness, the facial features that need change, and perception of profile phenotype. Treatment responses were defined as favorable (FR) and unfavorable (UFR) based on the perception of profile phenotype by the panel of orthodontists alone, which is considered as the expert panel.

4.6.1. Profile attractiveness

Regarding profile attractiveness as perceived on a 5 scale Likert, both panels had almost equal perceptions of profile attractiveness at T1 and T2 time points (p=0.862 and p=0.84 respectively). Profile attractiveness improved after treatment according to both panels with a mean Likert score increase of 0.33 (p<0.001). Orthodontists and dentists also showed the same trend of profile improvement after treatment with almost equal mean differences (0.332 and 0.335 respectively) (p=0.982) (Figs. 4.1, 4.2; Table 4.40).

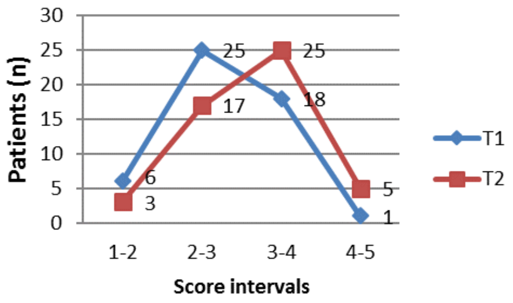


Fig 4.1: Line chart showing the improvement of profile attractiveness by orthodontists between T1 and T2.

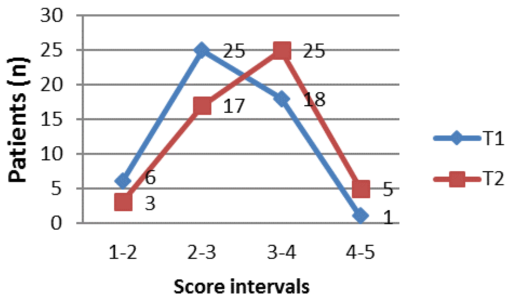


Fig 4.2: Line chart showing the improvement of profile attractiveness by dentists between T1 and T2.

4.6.2. Profile features needing improvement

According to both panels, all profile features showed some improvement after treatment except for the nose, which became worse. For orthodontists, the chin had the highest need for improvement at both T1 and T2. For dentists, the chin, chin throat angle and upper lip needed the most improvement at T1; at T2, the nose became the feature with mostly needing improvement next to the chin and chin throat angle.

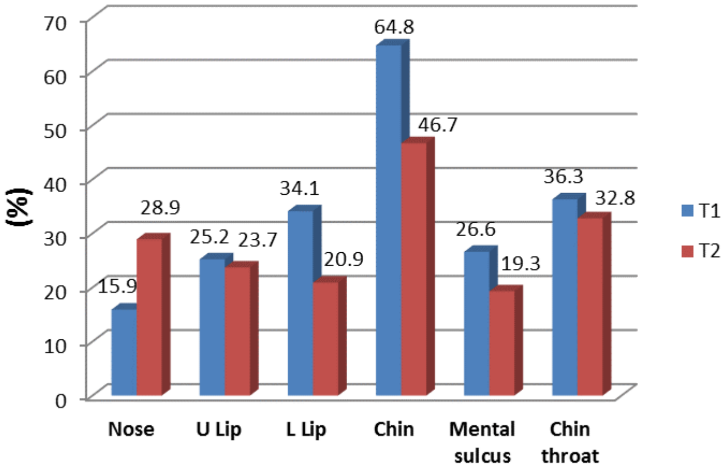


Fig 4.3: Bar graph showing the perception of orthodontists of the profile features needing change at T1 and T2

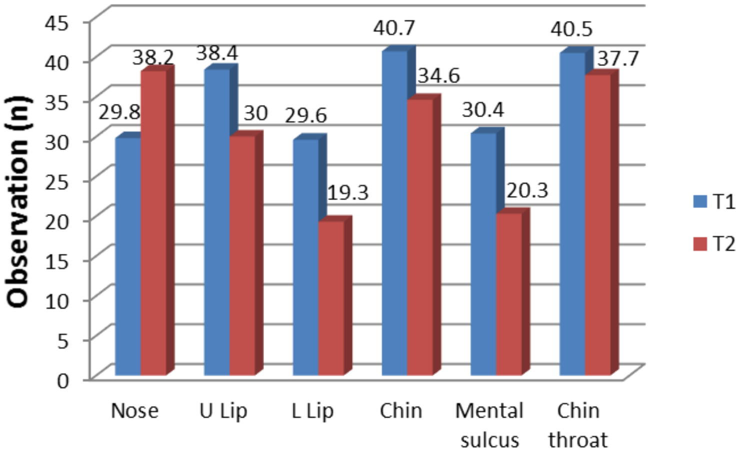


Fig 4.4: Bar graph showing the perception of dentists of the profile features needing change at T1 and T2

4.6.3. Profile phenotype

According to both panels, Class II profiles were mostly seen in pre-treatment (T1) photographs (68.5 % for orthodontists, 55.9 % for dentists). At T2, the trend shifted to a decrease in Class II designations (42.9% by orthodontists, 35.5 % by dentists) and prevalence of Class I profiles (55.2 % by orthodontists, 55.9 % by dentists).

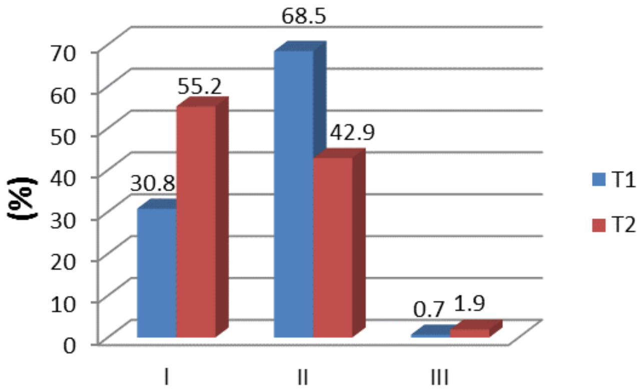


Fig 4.5: Bar graph showing the perception of profile phenotype judged by the panel of orthodontists at T1 and T2 time points.

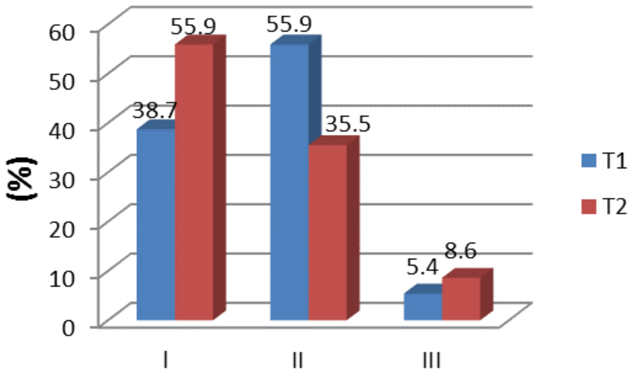


Fig 4.6: Bar graph showing the perception of profile phenotype judged by the panel of dentists at T1 and T2

4.6.4. Comparison between the different response groups based on the expert panel

Comparison of attractiveness between favorable (FR) and unfavorable responders (UFR) on the 5 choices Likert scale showed that both FR and UFR had almost equal mean scores of attractiveness (2.69 ± 0.47 and 2.49 ± 0.55 respectively) at T1. The unclassified group in which patients' profiles were perceived as Class I prior to treatment had a significantly higher mean score of attractiveness (3.21 ± 0.59) than either the FR and UFR groups at T1 ($p<0.05$). At T2, statistically significant differences were present between mean scores of FR (3.33 ± 0.46) and UFR (2.71 ± 0.48), and between UFR and the unclassified group (3.37 ± 0.5) [$p<0.001$].

Comparison of severity of the skeletal discrepancy between the 3 groups based in the ANB angle showed the following: The UFR group had a significantly greater mean ANB angle (6.83º ± 1.3) than the FR group (6.15º ± 1.54) [p=0.05], and the unclassified group (5.72º ± 1.12) [p=0.01] at T1. At T2, a statistically significant difference was found only between FR (4.29º ± 2.22) and UFR (5.73º ± 1.72) groups (p=0.01).

The anterior slope of the chin angle was significantly larger in the FR group (8.73º ±5.5) than in both the UFR (3.63º ± 3.94) and the unclassified (5.3º ± 5.09) groups ($p<0.05$) at T1. At T2, FR group also had a greater mean slope angle (11.44º ± 5.93) than the UFR group (4.95º ± 4.32) [$p<0.001$] (Tables 4.41, 4.42).

Differences in the vertical skeletal pattern (divergence between maxilla and mandible) were not statistically significant among all 3 groups at T1. At T2, UFR group had a significantly greater mean PP/MP (28.23º ± 4.56) than the FR group (24.87º ± 4.2) [$p<0.05$].

4.6.5. Prediction of Class II/1 treatment outcome based on the expert panel

The panel of orthodontists classified the participants' pre- and post-treatment profiles into different phenotypes (I, II, III). The rate of improvement in Class II treatment was based on the difference between the pre- and post-treatment numbers of orthodontists that chose the Class II phenotype. Accordingly, participants with better improvement rate had a negative sign because of lesser Class II profiles after treatment.

The pre- and post-treatment changes in various cephalometric measurements were associated with the amount of Class II improvement to explore the best measurement that can reflect the panel assessment. The only significant correlation found for the improvement assessment was with the treatment change in ANB angle ($r = -0.279$) (Table 4.43).

4.6.5.1 Association between response groups and relevant cephalometric variables

According to the panel’s assessment of improvement, 38 patients (perceived as having Class II before treatment) were categorized into favorable and unfavorable response groups. Odds ratio were calculated to measure the association between the response groups (FR/UFR) and pre-treatment cephalometric measurements (Table 4.44). Chin thickness was significantly associated with the improvement assessment: with every 1 mm increase in the pre-treatment soft tissue chin thickness, the odds for unfavorable response increase by 2.5. Pogonion projection and anterior chin slope angle were also significantly associated with the improvement assessment: with every 1º increase in the chin slope angle and with every 1 mm increase in the pogonion projection, the odds for a favorable response increase by 1.23 and 1.18 respectively.

4.6.5.2 Multivariate linear regression to predict the improvement of Class II/1

For the purpose of predicting Class II improvement after treatment, bivariate associations (correlations) were performed between the rate of improvement assessment (T2-T1) and pre-treatment cephalometric variables on the 38 patients. The rate of Class II improvement had a significant positive association with the pre-treatment soft tissue chin thickness (r= 0.55) and a negative association with the anterior chin slope angle (r= -0.45).

A negative change (T2-T1) in Class II perception reflects improvement of the Class II relationship toward a Class I profile phenotype; whenever the anterior chin slope angle increases, the change (T2-T1) in Class II perception decreases reflecting more improvement in the Class II. Conversely, whenever the soft tissue chin thickness increases, the change (T2-T1) in Class II perception increases reflecting less or no improvement of the Class II (table 4.45).

After the bivariate associations, multiple linear regressions were conducted on the 38 patients to predict the amount of Class II improvement, and included all variables with a p-value < 0.2 (table 4.45). The final model was significant ($p < 0.001$; r^2 0.37) and included two variables, with the following prediction equation (Table 4.46):

(t2 – t1) Improvement of Class II = (0.0625*Chin th) – (0.015*Antslope) - 0.906.

4.7. Assessment of chin extension

Based on the assessment of the throat line (T-line) intersection with the mandibular body, the mean percentage of the anterior portion of the mandibular body (ANT) relative to the total mandibular body length at T1 was 44.64 %. At T2, ANT decreased by almost 2.6 % to 42% (p=0.0016), showing no improvement of the chin extension relative to the T-line after treatment (Table 4.47). When evaluated in the different age groups, ANT worsened in the pre-pubertal group and did not improve in the post-pubertal and adult patients (Table 4.48).

CHAPTER 5

DISCUSSION

5.1. Introduction

Careful evaluation of treatment results has been a traditional interest for orthodontists and orthodontic researchers who try to scrutinize the efficiency of treatment modalities based on final outcomes. Such scrutiny is the basis to generate schemes for the prediction of treatment efficiency and prognosis that could have many benefits for patients, including the potential to communicate to patients the success rate of a proposed treatment option in an evidence-based approach. To this end, finding accurate and reliable predictors in science requires the application of appropriate statistical methods on credible and precise data which reveal the contribution of relevant variables to the final outcome.

Ideally, randomized clinical trials are gold standard research processes on which all health care decisions should be based (Cochrane, 1972). However, their application is limited for ethical and timing issues especially in orthodontics. In fact, retrospective data of orthodontically treated patients have inherent restrictions and should be treated with caution to reduce bias (Livieratos & Johnston, 1995). Nonetheless, confounding factors like the patient's treatment preferences, the clinician's own judgment and influence of growth in growing population of patients cannot be controlled (Tulloch et al, 1990; Tulloch et al, 1997).

We investigated treatment outcome of Class II division 1 malocclusion using an innovative 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 and by orthodontic mechanics in adult patients. Cephalometric analyses were the only means that were used in the literature to assess treatment outcome and explore predictors of Class II/1 treatment outcome. However, the influence of the soft tissue forces a different paradigm, because the amount of profile improvement after treatment to neutroclusion may define a different weight of treatment success. For this reason, an expert panel of orthodontists was sought in this study to assess profile photographs of a subsample of 50 patients to check the correspondence between cephalometric outcome measures and perception of "favorable" and "unfavorable" treatment responses. Accordingly, a complete assessment of treatment efficiency was pursued, a departure from the most common focus on dentoskeletal assessment.

5.2. Cephalometric changes across age groups and treatment duration

For the majority of variables, the two-way group x time interaction effect was statistically significant. This finding indicates different effects of the different groups on each variable over time; each variable changes differently over time depending on whether the patient started treatment in his pre-pubertal, post-pubertal or adult stage.

Cranial base: The anterior and posterior cranial base lengths (SN and S-Ar) were greatest in adults compared with growing groups. Prior to treatment, the mean differences of almost 2.5 mm were significant for both measurements, but statistical significance was absent between age groups after treatment. These results were concordant with those of Bjork (1955) and Ford (1958) that indicated growth cessation of most of the cranial base early in life, yet the remaining backward remodeling of sella and the increase in size of the frontal sinus would keep increasing the length of the anterior cranial base. The changes over time were statistically significant within each of the 3 age groups, between T1 and T2; however, the amount of SN and S-Ar change within the adult group is not considered clinically significant (0.18 mm and 0.3 mm respectively). Measurements of distances (mm) should be interpreted with caution because of possible errors in head positioning in the cephalostat or risk of radiographic magnification inherent to the dolphin imaging software (Power et al, 2005). The saddle angle did not show any group interaction with time interaction; it was more obtuse in growing groups than in adults with a mean difference of 2.2 ° and remained stable over time regardless of age groups.

Sagittal jaw relations: In the pre-pubertal group, a favorable statistically significant change over time was observed in the antero-posterior jaw relations (SNA, SNB, ANB, NA/Apog and Pog proj). This finding indicated a decrease in profile convexity and improvement of the skeletal discrepancy with more forward extension of the chin because of a combination of orthopedic treatment and growth. In the post-pubertal group, SNB remained stable over treatment time and all other angular measurements have shown a slight favorable change over time. A small change in pogonion projection to vertical (0.6 mm) was statistically significant but not considered as clinically significant. Expectedly, no clinically significant change was noted in the sagittal measurements in the adult group.

Vertical relations: Measurements reflecting the upper, anterior and posterior facial heights were all significantly highest in the adult group prior to treatment but not at post-treatment except for the anterior lower facial height (ANS-Me), which remained the highest in the adult group. Moreover, the ratio between lower and total facial heights LFH/TFH was statistically significantly higher in adult than pre-pubertal group at both

T1 and T2, possibly reflecting the effect of treatment in adults whereby at least part of such an increase in growing patients may be attributed to natural vertical increase within the “growth envelope.” The increase in facial heights over time within age groups were statistically significant in all age groups but cannot be considered as clinically significant in the adult group given the small amount of change.

From among the measurements reflecting the vertical jaw relationship, a significant decrease in vertical divergence reflected by the angle PP/MP occurred in the pre-pubertal group (-2°) but not in the other groups. This change was caused by a clockwise rotation of the palatal plane and a counter clockwise rotation of the mandibular plane, which might be caused by orthopedic treatment.

All mandibular linear measurements and maxillary length showed statistically significant increase over time within each age group, reflecting growth, while mean changes were not clinically significant in the adult group, indicating growth cessation. The mandibular angle Co/Go/Me was stable across age groups and over time except in the pre-pubertal group in which it significantly decreased by 1.8°, suggesting slight flattening over time that might also be related to earlier treatment (Muretić and Rak, 1991).

Dentoalveolar measurements: Inclinations of the maxillary incisors were not different across age groups prior to treatment and had close to normal mean values, indicating the absence of natural compensatory inclination of these teeth, on average, in Class II, division 1 malocclusion. After treatment, the maxillary incisors were significantly retroclined in the adult group, followed by lesser retroclination in the post-pubertal group, but nearly none in the pre-pubertal group in which less compensatory inclination of the maxillary incisors was needed, likely due to a successful orthopedic correction of skeletal jaw discrepancy.

On the other hand, the mandibular incisors were already proclined prior to treatment, reflecting –a- their compensation of the skeletal discrepancy without being significantly different between age groups, and –b- the potential for mandibular incisors to compensate for this discrepancy more than the maxillary incisors. The mandibular incisors remained relatively stable over time (increase of 1°), suggesting an underlying awareness of orthodontists to avoid tooth proclination. Such control would be required for periodontal and facial esthetic reasons (Ghafari and Macari, 2014). The substantial amount of increase in the inter-incisal angle in the adult group after treatment (6.7°) sums up the treatment mechanics, which mostly targeted the maxillary arch for overjet correction.

Soft tissue measurements: Variability between age groups prior to treatment included especially the naso-labial angle, which was more obtuse in the pre-pubertal group, but none of the variables were different across age groups after treatment. Among changes over time within each age group, a significant improvement was observed in both lips relative to the esthetic line in all age groups after treatment. In addition, a significant decrease of 2.75° in the naso labial angle in the pre-pubertal group contrasted and increase by 3.4° of this angle in the adult group. These differences can be explained by a possible diminution in upper lip strain in pre-pubertal patients after treatment, and by the greater maxillary incisors compensation in adult patients to camouflage the skeletal discrepancy and correct the overjet.

Concerning the thicknesses of the chin and both lips, and given the small amount of changes observed over time within each age group, only the chin and upper lip thicknesses can be considered as clinically significant in the pre-pubertal group with increases of 1.1 mm and 1.3 mm, respectively. As expected, nasal growth over time was statistically significant in all age groups, but not clinically significant in the adult group. The mentolabial angle had no significant group x time interaction and it increased by 5° over treatment time regardless of age groups.

Symphysis: Only the distance D-apex and chin width at the level of the lower incisor apex (CW-apex) were clinically different between age groups with D-apex being the smallest and CW-apex being the largest in the pre-pubertal group before and after treatment. Moreover, these measurements significantly changed over time in all age groups, but the slight changes cannot be considered clinically significant in the adult group. These findings reflect the continuous growth of the alveolar bone bringing the lower incisors away from the center of the symphysis (determined by the point D) which is not affected by dental movement and normal growth of underlying bony base (Steiner, 1959). The distances D-Me and CW-D were statistically but not clinically different over time within pre and post-pubertal groups, indicating their relative stability over time and further supporting the stability of point D. The anterior and posterior slopes changed favorably over time in the pre-pubertal group, suggesting more remodeling of the chin button during the pre-pubertal stage compared to adulthood.

5.3. Prediction of treatment outcome

Prediction of orthodontic treatment prognosis in term of profile improvement in a growing and adult patient having a Class II/1 malocclusion is a valuable mean of treatment planning. We investigated several methods of predicting whether responses to Class II division 1 treatment was favorable or unfavorable, based on 6 different cephalometric outcome measures quantifying treatment changes in the skeletal discrepancy (ANB and NA/Apog), in mandibular position relative to cranial base (SNB and Pog proj), in the subnasal profile determined by (upper lip - Eline) and in dentoalveolar compensation of the skeletal discrepancy (L1/MP).

In two previous studies, prediction of orthopedic treatment outcome alone was attempted whereby T2 lateral cephalograms were available immediately after the end of the orthopedic phase of treatment (Patel et al, 2002; Ghafari and Macari, 2014). We did not include the prediction of the outcome of orthopedic treatment in pre-pubertal patients because the treated data were collected retrospectively and the regimen of collection of the records was not as timely as in prospective studies. Therefore, the predictive model was developed separately for growing (pre- and post-pubertal) and adult patients at the end of comprehensive orthodontic treatment upon removal of the fixed appliances.

Methods of outcome assessment: The variability of methods of outcome assessment influences the results. In one study, a decrease of 3° in the ANB angle after treatment with functional jaw orthopedics was considered as a favorable response, but no explanation was given regarding their cutoff choice (Patel et al, 2002). In another study, the authors used an increase of more than 5.3 mm in total mandibular length (Co-Gn) as a cutoff between good and bad responses based on a calculation of a clinically significant difference for the mandibular length between their treated sample and an untreated control sample (Franchi and Baccetti, 2006). Other investigators used a composite outcome assessment that included the post-treatment PAR score, the inclination of the maxillary incisors and position of the mandibular incisors, based on norms and literature (Burden et al, 1999).

Unlike other studies, the cutoff used for each outcome measure to separate between favorable and unfavorable responses were simplified and individualized to the sample population by calculating the mean (T2-T1) change for each outcome measure within each age group and then assigning each patient to his response group based on his individual change. Regarding the statistical analysis, we used the multivariate discriminant analysis to differentiate between the two categories of favorable and unfavorable responses (Klecka, 1980). More specifically, the stepwise method selects the best and most correlated variables to use in the model. The pre-treatment variables were limited to 10 cephalometric measurements which mostly quantify the different facial components. Nevertheless, other cephalometric variables that were not included in the analyses might possibly have influenced the prediction models.

The reliability of the pretreatment predictors within each classification was cross-validated and compared with the proportional by chance accuracy rate to evaluate the usefulness of each model. Some cross-validation rates (Table 5.1) were lesser than the proportional by chance accuracy rate, thus the classification accuracy was not satisfied in those prediction models.

<u>Prevalence of mandibular predictors</u>: Most of the outcome predictors were related to the mandible (highlighted in yellow in Table 5.1), and the predictive equations prevailed in the growing patients compared with the adults, possibly emphasizing a greater potential for growth than orthodontic treatment to discriminate.

With almost 70% of power, the vertical relation between the mandible and the maxilla (PP/MP), the mandibular incisors compensatory inclination (L1/MP), the soft tissue chin thickness (St chin th) and the anterior slope of the bony chin (Ant slope) are significant predictors of individual responsiveness to Class II treatment based on the definition of a favorable response within each classification. The 30% of prediction error can be considered normal as there are multiple variables that influence orthodontic treatment outcome, such as the patients' compliance, the variety of operators in the residency program, and the treatment duration which differs between patients.

The absence of satisfied classification accuracy translated in the antero-posterior position of the mandible (SNB angle) and the amount of skeletal discrepancy between maxilla and mandible (ANB angle) as non-significant predictors of Class II/1 treatment responses, in contrast with previous results by Caldwell and Cook (1999) and by Patel et al (2002). However, comparisons with pre-existing literature are hindered by the variety of treatment modalities and analyses used. Nevertheless, ANB was used as a "discriminant" selection criterion, and SNB reflects mandibular retrognathism, the most common denominator among Class II/1 patients.

Table 5.1: Summary of the major prediction studies as compared to our study

Authors	Sample	Treatment (tx) modalities	Outcome measures	Statistics	Predictors
Burden et. al, 1999	N=212 OJ > 6	Orthodontic tx in permanent dentition	PAR score, U1°, L1/mm -at T2 based on norms-	Logistic / linear regression	- Overjet - U1°
Patel et. al, 2002	N = 72	Orthopedic tx using 3 appliances	(T2-T1) ANB < -3°	ANOVA	- ANB° *(mandible and cranial base)*
Franchi, Baccetti 2006	N=51 ANB>4° (19 control)	Orthopedic & orthodontic tx	(T2-T1)Co-Gn >5.3 mm	Discriminant analysis	Mandibular angle *(Co/Go/Me°)*
Ghafari, Macari 2014	N=61 / OJ>3mm ANB ≥ 4.5°	Orthopedic tx using 2 appliances	(T2-T1) Pog proj > 0	Discriminant analysis	ASA°
Present study	Growing n = 125 Adults n = 54 OJ > 3mm ANB ≥ 4.5° Panel n = 50	Growing: Orthopedic & orthodontic tx Adults: Orthodontic tx	ANB, SNB, NA/Apog, Pog proj, UL-Eline, L1/MP Favorable individual change ≥ mean group change	Discriminant analysis	All predictors are related to the mandible
			Improvement of Class II based on expert panel judgment	Logistic / multiple linear regressions	ASA° Pog proj St chin thickness

Table 5.2: Summary of all the predictors that emerged based on each of the 6 different classifications

Classification	Adults			Growing		
	Predictor	p-value	cross validation	Predictor	p-value	cross validation
Pog proj				St Chin thickness	0.009	63.20%*
				Pn-D	0.002	
Convexity				Co-Gn	0.006	60%*
ANB	St Chin thickness	0.014	63%	SN/Ar	0.017	59.20%*
				Pog proj	0.003	
SNB	Co-Gn	0.034	63%*	Pog proj	0.028	59.20%*
UL- E line	L1/MP	0.002	68.50%	Ant Slope	0.001	69.60%
	PP/MP	<0.001		St Chin thickness	<0.001	
L1/MP	SN/Ar	0.033	68.50%	L1/MP	<0.001	71.20%
				PP/MP	<0.001	

**Classification accuracy was not satisfied*

5.4. Comparison within and between severity subgroups

The fact that there was no age difference between severity subgroups within each age group at both treatment time points is a strength that allows more balanced comparisons while eliminating differences in growth potential, especially in the growing subgroups.

The inclinations of mandibular and maxillary incisors along with the saddle angle remained stable during treatment in both growing subgroups whereas all angular measurements reflecting the skeletal discrepancy as well as mandibular length and chin components improved significantly. Although the change in the ANB angle was greater in the GHS (2.28°) compared to GLS (1.44°), the GLS reached closer to a normal Class I skeletal relationship after treatment (ANB= 3.95°) whereas the GHS remained in the Class II domain but with less severity (ANB= 5.56°) than the original (ANB= 7.84°), a result similar to that reported by Ghafari and Macari (2014).

In both adult subgroups where growth has ceased, the only clinically significant difference between treatment time points was in the inclination of maxillary incisors, which represented the major compensation for the skeletal discrepancy.

Concerning significant differences between growing severity subgroups, the GHS had more severe features than the GLS before treatment: more maxillary prognathism (+1.7º) and mandibular incisors compensation (+3º), less mandibular length (-3 mm) and chin projection (-1.5 mm), and smaller anterior slope angle (-4.7º). After treatment, more maxillary prognathism remained in the GHS along with smaller anterior slope angle, seemingly indicating that the response of the chin was not as favorable in the GHS. Similarly, the AHS had greater maxillary prognathism SNA angle (+2.44º) and smaller mandibular length (-3.47 mm), which are also considered as clinically significant. Moreover, greater vertical skeletal divergence (2.14º), sagittal skeletal discrepancy (+2.56º) and mandibular incisors inclination (+3.45º) were present in the AHS prior to treatment. After treatment these differences remained the same indicating no skeletal changes within the adult subgroups.

Of distinct importance is the lack of high and significant correlations between the dental overjet and the corresponding skeletal jaw relationship (ANB), in both severity groups and in both growing patients groups (Table 4.39). This finding indicates that severe skeletal discrepancies with optimal natural compensation would not seem as severe. Accordingly, the overjet may not substitute for the ANB or other skeletal measures in, or represent alone, a selection criterion for Class II/1 in research.

5.5. Panel examination

Evaluation of profile attractiveness by both panels showed similar results reflecting no major differences in the perception of attractiveness between dentists and orthodontists. This conclusion cannot be generalized because the panel of dentists in this study had an extended exposure to orthodontic knowledge as applicants to postgraduate orthodontic studies. The amount of improvement in the 5 choices Likert scale was very weak (0.33) reflecting only 1 scale point, about 7% (0.33/5=6.6%) of the totality of the scale. This score represents almost no improvement in profile attractiveness after Class II treatment. In general terms, the finding joins prior reporting that the Class II profile, particularly corresponding to severe malocclusions, may not be transferred to a Class I phenotype, despite the correction to a Class I occlusion (Ghafari and Macari, 2014). Nevertheless, at T2, the choice of panelists shifted to a higher prevalence of Class I than Class II profiles, although including Class II patients that they perceived at T1 as having Class 1 profiles.

The orthodontists blamed mainly the chin for being the major feature behind the lower attractiveness of the Class II profiles, whereas the dentists perceived multiple features as culprits. Interestingly, while all features needed less improvement after treatment according to both panels, the nose was chosen as needing more improvement after treatment, probably reflecting the fact that continuous growth of the nasal cartilage increases the nose tip projection in a convex profile, increasing the profile's "unattractiveness."

5.5.1 Comparison between the different response groups

For more specific evaluation of the panel selections, the photographs from 50 patients were classified based on the perceived profile phenotype before and after treatment. The "unclassified" group in which patients where perceived as having Class I prior to treatment had a mean Likert score of 3.21, which placed them in the acceptable category of that scale (above the average of 2.5). The favorable and unfavorable response groups had similar Likert scores pre-treatment. Favorable responders to Class II treatment improved 0.636 in profile attractiveness on the Likert score (almost 12.7 %

of improvement), which placed them in the acceptable category of that scale. The unfavorable responders had an improvement of 0.223 (almost 4.5 %) in profile attractiveness, remaining in the moderately unattractive category.

After treatment, favorable responders matched the “unclassified” group, indicating preference toward straighter profiles and an increase in profile attractiveness that accompanies the decrease in profile convexity (Fig. 3.7, Table 4.39).

When the FR and UFR groups were compared in term of severity of the skeletal discrepancy, the previous results were objectively elucidated. The FR group belonged to the low severity subgroup (ANB= 6.1º), whereas the UFR group belonged to the high severity subgroup (ANB= 6.8º) prior to treatment. Parallel to previous results, the FR group reached an ANB angle closer to normal Class I skeletal relationship (4.3º) after treatment, while the UFR group shifted to the upper range of the low severity subgroup while maintaining a Class II phenotype (5.7º) (Ghafari and Macari, 2014). Similar findings were observed with the vertical measurements between the jaws. The UFR group had greater skeletal divergence (28.23º) than the FR group (24.87º) after treatment, indicating either a more vertical growth pattern in the UFR group, and/or less control of the vertical dimension during treatment. In both instances, management of this dimension in Class II, division 1 malocclusion would be more challenging (Schudy, 1965).

In addition, no statistically significant age difference was present among the “unclassified”, favorable and unfavorable groupings. The last parameter of importance that was compared between the groups was the anterior chin slope angle, which was significantly higher in the FR group (+5.7 º) than the UFR group. This finding was concordant with the findings by Ghafari and Macari (2014) of an increased anterior chin slope as a predictor of favorable response to Class II treatment.

5.5.2. Predictors of treatment outcome

Based on the orthodontic panel assessment, the ANB angle was the best of the 6 cephalometric outcome measures to predict treatment responses. Based on the ANB classification (Table 4.17), the soft tissue chin thickness was a significant predictor of treatment outcome in the adult group, while chin extension determined by pogonion projection to vertical through nasion was a significant predictor for the growing group.

On the other hand, the panel data resulted in 3 chin components that were significantly associated with treatment responses. The odds of having favorable responses according to the panel increase with the augmenting chin projection and anterior slope angulation, which is concordant with the findings of Ghafari and Macari (2014). The decrease in the odds for a favorable response with thicker soft tissue chin may be related by the fact that the majority of the patients included in the panel assessment were growing. When a patient with thick soft tissue chin prior to treatment is still perceived as having a Class II, more growth of the soft tissue chin to compensate for the skeletal discrepancy is needed but is less likely to happen, notwithstanding the fact that the UFR patients belonged to the high severity of skeletal discrepancy group in which additional increments in soft tissue chin thickness is needed to compensate for the inadequate chin extension. Similarly, the multivariate linear regression resulted in 2 significant predictors of the amount of Class II improvement which were the anterior chin slope and the soft tissue chin thickness.

5.6. Chin extension and throat line

Evaluation of the chin extension relative to the throat line (T-line) in a Class II population resulted in no change of this relation after treatment. The mean percentage of the anterior portion of the mandibular body (ANT) relative to the total body length prior to treatment was less than the average 50% (44.64%) in our subsample of 50 Class II patients (Table 4.47). The adult mean of 39.7% was close to the adult Class II mean (~36%) reported by Haddad and Ghafari (2017). Most noteworthy was the fact that at T2, no improvement was observed in the relationship of the T-line to mandibular body (Table 4.48), indicating the limitation of transfer from a Class II to an orthognathic profile. In the pre-pubertal group, the orthodontic panel judged a significant worsening of the profile at T2, warranting further research with larger samples on soft tissue changes in children whose treatment started at an early age.

5.7. Research considerations

Our findings improve existing knowledge of the change in various facial components throughout orthodontic treatment in growing patients and adults. Moreover, the severity of the skeletal discrepancy was proven as a key determinant of favorable and unfavorable responses, where most of the unfavorable responders to Class II treatment belonged to the high severity group according to the expert panel.

Different analyses converged in finding chin components as predictors of Class II treatment, a non-surprising result given that most orthodontists selected the chin as the feature that mostly needed improvement in Class II profiles. A potential contradiction emerges when considering the differences in results regarding the expression of the same parameter (chin thickness) predicting responses. Indeed, under categorization of favorable and unfavorable responses according to the initial ANB angle, in the adult sample only (n=54), increased chin thickness (11.79 mm) predicted FR while the mean thickness was lower (10.53) for UFR (Table 4.17).

Upon expert (panel) judgment of the 50 faces, the opposite pattern emerged: FR corresponded to the lower chin thickness values (Table 4.44). The discrepancy may be related to methodological variations, such as the largest number of patients and clear delineation of age groups in the discriminant analysis of the total sample, while in the panel sample only 38 of the 179 patients were assessed, belonging to various age groups, including 8 adults. In the latter group, there was no statistically significant difference for the soft tissue chin thickness (Pog-Pog') between favorable (n=3) and unfavorable (n=5) responders, whose PP/MP indicated a tendency to hypo and hyper divergent pattern, respectively. While these results would only reflect a potential pattern because of the very small numbers, they are concordant with findings on differences in adult chin thickness (Macari and Hanna, 2013). Further exploration is needed in a larger population subjected to expert panel opinion.

Also, possible new hypotheses might need investigation, such as the association of soft tissue chin thickness with different facial types and malocclusions. According to the expert panel, favorable treatment outcome was defined by reaching a Class I profile phenotype after treatment. This goal corresponded to a favorable change in the ANB angle that positioned this angle as the most cephalometric outcome measure to classify treatment responses. Nevertheless, the definition of favorable and unfavorable responses based on the change in any given outcome measure is in itself prone to bias. Profile improvement is a combination of the cumulative effects of small to moderate changes within the plethora of facial components; thus, placing profiles under scrutiny by an expert panel of orthodontists can be considered as the optimal assessment for Class II treatment outcome.

Methodological limitations of our study encompass the retrospective nature of our sample of patients who were treated by different residents under the supervision of different instructors. While this variation in the choice of treatment mechanics, orthopedic appliances and treatment timing inherently includes the bias for specific approaches to treatment, it reflects the reality across orthodontic practices, although controlled by regulatory academic imperatives. On the other hand, while rising to golden 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 Class II patients should be included in a future panel assessment to reach more solid and generalizable conclusions.

5.8. Clinical implications

This research showed that early orthopedic and orthodontic interventions in pre-pubertal patients have led to a more favorable correction of the skeletal discrepancy, decreasing the amount of incisors compensation, thus preserving the profile harmony. However, the expert panel judgment pointed out to the maintenance of profile convexity, despite the occlusal correction to neutroclusion. Accordingly, patients should be aware of the potential and limitations of treatment prior to its initiation.

Chin components arose as major predictors of Class II treatment outcome. A favorable pre-treatment chin extension and a well-defined (“strong”) chin button delineated by an increased anterior chin slope angle are signs of more favorable prognosis.

Careful examination of these components prior to treatment facilitates a thorough diagnosis and prediction of treatment outcome, thus more realistic treatment plans and prognosis.

Optimal dentoalveolar compensation is most likely to occur during “camouflage treatment” that bridges the overjet in adult Class II treatment. Given that this treatment involved significant proclination of mandibular incisors and retroclination of maxillary incisors that potentially worsen the profile, damage the roots of the incisors and the surrounding periodontium, it is important to consider the severity of the skeletal discrepancy and identify the possible hard and soft tissue limitations to orthodontic tooth movement. 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.

CHAPTER 6

CONCLUSIONS

1. Skeletal discrepancies accompanying Class II, division 1 malocclusion must be evaluated with regard of the different facial components to reach a comprehensive treatment plan not only to correct the occlusion but also achieve optimal facial harmony.
2. Both the quantitative cephalometric measurements and panel assessments converged regarding the post-treatment maintenance of the Class II phenotype, particularly in the most severe malocclusion (ANB > 6.6 º). Favorable responders to Class II treatment who reached an acceptable profile according to the panel had less severe malocclusions and close to normodivergent skeletal pattern.
3. The findings would indicate the inadequacy of growth modification to alter the growth potential enough to transform the Class II dysmorphology into a Class I phenotype.
4. Novel approaches in this study include the use of categorization on specific cephalometric components of the malocclusion to develop predictive models for favorable and unfavorable treatment response, as well as a panel of experts to determine facial perception of malocclusion, which was in turn associated with the quality of treatment outcome and predictive equations.
5. The panel assessment is considered in epidemiologic studies as a golden standard against which different characteristics of a research model are benchmarked. In this study, the panel judgments indicated that the ANB angle is a prime classifier of Class II/1 treatment response.

6. Unlike other studies in which various limitations are present in developing predictive models of treatment outcome, the various predictive equations in this study pointed to the mandible and its components as predictors of outcome. Among these components, chin characteristics were dominant, including increased chin extension (pogonion projection to nasion vertical) and the anterior chin slope angle.
7. The overjet is not a reliable classifier of the severity of Class II/1, as it did not correlate with the sagittal skeletal discrepancy (ANB), thus the severity of the overjet is camouflaged by the dentoalveolar compensations (inclinations of maxillary and mandibular incisors).
8. The results indicate an underlying awareness by orthodontists to avoid further proclination of mandibular incisors in Class II/1 treatment, as most of the overjet correction resulted from the retraction of the maxillary incisors. Such control would be required for periodontal and facial esthetic reasons.
9. Future research should expand the boundaries of the methodology used in this study, by including larger samples, particularly in the set-up of panels to judge facial characteristics in relation to the underlying structures before and after treatment.

Tables

Table 4.3: Two-way mixed analysis of variance (ANOVA) findings

Groups X Time	Type III sum of squares	df	Mean square	F	p-value
Cranial base measurements					
SN*	156.6	2	78.3	104.13	<0.001
SN/H	0.0002	2	1E-04	0.06	0.93
S-Ar*	90.38	2	45.19	50.34	<0.001
SN/Ar	2.24	2	1.12	0.53	0.58
Relationship between jaws, cranial base and horizontal					
SNA*	13.98	2	6.99	9.59	<0.001
SNB*	23.52	2	11.76	14.1	<0.001
ANB*	71.32	2	35.66	60.82	<0.001
Witts (Ao-Bo)	15.46	2	7.73	2.23	0.11
NA/Apog*	415.24	2	207.6	65.9	<0.001
N-ANS*	304.78	2	152.4	134.6	<0.001
ANS-Me (AFH)*	345.84	2	172.92	67.15	<0.001
Ar-Go (PFH)*	468.95	2	234.5	54.68	<0.001
LFH/TFH (%)*	2.16	2	1.08	5.72	0.003
PP/MP*	106.12	2	53.06	26.22	<0.001
MP/SN*	25.85	2	12.92	6.92	0.001
PP/H*	27.74	2	13.87	12.64	<0.001
MP/H*	25.85	2	12.92	6.92	0.001
Pog Proj*	116.46	2	58.23	18.15	<0.001
Jaw specific measurements					
Co-Gn*	1485.6	2	742.8	169.17	<0.001
Co-Go*	655.2	2	327.6	94.72	<0.001
Go-Gn*	435.57	2	217.8	86.52	<0.001
Co/Go/Me*	38.9	2	19.45	5.16	0.006
ANS-PNS*	181.3	2	90.65	82.5	<0.001
Relationship between teeth and jaws					
U1/NA*	1111	2	555.6	16.77	<0.001
U1-NA*	141	2	70.5	21.76	<0.001
U1/SN*	881	2	440.3	12.94	<0.001
U1/PP*	1219	2	609.4	18.53	<0.001
L1/NB	32.3	2	16.13	0.84	0.43
L1-NB*	19.1	2	9.55	5.54	0.004
L1/MP	31.8	2	15.89	0.77	0.46
Relationship between teeth					
U1/L1*	592	2	296.2	4.52	0.012
Overbite (OB)	0.19	2	0.09	0.04	0.95
Overjet (OJ)	6.54	2	3.27	2.12	0.122
Soft tissue measurments					
UL- E line*	63.4	2	31.7	26.61	<0.001
LL- E line*	16.1	2	8.03	5	0.007
Naso labial angle*	649	2	324.4	13.54	<0.001
Mento labial angle	0.41	2	0.2	0.003	0.996
U lip length	1.92	2	0.96	1.73	0.178
U lip thickness @ A*	26	2	12.99	18.94	<0.001
U lip inclination	87.1	2	43.55	2.37	0.096
L lip length*	44.8	2	22.41	30.2	<0.001
L lip thickness @ B*	10.2	2	5.11	5.53	0.004
St Chin thickness*	8.53	2	4.26	9.77	<0.001
Pn-D*	276	2	137.8	95.01	<0.001
Symphyseal components					
D-Apex*	81	2	40.51	27	<0.001
D-Me*	14.7	2	7.36	21.79	<0.001
CW-Apex*	6.89	2	3.44	6.07	0.002
(CW-D)*	5.15	2	2.57	10.44	<0.001
ASA*	150	2	74.93	17.69	<0.001
PSA*	97.9	2	48.97	8.13	<0.001

df, degree of freedom; *p≤0.05

Table 4.4: One-way analysis of variance findings and multiple comparisons between age groups at T1 (simple effect of groups)

Variables_T1	Pre-pubertal (1)		Post-pubertal (2)		Adults (3)		F	p-value	p-value†		
	Mean	SD	Mean	SD	Mean	SD			1-2	1-3	2-3
Cranial base measurements											
SN*	64.5	2.9	66.45	3.27	67.22	3.82	12.64	<0.001	0.007	<0.001	0.515
S-Ar*	32.16	3.02	34.12	3.44	34.77	3.81	11.26	<0.001	0.009	<0.001	0.638
Relationship between jaws, cranial base and horizontal											
SNA	81.6	2.91	82.37	3.26	82.6	4.12	1.64	0.195	0.479	0.206	0.946
SNB	75.24	2.76	76.56	2.99	76.28	3.97	2.97	0.053	0.094	0.147	0.916
ANB	6.35	1.45	5.81	1.23	6.32	1.45	2.08	0.127	0.124	0.99	0.21
NA/Apog*	12.49	4.06	10.51	3.49	11.67	3.47	3.64	0.028	0.022	0.421	0.325
N-ANS*	48.43	2.95	50.84	2.2	51.75	3.43	22.97	<0.001	<0.001	<0.001	0.321
ANS-Me (AFH)*	60.47	4.48	64.23	5.3	67.57	4.49	39.54	<0.001	<0.001	<0.001	0.002
Ar-Go (PFH)*	39.94	4.5	42.72	5.85	44.45	5.48	13.68	<0.001	0.016	<0.001	0.252
LFH/TFH (%)*	55.36	1.83	55.6	2	56.42	2.33	4.66	0.01	0.817	0.008	0.144
PP/MP	27.25	4.57	26.61	4.4	27.11	5.58	0.22	0.79	0.781	0.986	0.876
MP/SN	36.68	4.48	35.95	4.04	36.31	6.44	0.29	0.747	0.74	0.904	0.941
PP/H	2.43	2.65	2.33	3.2	2.21	3.66	0.08	0.915	0.986	0.907	0.979
MP/H	29.68	4.48	28.95	4.04	29.31	6.44	0.29	0.748	0.74	0.904	0.941
Pog Proj	-1.45	3.82	-0.64	3.67	0.25	4.66	2.99	0.052	0.566	0.041	0.553
Jaw specific measurements											
Co-Gn*	102.84	6.06	110.27	5.61	113.73	6.05	60.11	<0.001	<0.001	<0.001	0.019
Co-Go*	48.16	4.56	51.35	5.31	55.65	4.96	40.07	<0.001	0.002	<0.001	<0.001
Go-Gn*	68.61	4.35	74.81	3.93	75.33	5.31	45.18	<0.001	<0.001	<0.001	0.858
Co/Go/Me	122.8	5.23	120.95	4.87	121.24	5.74	2.25	0.1	0.18	0.21	0.963
ANS-PNS*	51.95	3.23	54	2.53	53.56	3.1	7.89	<0.001	0.002	0.007	0.777
Relationship between teeth and jaws											
U1/NA	21.25	6.87	21.76	6.37	20.78	7.36	0.22	0.8	0.924	0.919	0.785
U1-NA	3.3	2.23	3.82	2.43	3.95	2.6	1.41	0.246	0.508	0.265	0.967
U1/SN	102.84	7.13	104.13	7.12	103.38	8.58	0.38	0.682	0.662	0.913	0.887
U1/PP	112.28	6.44	113.47	6.55	112.6	7.88	0.38	0.683	0.658	0.962	0.826
L1-NB*	6.08	1.77	6.09	2.22	7.73	2.23	12.62	<0.001	0.999	<0.001	<0.001
Relationship between teeth											
U1/L1	121.73	8.6	122.94	10.02	120.9	10.59	0.5	0.6	0.792	0.87	0.576
Soft tissue measurements											
UL- E line*	-0.1	1.9	-1.44	1.8	-2.25	2.11	21.5	<0.001	0.001	<0.001	0.129
LL- E line*	1.7	2.24	0.42	2.71	0.81	2.86	4.09	0.018	0.029	0.105	0.758
Naso labial angle*	113.68	10.33	109.42	10.38	108.96	10.45	4.27	0.015	0.094	0.025	0.976
U lip thickness @ A*	14.73	1.7	15.59	1.91	16.07	2.2	8.74	<0.001	0.058	<0.001	0.465
L lip length*	16.36	2.35	17.9	2.36	18.38	2.96	11.81	<0.001	0.007	<0.001	0.646
L lip thickness @ B	11.59	1.92	11.54	1.81	12.25	1.76	2.48	0.086	0.988	0.104	0.175
St Chin thickness	10.48	1.76	10.78	2.12	11.14	1.91	2.06	0.13	0.689	0.109	0.65
Pn-D*	22.16	2.84	24.46	2.58	27.07	3.42	45.63	<0.001	<0.001	<0.001	<0.001
Symphyseal components											
D-Apex*	6.04	1.92	8.41	2.71	10.1	1.95	63.87	<0.001	<0.001	<0.001	<0.001
D-Me*	11.02	0.92	11.48	1.23	11.48	1.38	3.76	0.025	0.095	0.048	0.999
CW-Apex*	10.28	1.65	9.35	2.17	8.51	2.02	15.03	<0.001	0.033	<0.001	0.096
(CW-D)	12.65	1.52	13.03	2.01	12.96	2	0.81	0.443	0.528	0.572	0.983
ASA	4.5	6.77	6.82	6.34	6.28	6.62	2.11	0.124	0.176	0.267	0.923
PSA	-24.25	5.91	-22.26	6.97	-22.45	7.07	1.86	0.158	0.266	0.249	0.989

*p≤0.05; † adjustment for multiple comparisons: Tukey HSD.

Table 4.5: One-way analysis of variance findings and multiple comparisons between age groups at T2 (simple effect of groups)

Variables_T2	Pre-pubertal (1)		Post-pubertal (2)		Adults (3)		F	p-value	p-value†		
	Mean	SD	Mean	SD	Mean	SD			1-2	1-3	2-3
Cranial base measurements											
SN	67.7	3.36	68	3.45	67.4	3.89	0.32	0.724	0.901	0.875	0.706
S-Ar	34.69	3.33	35.09	3.57	35.07	3.53	0.28	0.753	0.828	0.796	0.999
Relationship between jaws, cranial base and horizontal											
SNA*	80.47	3.21	81.54	3.84	82.38	4.19	4.68	0.01	0.301	0.008	0.524
SNB	76.12	3.11	76.74	3.18	76.01	4.12	0.54	0.58	0.637	0.981	0.589
ANB*	4.35	1.49	4.79	1.58	6.37	1.65	28.61	<0.001	0.319	<0.001	<0.001
NA/Apog*	7.43	4.52	7.78	4.59	11.58	3.94	16.18	<0.001	0.913	<0.001	<0.001
N-ANS	52.87	2.93	52.35	2.62	52.12	3.4	1.11	0.33	0.658	0.325	0.93
ANS-Me (AFH)*	66	5.53	68.04	5.66	68.56	5.02	4.3	0.015	0.135	0.018	0.896
Ar-Go (PFH)	46.65	5.24	47.3	4.95	45.87	5.5	0.83	0.434	0.806	0.667	0.414
LFH/TFH (%)*	55.85	1.72	56.38	2.11	56.76	2.41	3.43	0.034	0.383	0.029	0.661
PP/MP*	25.18	4.62	26.22	4.63	27.46	6.02	3.38	0.036	0.549	0.027	0.488
MP/SN	35.93	4.91	35.91	4.41	36.77	6.76	0.46	0.631	0.999	0.642	0.737
PP/H*	3.74	3.31	2.68	3.38	2.32	3.79	3.11	0.046	0.269	0.05	0.876
MP/H	28.93	4.91	28.91	4.41	29.77	6.76	0.46	0.631	0.999	0.642	0.737
Pog Proj	0.73	4.98	-0.03	4.24	-0.13	4.85	0.66	0.515	0.693	0.551	0.995
Jaw specific measurements											
Co-Gn*	112.78	6.63	115.7	5.6	114.29	6.07	3.03	0.05	0.047	0.345	0.542
Co-Go	55.09	5.55	55.81	5.16	56.33	5.1	0.92	0.397	0.772	0.375	0.892
Go-Gn*	74.32	4.62	77.82	4.03	75.99	5.37	7.41	<0.001	<0.001	0.106	0.171
Co/Go/Me	121.03	5.47	120.45	5.09	120.82	5.97	0.14	0.866	0.854	0.974	0.947
ANS-PNS*	55.47	3.44	55.58	2.79	53.86	3.1	4.92	0.008	0.982	0.012	0.034
Relationship between teeth and jaws											
U1/NA*	21.73	6.03	17.81	5.14	13.22	6.88	32.37	<0.001	0.003	<0.001	0.001
U1-NA*	2.96	2.4	2.16	1.64	0.71	2.12	17.7	<0.001	0.151	<0.001	0.006
U1/SN*	102.21	6.66	99.34	5.46	95.61	8.55	14.56	<0.001	0.099	<0.001	0.038
U1/PP*	112.96	5.99	109.04	6.61	104.93	8.11	23.39	<0.001	0.01	<0.001	0.014
L1-NB	6.53	1.81	6.7	2.07	7.23	1.98	2.26	0.107	0.897	0.09	0.396
Relationship between teeth											
U1/L1*	122.53	8.48	125.71	8.97	127.64	10.45	5.42	0.005	0.185	0.004	0.588
Soft tissue measurements											
UL- E line	-3.05	2.19	-3.54	2.23	-3.26	2.19	0.66	0.514	0.49	0.844	0.821
LL- E line	-0.09	2.56	-0.44	2.64	-0.22	2.45	0.24	0.784	0.767	0.957	0.911
Naso labial angle	110.93	11.71	109.84	8.69	112.39	9.38	0.68	0.504	0.857	0.698	0.491
U lip thickness @ A	16.07	1.83	15.76	2.02	16.4	2.11	1.19	0.305	0.708	0.586	0.281
L lip length	18.65	2.24	19.53	2.17	19.03	2.83	1.75	0.176	0.158	0.628	0.61
L lip thickness @ B	12.15	1.76	11.73	1.56	12.02	1.82	0.72	0.484	0.451	0.911	0.719
St Chin thickness	11.61	1.91	11.3	2.21	11.64	1.99	0.37	0.688	0.72	0.993	0.705
Pn-D	26.36	3.07	26.14	3.18	27.32	3.37	2.03	0.133	0.933	0.188	0.191
Symphyseal components											
D-Apex*	8.69	2.07	9.82	2.49	10.6	2.25	12.8	<0.001	0.027	<0.001	0.235
D-Me	11.89	1.35	11.99	1.55	11.43	1.33	2.44	0.09	0.937	0.13	0.145
CW-Apex*	9.18	1.79	8.61	2.29	8.04	2.21	5.32	0.005	0.336	0.004	0.38
(CW-D)	13.12	1.75	13.28	2.21	12.87	2.05	0.52	0.594	0.901	0.748	0.587
ASA	7.56	7.3	8.13	7.16	6.42	5.92	0.77	0.462	0.906	0.602	0.474
PSA	-22.24	6.53	-21.67	7.66	-22.81	6.59	0.31	0.732	0.906	0.877	0.714

*p≤0.05; † adjustment for multiple comparisons: Tukey HSD

Table 4.6: Comparison between T1 and T2 within the pre-pubertal group (simple effect of time)

Variables	T1		T2		T2-T1	F	p-value
	Mean	SD	Mean	SD			
Cranial base measurements							
SN*	64.5	2.9	67.7	3.36	3.2	369.55	<0.001
S-Ar*	32.16	3.02	34.69	3.33	2.53	208.94	<0.001
Relationship between jaws, cranial base and horizontal							
SNA*	81.6	2.91	80.47	3.21	-1.13	53.84	<0.001
SNB*	75.24	2.76	76.12	3.11	0.88	25.25	<0.001
ANB*	6.35	1.45	4.35	1.49	-2	204.98	<0.001
NA/Apog*	12.49	4.06	7.43	4.52	-5.06	248.89	<0.001
N-ANS*	48.43	2.95	52.87	2.93	4.44	468.17	<0.001
ANS-Me (AFH)*	60.47	4.48	66	5.53	5.53	357.02	<0.001
Ar-Go (PFH)*	39.94	4.5	46.65	5.24	6.71	353.38	<0.001
LFH/TFH (%)*	55.36	1.83	55.85	1.72	0.49	42.79	<0.001
PP/MP*	27.25	4.57	25.18	4.62	-2.07	64.33	<0.001
MP/SN*	36.68	4.48	35.93	4.91	-0.75	9.2	0.003
PP/H*	2.43	2.65	3.74	3.31	1.31	49.67	<0.001
MP/H*	29.68	4.48	28.93	4.91	-0.75	9.2	0.003
Pog Proj*	-1.45	3.82	0.73	4.98	2.18	40.7	<0.001
Jaw specific measurements							
Co-Gn*	102.84	6.06	112.78	6.63	9.94	656.48	<0.001
Co-Go*	48.16	4.56	55.09	5.55	6.93	413.45	<0.001
Go-Gn*	68.61	4.35	74.32	4.62	5.71	373.27	<0.001
Co/Go/Me*	122.8	5.23	121.03	5.47	-1.77	28.17	<0.001
ANS-PNS*	51.95	3.23	55.47	3.44	3.52	290.56	<0.001
Relationship between teeth and jaws							
U1/NA	21.25	6.87	21.73	6.03	0.48	0.33	0.567
U1-NA	3.3	2.23	2.96	2.4	-0.34	1.79	0.184
U1/SN	102.84	7.13	102.21	6.66	-0.63	0.55	0.46
U1/PP	112.28	6.44	112.96	5.99	0.68	0.66	0.417
L1-NB*	6.08	1.77	6.53	1.81	0.45	6.65	0.011
Relationship between teeth							
U1/L1	121.73	8.6	122.53	8.48	0.8	0.53	0.465
Soft tissue measurements							
UL- E line*	-0.097	1.9	-3.05	2.19	-2.953	256.89	<0.001
LL- E line*	1.7	2.24	-0.09	2.56	-1.79	84.96	<0.001
Naso labial angle*	113.68	10.33	110.93	11.71	-2.75	13.01	<0.001
U lip thickness @ A*	14.73	1.7	16.07	1.83	1.34	98.84	<0.001
L lip length*	16.36	2.35	18.65	2.24	2.29	243.7	<0.001
L lip thickness @ B*	11.59	1.92	12.15	1.76	0.56	14.77	<0.001
St Chin thickness*	10.48	1.76	11.61	1.91	1.13	94.03	<0.001
Pn-D*	22.16	2.84	26.36	3.07	4.2	335.82	<0.001
Symphyseal components							
D-Apex*	6.04	1.92	8.69	2.07	2.65	202.06	<0.001
D-Me*	11.02	0.92	11.89	1.35	0.87	86.66	<0.001
CW-Apex*	10.28	1.65	9.18	1.79	-1.1	84.74	<0.001
(CW-D)*	12.65	1.52	13.12	1.75	0.47	29.97	<0.001
ASA*	4.5	6.77	7.56	7.3	3.06	74.06	<0.001
PSA*	-24.25	5.91	-22.24	6.53	2.01	28.74	<0.001

*$p \leq 0.05$

Table 4.7: Comparison between T1 and T2 within the post-pubertal group (simple effect of time)

Variables	T1		T2		T2-T1	F	p-value
	Mean	SD	Mean	SD			
Cranial base measurements							
SN*	66.45	3.27	68	3.45	1.55	62.25	<0.001
S-Ar*	34.12	3.44	35.09	3.57	0.97	27.56	<0.001
Relationship between jaws, cranial base and horizontal							
SNA*	82.37	3.26	81.54	3.84	-0.83	17.98	<0.001
SNB	76.56	2.99	76.74	3.18	0.18	1.82	0.185
ANB*	5.81	1.23	4.79	1.58	-1.02	45.85	<0.001
NA/Apog*	10.51	3.49	7.78	4.59	-2.73	45.93	<0.001
N-ANS*	50.84	2.2	52.35	2.62	1.51	47.94	<0.001
ANS-Me (AFH)*	64.23	5.3	68.04	5.66	3.81	133.22	<0.001
Ar-Go (PFH)*	42.72	5.85	47.3	4.95	4.58	75.24	<0.001
LFH/TFH (%)*	55.6	2	56.38	2.11	0.78	60.67	<0.001
PP/MP	26.61	4.4	26.22	4.63	-0.39	2.52	0.12
MP/SN	35.95	4.04	35.91	4.41	-0.04	0.02	0.887
PP/H	2.33	3.2	2.68	3.38	0.35	2.09	0.156
MP/H	28.95	4.04	28.91	4.41	-0.04	0.02	0.887
Pog Proj*	-0.64	3.67	-0.03	4.24	0.61	4.57	0.04
Jaw specific measurements							
Co-Gn*	110.27	5.61	115.7	5.6	5.43	104.13	<0.001
Co-Go*	51.35	5.31	55.81	5.16	4.46	89.82	<0.001
Go-Gn*	74.81	3.93	77.82	4.03	3.01	64.63	<0.001
Co/Go/Me	120.95	4.87	120.45	5.09	-0.5	1.33	0.256
ANS-PNS*	54	2.53	55.58	2.79	1.58	59.33	<0.001
Relationship between teeth and jaws							
U1/NA*	21.76	6.37	17.81	5.14	-3.95	9.04	0.004
U1-NA*	3.82	2.43	2.16	1.64	-1.66	13.97	<0.001
U1/SN*	104.13	7.12	99.34	5.46	-4.79	13.53	<0.001
U1/PP*	113.47	6.55	109.04	6.61	-4.43	11.19	0.002
L1-NB	6.09	2.22	6.7	2.07	0.61	3.58	0.066
Relationship between teeth							
U1/L1	122.94	10.02	125.71	8.97	2.77	2.2	0.146
Soft tissue measurements							
UL- E line*	-1.44	1.8	-3.54	2.23	-2.1	72.85	<0.001
LL- E line*	0.42	2.71	-0.44	2.64	-0.86	9.2	0.004
Naso labial angle	109.42	10.38	109.84	8.69	0.42	0.16	0.687
U lip thickness @ A	15.59	1.91	15.76	2.02	0.17	0.77	0.384
L lip length*	17.9	2.36	19.53	2.17	1.63	56.67	<0.001
L lip thickness @ B	11.54	1.81	11.73	1.56	0.19	0.93	0.34
St Chin thickness*	10.78	2.12	11.3	2.21	0.52	15.86	<0.001
Pn-D*	24.46	2.58	26.14	3.18	1.68	40.33	<0.001
Symphyseal components							
D-Apex*	8.41	2.71	9.82	2.49	1.41	23.22	<0.001
D-Me*	11.48	1.23	11.99	1.55	0.51	12.51	0.001
CW-Apex*	9.35	2.17	8.61	2.29	-0.74	18.81	<0.001
(CW-D)*	13.03	2.01	13.28	2.21	0.25	5.09	0.03
ASA*	6.82	6.34	8.13	7.16	1.31	8.26	0.006
PSA	-22.26	6.97	-21.67	7.66	0.59	1.1	0.3

*$p \leq 0.05$

Table 4.8: Comparison between T1 and T2 within the adult group (simple effect of time)

Variables	T1		T2		T2-T1	F	p-value
	Mean	SD	Mean	SD			
Cranial base measurements							
SN*	67.22	3.82	67.4	3.89	0.18	42.26	<0.001
S-Ar*	34.77	3.81	35.07	3.53	0.3	7.4	0.008
Relationship between jaws, cranial base and horizontal							
SNA*	82.6	4.12	82.38	4.19	-0.22	4.93	0.03
SNB*	76.28	3.97	76.01	4.12	-0.27	6.55	0.013
ANB	6.32	1.45	6.37	1.65	0.05	0.27	0.6
NA/Apog	11.67	3.47	11.58	3.94	-0.09	0.24	0.624
N-ANS*	51.75	3.43	52.12	3.4	0.37	27.91	<0.001
ANS-Me (AFH)*	67.57	4.49	68.56	5.02	0.99	26.91	<0.001
Ar-Go (PFH)*	44.45	5.48	45.87	5.5	1.42	35.46	<0.001
LFH/TFH (%)*	56.42	2.33	56.76	2.41	0.34	29.66	<0.001
PP/MP	27.11	5.58	27.46	6.02	0.35	2.77	0.1
MP/SN*	36.31	6.44	36.77	6.76	0.46	6.73	0.012
PP/H	2.21	3.66	2.32	3.79	0.11	0.82	0.36
MP/H*	29.31	6.44	29.77	6.76	0.46	6.73	0.012
Pog Proj	0.25	4.66	-0.13	4.85	-0.38	3.55	0.065
Jaw specific measurements							
Co-Gn*	113.73	6.05	114.29	6.07	0.56	55.16	<0.001
Co-Go*	55.65	4.96	56.33	5.1	0.68	39.81	<0.001
Go-Gn*	75.33	5.31	75.99	5.37	0.66	42.21	<0.001
Co/Go/Me	121.24	5.74	120.82	5.97	-0.42	2.21	0.142
ANS-PNS*	53.56	3.1	53.86	3.1	0.3	70.37	<0.001
Relationship between teeth and jaws							
U1/NA*	20.78	7.36	13.22	6.88	-7.56	41.09	<0.001
U1-NA*	3.95	2.6	0.71	2.12	-3.24	80.47	<0.001
U1/SN*	103.38	8.58	95.61	8.55	-7.77	42.55	<0.001
U1/PP*	112.6	7.88	104.93	8.11	-7.67	42.04	<0.001
L1-NB	7.73	2.23	7.23	1.98	-0.5	3.04	0.086
Relationship between teeth							
U1/L1*	120.9	10.59	127.64	10.45	6.74	14.09	<0.001
Soft tissue measurements							
UL- E line*	-2.25	2.11	-3.26	2.19	-1.01	37.62	<0.001
LL- E line*	0.81	2.86	-0.22	2.45	-1.03	18.6	<0.001
Naso labial angle*	108.96	10.45	112.39	9.38	3.43	13.17	<0.001
U lip thickness @ A*	16.07	2.2	16.4	2.11	0.33	5.4	0.024
L lip length*	18.38	2.96	19.03	2.83	0.65	34.79	<0.001
L lip thickness @ B	12.25	1.76	12.02	1.82	-0.23	1.3	0.258
St Chin thickness*	11.14	1.91	11.64	1.99	0.5	27.18	<0.001
Pn-D*	27.07	3.42	27.32	3.37	0.25	12.53	<0.001
Symphyseal components							
D-Apex*	10.1	1.95	10.6	2.25	0.5	4.69	0.034
D-Me	11.48	1.38	11.43	1.33	-0.05	0.4	0.526
CW-Apex*	8.51	2.02	8.04	2.21	-0.47	12.26	<0.001
(CW-D)	12.96	2	12.87	2.05	-0.09	1.57	0.214
ASA	6.28	6.62	6.42	5.92	0.14	0.21	0.643
PSA	-22.45	7.07	-22.81	6.59	-0.36	0.58	0.448

*$p \leq 0.05$

Table 4.9: One-way analysis of variance findings and multiple comparisons between age groups regardless of time (main effect of groups)

Variables	Pre-pubertal (1)	Post-pubertal (2)	Adults (3)	F	p-value	p-value†		
	Mean	Mean	Mean			1-2	1-3	2-3
SN/H	13.32	12.14	13.12	1.69	0.187	0.212	1	0.506
SN/Ar*	126.25	126.12	124.06	3.35	0.037	1	0.042	0.181
Witts (Ao-Bo)*	1.66	1.92	4.27	23.5	<0.001	1	<0.001	<0.001
L1/NB	31.02	30.57	32.37	1.81	0.166	1	0.346	0.267
L1/MP	99.03	97.99	99.67	0.84	0.431	1	1	0.587
Overbite (OB)	2.68	2.53	2.51	0.36	0.695	1	1	1
Overjet (OJ)	4.09	4.08	3.83	1.51	0.223	1	0.292	0.616
Mento labial angle	122.35	122.25	121.69	0.04	0.954	1	1	1
U lip length*	21.01	21.51	22.56	8.22	<0.001	0.748	<0.001	0.083
U lip inclination	7.16	8.78	6.18	1.08	0.338	0.957	1	0.426

*p≤0.05; † adjustment for multiple comparisons: Bonferroni correction

Table 4.10: Comparison between T1 and T2 regardless of age groups (main effect of time)

Variables	Mean T1	Mean T2	T2-T1	F	p-value
SN/H*	12.84	12.88	0.037	60.93	<0.001
SN/Ar	125.46	125.5	0.042	0.065	0.798
Witts (Ao-Bo)*	2.88	2.35	-0.533	6.48	0.011
L1/NB*	30.7	31.94	1.231	6.28	0.013
L1/MP*	98.36	99.43	1.071	4.44	0.036
Overbite (OB)*	3.22	1.93	1.293	66.77	<0.001
Overjet (OJ)*	5.62	2.38	3.243	539.7	<0.001
Mento labial angle*	119.64	124.56	4.925	29.52	<0.001
U lip length*	21.19	22.19	1	142.98	<0.001
U lip inclination*	8.92	5.83	-3.087	41.07	<0.001

* p≤0.05

Table 4.11: Descriptive statistics for the ten cephalometric variables at T1 (classification 1)

Growing patients	FR group		UFR group		Total group	
	n=55		n=70		n=125	
Cephalometric variables	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	126.64	5.6	125.73	5.08	126.13	5.31
Co-Gn	103.44	6.59	106.3	6.77	105.04	6.82
SNB	75.36	3.01	75.84	2.78	75.63	2.88
ANB	6.33	1.59	6.08	1.24	6.19	1.4
PP/MP	27.08	4.66	27.04	4.42	27.06	4.51
L1/MP	98.31	6.32	98.13	6.51	98.21	6.4
St chin Thickness*	10.07	1.74	10.95	1.89	10.56	1.87
Ant Slope	5.14	6.12	5.22	7.18	5.18	6.71
Pn-D*	22.18	2.92	23.36	2.89	22.84	2.95
Pog proj	-1.05	3.63	-1.34	3.91	-1.21	3.77

**Statistically significant: p<0.05.*

Table 4.12: Classification results for the stepwise discriminant analysis (classification 1)

Growing patients	**Predicted group membership**			
	FR		**UFR**	
Original group	n	%	n	%
FR (n=55)	29	52.7	26	47.3
UFR (n=70)	16	22.9	54	77.1
66.4% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=55)	27	49.1	28	50.9
UFR (n=70)	18	25.7	52	74.3
63.2% of cross-validated grouped cases correctly classified				

Table 4.13: Descriptive statistics for the ten cephalometric variables at T1 (classification 2)

Growing patients	**FR group**		**UFR group**		**Total group**	
	n=59		**n=66**		**n=125**	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	127.11	5.75	125.25	4.77	126.13	5.31
Co-Gn*	103.27	6.25	106.62	6.96	105.04	6.82
SNB	75.02	2.87	76.17	2.8	75.63	2.88
ANB	6.49	1.61	5.93	1.14	6.19	1.4
PP/MP	26.91	4.61	27.19	4.45	27.06	4.51
L1/MP	98.1	6	98.3	6.78	98.21	6.4
Chin Thickness	10.37	1.98	10.73	1.77	10.56	1.87
Ant Slope	5.48	6.59	4.92	6.85	5.18	6.71
Pn-D	22.48	2.67	23.16	3.16	22.84	2.95
Pog proj	-1.61	3.66	-0.85	3.87	-1.21	3.77

**Statistically significant: p<0.05.*

Table 4.14: Classification results for the stepwise discriminant analysis (classification 2)

Growing patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
UR (n=59)	30	50.8	29	49.2
LFR (n=66)	21	31.8	45	68.2
60% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=59)	30	50.8	29	49.2
UFR (n=66)	21	31.8	45	68.2
60% of cross-validated grouped cases correctly classified.				

Table 4.15: Descriptive statistics for the ten cephalometric variables at T1 (classification 3_Gr)

Growing patients	**FR group**		**UFR group**		**Total group**	
	n=58		**n=67**		**n=125**	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar*	127.34	5.18	125.08	5.24	126.13	5.31
Co-Gn	103.87	6.75	106.05	6.76	105.04	6.82
SNB	75.18	2.81	76.01	2.91	75.63	2.88
ANB	6.5	1.66	5.93	1.08	6.19	1.4
PP/MP	27.11	4.48	27.01	4.57	27.06	4.5
L1/MP	98.22	5.61	98.19	7.06	98.21	6.4
Chin Thickness	10.58	2.12	10.55	1.64	10.56	1.87
Ant Slope	4.84	7.24	5.48	6.25	5.18	6.71
Pn-D	22.42	2.74	23.2	3.09	22.84	2.95
Pog proj*	-2.04	3.6	-0.49	3.8	-1.21	3.77

**Statistically significant: p<0.05.*

Table 4.16: Classification results for the stepwise discriminant analysis (classification 3_Gr)

Growing patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=58)	28	48.3	30	51.7
UFR (n=67)	19	28.4	48	71.6
60.8% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=58)	28	48.3	30	51.7
UFR (n=67)	21	31.3	46	68.7
59.2% of cross-validated grouped cases correctly classified				

Table 4.17: Descriptive statistics for the ten cephalometric variables at T1 (classification 3_Ad)

Adult patients	**FR group**		**UFR group**		**Total group**	
	n=26		**n=28**		**n=54**	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	123.42	5.25	124.78	3.96	124.12	4.63
Co-Gn	115.41	6	112.17	5.77	113.73	6.05
SNB	77.1	4.66	75.52	3.1	76.28	3.97
ANB	6.39	1.54	6.25	1.39	6.32	1.45
PP/MP	26.81	6.33	27.4	4.88	27.11	5.58
L1/MP	98.61	8.08	100.11	5.41	99.39	6.8
Chin Thickness*	11.79	1.39	10.53	2.14	11.14	1.91
Ant Slope	6.54	7.01	6.05	6.35	6.28	6.62
Pn-D	27.24	3.5	26.91	3.4	27.07	3.42
Pog proj	0.65	4.92	-0.1	4.46	0.25	4.66

**Statistically significant: p<0.05.*

Table 4.18: Classification results for the stepwise discriminant analysis (classification 3_Ad)

Adult patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=26)	16	61.5	10	38.5
UFR (n=28)	10	35.7	18	64.3
63% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=26)	16	61.5	10	38.5
UFR (n=28)	10	35.7	18	64.3
63% of cross-validated grouped cases correctly classified				

Table 4.19: Descriptive statistics for the ten cephalometric variables at T1 (classification 4_Gr)

Growing patients	**FR group**		**UFR group**		**Total group**	
	n=58		**n=67**		**n=125**	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	126.89	5.24	125.46	5.33	126.13	5.31
Co-Gn	104.88	7.47	105.17	6.25	105.04	6.82
SNB	75.28	2.99	75.92	2.77	75.63	2.88
ANB	6.41	1.6	6.01	1.19	6.19	1.4
PP/MP	27.06	4.65	27.05	4.42	27.06	4.51
L1/MP	98.72	5.89	97.76	6.83	98.21	6.4
Chin Thickness	10.5	1.96	10.62	1.8	10.56	1.87
Ant Slope	4.79	6.6	5.53	6.83	5.18	6.71
Pn-D	22.49	2.9	23.14	2.98	22.84	2.95
Pog proj*	-2.01	3.77	-0.52	3.67	-1.21	3.77

**Statistically significant: p<0.05.*

Table 4.20: Classification results for the stepwise discriminant analysis (classification 4_Gr)

Growing patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=58)	23	39.7	35	60.3
UFR (n=67)	15	22.4	52	77.6
60% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=58)	23	39.7	35	60.3
UFR (n=67)	16	23.9	51	76.1
59.2% of cross-validated grouped cases correctly classified				

Table 4.21: Descriptive statistics for the ten cephalometric variables at T1 (classification 4_Ad)

Adult patients	FR group		UFR group		Total group	
	n=30		n=24		n=54	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	123.19	4.88	125.3	4.11	124.12	4.63
Co-Gn*	115.29	5.89	111.8	5.8	113.73	6.05
SNB	76.61	3.92	75.88	4.08	76.28	3.97
ANB	6.41	1.48	6.21	1.44	6.32	1.45
PP/MP	26.9	6.06	27.38	5.02	27.11	5.58
L1/MP	100.17	7.25	98.42	6.21	99.39	6.8
Chin Thickness	11.24	1.47	11.01	2.38	11.14	1.91
Ant Slope	6.28	6.56	6.29	6.83	6.28	6.62
Pn-D	27.07	3.7	27.07	3.12	27.07	3.42
Pog proj	-0.15	5.01	0.77	4.23	0.25	4.66

**Statistically significant: p<0.05.*

Table 4.22: Classification results for the stepwise discriminant analysis (classification 4_Ad)

Adult patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=30)	22	73.3	8	26.7
UFR (n=24)	11	45.8	13	54.2
64.8% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=30)	21	70	9	30
UFR (n=24)	11	45.8	13	54.2
63% of cross-validated grouped cases correctly classified				

Table 4.23: Descriptive statistics for the ten cephalometric variables at T1 (classification 5_Gr)

Growing patients	FR group		UFR group		Total group	
	n=104		n=21		n=125	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	126.08	5.27	126.38	5.66	126.13	5.31
Co-Gn	104.38	6.77	108.3	6.21	105.04	6.82
SNB	75.58	2.83	75.88	3.21	75.63	2.88
ANB	6.37	1.44	5.32	0.77	6.19	1.4
PP/MP	27.19	4.47	26.39	4.74	27.06	4.51
L1/MP	98.48	6.61	96.83	5.18	98.21	6.4
Chin Thickness*	10.46	1.83	11.07	2.01	10.56	1.87
Ant Slope*	4.31	6.54	9.5	5.93	5.18	6.71
Pn-D	22.74	2.69	23.34	4.03	22.84	2.95
Pog proj	-1.45	3.84	-0.04	3.27	-1.21	3.77

**Statistically significant: p<0.05.*

Table 4.24: Classification results for the stepwise discriminant analysis (classification 5_Gr)

Growing patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=104)	75	72.1	29	27.9
UFR (n=21)	9	42.9	12	57.1
60.8% of original grouped cases correctly classified.				
Cross-validated	n	%	n	%
FR (n=104)	75	72.1	29	27.9
UFR (n=21)	9	42.9	12	57.1
69.6% of cross-validated grouped cases correctly classified.				

Table 4.25: Descriptive statistics for the ten cephalometric variables at T1 (classification 5_Ad)

Adult patients	**FR group**		**UFR group**		**Total group**	
	n=33		**n=21**		**n=54**	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	123.63	4.36	124.91	5.04	124.12	4.63
Co-Gn	113.09	6.21	114.74	5.81	113.73	6.05
SNB	76.23	3.92	76.37	4.15	76.28	3.97
ANB	6.63	1.52	5.84	1.23	6.32	1.45
PP/MP*	27.47	5.19	26.55	6.22	27.11	5.58
L1/MP*	101.64	6.31	95.84	6.1	99.39	6.8
Chin Thickness	10.81	1.74	11.65	2.08	11.14	1.91
Ant Slope	5.44	7.35	7.6	5.16	6.28	6.62
Pn-D	26.61	3.88	27.78	2.48	27.07	3.42
Pog proj	-0.45	4.46	1.38	4.86	0.25	4.66

**Statistically significant: p<0.05.*

Table 4.26: Classification results for the stepwise discriminant analysis (classification 5_Ad)

Adult patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=33)	23	69.7	10	30.3
UFR (n=21)	6	28.6	15	71.4
70.4% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=33)	22	66.7	11	33.3
UFR (n=21)	6	28.6	15	71.4
68.5% of cross-validated grouped cases correctly classified				

Table 4.27: Descriptive statistics for the ten cephalometric variables at T1 (classification 6_Gr)

Growing patients	FR group		UFR group		Total group	
	n=69		n=56		n=125	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar	126.4	5.68	125.79	4.85	126.13	5.31
Co-Gn	104.79	6.54	105.35	7.19	105.04	6.82
SNB	75.59	3	75.68	2.75	75.63	2.88
ANB	6.24	1.46	6.13	1.34	6.19	1.4
PP/MP*	27.17	4.52	26.91	4.54	27.06	4.51
L1/MP*	100.44	6.27	95.45	5.46	98.21	6.4
Chin Thickness	10.85	1.88	10.22	1.82	10.56	1.87
Ant Slope	3.52	6.98	7.24	5.78	5.18	6.71
Pn-D	22.59	2.56	23.15	3.37	22.84	2.95
Pog proj	-2.04	3.96	-0.18	3.29	-1.21	3.77

**Statistically significant: p<0.05.*

Table 4.28: Classification results for the stepwise discriminant analysis (classification 6_Gr)

Growing patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=69)	50	72.5	19	27.5
UFR (n=56)	16	28.6	40	71.4
72% of original grouped cases correctly classified				
Cross-validated	n	%	n	%
FR (n=69)	50	72.5	19	27.5
UFR (n=56)	17	30.4	39	69.6
71.2% of cross-validated grouped cases correctly classified				

Table 4.29: Descriptive statistics for the ten cephalometric variables at T1 (classification 6_Ad)

Adult patients	FR group		UFR group		Total group	
	n=22		n=32		n=54	
Cephalometric variables at T1	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN/Ar*	125.74	4.97	123.02	4.1	124.12	4.63
Co-Gn	112.45	5.8	114.62	6.15	113.73	6.05
SNB	75.82	3.77	76.6	4.13	76.28	3.97
ANB	6.59	1.54	6.14	1.39	6.32	1.45
PP/MP	28.01	5.4	26.5	5.7	27.11	5.58
L1/MP	100.87	7.71	98.37	6.01	99.39	6.8
Chin Thickness	10.55	1.93	11.54	1.81	11.14	1.91
Ant Slope	5.28	6.55	6.97	6.68	6.28	6.62
Pn-D	26.19	3.87	27.67	3	27.07	3.42
Pog proj	-1.09	4.41	1.18	4.67	0.25	4.66

**Statistically significant: p<0.05.*

Table 4.30: Classification results for the stepwise discriminant analysis (classification 6_Ad)

Adult patients	Stepwise DA			
	FR		LFR	
Original group	n	%	n	%
FR (n=22)	15	68.2	7	31.8
UFR (n=32)	10	31.2	22	68.8
68.5% of original grouped cases correctly classified.				
Cross-validated	n	%	n	%
FR (n=22)	15	68.2	7	31.8
UFR (n=32)	10	31.2	22	68.8
68.5% of cross-validated grouped cases correctly classified.				

Table 4.31: Comparison between T1 and T2 within the growing low severity subgroup (n=84)

Variables	**T1**		**T2**		**Mean #**	**p-Value**
	Mean	**SD**	**Mean**	**SD**		
SN*	65.27	3.03	67.94	3.19	2.67	<0.001
SN/Ar	126.15	5.3	126.6	5.22	0.45	0.072
SNA*	81.26	2.71	80.32	3	-0.94	<0.001
SNB*	75.87	2.66	76.36	2.87	0.49	<0.001
ANB*	5.39	0.65	3.95	1.19	-1.44	<0.001
PP/MP*	26.77	4.49	25.11	4.61	-1.66	<0.001
Co-Gn*	106.03	6.85	114.3	6.68	8.27	<0.001
U1/PP	113.07	6.39	112.2	6.66	-0.87	0.34
i/MP	97.25	6.19	98.47	6.72	1.22	0.075
Pog proj*	-0.7	3.8	0.78	4.83	1.48	<0.001
St chin th*	10.61	1.97	11.55	2.07	0.94	<0.001
ANT slope*	6.73	6.51	9.27	7.34	2.54	<0.001
Pn-D*	22.75	7.34	26.02	3.25	3.27	<0.001
Age*	11.69	1.62	15.74	2.11	4.05	<0.001

* p≤0.05

Table 4.32: Comparison between T1 and T2 within the growing high severity subgroup (n=41)

Variables	T1		T2		Mean #	p-Value
	Mean	SD	Mean	SD		
SN*	64.7	3.34	67.47	3.75	2.77	<0.001
SN/Ar	126.08	5.4	125.7	6.16	-0.38	0.25
SNA*	82.98	3.34	81.75	4.05	-1.23	<0.001
SNB*	75.14	3.28	76.18	3.64	1.04	<0.001
ANB*	7.84	1.05	5.56	1.59	-2.28	<0.001
PP/MP*	27.63	4.56	26.26	4.64	-1.37	<0.001
Co-Gn*	103	6.35	112.31	5.84	9.31	<0.001
U1/PP	111.73	6.6	110.95	5.86	-0.78	0.52
i/MP	100.18	6.44	100.79	6.24	0.61	0.52
Pog proj*	-2.26	3.53	-0.06	4.67	2.2	<0.001
St chin th*	10.47	1.67	11.43	1.88	0.96	<0.001
ANT slope*	2.02	6.02	4.57	5.93	2.55	<0.001
Pn-D*	23.02	2.66	26.85	2.69	3.83	<0.001
Age*	11.2	2.04	15.86	2.05	4.66	<0.001

* $p \leq 0.05$

Table 4.33: Comparison between growing severity subgroups at T1

Variables	Low severity		high severity		Mean #	p-Value
	Mean	SD	Mean	SD		
SN	65.27	3.03	64.7	3.34	-0.57	0.33
SN/Ar	126.15	5.3	126.08	5.4	-0.07	0.94
SNA*	81.26	2.71	82.98	3.34	1.72	0.002
SNB	75.87	2.66	75.14	3.28	-0.73	0.18
ANB*	5.39	0.65	7.84	1.05	2.45	<0.001
PP/MP	26.77	4.49	27.63	4.56	0.86	0.32
Co-Gn*	106.03	6.85	103	6.35	-3.03	0.019
U1/PP	113.07	6.39	111.73	6.6	-1.34	0.27
i/MP*	97.25	6.19	100.18	6.44	2.93	0.015
Pog proj*	-0.7	3.8	-2.26	3.53	-1.56	0.029
St chin th	10.61	1.97	10.47	1.67	-0.14	0.68
ANT slope*	6.73	6.51	2.02	6.02	-4.71	<0.001
Pn-D	22.75	7.34	23.02	2.66	0.27	0.64
Age	11.69	1.62	11.2	2.04	-0.49	0.14

* $p \leq 0.05$

Table 4.34: Comparison between growing severity subgroups at T2

Variables	Low severity		high severity		Mean #	p-Value
	Mean	SD	Mean	SD		
SN	67.94	3.19	67.47	3.75	-0.47	0.46
SN/Ar*	126.6	5.22	125.7	6.16	-0.9	0.406
SNA	80.32	3	81.75	4.05	1.43	0.027
SNB	76.36	2.87	76.18	3.64	-0.18	0.765
ANB	3.95	1.19	5.56	1.59	1.61	<0.001
PP/MP	25.11	4.61	26.26	4.64	1.15	0.19
Co-Gn	114.3	6.68	112.31	5.84	-1.99	0.107
U1/PP	112.2	6.66	110.95	5.86	-1.25	0.3
i/MP	98.47	6.72	100.79	6.24	2.32	0.066
Pog proj	0.78	4.83	-0.06	4.67	-0.84	0.35
St chin th	11.55	2.07	11.43	1.88	-0.12	0.75
ANT slope*	9.27	7.34	4.57	5.93	-4.7	<0.001
Pn-D	26.02	3.25	26.85	2.69	0.83	0.16
Age	15.74	2.11	15.86	2.05	0.12	0.76

* $p \leq 0.05$

Table 4.35: Comparison between T1 and T2 within the adult low severity subgroup (n=34)

Variables	T1		T2		Mean #	p-Value
	Mean	SD	Mean	SD		
SN*	68.05	3.63	68.19	3.68	0.14	<0.001
SN/Ar	124.31	4.59	124.3	4.59	-0.01	0.83
SNA	81.72	3.68	81.46	3.79	-0.26	0.24
SNB	76.3	3.45	76.07	3.61	-0.23	0.07
ANB	5.37	0.67	5.39	1	0.02	0.58
PP/MP	26.32	5.31	26.43	5.36	0.11	0.73
Co-Gn*	115.02	6.04	115.52	6.08	0.5	<0.001
U1/PP*	113.6	7.9	105.74	6.95	-7.86	<0.001
i/MP	98.11	5.76	99.02	8.17	0.91	0.27
Pog proj	0.21	4.96	-0.06	5.23	-0.27	0.36
St chin th*	11.42	2.03	11.95	2.19	0.53	<0.001
ANT slope	6.43	6.2	6.71	5.59	0.28	0.27
Pn-D	26.76	3.15	26.94	3.16	0.18	0.002
Age*	25.77	8.9	29.21	9.26	3.44	<0.001

* $p \leq 0.05$

Table 4.36: Comparison between T1 and T2 within the adult high severity subgroup (n=20)

Variables	T1		T2		Mean #	p-Value
	Mean	SD	Mean	SD		
SN*	65.82	3.83	66.04	3.95	0.22	<0.001
SN/Ar	123.81	4.8	123.48	4.65	-0.33	0.35
SNA	84.16	4.53	83.96	4.46	-0.2	0.19
SNB	76.26	4.84	75.91	4.97	-0.35	0.2
ANB	7.935	0.89	8.04	1.12	0.105	0.66
PP/MP	28.46	5.89	29.22	6.79	0.76	0.57
Co-Gn*	111.55	5.56	112.19	5.57	0.64	<0.001
U1/PP*	110.89	7.74	103.56	9.82	-7.33	0.003
i/MP	101.56	7.97	101.55	8.39	-0.01	0.07
Pog proj	0.33	4.22	-0.25	4.24	-0.58	0.16
St chin th*	10.65	1.61	11.13	1.52	0.48	<0.001
ANT slope	6.04	7.43	5.93	6.57	-0.11	0.86
Pn-D*	27.59	3.87	27.98	3.68	0.39	0.005
Age*	25.71	8.9	29.71	8.76	4	<0.001

* $p \leq 0.05$

Table 4.37: Comparison between adult severity subgroups at T1

Variables	Low severity		high severity		Mean #	p-Value
	Mean	SD	Mean	SD		
SN	68.05	3.63	65.82	3.83	-2.23	0.058
SN/Ar	124.31	4.59	123.81	4.8	-0.5	0.74
SNA	81.72	3.68	84.16	4.53	2.44	0.07
SNB	76.3	3.45	76.26	4.84	-0.04	0.693
ANB*	5.37	0.67	7.935	0.89	2.565	<0.001
PP/MP*	26.32	5.31	28.46	5.89	2.14	<0.001
Co-Gn	115.02	6.04	111.55	5.56	-3.47	0.062
U1/PP	113.6	7.9	110.89	7.74	-2.71	0.216
i/MP*	98.11	5.76	101.56	7.97	3.45	<0.001
Pog proj	0.21	4.96	0.33	4.22	0.12	0.985
St chin th	11.42	2.03	10.65	1.61	-0.77	0.123
ANT slope	6.43	6.2	6.04	7.43	-0.39	0.822
Pn-D	26.76	3.15	27.59	3.87	0.83	0.375
Age	25.77	8.9	25.71	8.9	-0.06	0.808

* $p \leq 0.05$

Table 4.38: Comparison between adult severity subgroups at T2

Variables	Low severity		high severity		Mean #	p-Value
	Mean	SD	Mean	SD		
SN	68.19	3.68	66.04	3.95	-2.15	0.069
SN/Ar	124.3	4.59	123.48	4.65	-0.82	0.584
SNA	81.46	3.79	83.96	4.46	2.5	0.095
SNB	76.07	3.61	75.91	4.97	-0.16	0.667
ANB*	5.39	1	8.04	1.12	2.65	<0.001
PP/MP*	26.43	5.36	29.22	6.79	2.79	<0.001
Co-Gn	115.52	6.08	112.19	5.57	-3.33	0.056
U1/PP	105.74	6.95	103.56	9.82	-2.18	0.24
i/MP*	99.02	8.17	101.55	8.39	2.53	<0.001
Pog proj	-0.06	5.23	-0.25	4.24	-0.19	0.893
St chin th	11.95	2.19	11.13	1.52	-0.82	0.116
ANT slope	6.71	5.59	5.93	6.57	-0.78	0.992
Pn-D	26.94	3.16	27.98	3.68	1.04	0.259
Age	29.21	9.26	29.71	8.76	0.5	0.957

* p≤0.05

Table 4.39: Correlations of dental overjet with age, and with skeletal sagittal jaw relations (ANB)

Age			Severity			
			Low		High	
Total	Growing	Adults	Growing	Adults	Growing	Adults
0.144	0.206	0.006	0.117	0.037	0.069	0.079

Table 4.40: Mean scores of both panels based on a 5 scale Likert assessment of profile attractiveness

Panel	T1 photographs (n=50)		T2 photographs (n=50)		Mean (t2-T1)	p-value
	Mean	SD	Mean	SD		
Orthodontists (n=15)	2.728	0.602	3.06	0.57	0.332	<0.001
Dentists (n=19)	2.749	0.636	3.084	0.625	0.335	<0.001
p-value	0.862		0.84		0.982	

Table 4.41: Comparison between the different response groups based on the panel classification

	Favorable response (1) n=15		Unfavorable response (2) n=23		Unclassified (Cl I at T1) (3) n=12		p-Value Kruskal Wallis
Variables	Mean	SD	Mean	SD	Mean	SD	
Attractiveness_T1	2.69	0.47	2.49	0.55	3.21	0.59	0.008
Attractiveness_T2	3.33	0.46	2.71	0.48	3.37	0.5	<0.001
ANB_T1	6.15	1.54	6.83	1.3	5.72	1.12	0.047
ANB_T2	4.29	2.22	5.73	1.72	4.89	1.72	0.077
Ant Slope_T1	8.73	5.5	3.63	3.94	5.3	5.09	0.012
Ant Slope_T2	11.44	5.93	4.95	4.32	7.29	5.14	0.004
PP/MP_T1	26.1	3.5	28.6	4.28	28.17	3.86	0.162
PP/MP_T2	24.87	4.2	28.23	4.56	27	4.1	0.07

* p≤0.05

Table 4.42: Pairwise comparisons between response groups based on the panel's classification

Variables	1 vs 2	2 vs 3	1 vs 3
Attractiveness_T1	NS	0.001	0.03
Attractiveness_T2	<0.001	0.001	NS
ANB_T1	0.05	0.01	NS
ANB_T2	0.01	NS	NS
Ant Slope_T1	0.001	NS	0.03
Ant Slope_T2	<0.001	NS	NS
PP/MP_T1	NS	NS	NS
PP/MP_T2	0.028	NS	NS

Table 4.43: Correlation between 6 cephalometric outcome measures and rate of Class II improvement

Variables	r	p-value
Pog proj (t2-t1)	0.1877	0.1919
Convexity (t2-t1)	-0.2746	0.0536
SNB (t2-t1)	0.21	0.1433
ANB (t2-t1)*	-0.2796	0.0492
UL- E line (t2-t1)	0.1075	0.4574
L1/MP (t2-t1)	0.1487	0.3027

* p≤0.05

Table 4.44: Bivariate association between panel response groups and 10 cephalometric variables quantifying facial components

Variables at t1	Unadjusted OR	P-value
SN/Ar	1.03	0.7094
Co-Gn	1.06	0.2367
SNB	1.05	0.6495
ANB	1.4	0.1418
PP/MP	1.2	0.0531
L1/MP	1.02	0.622
St chin th*	2.5	0.0001
Ant Slope*	0.77	0.0014
Pn-D	1.06	0.5529
Pog proj*	0.82	0.0424

* p≤0.05

Table 4.45: Association between the 10 cephalometric variables at T1 and the amount of Class II improvement based on the panel assessment

Variables at T1	r	p-value
SN/Ar	-0.0191	0.9093
Co-Gn	0.2911	0.0762
SNB	0.0844	0.6142
ANB	0.1357	0.4165
PP/MP	0.244	0.1398
L1/MP	0.148	0.3754
St chin th*	0.5541	0.0003
Ant Slope*	-0.455	0.0041
Pn-D	0.1711	0.3044
Pog proj	-0.2236	0.1772
Age	0.2508	0.1288

* p≤0.05

Table 4.46: Multiple linear regressions for the outcome (Improvement of Class II)

Variables	Coef.	P>t	[95% Conf. Interval]		P-value	R2
St Chin th	0.062579	0.004	0.020854	0.104304	0.0003	0.37
Ant Slope	-0.01552	0.063	-0.03193	0.000885		
Constant	-0.90683	0.001	-1.40703	-0.40662		

Table 4.47: Mean percentage of the anterior and posterior portions of the mandibular body as determined by the T-line at T1 and T2 time points

T-Line	T1		T2		Mean T2-T1	p-value
	Mean %	SD	Mean %	SD		
ANT	44.64	7.56	42	7.63	-2.64	0.0016
POST	55.36	7.56	58	7.63	2.64	0.0016
p-value	<0.001		<0.001		0.001	

Table 4.48: Means (SD) of the anterior portion of the mandibular body as determined by the T-line at T1 and T2 in the 3 age groups

T-Line	n	ANT (T1)		ANT (T2)		p
		Mean	SD	Mean	SD	
Pre-pubertal	29	46.72	0.06	41.31	0.05	<0.001
Post-pubertal	10	44.38	0.07	44.77	0.08	0.87
Adults	11	39.37	0.08	37.79	0.08	0.41

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Appendix 1

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

Variables	T1		T2	
	r	p-Value	r	p-Value
SN	0.906	<0.001	0.997	<0.001
SN/H	0.982	<0.001	0.999	<0.001
S-Ar	0.904	<0.001	0.962	<0.001
SN/Ar	0.991	<0.001	0.976	<0.001
SNA	0.973	<0.001	0.993	<0.001
SNB	0.989	<0.001	0.996	<0.001
ANB	0.983	<0.001	0.991	<0.001
Witts (Ao-Bo)	0.929	<0.001	0.938	<0.001
NA/Apog	0.994	<0.001	0.994	<0.001
N-ANS	0.987	<0.001	0.975	<0.001
ANS-Me (AFH)	0.997	<0.001	0.992	<0.001
Ar-Go (PFH)	0.897	<0.001	0.93	<0.001
LFH/TFH (%)	0.901	<0.001	0.99	<0.001
PP/MP	0.951	<0.001	0.979	<0.001
MP/SN	0.977	<0.001	0.979	<0.001
PP/H	0.98	<0.001	0.97	<0.001
MP/H	0.964	<0.001	0.979	<0.001
Pog Proj	0.987	<0.001	0.985	<0.001
Co-Gn	0.98	<0.001	0.997	<0.001
Co-Pog	0.982	<0.001	0.997	<0.001
Co-Go	0.922	<0.001	0.893	<0.001
Go-Gn	0.933	<0.001	0.938	<0.001
Co/Go/Me	0.912	<0.001	0.96	<0.001
ANS-PNS	0.98	<0.001	0.997	<0.001
U1/NA	0.919	<0.001	0.99	<0.001
U1-NA	0.97	<0.001	0.984	<0.001
U1/SN	0.946	<0.001	0.985	<0.001
U1/PP	0.93	<0.001	0.985	<0.001
L1/NB	0.987	<0.001	0.981	<0.001
L1-NB	0.988	<0.001	0.987	<0.001
L1/MP	0.937	<0.001	0.985	<0.001
U1/L1	0.969	<0.001	0.982	<0.001
Overbite (OB)	0.995	<0.001	0.956	<0.001
Overjet (OJ)	0.991	<0.001	0.949	<0.001
UL- E line	0.971	<0.001	0.933	<0.001
LL- E line	0.972	<0.001	0.981	<0.001
Naso labial angle	0.986	<0.001	0.988	<0.001
Mento labial angle	0.987	<0.001	0.994	<0.001
U lip length	0.967	<0.001	0.972	<0.001
U lip thickness @ A	0.893	<0.001	0.964	<0.001
U lip inclination	0.974	<0.001	0.986	<0.001
L lip length	0.972	<0.001	0.958	<0.001
L lip thickness @ B	0.883	<0.001	0.882	<0.001
St Chin thickness	0.991	<0.001	0.987	<0.001
Pn-D	0.97	<0.001	0.994	<0.001
D-Apex	0.88	<0.001	0.89	<0.001
D-Me	0.91	<0.001	0.92	<0.001
CW-Apex	0.893	<0.001	0.891	<0.001
(CW-D)	0.936	<0.001	0.984	<0.001
ASA	0.989	<0.001	0.996	<0.001
PSA	0.992	<0.001	0.947	<0.001

Appendix 2

Descriptive statistics for all cephalometric variables of the 3 age groups at T1

Descriptive	T1											
	Pre-pubertal (n=88)				Post-pubertal (n=37)				Adults (n=54)			
Variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Cranial base measurements												
SN	64.5	2.9	56.4	71.6	66.45	3.27	60.1	73.2	67.22	3.82	59	77
SN/H	13.3	3.07	5.5	21.2	12.12	3.47	2.5	17.8	13.1	3.55	4.1	21.3
S-Ar	32.16	3.02	24	38.4	34.12	3.44	27.3	41.3	34.77	3.81	27.2	44.7
SN/Ar	126.1	5.42	111.3	139.5	126.11	5.13	112.1	135.1	124.13	4.63	113.4	135.6
Relationship between jaws, cranial base and horizontal												
SNA	81.6	2.91	74.7	89.4	82.37	3.26	76.9	91.7	82.6	4.12	74	93.4
SNB	75.24	2.76	69.1	82.2	76.56	2.99	69.9	84.8	76.28	3.97	68.9	85.6
ANB	6.35	1.45	4.5	10.8	5.81	1.23	4.5	9.1	6.32	1.45	4.5	10.3
Witts (Ao-Bo)	1.77	2.2	-2.8	7.8	2.05	2.47	-3.4	6.8	4.84	3.19	-1.1	10.9
NA/Apog	12.49	4.06	4.5	22.4	10.51	3.49	5.6	18.7	11.67	3.47	6.6	21
N-ANS	48.43	2.95	41.7	56.9	50.84	2.2	46.4	56.1	51.75	3.43	43.6	58.4
ANS-Me (AFH)	60.47	4.48	50.5	76.8	64.23	5.3	54.8	81	67.57	4.49	56.5	76.9
Ar-Go (PFH)	39.94	4.5	30	53.1	42.72	5.85	32.4	59.6	44.45	5.48	33.4	55.7
LFH/TFH (%)	55.36	1.83	49.5	58.8	55.6	2	51.1	61.2	56.42	2.33	51.3	61.8
PP/MP	27.25	4.57	15.7	41.2	26.61	4.4	20.4	39.4	27.11	5.58	18.4	41.5
MP/SN	36.68	4.48	26.1	51.7	35.95	4.04	26	42.1	36.31	6.44	26.2	50.9
PP/H	2.43	2.65	-4.1	9.2	2.33	3.2	-4.3	9.5	2.21	3.66	-7.2	9.2
MP/H	29.68	4.48	19.1	44.7	28.95	4.04	19	35.1	29.31	6.44	19.2	43.9
Pog Proj	-1.45	3.82	-10.9	6.3	-0.64	3.67	-9.1	9.9	0.25	4.66	-13.2	10.1
Jaw specific measurements												
Co-Gn	102.84	6.06	91	121.2	110.27	5.61	102.5	123.1	113.73	6.05	101	124.4
Co-Go	48.16	4.56	37	62.7	51.35	5.31	41.6	65.3	55.65	4.96	44.5	68.2
Go-Gn	68.61	4.35	59.7	79	74.81	3.93	65.8	83.3	75.33	5.31	63.8	87.8
Co/Go/Me	122.8	5.23	113.3	139.3	120.95	4.87	111.1	131.2	121.24	5.74	109.1	134.7
ANS-PNS	51.95	3.23	43.7	59.6	54	2.53	49.5	59.4	53.56	3.1	48.4	62
Relationship between teeth and jaws												
U1/NA	21.25	6.87	8.1	35.2	21.76	6.37	11.4	36.8	20.78	7.36	1.6	36.1
U1-NA	3.3	2.23	-1.1	8.3	3.82	2.43	-0.3	9.2	3.95	2.6	-1.2	9.4
U1/SN	102.84	7.13	86.4	117.3	104.13	7.12	90	117.2	103.38	8.58	79.6	121.6
U1/PP	112.28	6.44	100.4	125.8	113.47	6.55	99.8	129.4	112.6	7.88	90.8	130
L1/NB	30.66	4.86	17.1	42.1	29.46	6.73	17.9	47.1	31.99	6.25	17	46.2
L1-NB	6.08	1.77	1.5	9.6	6.09	2.22	2.2	11.4	7.73	2.23	3	13
L1/MP	98.73	5.77	83.9	116.2	96.96	7.65	84.2	118.1	99.39	6.8	87	113.9

Descriptive	**T1**											
	Pre-pubertal (n=88)				**Post-pubertal (n=37)**				**Adults (n=54)**			
Variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Relationship between teeth												
U1/L1	121.73	8.6	101.7	137.7	122.94	10.02	99.4	142.1	120.9	10.59	97.3	147.4
Overbite (OB)	3.29	2.03	-2.3	7.9	3.21	2.01	-1	6.8	3.16	2.13	-1.2	8.5
Overjet (OJ)	5.75	1.72	3.3	10	5.86	2.04	3.4	12.1	5.26	1.51	3.3	10.1
Soft tissue measurments												
UL- E line	-0.097	1.9	-4.8	4.2	-1.44	1.8	-5.2	3.4	-2.25	2.11	-7.1	2.9
LL- E line	1.7	2.24	-3.6	8.8	0.42	2.71	-5.9	5.9	0.81	2.86	-5	8.4
Naso labial angle	113.68	10.33	88	135	109.42	10.38	87.9	129.2	108.96	10.45	73.6	130.1
Mento labial angle	119.89	15.73	80.5	151.2	119.74	14.01	88.9	149.5	119.28	15.13	83.4	157.4
U lip length	20.42	2.09	14.6	27.5	21.07	2.37	16.4	28.8	22.1	2.31	18	27.4
U lip thickness	14.73	1.7	11.8	19	15.59	1.91	12.6	22.1	16.07	2.2	12	21.5
U lip inclination	8.23	8.68	-9.8	29.4	10.15	9.18	-4	32.1	8.37	8.59	-6.3	29
L lip length	16.36	2.35	10.1	25.7	17.9	2.36	13.2	23	18.38	2.96	14	27.7
L lip thickness	11.59	1.92	8.3	18.3	11.54	1.81	8.6	16.9	12.25	1.76	9.5	18.6
St Chin thickness	10.48	1.76	6.1	15.3	10.78	2.12	6.1	14.8	11.14	1.91	6.7	16
Pn-D	22.16	2.84	14.8	28.4	24.46	2.58	18.6	30.1	27.07	3.42	18.7	33.4
Symphyseal components												
D-Apex	6.04	1.92	1.8	9.8	8.41	2.71	2.9	15.3	10.1	1.95	5.8	14.8
D-Me	11.02	0.92	9.2	13.5	11.48	1.23	9.6	15.7	11.48	1.38	9	14.8
CW-Apex	10.28	1.65	7.1	14.8	9.35	2.17	4.9	14.1	8.51	2.02	4.8	16.3
(CW-D)	12.65	1.52	8.4	16.4	13.03	2.01	8.1	17.6	12.96	2	9.6	20
ASA	4.5	6.77	-11.9	18.4	6.82	6.34	-10.5	20	6.28	6.62	-11.2	17.6
PSA	-24.25	5.91	-36.9	-10.1	-22.26	6.97	-33.7	-8.3	-22.45	7.07	-35.8	-5.1
Time factors												
Age	10.75	1.32	7.41	13.33	13.39	1.27	11.75	16.83	25.75	8.82	15	52.33

Appendix 3

Descriptive statistics for all cephalometric variables of the 3 age groups at T2

Descriptive	T2											
	Pre-pubertal (n=88)				Post-pubertal (n=37)				Adults (n=54)			
Variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Cranial base measurements												
SN	67.7	3.36	59.3	76.3	68	3.45	60.8	75.2	67.4	3.89	59.1	77.3
SN/H	13.34	3.08	5.5	21.2	12.16	3.44	2.6	17.8	13.14	3.55	4.1	21.4
S-Ar	34.69	3.33	26.1	43.4	35.09	3.57	29	42.1	35.07	3.53	27.2	43.7
SN/Ar	126.37	5.7	109.9	138.4	126.13	5.2	112.4	137.5	123.99	4.59	114.6	134.1
Relationship between jaws, cranial base and horizontal												
SNA	80.47	3.21	73.3	88.9	81.54	3.84	75.5	91.3	82.38	4.19	73.2	92.5
SNB	76.12	3.11	70	84.5	76.74	3.18	70.4	84.7	76.01	4.12	67.7	85.3
ANB	4.35	1.49	1	7.9	4.79	1.58	2	9	6.37	1.65	3.5	10.1
Witts (Ao-Bo)	1.55	2.12	-2.7	6.2	1.8	3.01	-5.1	8.9	3.71	3.19	-5.8	10.8
NA/Apog	7.43	4.52	-1.9	18	7.78	4.59	-0.3	18	11.58	3.94	3.8	22.1
N-ANS	52.87	2.93	46.9	59.7	52.35	2.62	47	57.3	52.12	3.4	43.6	58.4
ANS-Me (AFH)	66	5.53	51.9	80.9	68.04	5.66	59.3	83.9	68.56	5.02	56.7	80.1
Ar-Go (PFH)	46.65	5.24	36.7	65.1	47.3	4.95	37.6	59.6	45.87	5.5	33.4	57.4
LFH/TFH (%)	55.85	1.72	50	59.4	56.38	2.11	51.9	61.2	56.76	2.41	51.3	62
PP/MP	25.18	4.62	12.2	36.8	26.22	4.63	17.7	38.1	27.46	6.02	16.5	44.4
MP/SN	35.93	4.91	23.3	48.4	35.91	4.41	26.3	43.5	36.77	6.76	25.8	52.7
PP/H	3.74	3.31	-4.1	13.4	2.68	3.38	-3.1	10.4	2.32	3.79	-8.3	10.5
MP/H	28.93	4.91	16.3	41.4	28.91	4.41	19.3	36.5	29.77	6.76	18.8	45.7
Pog Proj	0.73	4.98	-12.9	12.9	-0.03	4.24	-9.6	10.3	-0.13	4.85	-13.4	10.8
Jaw specific measurements												
Co-Gn	112.78	6.63	96.6	129.8	115.7	5.6	105.4	127.6	114.29	6.07	101.7	125.3
Co-Go	55.09	5.55	42.3	69.1	55.81	5.16	44.3	69.3	56.33	5.1	44.6	68.5
Go-Gn	74.32	4.62	63.8	85	77.82	4.03	70.1	84.3	75.99	5.37	64.2	87.8
Co/Go/Me	121.03	5.47	108.5	135.5	120.45	5.09	110.9	131.2	120.82	5.97	105.2	132.7
ANS-PNS	55.47	3.44	48.5	65.7	55.58	2.79	50.5	62.4	53.86	3.1	48.7	62.1
Relationship between teeth and jaws												
U1/NA	21.73	6.03	6.9	34.6	17.81	5.14	7	25.9	13.22	6.88	-0.9	27
U1-NA	2.96	2.4	-3.9	6	2.16	1.64	-0.6	5.8	0.71	2.12	-3.4	5.9
U1/SN	102.21	6.66	86.4	117.8	99.34	5.46	88.3	113.3	95.61	8.55	78.3	118.5
U1/PP	112.96	5.99	97.8	125.2	109.04	6.61	95	121.8	104.93	8.11	88.5	127.6
L1/NB	31.38	5.27	18.5	41.1	31.68	6.69	17	42.8	32.74	6.24	15.7	47.5
L1-NB	6.53	1.81	2.8	11.2	6.7	2.07	3.5	12	7.23	1.98	3.2	12.1
L1/MP	99.32	5.95	82.2	112.5	99.02	8.13	81	113.1	99.95	8.27	80.6	115.3

Descriptive	**T2**											
	Pre-pubertal (n=88)				**Post-pubertal (n=37)**				**Adults (n=54)**			
Variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Relationship between teeth												
U1/L1	122.53	8.48	105.5	145.9	125.71	8.97	111.3	144.9	127.64	10.45	106.4	154
Overbite (OB)	2.06	0.78	0.5	4	1.86	0.88	0.3	3.9	1.86	0.95	-0.1	4.2
Overjet (OJ)	2.43	0.37	1.7	2.9	2.29	0.38	1.8	2.9	2.41	0.36	1.8	2.9
Soft tissue measurments												
UL- E line	-3.05	2.19	-8.3	2	-3.54	2.23	-8.2	1.8	-3.26	2.19	-7.4	1.9
LL- E line	-0.09	2.56	-6.7	5.8	-0.44	2.64	-7.1	3	-0.22	2.45	-4.6	4.6
Naso labial angle	110.93	11.71	79.5	135.1	109.84	8.69	95.4	132.9	112.39	9.38	82.3	138.8
Mento labial angle	124.81	12	81.1	151.4	124.76	12.46	100.7	145.2	124.11	13.46	89.1	152.1
U lip length	21.61	2.11	17.2	27.9	21.96	2.55	17.9	29.5	23.02	2.43	18.4	29.2
U lip thickness @ A	16.07	1.83	12.6	21.1	15.76	2.02	12.8	22.2	16.4	2.11	11.7	21.5
U lip inclination	6.1	9.47	-16	30.2	7.41	8.15	-10.9	26.8	3.98	8.25	-14.9	21.6
L lip length	18.65	2.24	13.5	25.7	19.53	2.17	14.7	25.2	19.03	2.83	14.5	27.7
L lip thickness @ B	12.15	1.76	8.9	18.1	11.73	1.56	8.6	15.5	12.02	1.82	8.7	16.7
St Chin thickness	11.61	1.91	7.3	20	11.3	2.21	6.1	15.7	11.64	1.99	7.3	17
Pn-D	26.36	3.07	18.4	33.3	26.14	3.18	18.6	32.5	27.32	3.37	18.7	33.4
Symphyseal components												
D-Apex	8.69	2.07	4.3	15	9.82	2.49	4.2	15	10.6	2.25	6	17.1
D-Me	11.89	1.35	9.3	15.8	11.99	1.55	9.3	15.9	11.43	1.33	8.6	14.7
CW-Apex	9.18	1.79	5.3	13.4	8.61	2.29	4.2	13.2	8.04	2.21	4.3	15.8
(CW-D)	13.12	1.75	9.6	17.4	13.28	2.21	7.9	18	12.87	2.05	9.5	19.4
ASA	7.56	7.3	-10.7	22.5	8.13	7.16	-10.2	20.3	6.42	5.92	-8.8	17.2
PSA	-22.24	6.53	-37.1	-6.5	-21.67	7.66	-35.1	-8	-22.81	6.59	-38.9	-6.2
Time factors												
Age	15.13	1.82	11.75	19.83	17.33	1.85	14.26	20.92	29.14	8.99	19.15	58
Tx time	4.37	1.57	1.75	8.1	3.94	1.4	2.1	7.42	3.39	1.14	1.1	6.75