Long Term Skeletal Effects of Rapid Maxillary Expansion

by

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Submitted to the Faculty of Graduate Studies, University of Manitoba
in partial fulfillment of the requirements for the degree of

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in
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The undersigned certify that they have read and approved the Master's thesis entitled:

"Evaluation of the Long Term Skeletal Effects of Rapid Maxillary Expansion"

Submitted by

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ABSTRACT

Rapid palatal expansion (RPE) is a popular treatment modality utilized by practicing orthodontists to create additional space in the dental arches as well as address transverse discrepancies caused by constricted maxillary arches. However, negative biomechanical treatment effects such as bite-opening, particularly in patients with existing vertical growth patterns, remain a concern to many practitioners. The purpose of the present study was to evaluate long-term effects of RPE on the vertical and anteroposterior skeletal relationships of orthodontic patients following treatment with RPE and full fixed orthodontic appliances, as well as the permanence and stability of any such effects in a 4 year post-treatment period. Two sample groups were compared: patients who received RPE as part of their overall treatment protocol (N=17) with a matched group of patients whose orthodontic treatment did not include RME (N=18). All patients were treated according to the Alexander philosophy in a single, dedicated practice. Long-term lateral cephalograms studied on these patients included initial (T_1), deband (T_2), and 4 or more years post follow-up (T_3) records. Twelve various linear and angular measurements were derived, using the Dolphin™ software program. Comparative cephalometric data were analyzed using the repeated measures analysis of variance (ANOVA) technique. Of the variables examined which remain constant with age, according to Ricketts (facial axis, lower facial height, palatal plane inclination and maxillary depth) only lower facial height showed significant differences after treatment, in both the control and RPE groups ($p<0.05$). Lower facial height values behaved identically within each group over time, showing

a statistically significant increase between T_1 and T_2 ($p< 0.05$) and remaining unchanged between T_2 and T_3 ($p<0.05$). This increase between T_1 and T_2 for each group was negligible (1.93° for the RPE group, 1.46° for the control group). Hence, RPE did not have a significant long-term effect on vertical or anteroposterior dimensions on the face. Additionally, no significant vertical or anteroposterior facial skeletal differences were found between subjects who had received RPE, followed by edgewise treatment and subjects treated with standard edgewise therapy alone ($p> 0.05$). Therefore, it can be concluded that classically described treatment effects, often feared by orthodontists, resulting from rapid palatal expansion, such as increased lower facial dimension and mandibular posterorotation, seem to be compensated for, or corrected, in the course of orthodontic treatment and during continued growth.

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INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 FOREWORD

The present appeal of nonextraction treatment to correct tooth-size arch form discrepancies has created a renewed interest in alternative methods to increasing arch perimeter. Orthopaedic expansion of the maxillary arch or rapid maxillary expansion (RME) is a viable option to create additional space in the dental arches (Haas 1970; Adkins 1990; McNamara and Brudon 2001) as well as address transverse discrepancies caused by constricted maxillary arches. It is a commonly used technique and has become increasingly popular during the last 30 years.

Originally described by Angell in 1860, rapid maxillary expansion is a technique which involves opening of the midpalatal suture accompanied by downward and forward displacement of the maxilla, with resulting lateral buccal tipping of the two maxillary alveolar shelves. These changes have been accompanied by buccal tipping and extrusion of the maxillary posterior teeth with resulting autorotation of the mandible in a downward and backward direction. This leads to an increase in facial convexity and vertical dimension of the lower face, which improves patients with skeletal Class III malocclusions and worsens Class II and open bite problems.

In order to successfully diagnose and treat patients requiring RME, changes potentially affecting the vertical dimension must be evaluated critically. Exacerbation of open bite tendencies, facial convexity and elongation of lower face heights associated with permanent vertical skeletal alterations may present the clinician with challenges during treatment and prove undesirable, hence limiting use of RME as a viable treatment modality for certain groups of patients. These include patients with increased facial convexity, vertical growth patterns and open bites. However, in Class III patients with short faces, decreased convexity and deep bites, these changes may prove desirable and aid in the overall treatment of the malocclusion.

Evaluation of the long-term stability of vertical skeletal alterations induced by rapid palatal expansion will also assist clinicians during case selection and treatment planning. This is especially important in growing patients where any treatment effects may exacerbate natural growth patterns, or alternatively, relapse as a result of normal growth and development. Additionally, knowledge of long-term effects will aid in determination of overtreatment and retention protocols with this treatment modality.

1.2 SIGNIFICANCE OF THE PROBLEM

One of the troublesome problems confronting the orthodontist during treatment with rapid maxillary expansion is the potential loss of anterior overbite. " I didn't want to expand the patient because I was afraid of opening his bite" is a statement often heard by practicing orthodontists. Given the assumption that RME opens the bite, many clinicians consider an anterior open bite or a steep mandibular plane angle (or both) to be an outright contraindication to RME use. Hultgren *et al.* (1978) have shown the unfavorable treatment effects associated with excessive bite opening during treatment.

Many studies reported in the literature report that RME opens the bite and also moves the maxilla downward and forward. Most studies, however, have only reported on changes in the short-term and describe skeletal changes following RME using cephalometric data collected before and immediately following active expansion (Haas 1961, Isaacson and Murphy 1964; Davis 1969; Inoue *et al.*, 1970; Wertz 1970).

Theories put forth in an attempt to explain the bite-opening effect of RME therapy, over the short term, concern the disruption of the posterior occlusion. The maxillary arch is typically overexpanded relative to the mandibular arch, and the resultant posterior cuspal relationships cause transient bite opening. In addition, the maxillary first molars may be extruded during the process of maxillary expansion, and this movement contributes to bite opening (Bishara and Staley, 1987). Melsen and Melsen (1982) have also argued that RME is sufficiently traumatic to produce fractures in the region of the maxillary tuberosity, thus facilitating maxillary displacement, hence resulting in downward and forward displacement of the maxilla.

There are few long-term studies documenting skeletal changes with RME, and studies that have examined patients 5 or more years after treatment (Wertz 1977; Linder-Aronson 1979; Haas 1980) typically lacked both treated and untreated controls, lacked adequate statistical power and had samples which spanned wide ranges (Chang *et al.*, 1997). Some studies have examined the tendency of relapse and systematic recovery of the maxilla and mandible to their original positions following interruption of RME treatment (Wertz 1970; Bishara and Staley 1987, Velazquez *et al.*, 1996). To date, only one study has examined the long term vertical effects following RME and comprehensive orthodontic treatment (more than 6 years after treatment). Skeletal alterations such as anterior open bite and mandibular posterior rotations were found to be corrected or compensated for as a result of orthodontic treatment and normal growth (Chang *et al.*, 1997)

There are many explanations as to how the side-effects of RME may be produced, but few studies have considered the long-term significance of these treatment effects. This current retrospective longitudinal study was conducted to examine the nature of side effects produced as a result of RME treatment in combination with conventional edgewise mechanics, as well as the persistence of such effects during the post-treatment period. Specifically, the effects to be examined are skeletal alterations to maxillary and mandibular positions in the vertical and anteroposterior dimension induced by RME, which could potentially lead to increased vertical dimension and bite-opening.

1.3 PURPOSE OF THE STUDY

The purpose of the present study was to evaluate long-term side-effects rapid palatal expansion on vertical and anteroposterior skeletal relationships following treatment with RME and full fixed orthodontic appliances, as well as the permanence and stability of such side effects in a 4 year post-treatment period. Additionally, to determine differences in cephalometric skeletal parameters between patients treated with RME and full fixed orthodontic appliances and those treated with full fixed orthodontic appliances alone.

1.4 NULL HYPOTHESES

Null Hypothesis # 1: Rapid maxillary expansion treatment results in no long-term vertical and anteroposterior skeletal changes.

Null Hypothesis # 2: There is no difference in skeletal vertical and anteroposterior relationships between subjects treated with rapid maxillary expansion and subjects treated without rapid palatal expansion.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF RAPID MAXILLARY EXPANSION

Lateral maxillary expansion with midpalatal suture opening, often referred to as rapid maxillary expansion (RME) or rapid palatal expansion (RPE) is a procedure which has been utilized in orthodontics for more than 100 years. The first published work reporting on this procedure appeared in 1860, when E.H. Angell described the rapid expansion of the upper arch to provide space for maxillary canines (Angell, 1860). Since its introduction, this procedure has undergone periods of popularity and decline.

During the 1900's the procedure was discussed frequently in the early dental, orthodontic and rhinologic literature. Numerous workers referred to the procedure and its favorable nasal respiratory implications, which included lowering of the palatal vault with consequent straightening of the nasal septum and increase in air volume (Wertz, 1970) These opinions, however, were based mostly on subjective findings.
Opponents to the procedure believed that it was either anatomically impossible, or too dangerous to be used (Wertz 1970). European orthodontists, on the other hand, continued the use of RME and continued reporting on it through the years: Korkhuas (1953, 1960), Krebs (1958, 1959) and others.

In the late 1940's, Graber advocated RME for the treatment of cleft lip and palate patients (Bishara, 1987). In 1958, Korkhaus renewed interest in this procedure in North America during a visit to the University of Illinois, and the concept was reintroduced by

Haas in 1961 (Bishara, 1987). As a result, the effect of maxillary expansion on skeletal, dental and nasal structures was studied extensively in the 1960's and 1970's (Krebs 1964; Haas 1965; Wertz 1970). However, since the advent of extraction-oriented treatment plans in the United States at mid 20^{th} century, its popularity waned. More recently a resurgence of interest in palatal expansion has developed as orthodontists seek more dentally conservative treatments that try to limit dental extraction if possible.

While the skeletal effects, dental effects and stability after RME, have been studied by several researchers, palatal expansion is not yet fully understood and the different findings are contradictory (Warren *et al.*, 1987) The indication and stability of maxillary expansion has been continually debated in the literature. While some investigators have non-equivocally advocated the splitting of the midpalatal suture to widen narrow maxillary arches deeming it a stable and reliable technique (Haas 1965; Isaacson and Murphy 1964; Wertz 1970; MacNamara *et al.*, 2003) other believed that the procedure was dropped because of the development of open bites, relapse and the fact that improvement of nasal breathing was only temporary (Bishara, 1987). Nevertheless, rapid maxillary expansion remains a viable technique today in the orthodontist's armantarium with multiple uses, provided cautious case selection is utilized. Additionally many types and designs of expansion appliances have been described to maximize orthopaedic expansion of the midpalatal suture, and some of these shall be illustrated in the upcoming sections.

2.2 INDICATIONS AND CONTRAINDICATIONS FOR RAPID PALATAL EXPANSION

Rapid maxillary expansion has been indicated for :

1) Correction of lateral discrepancies that result in either unilateral or bilateral posterior crossbites involving several teeth. The cause may be skeletal (narrow maxillary base or wide mandible), dental, or a combination of both skeletal or dental lateral discrepencies (Haas 1965; Haberson and Myers, 1978; Hesse *et al.*, 1997)
2) Increase of supplementary arch perimeter to accommodate teeth in patients with tooth size- arch size discrepancies (Adkins *et al.*, 1990; McNamara and Brudon, 1993)
3) Activation of the circummaxillary sutural system in treatment protocols for Class III malocclusions involving maxillary expansion and protraction (McNamara and Brudon, 1993; Bacetti *et al.*, 1998)
4) Elimination of inter-arch transverse discrepancies prior to orthopaedic intervention in Class II malocclusions (Tollaro *et al.*, 1996; Bacetti *et al.*, 1998)
5) Cleft lip and palate patients with collapsed maxillae (Cavassan *et al.*, 2004)
6) Reduction in apnea-hypopnea index of patients who suffer sleep apnea (Pirelli *et al.*, 2004)
7) Reduction in nasal airway resistance (Doruk *et al.*, 2004) although this has been shown to relapse and is unpredictable (Basciftci *et al.*, 2002)

8) Correction of asymmetries of condylar position. According to Bell (1982), the enhanced skeletal response that accompanies RME redirects the developing posterior teeth into normal occlusion, allows more vertical closure of the mandible, and eliminates both functional shifts and possible temporomandibular joint dysfunction.

Contraindications for rapid palatal expansion include:

1) Patients with poor cooperation
2) Single tooth crossbites
3) Patients exhibiting anterior open bites, steep mandibular planes, and convex profiles
4) Adults with severe anteroposterior and vertical skeletal discrepancies (Wertz, 1970; Alpiner 1971; Bishara 1987)

2.3 TYPES OF APPLIANCES USED FOR RAPID PALATAL EXPANSION

Different types of appliances have been described to accomplish rapid palatal expansion:

1) ***Removable appliances***: While midpalatal splitting with these appliances is possible, it is not predictable. For maximum efficacy, these appliances must be used in the deciduous or early mixed dentition and have sufficient retention to be stable during active expansion phase (Skieller 1964; Ivanovski 1985; Bishara 1987)
2) ***Haas-type banded expander*** (tissue borne) (Haas 1965, 1980). This is a fixed split acrylic appliance and consists of an expansion screw with acrylic abutting the alveolar ridges. The expansion screw can be either a spring loaded or a nonspring- loaded jackscrew and has been shown to deliver 3 to 10 pounds of orthopaedic forces (Issacson *et al.*, 1964). The appliance is attached to the teeth with bands on the first molars and first premolars. Advocates of this tissue borne fixed appliance believe that greater parallel expansion occurs on the maxillary two halves hence allowing even force distribution on the teeth and alveolar processes.
3) ***Hyrax*-type banded expander*** (Biederman, 1968) This tooth-borne appliance is essentially a nonspring-loaded jackscrew with heavy wire extensions that are soldered to the palatal aspects of the bands on the first molars and premolars. It is thought that this appliance causes less irritation to the palatal mucosa and is more hygienic.

4) ***Minne-banded expander*** (Issacson *et al.*, 1964) is a heavy-caliber coil spring-loaded appliance adapted to the first permanent molar bands It could be reduced in length to adapt to a narrow maxilla by shortening the spring, tube and rod.

5) ***Bonded expander***: This occlusal-coverage Haas-type appliance is basically a hybrid of the Haas appliance and a flat-plane occlusal coverage splint. It must be physically bonded to the maxillary teeth. It has been recommended in patients with a periodontally compromised dentition (Betts *et al.*, 1995) , and patients exhibiting a Class II dentition, long face and an open bite. Advocates of this appliance believe that the increased surface area of acylic bonded to the teeth increases rigidity, controls tooth super-eruption because of the bonding to posterior teeth, and limits changes in vertical dimension. It also serves as a functional appliance with intrusive forces against the maxilla and mandible (Sarver and Johnston, 1989)

6) ***Fan-type rapid maxillary expander***: designed in 1996 by Schellino *et al.*, (Schellino *et al.*, 1996). This expansion appliance affects the anterior region of the maxilla and incorporates a spider screw names "Ragno" which works asymmetrically and allows "fan opening". It has been advocated as a means to avoid undesirable expansion of the maxilla in the region of the upper first and second premolars (Levrini and Filippi,1999; Doruk *et al.*, 2004)

2.4 EFFECTS OF RAPID PALATAL EXPANSION

Rapid palatal expansion seeks to coordinate maxillary and mandibular dentoalveolar bases by maximizing orthopaedic jaw movement while minimizing orthodontic tooth movement, and allowing for physiologic adjustment of the suture during separation (Haas 1965; Issacson *et al.*, 1964; Storey 1973). This is accomplished when the pressure applied to the teeth and the maxillary alveolar processes exceeds the limits needed for orthodontic tooth movements. As Bell (1982) has reported, "If the applied transverse forces are of sufficient magnitude to overcome the bioelastic strength of the sutural elements, orthopaedic separation of the maxillary segments can occur." The physiologic response of the midpalatal suture to this force application is one of injury followed by repair and regeneration of the sutural bony architecture.

2.4.1 PHYSIOLOGY

Typically rapid palatal expansion is done with a jacksrew that is activated 0.5 to 1mm per day. A centimeter or more of expansion is obtained in 2 to 3 weeks after which the appliance is stabilized, or a fixed retainer is used for 3 to 4 months to hold the desired expansion and allow for adequate bony closure at the expanded sutural site. At each of these stages, distinct physiologic mechanisms take place to allow for adequate healing and bone deposition.

Ten Cate *et al.*, (1977) found that the immediate effect of applying force to the suture was one of trauma resulting in small localized tears within the suture. These tears are filled with tissue fluids, hemorrhage and an inflammatory cell infiltrate. The initial hematoma is then replaced by granulation tissue. Large numbers of fibroblasts and mesenchymal stem cells are recruited to the region, and synthesis of type I collagen is seen within the sutural separation zone. In addition, there is a vascular response marked by formation of new capillaries. During the active expansion phase, sutural expansion involves injury followed by repair, but not regeneration.

However, with the cessation of sutural expansion, regeneration of the suture occurs. There is continued in-growth of new capillaries within this fibrous tissue, and osteoprogenitor cells recruited from the surrounding periosteum begin to deposit osteoid along the collagen fiber network. The response of the suture is one of osteogenesis and fibrillogenesis followed finally by remodeling (Ten Cate *et al.*, 1977)

During the stabilization phase, there is a progressive remineralization of the soft callus, resulting in the formation of a hard callus which is composed of immature bone also known as woven bone. Extensive remodeling of this woven bone then restores the normal lamellar architecture, the bone then matures (Proffit, 2003) and returns to its initial level within 3 months (Ekstrom *et al.*, 1977).

While the sequences of expansion with subsequent repair and regeneration in the midpalatal suture are predictable following RME, there are definite anatomical limitations to the amount of expansion possible.

2.4.2 ANATOMICAL LIMITATIONS TO EXPANSION

In a finite element analysis of a dry human skull, Jafari *et al.*, (2003) found that as expansion occurred, the inferior parts of the pterygoid plates of the sphenoid bone markedly displaced laterally, but more rigid regions of the plates towards the cranial base had minimal displacements. This supports numerous studies by Wertz (1970) and Isaacson *et al.*, (1964) which suggested that the main resistance to midpalatal suture opening is not the suture itself, but surrounding structures of the sphenoid and zygomatic bones. Chaconas and Caputo (1982) also mentioned a limiting factor for maxillary expansion, which may depend on the fusion or lack of fusion between the maxilla and pterygoid plates of the sphenoid bone.

Despite these limitations, much documentation exists describing the skeletal effects of RME on the maxilla and mandible in each of the transverse, anteroposterior, and vertical dimensions.

2.5 SKELETAL EFFECTS OF RAPID PALATAL EXPANSION

2.5.1 EFFECTS ON THE MAXILLA : TRANSVERSE DIMENSION

Different types of RME devices have been used by clinicians and many studies have been conducted to investigate the response of the maxillary complex.

Viewed occlusally, several authors have found that the palatine processes of the maxilla separate laterally in a non-parallel- i.e. wedge-shaped- manner, with more widening apparent in the anterior region. (Debbane 1958; Harvold 1963; Haas 1965; Davis, 1969; Inoue 1970; Wertz 1970; Ekstrom *et al.*, 1977; Bell 1982; Braun 2000; Jafari 2003).

Viewed frontally, the maxillary suture was found to separate superoinferiorly in a non parallel manner . The separation is pyramidal in shape with the base of the pyramid located at the oral side of the bone, the apex towards the nasal bone, (Krebs 1959, Cleall *et al.*, 1965; Haas 1965; Davis and Kronman 1969; Haas 1970; Wertz 1970; Iseri *et al.*, 1998; Memikoglu *et al.*, 1999; Franchi *et al.*, 2002,; Jafari 2003; Doruk *et al.*, 2004), and the fulcrum of rotation of each maxilla near the frontomaxillary suture (Haas 1965; Wertz 1970; Storey 1973; Iseri *et al.*, 1998).

2.5.2 EFFECT OF RAPID PALATAL EXPANSION ON THE MAXILLA: ANTEROPOSTERIOR AND VERTICAL DIMENSIONS

Publications in the literature on the vertical skeletal displacements of the upper jaw after RME have reported that the maxilla descends either parallel or rotates anteriorly or posteriorly but their results are inconclusive. Haas (1965) and others (Davis and Kronman, 1969; Gardner and Kronman 1971; Iseri *et al.*, 1998; Memikoglu and Iseri, 1999; Jafari 2003; Chung and Font, 2004) found the maxilla to be more frequently displaced downward and forward. The palate moved slightly downward, more in the posterior than anterior (forward rotation of the palatal plane).

De Silva Filho *et al.*, (1991) found the maxilla did not change saggitally but moved downward after RPE, displaying a downward and backward rotation in the palatal plane. Wertz (1970) and Wertz and Dreskin (1977) reported that the maxilla moved downward and backward in some patients and downward and forwards in others after RPE treatment. Using a bonded RPE appliance with occlusal coverage Akkaya *et al.* (1999) and Basciftci and Karaman (2002) reported the maxilla moved forwards after expansion. Nonetheless, Sarver and Johnston (1989) reported the maxilla moved forward less in the bonded RPE sample than in the banded RPE sample, with some cases exhibiting backward displacement of the maxilla.

Despite contradictory findings, some theories have been put forth to explain the mechanism of maxillary movement following rapid maxillary expansion, and the relationship of this displacement to increased vertical dimension. These theories explore the articulations of the maxilla with circummaxillary and other craniofacial sutures and the relationship between movements of the maxilla following RPE and growth of the maxilla.

THEORIES FOR RPE EFFECTS ON THE MAXILLA AND CRANIOFACIAL STRUCTURES

Because of the sutural orientation of the maxilla, growth produces a downward and forward vector of maxillary movement. Haas (1970) proposed that following palatal expansion, the circummaxillary sutures disengage, and "as the maxillae are forces apart and these sutures begin to open, the force produces an effect similar to growth, so that the maxilla moves downward and forward." As the sutures open, the bones slide, and the sutural denticles bind to prevent return of the maxilla to its former position.

Another possible mechanism of maxillary movement was hypothesized by Ohshima (1972). He asserted that following rapid maxillary expansion, bony spicules were deposited in a direction perpendicular to the inferior border of the vomer. Hence, it was proposed that osteogenic activity at the vomeromaxillary suture pushes, or at least facilitates, downward displacement of the maxilla.

In a 1973 study, Biederman suggested that if the center of rotation of the expansion is located at the posterior of the maxilla at the junction between the hamular and pterygoid plates, then the paired maxillae rotate around these points and point A comes forward. Wertz (1970) also believed that the disjunction of the maxillopalatine complex from the pterygoid process could provide a possible answer to instances when the maxilla was moved forward by a significant amount. Biederman (1973) also proposed a mechanism for bite opening: if the maxilla disarticulates from the nasal bones and walls of the ethmoid, then the bite closes. If these bones do not disarticulate but bend instead, then subsequent remodeling tips the palatal plane down at the nasal spine, which causes an increase in the mandibular plane angle and thereby opening the bite.

Another mechanism was also put forth by Melsen and Melsen (1982) who argued that RME is sufficiently traumatic to produce fractures in the region of the maxillary tuberosity, thus facilitating maxillary displacement in a downward and forward direction.

Additional mechanisms have been proposed that involve structures distant from the circummaxillary sutural system. Since the maxillary bone abuts ten other osseous structures, it is plausible that rapid maxillary expansion could produce skeletal effects remote from the maxilla. Given that it has been shown that an RME appliance can exert up to 30 pounds of force against the maxilla (Isaacson *et al.*, 1964), enough force might be exerted against other facial sites that circummaxillary sutural growth may be promoted. By encouraging such growth, RME could cause bite opening (Chang *et al.*, 1997).

In a study with rhesus monkeys, (Gardner and Kronman, 1971) RME produced 0.5 to 1.5 mm of opening at the sphenooccipital syncondrosis. From this observation, the authors suggested that the downward and forward movement of the maxilla during the expansion procedure may be correlated with opening of the sphenooccipital synchondrosis. This theory, however, was refuted by Jafari *et al.*,(2003) who examined the stress accumulation, dissipation and displacement of various craniofacial structures after rapid maxillary expansion using a finite element analysis on a young human skull. They found no evidence for the sphenooccipital synchondrosis as a contributing factor to maxillary displacement. The also found that bones that did not have a direct sutural articulation with the maxillae and palatine bones had little displacement

2.5.3 EFFECTS ON THE MANDIBLE

It is generally agreed that with RME there is a concomitant tendency for the mandible to swing downward and backward resulting in a higher mandibular plane angle and an increased lower facial height. (Davis and Kronman 1969; Wertz 1970; Sandlkcloglu and Hazar 1997; Akkaya et al., 1999; Basciftci and Karaman 2002; Chung and Font 2004). The fairly consistent opening of the mandibular plane during RME treatment is probably explained by the disruption of occlusion caused extrusion and tipping of maxillary posterior teeth along with alveolar bending (Bishara 1987). There is, however, some disagreement regarding the magnitude and the permanency of the change (Haas 1965, 1970; Wertz 1970).

2.6 DENTAL EFFECTS OF RAPID PALATAL EXPANSION

2.6.1 EFFECTS ON THE MAXILLARY DENTITION

It is estimated that during active suture opening, the incisors separate approximately half the distance the expansion screw has been opened (Haas 1961) and a central diastema between the maxillary central incisors results (Bishara 1987). Following this separation, the incisor crowns converge and establish proximal contact; this is thought to be induced by the elastic recoil of the transseptal fibers (Bishara 1987). The maxillary incisors tend to be extruded relative to the S-N plane and in 76% of cases they upright or tip lingually. This movement helps to close the diastema and shorten arch length and is thought to be caused by the stretched circumoral musculature (Haas 1965; Wertz 1970). On the other hand, Sandlkcoglu and Hazar (1997) reported that maxillary incisors became more proclined after RPE.

With the initial alveolar bending and compression of the periodontal ligament, there is a definite change in the long axis of the posterior teeth. However, not all of the change is caused by alveolar bending, but is partly due to tipping of the teeth in the alveolar bone (Bishara 1987). This tipping is usually accompanied by some extrusion (Byrum, 1971).

2.6.2 EFFECTS ON THE MANDIBULAR DENTITION

Following RME, the mandibular teeth have been observed to upright (Haas 1965,1970; Gryson 1977; Sandstrom et al., 1988; Cross and McDonald ,2000; McNamara *et al.*, 2003) or to remain relatively stable over the short period of treatment (Wertz 1970). The mechanism of uprighting appears to be due to either altered muscle balance or to occlusal forces secondary to maxillary expansion or a combination of both (Haas 1980). In general, it has been shown that while RME could influence the mandibular dentition, the accompanying changes are neither pronounced nor predictable (Bishara 1987). Gryson (1977) studied changes in maxillary and mandibular intercanine and intermolar widths before and after expansion in 38 patients aged between 6 and 13 years. He found no correlation between the change in mandibular intercanine and intermolar distances with respect to corresponding increases in maxillary intercanine and intermolar distances.

2.7 TIMING OF TREATMENT WITH RAPID PALATAL EXPANSION

By means of implants, Bjork and Skieller (1974) found that growth at the midpalatal suture of the maxilla might be occurring as late as 13 years of age. Persson and Thilander (1977) in a study on cadavers found that 5% of the suture was obliterated by age 25 years, yet the variation was such that a 15-year-old cadaver had an ossified suture, while a 27-year-old cadaver had an unossified suture. Knaup *et al.*, (2004) in a histomorphetric study on human palate specimens found that the oldest subject without ossification was in a 54-year-old man while the earliest ossification was registered in a 21-year old man. Thus midpalatal suture opening can be accomplished in youths and adults, but may involve fracturing of the bony interdigitations.

Bacetti *et al.*, (2001) assessed dental changes through posteroanterior radiographs and compared early- and late-treated RME groups with their respective controls. They concluded that dental changes after RME are more of a skeletal nature before pubertal peak, and more dentoalveolar after pubertal peak. However, Stuart and Wiltshire (2003) were able to demonstrate that rapid maxillary expansion does provide orthopaedic midpalatal suture opening in a young male adult. This is in agreement with Handelman *et al.*, (2000) who examined 47 adult patients successfully treated with RPE. The 47 adults ranged in age from 18 years to 49 years (mean age of 29 years, 9 months +/- 8 years) and were compared with 47 children treated with nonsurgical RPE and a control group of 52 adult orthodontic patients who did not require RPE. They showed that alveolar bone was in fact translated with minimal molar tipping, and concluded that nonsurgical RPE in adults is a clinically successful and safe method for correcting transverse maxillary deficiency.

Most investigators do agree however, that with advancing maturity, the rigidity of the skeletal components and other sutures adjacent to the midpalatal suture limit the extent and stability of the expansion (Krebs 1959; Isaacson and Murphy 1964; Zimring and Isaacson 1965; Wertz 1970; Melsen and Melsen 1982; McNamara and Brudon 1993). As a result, this may necessitate a Le Fort I multiple-piece maxillary osteotomy to address the transverse deficiency, or a surgically assisted RME (Northway 1997, Berger 1998) which involves osteotomies of the palatal midline and lateral aspects of the maxillae combined with RPE.

2.8 STABILITY OF RAPID PALATAL EXPANSION

2.8.1 IMMEDIATE STABILITY

A meta analysis conducted by Schiffman and Tuncay (2001) investigating the stability of transverse expansion of the human maxilla found that in the short term (< 1 year) a 6-mm average expansion with retention yielded a 4.71mm residual expansion. Additionally, Velazquez *et al.*, (1996) found that skeletal alterations such as anterior open bite and mandibular postero-rotations resulting from RME therapy were found to be corrected or compensated for as a result of orthodontic treatment and normal growth. Using lateral cephalometric radiographs to assess short-term results of RME on dental changes, Cozza *et al.*, (2001) found no statistically or clinically significant differences in molar or incisor positions when comparison of results before and after treatment with RME.

2.8.2 LONG-TERM STABILITY

2.8.2.1 LONG TERM ARCH WIDTH AND DENTAL CHANGES

Using metallic implant markers in the zygomatico-alveolar crest and in the hard palate, lingual to the canines and first molars, Krebs (1964) found that stability of RME expansion gradually decreased over a 4 to 5 year period particularly when retention was discontinued. The net width gain at the end of the observation period was about 5mm (60%) for the first molars and 2mm (25%) for the canines with large individual variations. Similar results with regard to long-term residual expansion in the first molar and canine areas with RME were later reported by Linder-Aronson and Lindgren (1979) in a consecutive series of 23 patients with a mean age of 14.4 years, a retention period of 1.7 years, and a post-retention period of 4.7 years; by Herold (1989) at 5.5 years postretention in 19 patients whose treatment was initiated at 12.9 years of age; by Moussa *et al.*, (1995) in a random sample of 55 patients 12.1 years of age at pretreatment, subjected to prolonged retention (6.5 years), and re-examined 8 years later, and by Cameron *et al.*, (2002). Together, these studies demonstrated that a residual intermolar expansion of 50% to 60% or more of the initial (over) expansion can be expected to remain 5 to 8 years after treatment.

In a systemic literature review, Lagravere *et al.*, (2005) found that clinically significant long-term maxillary molar width increase (3.7-4.8mm) can be achieved, and that no anteroposterior or vertical dental changes (molar vertical position, incisor inclination) were associated with RME (Garib *et al.*, 2001) as reported by Lagravere *et al.*, (2005).

In contrast, by using a meta analysis for the long-term evaluation of RME stability (> 1 year), Schiffman and Tuncay (2001) found that only 2.4 mm of the residual expansion was reported to have remained. This 2.4 mm of expansion was no greater than what has been documented with normal growth. They therefore concluded, that maxillary expansion stability is minimal, and that insufficient data exists to demonstrate any useful expansion beyond what can be expected with normal growth.

2.8.2.2 LONG-TERM TRANSVERSE, ANTEROPOSTERIOR AND VERTICAL SKELETAL CHANGES

There have been few studies that have examined long-term skeletal changes induced in the maxilla and mandible following interruption of RME treatment. Franchi *et al.*, (2002), using thin-plate spline analysis, found that the shape of the maxilla in patients treated with RME in the transverse plane is normalized with respect to controls after an average time period of eight years after expansion. Moreover, patients treated with RME exhibited an enlargement of the maxillary complex in the vertical plane due mainly to an upward displacement of the orbits. They theorized that the shape change in the vertical change dimension of the maxilla in their treated sample was most likely the result of growth changes involving both bone remodeling and enlargement of the maxillary sinuses.

Chang *et al.*, (1997) examined long term (>6 years) vertical and anteroposterior skeletal effects following RME and comprehensive orthodontic treatment. Increases in lower anterior face height and mandibular plane angle did not occur in patients treated with RME. Furthermore, their study showed that RME does not significantly alter the anteroposterior maxillary position over the long term. This is in agreement with a systematic review conducted by Lagravere *et al.*, (2005) which evaluated long-term skeletal changes with rapid maxillary expansion. They concluded that RME did not produce significant long-term (more than five years after finishing full active treatment) anteroposterior or vertical changes in the position of the maxilla and mandible.

2.9 STABILITY OF RICKETTS VALUES: LOWER FACE HEIGHT AND FACIAL AXIS

The Rickett's cephalometric analysis and growth prediction approach is based on a variety of constants representing mean values that have been available as a result of diagnostic analysis over several years (Ricketts 1955, 1975). Very few studies have been published examining the validity of these constant means. Two of these constant means are Rickett's lower face height and facial axis angular values which are presumed constant with age.

McNamara *et al.*, (unpublished study as reported by Ricketts JCO, 1975) examined 50 patients and found facial axis values to increase by only 0.22 degrees, on average, per year. This increase was considered negligible. Kocadereli *et al.*, (1999) found a strong correlation between predicted and actual measurements in lower facial height and facial axis values when applied to untreated Turkish children over 7 years (Pearson correlation coefficient greater than 0.7).

Using lateral cephalometric records of 74 untreated subjects obtained from the archives of Burlington Growth Center (Toronto), evaluated at three time points: 9 years (T1), 12 years(T2) and 20 years (T3) of age, Morra *et al.*, (2005) demonstrated that facial axis values remained constant between T1 and T2 but increased by 0.63° between T2 and T3 ($p<0.05$). Lower facial height values were found to remain constant with age with a decrease of only 0.59° between T1 and T2 ($p<0.05$). Despite the statistically significant increase in facial axis values, this was not considered clinically significant (less than 1 degree). Hence, it was concluded that these values are reliable indicators of vertical changes which have been induced by orthodontic treatment, and can be used to accurately predict growth pattern in orthodontic patients.

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

3.1 SAMPLE SELECTION

This study compared a group of patients who received RME as part of their overall treatment protocol with a matched group of patients whose orthodontic treatment did not include RME. The two samples were chosen from the archives of the private orthodontic practice of Dr Wick Alexander in Arlington, Texas, USA thereby minimizing the potential effects of interclinician differences. All patients were treated according to the Alexander philosophy. Treatment mechanics were based on Tweed's philosophy of continuous archwires, minimal alteration of the mandibular arch form, tip back bends for anchorage control, headgear and intermaxillary elastics, as necessary.

Out of 5000 long-term records of patients who had undergone non-extraction Alexander philosophy edgewise appliance therapy, a total of 35 subjects were selected (22 females and 13 males). Subjects were selected according to predetermined inclusion and exclusion criteria (Table 3.1). These subjects were consequently divided into two sample groups.

Table 3.1: Inclusion and exclusion criteria

INCLUSION criteria	EXCLUSION criteria
1. Caucasian background 2. Orthodontically untreated subjects 3. Subjects that are growing; (preferably between 10-12 years if female; 12-14 years if male) 4. Mixed or early permanent dentition 5. Minimum follow-up of 4 years into the retention phase of treatment.	1. Subjects with previous orthodontic treatment. 2. Subjects treated with extraction therapy. 3. Subjects with missing teeth or congenitally missing teeth. 4. Subjects with congenital clefts, or any suspected or identifiable syndromes. 5. Subjects past peak height velocity (> 16 years for females, > 18 years for males)

RME GROUP (GROUP 1):

The RME sample included seventeen subjects (10 females, 7 males) treated with rapid palatal expansion followed by fixed orthodontic appliances. Long-term records obtained on these patients included initial (T_1), deband (T_2) lateral cephalograms, photos and study casts. Lateral cephalograms and study casts were also obtained 4 or more years after treatment (T_3).

These patients originally were judged by the practitioner to have transverse maxillary deficiency as part of their overall orthodontic problem. For each patient, a Hyrax-type palatal expander was banded on the maxillary first premolars and molars. When the maxillary first premolars were not erupted, the expander was banded only on the maxillary first molars (6 patients). For each patient, the expander was activated 1 turn every 24 hours (0.2mm) for 2 to 4 weeks, until the required expansion was achieved. Then, the expander was sealed with composite resin and left for an average of 6 months to hold the desired expansion and serve as a maxillary space maintainer. The RME was subsequently removed and fixed standard edgewise appliances were placed immediately thereafter. Average treatment and retention time with the RME appliance is indicated in Table 3.2

Table 3.2 Mean length of treatment with RPE and length of post-expansion retention for subjects treated with RPE, prior to initiation of full fixed orthodontics

	Treatment (weeks)		Retention (months)	
	x	Range	x	Range
Males (n=7)	4.9 weeks	3-8 weeks	6.0 months	5-6 months
Females (n=10)	3.1 weeks	3-4 weeks	5.2 months	3-11months
Total (N=17)	3.8 weeks	3-8 weeks	5.5 months	3-11months

x=mean value

CONTROL GROUP (GROUP 2):

This sample consisted of eighteen patients (12 females, 6 males) that were matched to the RME group in terms of Angle classification, growth pattern, age at initiation of treatment, sex distribution, and comprehensive orthodontic treatment mechanics; but were otherwise selected randomly. Long-term records at T_1, T_2 and T_3 were also available for this sample.

The control group served as a positive control: both Group 1 and Group 2 were treated similarly, except for the use of the RME appliance in Group 1, hence inclusion of Group 2 controlled for bite opening that can occur from leveling with fixed appliances alone.

Lateral cephalograms were analyzed at the three time-points (T_1, T_2, and T_3). Lateral cephalograms at each time point were traced (Orthopli corp. Cephalometric tracing paper, Philadelphia, PA, USA) and subsequently scanned by a single operator using the hp Scanjet 4570c scanner (Hewlett-Packard Development Company, L.P., U.S.A) and subjected to cephalometric analysis using the Dolphin™ treatment planning software program (Dolphin Imaging and Management Systems, Chatsworth, CA, USA). In cases of a double image, the midline between both structures was chosen. All the cephalograms belonging to an individual subject were digitized at the same sitting.

3.2 CEPHALOMETRIC ANALYSIS

All the cephalograms were obtained on a Quint X-ray sectograph radiographic machine using a high-kilovoltage technique at Dr Wick Alexander's private practice in Arlington, Texas.

The definition of the landmarks corresponded to those given by Ricketts *et al.* (1981) and Riolo *et al.* (1974). Twenty-seven landmarks were identified on each cephalogram, from which twelve various linear and angular measurements were derived.

The following landmarks were identified on each cephalogram: Sella turcica (*S*), Nasion (*N*), A-point (A), B-point (B), Menton (*Me*), Anterior Nasal Spine (*ANS*), Posterior Nasal Spine (*PNS*), Gonion (*Go*), Gnathion (*Gn*), Pogonion (*Pog*), Porion (*Pr*), Orbitale (*Or*), Basion (*Ba*) , PT point (*PT*) , CF point (*CF*), Protuberance Menti (*PM*), Center of Cranium (*CC*), Xi point (*Xi*), DC point (*DC*), Root of Upper Incisor (*AR*), Incisal Edge of Upper Incisor (*A1*), Incisal Edge of Lower Incisor (*B1*), Root of Lower Incisor (*BR*), Upper Molar (A6), Upper Molar (*U6*), Lower Molar (*L6*), Articulare (*Ar*) (Figures 3.1 and 3.2).

From these landmarks, the following linear and angular measurements were derived and evaluated at T_1, T_2 and T_3: Facial Axis, Lower Anterior Facial Height, Mandibular Plane Angle, Palatal Plane Angle, Y-axis, Palatal/Mandibular Plane Angle, Anterior to Posterior Face Height, SNA angle, SNB angle, ANB angle, Maxillary Depth, Facial Convexity. (Figures 3.3-3.15)

The selection of these measurements was based on the fact that they are widely used by orthodontists to evaluate vertical and anteroposterior skeletal relations. Additionally, any changes seen in the variables as established by Ricketts (1981) to be constant with age will indicate that these changes are induced by orthodontic treatment. These variables include the facial axis and lower facial height angular measurements (Morra *et al.*, 2005)

3.3 RELIABILITY

To test intraexaminer reliability, 12 cephalograms (11.7%) were randomly selected, retraced and redigitized by the same examiner and compared with the original measurements. The systematic error was assessed by a Student paired *t*-test to see whether there were significant differences between measurements taken on two separate occasions. The level of significance was predetermined at the 0.05 level.

3.4 STATISTICAL ANALYSIS

Cephalometric measurements were entered into a Microsoft Excel spreadsheet (Microsoft Corp., Redmond WA). Data were analyzed using SAS Version 9.0 statistical software (2006 SAS Institute Inc., Cary, North Carolina). Descriptive statistics including the mean, standard deviation, and ranges were calculated for each parameter measured at each time point in both Group 1 and Group 2. The cephalometric parameters at specific times were analyzed for each of the two groups by comparing the differences among groups between each timepoint (ΔT_2-T_1, ΔT_3-T_2 and ΔT_3-T_1)

These measures were statistically analyzed more extensively with a one-way repeated-measures analysis of variance (ANOVA) to examine patterns over time and to analyze statistical differences within and between the two groups between each time interval. Chi-square testing was performed to verify whether the proportion of males to females was equal in both samples at T_1.

2-way repeated measures testing were used to determine the significant differences in parameter changes between sexes within each group at T_1, T_2 and T_3, as well as gender differences between the groups for each parameter. Significance for all statistical tests were predetermined at $p < 0.05$.

3.5 DEFINITIONS

3.5.1 Cephalometric landmarks

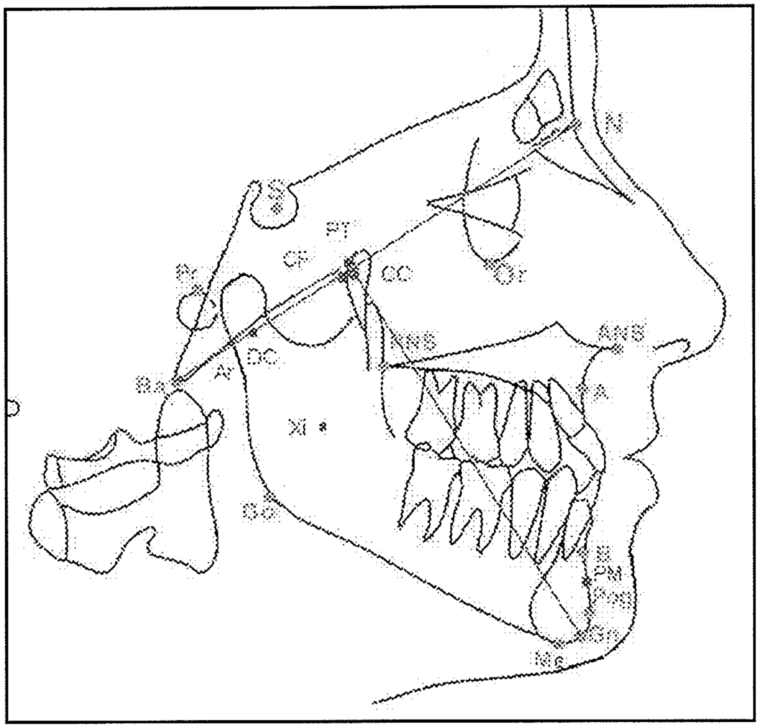

Figure 3.1 Lateral cephalometric analysis points.

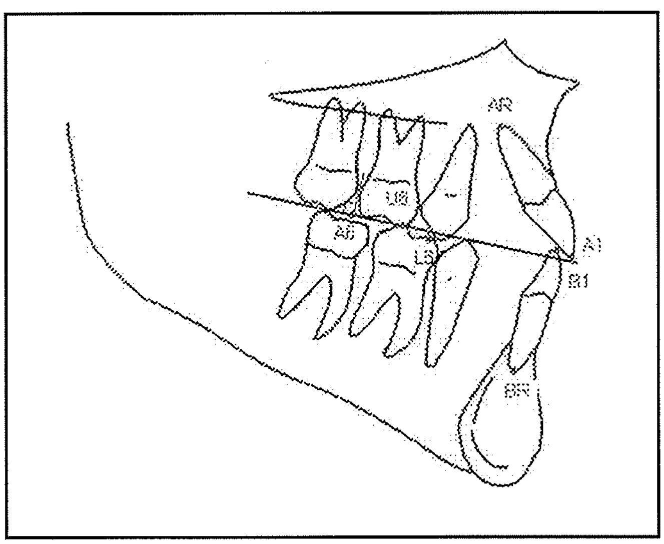

Figure 3.2 Lateral cephalometric analysis points.

Sella turcica (S) – the geometric center of the pituitary fossa (sella turcica), determined by inspection – a constructed point in the midsagittal plane (Downs, 1948).

Nasion (N) – craniometric point where the midsagittal plane intersects the most anterior point of naso-frontal suture (Broadbent, Broadbent & Golden, 1975).

A point (A) – the innermost point on the contour of the premaxilla between anterior nasal spine and the incisor tooth (Proffit 2000)

B point (B) – the innermost point on the contour of the mandible between the incisor tooth and the bony chin (Proffit 2000)

Menton (Me) – most inferior point on the symphysis of the mandible in the median plane. Seen in the lateral radiograph as the most inferior point on the symphyseal outline when the head is oriented in the Frankfort Relation (Broadbent, Broadbent & Golden, 1975).

Anterior Nasal Spine (ANS) – sharp median process formed by the forward prolongation of the two maxillae at the lower margin of the anterior aperture of the nose (Broadbent, Broadbent & Golden, 1975). The tip of the bony anterior nasal spine at the inferior margin of the piriform aperture, in the midsagittal plane (Daskalogiannakis, 2000).

Posterior Nasal Spine (PNS) – process formed by the union of projecting medial ends of the posterior borders of the two palatine bones (Broadbent, Broadbent & Golden, 1975). The most posterior point on the bony hard palate in the midsagittal plane; the meeting point between the inferior and the superior faces of the bony hard palate (nasal floor) at its posterior aspect (Daskalogiannakis, 2000).

Gonion(Go) – the constructed point at the intersection of the ramus plane and the mandibular plane (Ricketts, 1981).

Gnathion (Gn) – the most anterior inferior point of the bony chin in the midsagittal plane (Daskalogiannakis, 2000).

Pogonion (Pog) – the most anterior point of the symphysis of the mandible in the median plane when the head is viewed in Frankfort relations (Broadbent, Broadbent & Golden, 1975).

Porion (Pr) – the most superior point of the outline of the external auditory meatus (Daskalogiannakis, 2000).

Orbitale (Or) – the lowest point on the inferior orbital margin (Daskalogiannakis, 2000).

Basion (Ba) – point where the median sagittal plane of the skull intersects the lowest point on the anterior margin of the foramen magnum (Broadbent, Broadbent & Golden, 1975);

Articulare (Ar) – intersection of the lateral radiographic image of the posterior border of the ramus with the base of the occipital bone (Broadbent, Broadbent & Golden, 1975).

PT point (PT) – intersection of the inferior border of the foramen rotundum with the posterior wall of the pterygomaxillary fissure (Ricketts, 1981);

CF point (CF) – cephalometric landmark formed by the intersection of the line connecting Pr and Or and a perpendicular through PT (Ricketts, 1981).

Protuberance Menti (PM) – a point selected where the curvature of the anterior border of the symphysis changes from concave to convex (Ricketts, 1981).

Center of Cranium (CC) – cephalometric landmark formed by the intersection of Ba-Na line and facial axis (PT- Gn line) (Ricketts, 1981).

Xi point (Xi) – a point located at the geometric center of the ramus, derived by bisecting the vertical height and the horizontal depth of the ramus (Ricketts, 1981);

DC point (DC) – cephalometric landmark representing the center of the neck of the condyle on the Ba-Na line (Ricketts, 1981).

Root of Upper Incisor (AR) – the root tip of the maxillary central incisor. In cases where the root is not yet completed, the midpoint of the growing root tip is marked (Riolo et al, 1974).

Incisal Edge of Upper Incisor (A1) – the incisal tip of the most labially placed maxillary central incisor (Daskalogiannakis, 2000).

Incisal Edge of Lower Incisor (B1) – the incisal tip of the most labially placed mandibular incisor (Daskalogiannakis, 2000).

Root of Lower Incisor (BR) – the root tip of mandibular incisor. When the root is not yet completed, the midpoint of the growing root tip is marked (Riolo et al, 1974).

Upper Molar (A6) – a point on the occlusal plane perpendicular to the distal surface of the crown of the upper first molar (Ricketts, 1981).

Upper Molar (U6) – the tip of the mesial buccal cusp of the upper first molar (Siriwat & Jarabak, 1985).

Lower Molar (L6) – the tip of mesial buccal cusp of the lower first molar (Siriwat & Jarabak, 1985).

3.5.2 Cephalometric measurements

3.5.2.1 *Variables measuring vertical skeletal proportions*

1. Facial Axis (Ba-N/PT-Gn) – the inferior angle formed by the intersection of the facial (PT-Gn) and cranial (Ba-N line) axes. Indicates the direction of mandibular growth with respect to the cranial base. Normal value is 90° (SD=3.5°). No change with age. (Ricketts, 1981) (Figure 3.3).

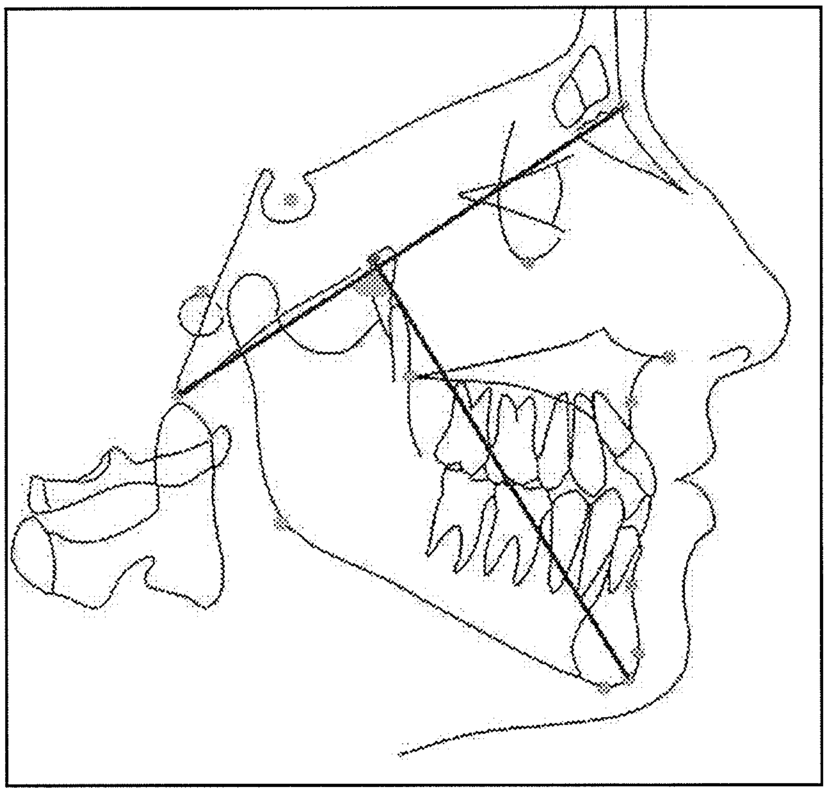

Figure 3.3 Facial Axis

2. Lower Anterior Facial Height (ANS-Xi-PM) - acute angle formed by Corpus Axis (line from Xi to PM) and a line from Xi to ANS. Relates the vertical position of the mandibular body to the upper jaw. The normal value is 46° (SD=3°). No change with age. (Ricketts, 1981) (Figure 3.4).

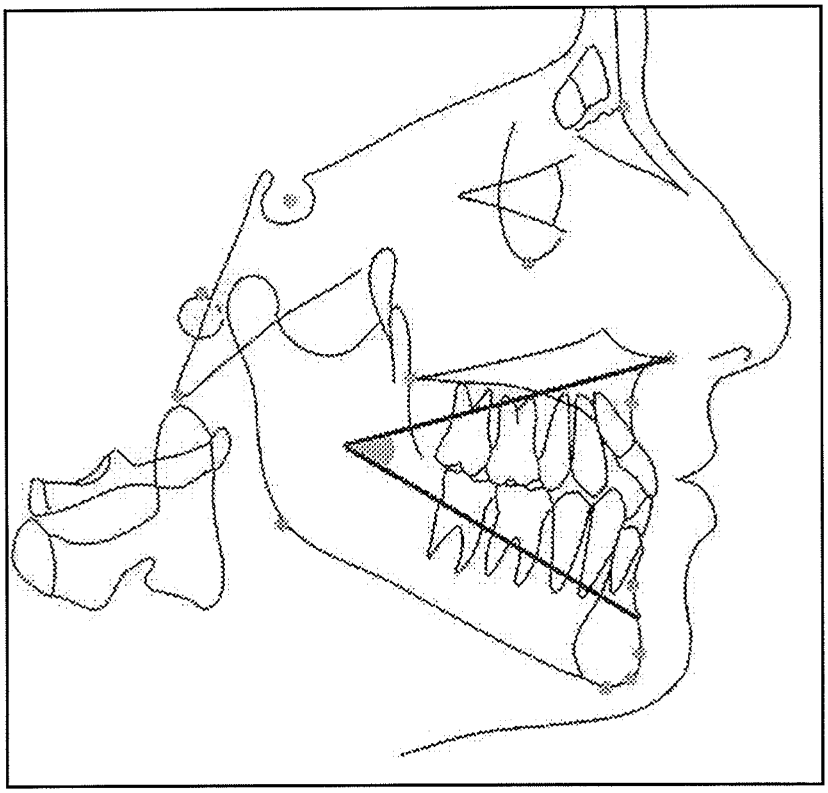

Figure 3.4 Lower anterior facial height

3. Mandibular Plane Angle (MPA) – the anterior angle formed by the intersection of the Frankfort horizontal plane and a tangent to the lower border of the mandible and symphysis. Normal value is 26° (SD=4.5°) for 9 year old patients, with a decrease of 1° every 3 years. (Ricketts 1981) (Figure 3.5).

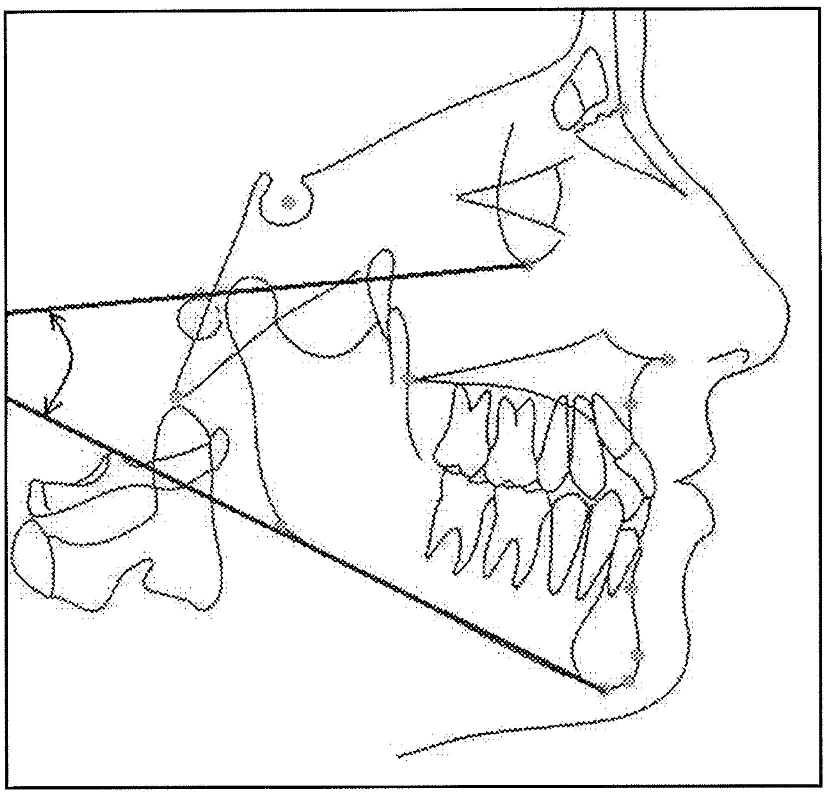

Figure 3.5 Mandibular plane angle

*4. **Palatal Plane Angle (PPA)*** – angle created by palatal plane (PP) and FH. PP extends from ANS to PNS. Indicates the inclination of the palatal plane with respect to Frankfort plane. The normal value for PPA is 1° (SD=3.5°). No change with age. (Ricketts, 1980) (Figure 3.6).

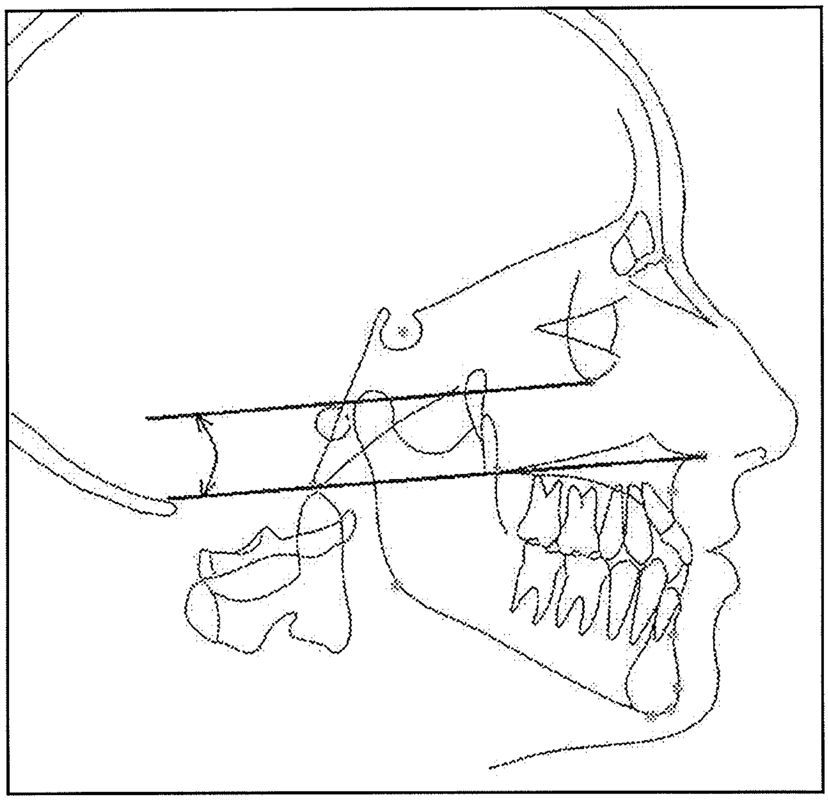

Figure 3.6 Palatal plane angle

5. Y-Axis – acute angle formed by intersection of a line from S to Gn with a line from S to N. Normal value is 66° (SD=5°) (Brodie, 1953) (Figure 3.7).

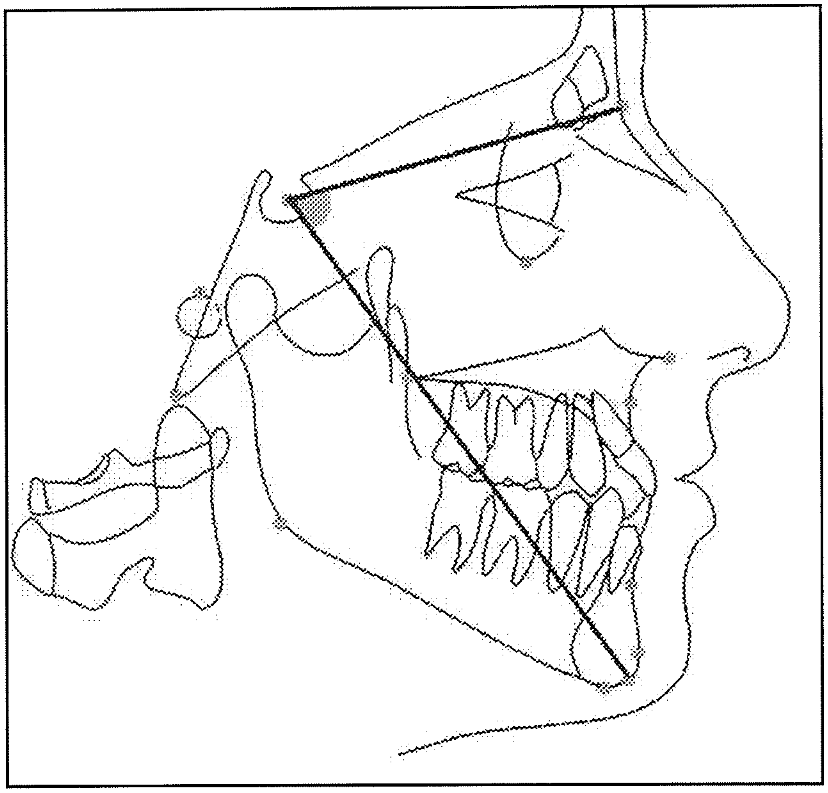

Figure 3.7 Y-Axis

6. Palatal/Mandibular Plane Angle (PP-MP) – angle created by intersection of palatal and mandibular planes. Normal value is 28° (SD=6°) (Siriwat & Jarabak, 1985) (Figure 3.8).

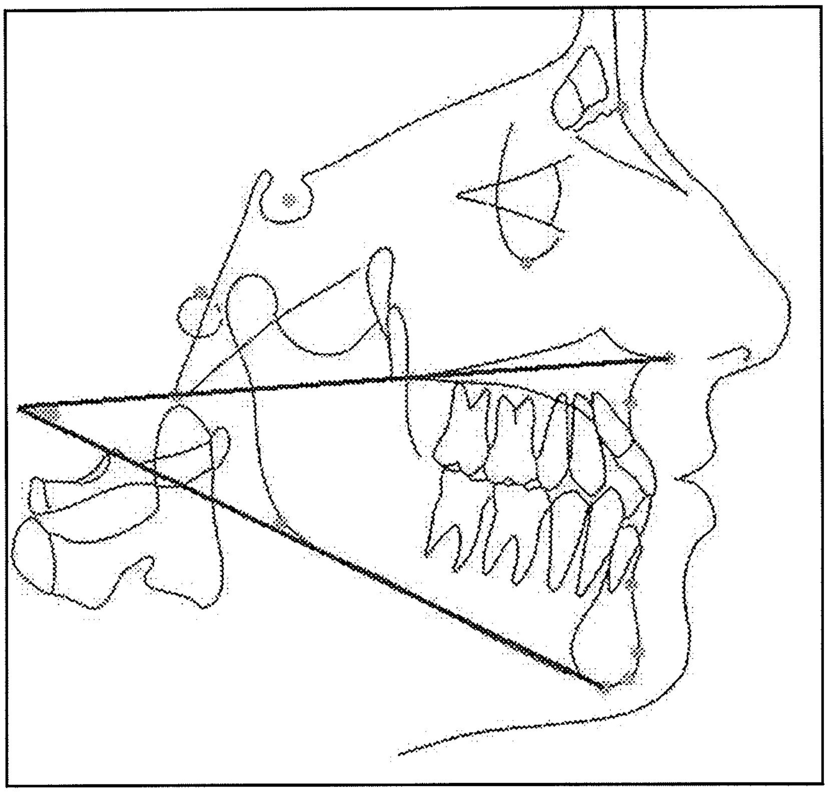

Figure 3.8 Palatal to mandibular plane angle

7. ***Anterior to Posterior Face Height*** (S-Go/N-Me) – proportion of total posterior face height to total anterior face height. Normal value is 65 % (SD=4%) (Siriwat & Jarabak, 1985).

Total Posterior Face Height (S-Go) – linear distance from Sella to Gonion. Normal value for adult male is 88 mm (SD=6 mm), for adult female – 79 mm (SD=4 mm); however, this measurement depends largely on the size of the individual (Riolo *et al.*, 1974) (Figure 3.9).

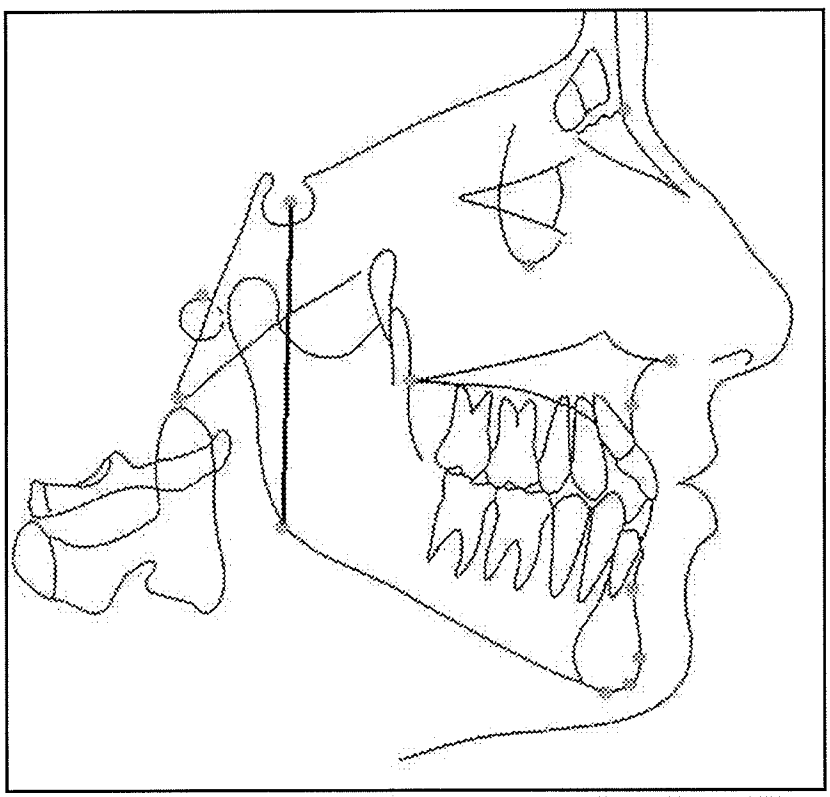

Figure 3.9 Total posterior face height

Total Anterior Face Height (N-Me) – linear distance from Nasion to Menton. Normal values can vary depending on the size of the person. Adult normal measurement for male is 137 mm (SD=8 mm), for female it's 123 mm (SD=5 mm) (Riolo *et al.*, 1974) (Figure 3.10).

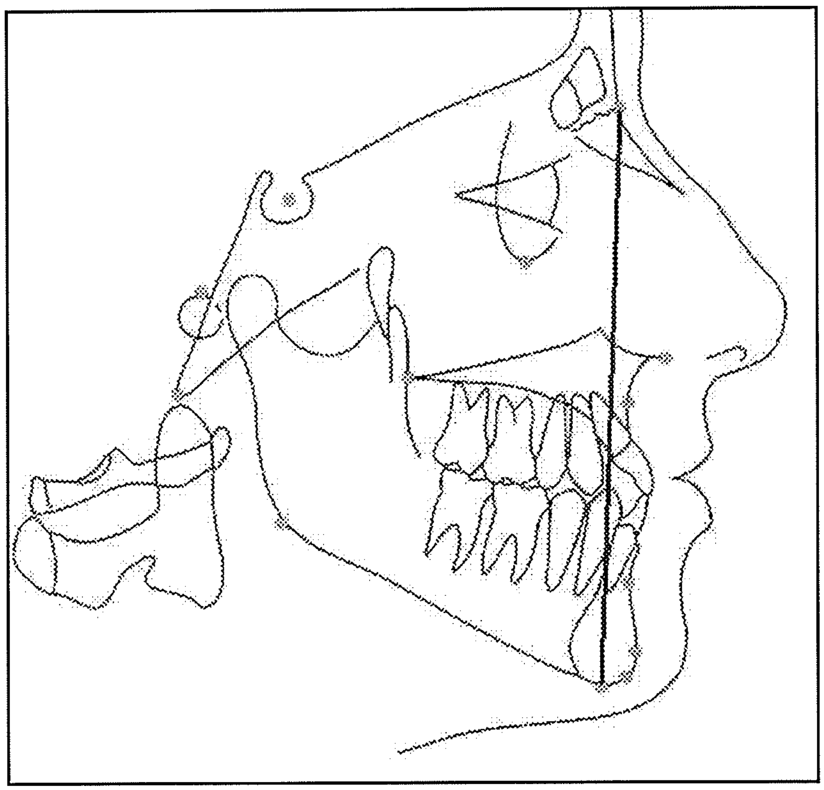

Figure 3.10 Total anterior face height

3.5.2.2 *Variables measuring anteroposterior skeletal proportions*

1. Maxillary Depth (FH-NA)- indicates the anteroposterior position of the maxilla. Normal value is 90°. (S.D=3°) (Ricketts, 1981) (Figure 3.11)

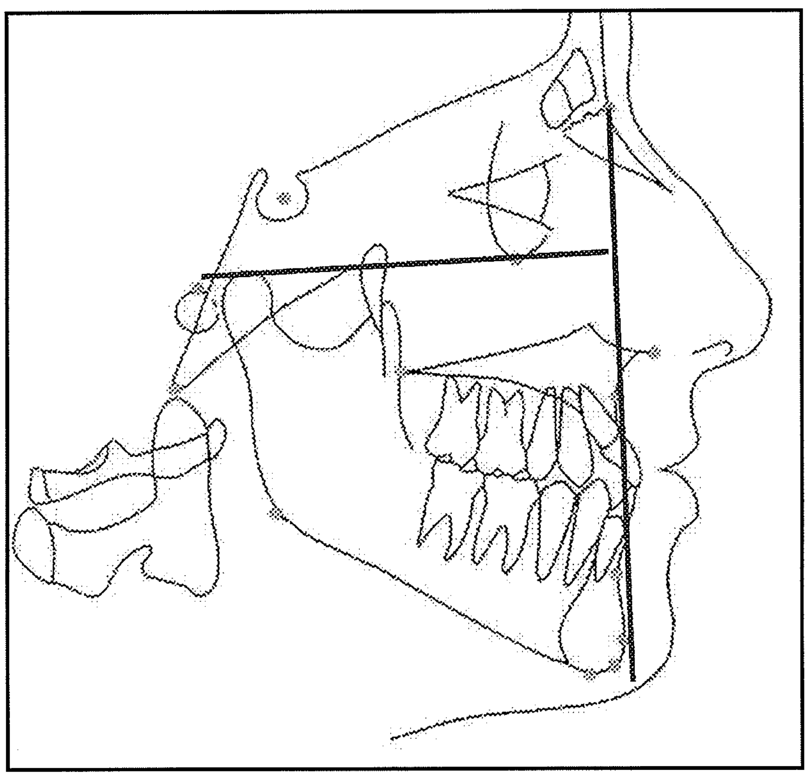

Figure 3.11 Maxillary depth

2. Facial Convexity (A-NPo)- indicates the anteroposterior position of the maxilla with respect to the anteroposterior position of the mandible. Normal value is 2mm (S.D.=2mm) for 9 year-old patients with a decrease of 1mm every 3 years. (Ricketts, 1979). (Figure 3.12).

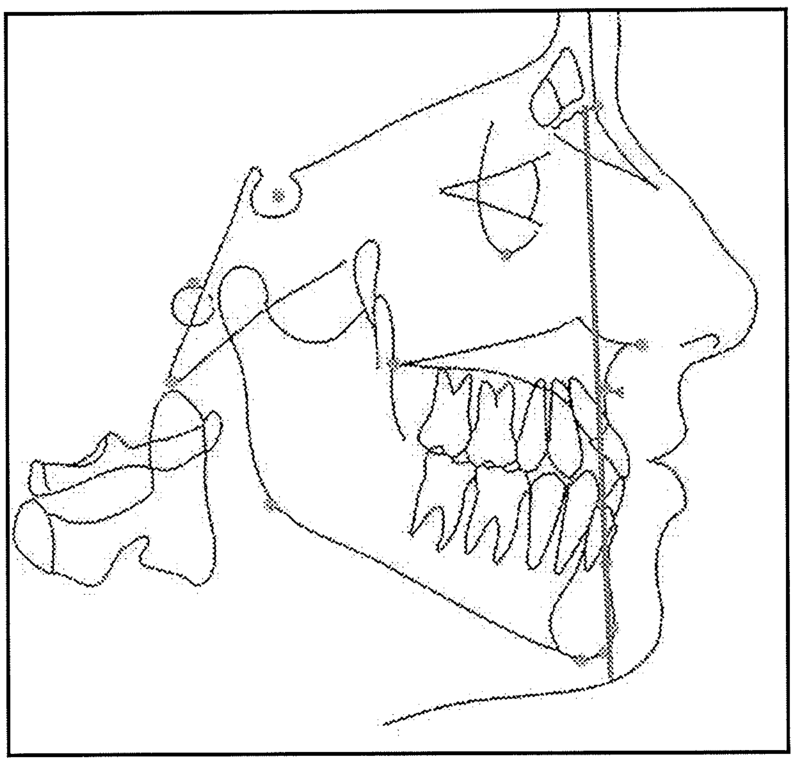

Figure 3.12 Facial convexity

3. SNA angle (SN-NA) - angle formed by the intersection of SN with NA. Used for evaluation of the anteroposterior position of the maxilla relative to the cranial base. Normal value is 82°. (S.D.= 2°) (Steiner, 1960) (Figure 3.13).

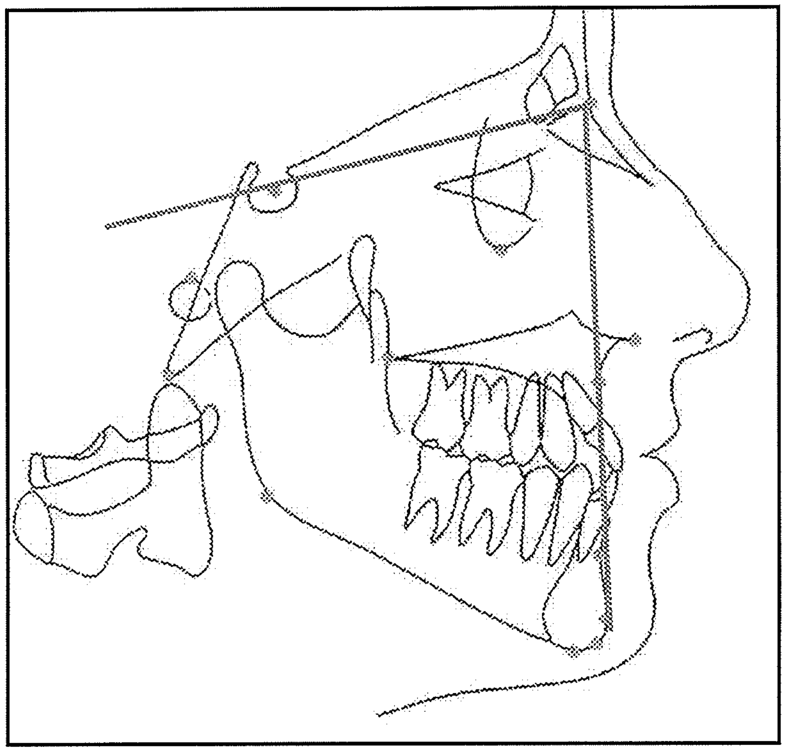

Figure 3.13 SNA angle

4. SNB angle (SN-NB) - angle formed by the intersection of SN with NB. Used to evaluate the anteroposterior position of the mandible relative to the cranial base. Normal value is 78°. (S.D. = 2°). (Steiner, 1960). (Figure 3.14).

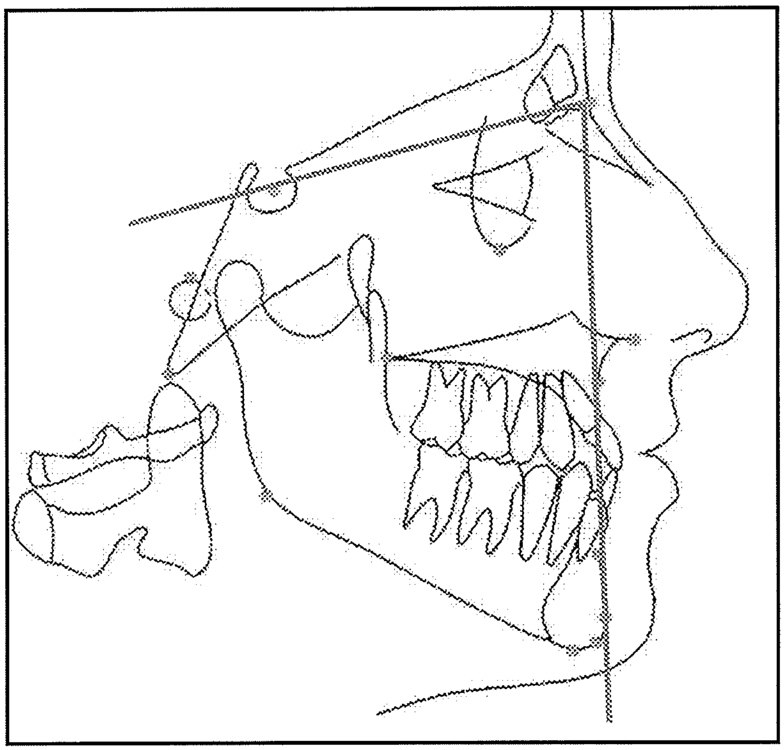

Figure 3.14 SNB angle

5. ANB angle (NA-NB) - acute angle formed by the intersection of NA with NB. This angle represents the difference between SNA and SNB angles and indicates the magnitude of skeletal jaw discrepancy. Normal value is 2° (S.D. = 2°) (Steiner, 1960). (Figure 3.15).

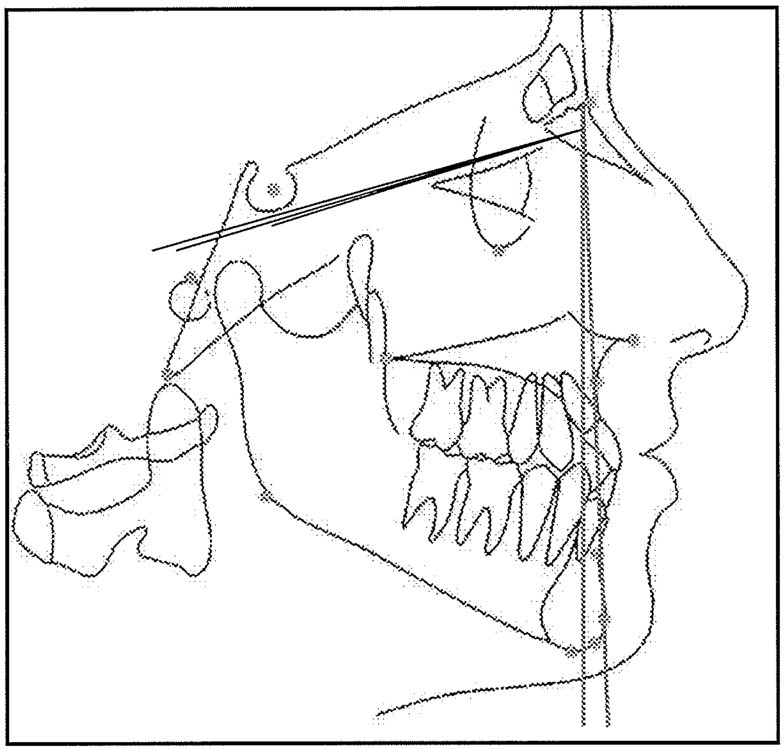

Figure 3.15 ANB angle

CHAPTER 4

RESULTS

CHAPTER 4

RESULTS

4.1 CALIBRATION

The reproducibility of measurements was assessed on 11.7 % of the studied sample (selected at random) by a paired *t*-test on the means of individual variables obtained from manually retraced lateral cephalograms and redigitized measurements. The measurement errors were found to be well below one degree for angular measurements, one millimeter for linear measurements, and one percent for ratio measurements. The results of the paired *t*-tests are given in Tables 4.1.

Table 4.1 Measurement error for 11.7% manually retraced and redigitized cephalograms for all the variables.

Variable	Retraced & Redigitized		
	$\|x\|$	SD	*t*-test
Facial axis (Ba-N/PT-Gn)	0.02	1.93	NS
LAFH (ANS-Xi-PM)	0.09	0.27	NS
MP-FH	0.03	0.54	NS
PPA (PP-FH)	0.09	0.48	NS
Y-axis	0.15	1.43	NS
PP-MP	0.03	0.37	NS
S-Go/N-Me	0.25	1.19	NS
Maxillary Depth	0.31	1.11	NS
Facial Convexity	0.02	0.37	NS
SNA	0.04	0.07	NS
SNB	0.08	0.42	NS
ANB	0.04	0.19	NS

$|x|$ - Mean change; SD – Standart deviation; S – Significant difference at $p \leq 0.05$ level; NS – No significant difference at $p > 0.05$ level

4.2 DESCRIPTION OF THE SAMPLES

Table 4.2: Sample characteristics

	Group 1 RPE Group (n = 17)	Group 2 Control Group (n = 18)
Gender		
Male	7	6
Female	10	12
Treatment Duration		
Mean	2.2 years	1.4 years
Range	1.3-4.5 years	1.8-5.3 years

Post-retention records (T_3) were taken at an average of 6.6 years following post-treatment records (range: 3.6 years to 14.1 years) for the RPE group and at 12.3 years following post-treatment records (range: 4.9 years to 18.7 years) for the control group. Means and ranges for patient ages are indicated in Table 5.3.

Table 4.3: Mean and range of patient ages at T_1, T_2, T_3

	RPE group		Control group	
	Mean (years)	Range (years)	Mean (years)	Range (years)
Age (yrs-mos)				
Pre-treatment (T_1)	12-4	9-3 to 13-6	11-10	8-11 to 14-5
Post-treatment (T_2)	14-7	12-8 to 16-3	13-4	13-5 to 16-4
Post-retention (T_3)	21-2	18-3 to 29-3	25-7	19-5 to 33-8

The average ages for each group taken at T_1, T_2 and T_3 were comparable (Table 4.3), except at T_3 where the mean age was significantly higher in the control group than the RPE group (mean difference in age = 4 years, 6months, $p<0.05$). Both the RPE and control groups had the same proportions of male and female patients in each sample, as verified by Chi-square testing.

The distribution of Angle classification for each group at the start of treatment was similar. The distribution of patients in mixed and permanent dentitions in each sample was also similar (approximately 2/3 in permanent dentition, 1/3 in mixed dentition) (Table 4.4)

Table 4.4 Distribution of Angle Classification and stage of dental development in each sample at T_1

# of patients	Angle's Classification			Dental Development	
	Class I	Class II	Class III	Permanent Dentition	Mixed Dentition
RPE n=17	8 (47%)	6 (35%)	3 (18%)	11 (64.7%)	6 (35.3%)
Control n=18	8 (44%)	8 (44%)	2 (12%)	12 (66.7%)	6 (33.3%)

The control group and RPE group generally had similar characteristics for the twelve cephalometric measurements at initial presentation. The descriptive statistics mean values for all the studied variables and results of ANOVA are given in Table 5.5. There were statistically significant differences facial axis, lower face height, Y-axis and PFH:AFH values between the RPE group and the control group ($p<0.05$). Facial axis values and PFH:AFH were, respectively 2.4 degrees and 2.15 % higher in the control group respectively ($p<0.01$), whereas lower face height and Y-axis, on average, were respectively 1.3 and 1.56 degrees lower ($p<0.05$).

Table 4.5 Comparison of cephalometric measures at T_1 between RPE and control groups

Variable	RPE Group			Control Group			p-value (ANOVA)
	Mean	**S.D.**	**S.E.**	**Mean**	**S.D.**	**S.E.**	
Facial axis	87.88	3.51	0.50	90.23	3.63	0.48	S (p=0.001)
Lower face height	42.16	2.86	0.43	40.86	3.27	0.42	S (p=0.03)
MPA	25.32	6.14	1.09	23.24	5.28	1.06	N/S (p=0.18)
PPA	-1.98	3.48	0.79	-1.81	4.87	0.77	N/S (p=0.87)
Y-axis	66.46	3.68	0.32	64.90	2.89	0.31	S (p<0.01)
PP-MP	26.12	4.04	0.55	25.04	4.67	0.53	N/S (p=0.163)
S-Go/N-Me	63.82	3.74	0.57	65.97	3.94	0.55	S (p<0.01)
Maxillary depth	90.16	2.92	0.74	90.10	4.51	0.72	N/S (p=0.94)
Facial convexity	1.41	2.96	0.37	1.73	2.34	0.36	N/S (p=0.52)
SNA	80.83	3.41	0.40	81.69	3.09	0.39	N/S (p=0.13)
SNB	78.18	3.91	0.37	78.94	3.26	0.36	N/S (p=0.14)
ANB	2.67	2.36	0.34	2.73	2.2	0.33	N/S (p=0.90)

SD – Standard Deviation, SE – Standard Error

The mean changes to the parameters measured over time for both groups as measured at T_1, T_2 and T_3 are illustrated in Tables 4.6 and 4.7. The significant changes to each parameter within each treatment group will be discussed in more detail in the upcoming section when comparisons between the groups are made.

Table 4.6 **Descriptive statistics and results of ANOVA test for incremental changes in various parameters evaluated during the three time-points as measured for the RPE group.**

Variable	Normal		T_1		T_2		T_3		ANOVA		
	x	SD	x	SD	x	SD	x	SD	T_1-T_2	T_2-T_3	T_1-T_3
Facial axis	90	3.5	87.88	3.51	86.81	3.43	87.28	3.56	NS	NS	NS
LFH	46	3	42.16	2.86	44.08	3.64	44.04	3.80	S	NS	S
MPA	26	4.5	25.32	6.14	25.08	5.25	24.08	6.61	NS	NS	NS
PPA	1	3.5	-1.98	3.48	-0.36	3.95	-0.89	4.91	NS	NS	NS
Y-axis	66	5	66.46	3.68	66.53	4.08	66.79	4.02	NS	NS	NS
PP-MP	28	6	26.12	4.04	25.44	4.19	24.96	4.93	NS	NS	NS
PFH:AFH (%)	65	4	63.82	3.74	65.2	4.51	65.69	4.19	NS	NS	S
FH-NA	90	3	90.16	2.92	88.22	4.63	88.88	4.63	NS	NS	NS
A-NPo (mm)	2	2	1.41	2.96	-0.67	2.41	-0.48	3.66	S	NS	S
SNA	82	2	80.83	3.41	80.14	3.34	80.69	3.40	NS	NS	NS
SNB	78	2	78.18	3.91	79.06	4.15	79.3	3.79	NS	NS	S
ANB	2	2	2.67	2.36	1.06	1.78	1.41	2.67	S	NS	S

x – Mean; SD – Standard deviation; S – Significant change; NS – Not significant change.

Table 4.7 **Descriptive statistics and results of ANOVA test for incremental changes in various parameters evaluated during the three time-points as measured for the control group.**

Variable	Normal		T_1		T_2		T_3		ANOVA		
	x	SD	x	SD	x	SD	x	SD	T_1-T_2	T_2-T_3	T_1-T_3
Facial axis	90	3.5	90.28	3.63	89.23	4.29	90.14	3.85	NS	NS	NS
LFH	46	3	40.86	3.27	42.32	3.68	42.29	4.31	S	NS	S
MPA	26	4.5	23.24	5.29	23.39	5.25	22.06	8.76	NS	NS	NS
PPA	1	3.5	-1.81	4.87	-0.57	3.73	-0.64	4.03	NS	NS	NS
Y-axis	66	5	64.91	2.89	65.98	3.41	65.62	3.73	S	NS	NS
PP-MP	28	6	25.04	4.67	23.94	5.56	22.68	6.61	NS	NS	S
PFH:AFH (%)	65	4	65.97	3.94	66.15	4.22	68.74	6.36	NS	S	S
FH-NA	90	3	90.09	4.51	89.05	3.84	88.19	4.06	NS	NS	NS
A-NPo (mm)	2	2	1.73	2.34	0.05	2.21	-0.98	2.24	NS	NS	S
SNA	82	2	81.69	3.09	80.48	3.18	80.50	3.31	S	NS	S
SNB	78	2	78.94	3.26	78.63	3.01	79.29	3.39	NS	NS	NS
ANB	2	2	2.73	2.17	1.84	1.67	1.22	1.45	NS	NS	S

x – Mean; SD – Standard deviation; S – Significant change; NS – Not significant change.

4.3 CHANGES IN CEPHALOMETRIC MEASUREMENTS

In Tables 4.8-4.19 the mean results for male and female subjects in each group are given for information only, since sample sizes of each gender group are too small to draw meaningful conclusions.

4.3.1 VARIABLES MEASURING VERTICAL SKELETAL PROPORTIONS

4.3.1.1 FACIAL AXIS (Ba-N/PT-Gn)

There were no statistically significant ($p>0.05$) or clinically important changes to the facial axis parameter between T_1, T_2 and T_3 within each group (Tables 4.6 and 4.7). The mean facial axis value in the control group was 2.4° higher than in the RPE group at T_1 This difference remained consistent between the groups at T_2 (2.63°) and T_3 (2.86°) and was statistically significant at T_1, T_2 and T_3 ($p<0.05$) as illustrated in Table 4.8.

Table 4.8 Results of *facial axis* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
Facial axis/T_1	**87.88**		**90.28**		**P=0.001**	
	87.85	87.91	90.46	89.92		
Facial axis/T_2	**86.61**		**89.24**		**P<0.001**	
	87.79	85.22	88.69	90.33		
Facial axis/T_3	**87.28**		**90.14**		**P<0.001**	
	87.27	87.30	89.81	90.82		

4.3.1.2 LOWER ANTERIOR FACIAL HEIGHT (ANS-Xi-PM)

The RPE group showed higher lower facial height values than the control group at T_1, T_2 and T_3 ($p<0.05$) but although this was statistically highly significant, it may not be clinically important since the difference was less than 2° at each time-point (Table 4.9). Despite this difference between the groups, changes to lower facial height values behaved identically within each group over time: showing a statistically significant increase between T_1 and T_2 ($p< 0.05$) and remaining unchanged between T_2 and T_3($p<0.05$)(Tables 4.6 and 4.7). The increase between T_1 and T_2 for each group was negligible (1.93° for the RPE group, 1.46° for the control group) ($p>0.05$).

Table 4.9 Results of *lower anterior facial height* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
LFH/T_1	**42.16**		**40.86**		**P<0.05**	
	41.68	42.84	40.34	41.88		
LFH/T_2	**44.09**		**42.32**		**P<0.05**	
	43.63	44.88	42.58	41.78		
LFH/T_3	**44.04**		**42.29**		**P=0.05**	
	43.12	45.36	42.31	42.27		

4.3.1.3 MANDIBULAR PLANE ANGLE (MPA)

This parameter showed no significant trends within either group and no significant differences were observed between the RPE and control groups at T_1, T_2 or T_3 ($p>0.05$) (Table 4.10).

Table 4.10 Results of *mandibular plane angle* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
MPA/T_1	**25.32**		**23.24**		**P=0.18**	
	25.85	24.56	22.24	25.23		
MPA/T_2	**24.80**		**23.39**		**P=0.39**	
	23.98	27.06	23.47	23.23		
MPA/T_3	**24.08**		**22.06**		**P=0.19**	
	23.80	24.47	24.14	17.9		

4.3.1.4 PALATAL PLANE ANGLE (PPA)

Despite a slight increase in this value between T_1 and T_2 for both groups, none of the measurements were statistically different and no significant trends was observed (Tables 4.6 and 4.7). There were no statistically significant differences between the groups ($p>0.05$) (Table 4.11)

Table 4.11 Results of *palatal plane angle* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
PPA/T_1	**-1.98**		**-1.81**		**P=0.87**	
	-2.21	-1.66	-2.31	-0.8		
PPA/T_2	**-0.52**		**-0.57**		**P=0.96**	
	-1.17	1.1	-0.68	-0.35		
PPA/T_3	**-0.89**		**-0.64**		**P=0.82**	
	-1.51	-0.01	0.61	-3.13		

***Negative sign denotes counterclockwise rotation of the palatal plane with respect to FH.**

4.3.1.5 Y-AXIS

There was no statistically significant pattern of change in the value of this parameter in both groups. The control group showed a statistically significant increase in the y-axis value between T_1 and T_2 equal to 1.07° ($p < 0.05$) (Table 4.7). When comparing both groups, the RPE group showed significantly increased Y-axis means at T_1 and T_3 when compared to the control group ($p<0.05$). These larger values were statistically significant but not clinically important (less than 1.5° difference). The difference between the control group and the RPE group at T_1 and T_3 were statistically highly significant for T_1 ($p<0.001$) and significant for T_3. (Table 4.12).

Table 4.12 Results of *y-axis* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
Y-axis/T_1	**66.46**		**64.91**		**P<0.001**	
	66.37	66.59	64.94	64.83		
Y-axis/T_2	**66.53**		**65.98**		**P=0.256**	
	66.39	66.78	65.93	66.07		
Y-axis/T_3	**66.79**		**65.62**		**P<0.05**	
	67.33	66.01	65.91	65.03		

4.3.1.6 PALATAL/MANDIBULAR PLANE ANGLE (PP-MP)

There was a statistically significant trend in that PP-MP decreased with time for both groups (p=0.0172). This decrease, however, is negligible (less than 1° between each timepoint). This parameter showed no statistically significant changes between T_1, T_2 and T_3 in the RPE group ($p > 0.05$) (Table 4.6). The control group had a significantly lesser mean PP-MP value at T_1 when compared to T3 ($p<0.01$) (Table 4.7).

Statistically significant differences between the groups were observed at T_3 ($p<0.05$), with the RPE group showing 2.28° greater average PP-MP value than the control group (Table 4.13).

Table 4.13 Results of *PP-MP* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
PP-MP/T_1	**26.12**		**25.04**		**P=0.163**	
	26.04	26.24	24.54	26.05		
PP-MP/T_2	**25.47**		**23.94**		**P=0.07**	
	25.16	25.96	24.13	23.58		
PP-MP/T_3	**24.96**		**22.68**		**P<0.05**	
	25.29	24.49	23.52	21.00		

4.3.1.7 POSTERIOR TO ANTERIOR FACE HEIGHT (S-GO/N-ME)

While this value showed statistically significant increases between T_1, T_2 and T_3 for both groups ($p<0.001$ the increases were not statistically different between the RPE group and the control group ($p>0.05$).

For the RPE group, this value increased by 1.39 % between T_1 and T_2 and only 0.48 % between T_2 and T_3 (Table 4.6). In the control group, there was a negligible increase (0.2%) between T_1 and T_2 ($p>0.05$) and a statistically significant increase between T_2 and T_3 of 2.7% ($p<0.01$) (Table 4.7).

Statistically significant and potentially clinically important differences between the groups were observed with the RPE group showing 2.15% and 3% smaller AFH:PFH mean value at T_1 and T_3 respectively (Table 4.14).

Table 4.14 Results of *posterior to anterior face height* (%) measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
PFH:AFH/T_1	**63.82**		**65.97**		**P<0.05**	
	63.87	63.74	65.6	66.72		
PFH:AFH/T_2	**65.21**		**66.15**		**P=0.276**	
	65.40	64.84	65.63	67.18		
PFH:AFH/T_3	**65.69**		**68.74**		**P<0.001**	
	64.23	67.79	66.59	73.03		

4.3.2 VARIABLES MEASURING ANTEROPOSTERIOR SKELETAL PROPORTIONS

4.3.2.1 MAXILLARY DEPTH (FH-NA)

This value showed no statistically significant changes between T_1, T_2 and T_3 for both groups ($p>0.05$). There were no statistically significant differences between the groups and no specific pattern was found in the changes (Tables 4.6, 4.7 and 4.15).

Table 4.15 Results of *maxillary depth* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
FH-NA/T_1	**90.16**		**90.09**		**P=0.94**	
	90.95	89.04	91.03	88.20		
FH-NA/T_2	**88.65**		**89.05**		**P=0.72**	
	89.73	85.50	88.92	89.32		
FH-NA/T_3	**88.88**		**88.19**		**P=0.50**	
	90.29	86.87	87.58	89.42		
P-VALUE ANOVA	**P>0.05**		**P>0.05**			

4.3.2.2 FACIAL CONVEXITY (A-NPo)

A statistically significant trend was observed in both groups with facial convexity values showing decreases between T_1, T_2 and T_3 ($p<0.0001$). Mean facial convexity values decreased significantly by an identical increment (1.68°) between T_1 and T_2 for both RPE and control groups (Tables 4.6 and 4.7). Moreover, there was a statistically significant decrease of 1.03° between T_2 and T_3 ($p<0.05$) in mean facial convexity in the control group. No significant differences between the groups were found at T_1, T_2 or T_3 ($p>0.05$). (Table 4.16).

Table 4.16 Results of *facial convexity (mm)* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
A-NPo/T_1	**1.41**		**1.73**		**P=0.52**	
	2.10	0.41	1.43	2.33		
A-NPo/T_2	**-0.27**		**0.05**		**P=0.56**	
	-0.22	-1.48	-0.29	0.73		
A-NPo/T_3	**-0.48**		**-0.98**		**P=0.33**	
	0.72	-2.19	-0.78	-1.38		
P-VALUE ANOVA	**P<0.0001**		**P<0.0001**			

5.3.2.3 SNA ANGLE (SN-NA)

SNA mean values showed no significant changes between T_1, T_2 and T_3 in the RPE group ($p>0.05$) (Table 4.6). There was a statistically ($p<0.05$), yet not clinically important decrease between T_1 and T_2 in the control group: a difference of 1.21° (Table 4.7). No significant trends were observed for this parameter in either group.

There were no statistically significant differences ($p>0.05$) between the two groups in this measurement at any time-point (Table 4.17).

Table 4.17 Results of *SNA* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
SNA/T_1	**80.83**		**81.69**		**P=0.13**	
	81.62	79.70	81.32	82.45		
SNA/T_2	**80.47**		**80.48**		**P=0.98**	
	80.70	79.12	80.00	81.45		
SNA/T_3	**80.69**		**80.50**		**P=0.73**	
	80.82	80.51	80.07	81.37		

4.3.2.4 SNB ANGLE (SN-NB)

There were no significant trends in mean SNB values for both groups. The control group showed no significant changes in SNB measurements between T_1, T_2 and T_3 ($p>0.05$). A statistically significant increase ($p<0.05$) was observed between T_1 and T_3 in the RPE group, but this was negligible clinically (1.13°) (Table 4.6). There were no statistically significant differences between the groups ($p>0.05$) (Table 4.18).

Table 4.18 Results of *SNB* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
SNB/T_1	**78.17**		**78.94**		**P=0.14**	
	78.45	77.79	78.96	78.92		
SNB/T_2	**79.09**		**78.63**		**P=0.40**	
	79.56	78.24	78.41	79.05		
SNB/T_3	**79.30**		**79.29**		**P=0.98**	
	78.83	79.97	78.75	80.37		

4.3.2.5 ANB ANGLE (NA-NB)

This angle decreased 1.28° between T_1 and T_2 ($p<0.05$) but showed no significant changes between T_2 and T_3 ($p>0.05$) for the RPE group (Table 4.6). Statistically significant differences were found between T1 and T3 for both groups with ANB mean values decreasing by 1.26° in the RPE group ($p<0.05$), and by 1.51° in the control group ($p<0.01$) with no significant changes seen between T_2 and T_3 ($p>0.05$). No statistically significant differences between the groups were found at any time-point ($p>0.05$). (Table 4.19).

Table 4.19 Results of *ANB* measurements within and between RPE and control groups at T_1, T_2, T_3

Variable	RPE		CONTROL		P-VALUE ANOVA	
	F	M	F	M	F	M
ANB/T_1	**2.67**		**2.73**		**P=0.90**	
	3.19	1.93	2.35	3.48		
ANB/T_2	**1.39**		**1.84**		**P=0.38**	
	1.17	0.88	1.57	2.40		
ANB/T_3	**1.41**		**1.22**		**P=0.69**	
	1.99	0.57	1.32	1.02		

CHAPTER 5

DISCUSSION

CHAPTER 5

DISCUSSION

5.1 OVERVIEW AND GENERAL TRENDS

Transverse, vertical, and anteroposterior skeletal malrelationships often coexist in a single patient. A clinician who wishes to correct a transverse problem in such a patient and who bases treatment decisions on the existing literature might initiate unnecessary treatment (e.g. vertical-pull chincup) to control perceived deleterious treatment effects, such as bite opening in vertically growing patients. Alternatively this may cause failure to render appropriate treatment, such as rapid maxillary expansion, for fear of "opening the bite".

The results of this study do not support the claim that bite opening (i.e. increase in facial axis or lower anterior facial height or opening of the mandibular plane angle) occurs in patients treated with rapid maxillary expansion. Overall, no statistically significant differences were found among the control group and RME group studied for any of the 12 cephalometric variables sensitive to anteroposterior and vertical skeletal changes. Despite the RME group showing statistically significant lower values for facial axis and PFH:AFH and higher values for Y-axis and LAFH than the control group at the start of treatment, these differences were maintained, or became negligible following standard edgewise therapy and during long-term follow-up.

Both groups tended to respond in a similar fashion to treatment, with no significant differences observed which may have potentially been induced by RME. Therefore, no significant long-term alterations to vertical and anteroposterior positions of the maxilla and mandible were found to be affected by rapid maxillary expansion treatment.

5.2 EFFECT OF RME ON VERTICAL SKELETAL PARAMETERS

5.2.1 FACIAL AXIS AND LOWER ANTERIOR FACIAL HEIGHT

According to Ricketts (1981) the facial axis and lower anterior facial height parameters remain constant with time and are not influenced by natural growth. These findings have been confirmed by several investigators (Kocadereli et al., 1999; Morra et al., 2005). Hence any changes to these parameters would indicate changes to the skeletal vertical dimension induced by orthodontic mechanotherapy, and not growth.

Most earlier investigations have reported significant changes to vertical parameters induced with rapid maxillary expansion (Davis and Kronman 1969; Haas 1970; Wertz 1970; Bascificti and Karaman, 2002; Chung and Font, 2004). However, these studies were carried out on completion of the opening of the midpalatal suture, or no later than 3 months after passive retention with the rapid maxillary device (Wertz, 1970; Chung and Font, 2004). According to these authors, the facial axis opens to yield an increase in vertical dimension shortly after finalizing RME. However, in this study, the facial axis, on average, was found not to vary significantly, in either treatment groups.

This means that the direction of growth stays constant, as reflected by comparing radiographs before and after full orthodontic treatment both in the immediate and long-term follow-up phases. This trend is in agreement with Velasquez *et al.*, 1996 who found no changes to facial axis following RME therapy and comprehensive orthodontic treatment, but did not examine long-term follow up data.

While our RPE sample did demonstrate a statistically significant increase in lower anterior facial height by 1.93° after treatment with RPE and full fixed orthodontics, this was comparable to changes found in the control group following active orthodontic treatment where lower anterior facial height values increased, on average, by 1.46°. This value should stay constant with normal growth and this observed increase could be attributed to extrusive mechanics used in the Alexander philosophy of treatment. Mechanics employed for both groups included intermaxillary elastics, lip bumper therapy and cervical-pull headgear (Table 5.1)

Table 5.1 Treatment mechanics employed for RPE group and control group between T_1 and T_2

Number of patients	Cervical Headgear	Lip Bumper	Face-mask	Intermaxillary elastics
Control group (N=18)	14	1	1	18
RPE group (N=17)	7	9	2	17

However, the increase to the mean lower anterior facial height value, although significant statistically, is small enough to be considered clinically unimportant. This value remained constant and showed no statistically significant changes in the long-term follow up period (between T_2 and T_3) for both treatment groups indicating that any changes observed between T_1 and T_2 were a result of orthodontic treatment which may have rendered permanent long-term vertical skeletal changes.

5.2.2 MANDIBULAR PLANE ANGLE, Y-AXIS

According to Ricketts, the norm for the mandibular plane inclination to FH is 26° +/- 4° (mean +/- sd) for 9-year-old patients, and decreases 1° every 3 years. Thus growth leads to mandibular anterorotation, due to greater growth posteriorly than in the anterior part of the mandible. The mandibular plane angle therefore becomes more horizontal. Authors who have investigated mandibular changes immediately after RME (Davis and Kronman 1969; Haas 1970; Wertz 1970; Silva Filfo 1991; Bascificti and Karaman, 2002; Chung and Font, 2004) however, describe mandibular posterorotation.

Three months after retention, Wertz (1970) described a systematic recovery of the mandibular posterorotation caused by rapid maxillary expansion. Bishara and Staley (1987), reported a partial recovery of this treatment-induced change during retention; similarly, they observed a 10-15% recovery of the skeletal changes in general. It thus seems that if this treatment change begins to recover or relapse while the RME appliance is still in place, posterorotation fully recovers after removal of the RME appliance. As Velasquez *et al.,* (1996) documented, the mandibular angle decreases following removal of RME and following continuing full-fixed orthodontic treatment (for an average of three years), becoming more horizontal than at the start of treatment. This pattern of mandibular movement was confirmed by Chang *et al.*, (1997) who found a tendency towards bite closure in subjects treated with RME and standard edgewise therapy six years following treatment. However, the long-term changes in mandibular plane angle (0.85° decrease) reported by these authors may be of little, if any clinical importance. It is reasonable to assume that the leveling and alignment of the arches during the full fixed orthodontic phase assists in bite closure, which in addition to posterior ramal growth, produces the net effect of apparent normalization.

Our long-term follow up data indicate no changes to the mandibular plane angle despite slight decreases with time which are not statistically significant ($p>0.05$). This is in agreement with Garib et al (2001) who found no significant changes for mandibular plane angle between the end of active treatment and the long-term follow-up. Similar trends were observed for changes in Y-axis values, with no significant differences among the groups. While the control group averaged a slight increase of 1.07° in Y-axis values between T_1 and T_2 which was found to be statistically significant ($p<0.05$), and although this change was greater than noted in the RME group, this difference may not be of clinical importance due to its small magnitude. Considering the findings of Morra *et al.*, (2005) in an untreated sample, this small change in Y-axis can be attributed to treatment-induced changes. Interestingly, rapid maxillary expansion produced a lesser effect than the control group.

5.2.3 PFH:AFH

Also of interest, the PFH:AFH ratio increased between T_1 and T_2 for the RPE group by 1.4 % ($p<0.05$) but only 0.2% in the control group. Possible explanations could be longer treatment times for the RPE group coinciding with a rate of increased posterior face height growth. However, on average, treatment time for the RPE group was only 9.6 months longer that the control group which may be insignificant in producing changes that can be attributed to growth alone. During long-term follow-up between T_2 and T_3, the control group had a significant increase of 2.7% in PFH:AFH compared to 0.2% in the RPE group. This may be explained by the fact that, on average, post-retention records were taken 4 years, 5 months later for the control group which may have allowed for greater changes in posterior face heights due to an increased duration of normal growth.

5.2.4 PALATAL PLANE

The palatal plane inclination showed no significant changes, on average, between groups in the present study. These results do not agree with the findings of Garib *et al.*, (2001) who found statistically significant long-term differences (greater than five year follow-up) in the SN-PP (0.8°) angles when comparing their treatment group with the control group.

Most authors have found the palatal plane to descend under the effect of RME. This descent is either parallel to its initial position (Wertz, 1970) or the result of posterior rotation (Wertz 1970; Sarver and Johnston, 1989; de Silva Filho 1991). These authors also described anterior rotations in a smaller percentage of patients. In our study no significant changes were observed: i.e., although on average the palatal plane changed its inclination in less than 1° on anterior rotation between T_1 and T_2 for both groups, followed by slight posterior rotation (less than 0.25°) between T_2 and T_3, this observation cannot be accepted as statistically or clinically important.

5.3 EFFECT OF RME ON ANTEROPOSTERIOR SKELETAL PARAMETERS

5.3.1 MAXILLARY DEPTH , SNA

In this investigation, maxillary depth underwent no significant changes in either group as with normal growth. Mean SNA angle values showed similar trends, despite the slight decrease of SNA values in the control group (1.21°) between T_1 and T_2 which could have been attributed to headgear therapy. As demonstrated in the randomized clinical trials carried out at University of Carolina, headgear reduces the prominence of point A, decreases SNA and restrains maxillary growth (Proffit, 2003).

However, in general no significant differences were found between both groups. Thus no long-term changes seem to have occurred in the anteroposterior position of the upper jaw after RPE and orthodontic treatment. This is in agreement with Lagravere *et al.*, (2005) who also showed that the maxilla of treated groups show no statistical or clinically significant differences between treatment and control groups long-term (> 5 years follow-up).

Previous authors have reported a slight maxillary displacement forward (Haas, 1970, 1980; Wertz 1970); nevertheless, in some cases the maxilla has been reported to recede. However, most of these studies quantified the amount point A came forward, and none compared that amount with the normative data. According to Bishara and Staley (1987) the final position of the upper jaw is unpredictable. Wertz (1970) described a return of point A to its initial position in 50% of cases 3 months following retention.

Since no long-term anteroposterior changes were noted in our RME sample, is suggests that, if changes did happen after RME, they disappeared later on as the maxilla continued to return to its initial position after rapid expansion.

5.3.2 FACIAL CONVEXITY

Facial convexity decreased significantly by 1.68° for both groups between T_1 and T_2 and slightly more for the control group in the long term (1.03° versus 0.21° for the RME group). The latter discrepancy may be due to longer follow-up times at T_3 in the control group, leading to decreased convexity as a result of continued growth. Decrease in convexity with continued growth has been attributed to physiologic advance in the mandible, which inclines the nasion-pogonion (facial plane) forward, thereby shortening the distance between the latter and point A. Several authors described an advance of point A with RME, measured when concluding suture opening (Wertz 1970; Haas 1975; Sarver and Johnston 1989). Results of this study regarding this variable differ from those of earlier studies but are in agreement with findings of Velasquez *et al.*, (1996) and Chang *et al.*, (1997) which found no significant changes to the maxilla and A point during long-term follow-up treatment with RPE, suggesting a normalization of the position of the maxilla and A point following fixed orthodontic appliances and continued growth.

5.3.3 SNB ANGLE

Most authors agree that mandibular backward displacement is the result of the posterorotation produced by rapid expansion, with a retrusion of point B. Only Wertz (1970), Velasquez *et al.*, (1996) and Chang *et al.*, (1997) described a forward displacement of point B following treatment with RME. Wertz claimed that the mandible can be propelled or retruded with RME, exhibiting a routine return to the initial position during retention. The results of this investigation found no significant trends or changes in SNB between the groups or within the groups, despite a 1.13° increase between T_1 and T_3 in the RPE group which is probably not of clinical importance.

5.3.4 ANB ANGLE

ANB angle showed a decrease in value for both groups which is to be expected with Class II growth modification therapy, Class II elastic effects and continued differential forward growth of the mandible with respect to the maxilla. It would be expected, that if one were to assume that A point comes forward and B point retrudes with RME therapy, as has been widely reported in the literature, then this value would increase. No significant differences were found between the groups, hence RME therapy did not affect the long-term anteroposterior relationship of the maxilla to the mandible. This is in agreement with other investigations which found no long-term effect of RME on the anteroposterior dimensions of the maxilla and mandible (Chang *et al.*, 1997; Lagravere et al., 2005). These studies found that following post-treatment and post-retention the maxilla and mandible of treated groups presented similar behavior to those of the control group, i.e. the differences presented no statistical or clinical significance.

5.4 FACIAL GROWTH TYPES AND RAPID MAXILLARY EXPANSION

A popular conjecture that has been posed is that patients with high mandibular plane angles tend to react more negatively to RME therapy by having greater bite opening than patients with low angles. Chang *et al.*, (1997) tested this idea and found no relationship between a high pre-treatment MPA (defined as MPA> 27°) and a tendency to increase MPA following RME treatment and standard edgewise mechanics. They found that 76.5% of patients with high MPA showed bite closure from pretreatment (T1) to 6 years post-treatment (T3); whereas only 37.5% of the patients with low MPA showed bite closure over the same observation period. Velasquez *et al.*, (1996) found that patients with dolicofacial patterns (as defined by Ricketts) showed that facial axis and mandibular plane angle values did not show statistically significant differences after treatment with RME and full fixed appliances when compared to brachyfacial and mesofacial types treated with the same mechanics.

To test whether vertical facial type had any influence on the changes in the skeletal parameters measured between the two groups, subjects were classified according to brachyfacial, mesofacial and dolicofacial types as defined by Meldrum *et al.*, 2003. Out of the 35 subjects, only 7 exhibited "extreme" growth patterns: the control group with four (3 brachyfacial and one dolicofacial type) and the RPE group with 3 (2 dolicofacial and one brachyfacial type). To remove the effect of extreme growth patterns, statistical analysis was carried out on mesofacial subjects only (N=28). The twelve skeletal parameters examined showed trends and differences similar to those observed in the original sample (N=35). No significant differences in any of the parameters examined were observed between or within the control and RME groups.

5.5 NULL HYPOTHESIS DEDUCTIONS

Null Hypothesis # 1: Rapid maxillary expansion treatment results in no long-term vertical and anteroposterior skeletal changes.

This statement was **accepted** as the only statistically significant changes observed in the post-treatment period were those expected from normal growth.

Null Hypothesis # 2: There is no difference in skeletal and anteroposterior vertical relationships between subjects treated with rapid maxillary expansion and subjects treated without rapid palatal expansion.

This statement was **accepted** as no significant vertical or anteroposterior facial skeletal differences were found between the two treatment groups that could be attributed to rapid maxillary expansion.

CHAPTER 6

CONCLUSIONS

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6.1 LIMITATIONS OF THE STUDY

Potential limitations of the present study need to be discussed in order to provide direction for the future research in this area, as well as put our findings into a better, unbiased perspective.

One limitation of the current study was the size of the sample. It was decided to increase the strength of the study by using only longitudinal data and by applying very stringent inclusion criteria. Accordingly, the control group had only 18 subjects, and the RME group only 17 subjects. Furthermore, only subjects of Northern European descent were included in this study. Therefore, due to the skeletal differences evident between racial and ethnic groups the conclusions may not be applicable to other ethnic groups.

While both groups were matched according to Angles classification, growth patterns, treatment philosophy and mechanics, drawing significant conclusions regarding side-effects induced by rapid maxillary expansion should be done with caution. Changes to vertical and anteroposterior skeletal parameters will be confounded with changes induced by other orthopaedic growth modification treatment modalities (facemasks, cervical headgear, lip-bumpers). The orthodontic literature is replete with temporary and permanent skeletal changes induced by these treatment modalities which may have potentially exacerbated or reversed possible skeletal alterations induced by RME. Ideally, criteria to eliminate growth modification orthopaedics in both treatment groups would have assisted in reducing the effect of this limitation. However this would be very difficult to accomplish.

The last limitation of this study is that these results cannot be applied to extreme growth patterns. Eighty percent of the subjects examined exhibited a normal or mesofacial facial growth pattern and inclusion of subjects with extreme growth patterns did not influence the findings in our study. However, the number of subjects exhibiting these extreme growth patterns was very low (n=7). Examination of different facial patterns and comparison of long-term side-effects of RME as it is related to brachyfacial-only or dolicofacial-only subjects could prove beneficial in determining whether extreme growth patterns react differently to RME therapy.

6.2 CONCLUDING REMARKS

The following conclusions can be drawn from the present study:

1. No significant vertical or anteroposterior facial skeletal differences were found between subjects receiving rapid maxillary expansion, followed by edgewise treatment and subjects treated with standard edgewise therapy alone.
2. Rapid maxillary expansion with a Hyrax-type expander does not have a significant long-term effect on vertical or anteroposterior dimensions of the face.
3. Classically described alterations, often feared by orthodontists, resulting from rapid maxillary expansion, such as increased lower facial dimension and mandibular posterorotation, seem to be compensated for, or corrected in the course of orthodontic treatment and continued growth
4. Rapid maxillary expansion is a useful treatment modality and may be used without the anecdotal fear of negative bite-opening. However, the orthodontist needs to be mindful of individual variation and the potential of extreme vertical growth patterns in clinical decision making.
5. Further research using randomized control trials and long-term prospective studies with aberrant growth patterns would be of value to determine the permanency of undesirable skeletal effects such as mandibular posterorotation and bite-opening resulting from RME therapy.

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