Skeletal and Dental Factors Affecting Overbite and Open Bite

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

MASTER OF SCIENCE

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ABSTRACT

The purpose of this study was to determine how overbite correlates to skeletal and dentoalveolar changes taking place in the craniofacial skeleton and to identify the differences in these changes between subjects with minimal overbite and deep bite. 74 subjects from the archives of the Burlington Growth Center in Toronto were studied. Medical and dental histories were analyzed along with lateral cephalograms and plaster models at 9, 12, and 20 years of age. Subjects were divided into three groups: 1)Deep overbite (n=22, OB≥4.0 mm), 2)Normal overbite (n=31, OB of 2.2-3.9 mm), and 3)Minimal overbite (n=21, OB≤2.1 mm) based on the last available plaster model (age 20 years). 28 various linear and angular measurements were derived, using the Dolphin™ software program. Comparative cephalometric data were analyzed by both univariate and multivariate techniques. In subjects with minimal and normal overbites, overbite increased from the mixed to early permanent dentition and then gradually decreased from that point into adulthood. In subjects with a deep overbite, the bite continued to increase over time. These changes in overbite over time were not statistically significant. Based on the overbite and other skeletal and dentoalveolar parameters, it is evident that overbite changes cannot be accurately predicted at age 9 and/or 12 years, due to incredible individual variability.

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INTRODUCTION

1.1 FOREWORD

Overbite is of critical importance in orthodontic diagnosis and treatment planning and it strongly affects the type of treatment required. It is often used as a criterion for judging the success of orthodontic treatment and is considered in most malocclusion assessment indices.

To treat overbite problems successfully, clinicians should have a good understanding of the etiological factors that lead to the development of abnormal overbite. In order to successfully diagnose and treat each patient, growth processes that are associated with this vertical dimension must be evaluated critically. The potential problem in evaluation of overbite relapse is the clinician's inability to determine whether the changes occurred primarily as the result of relapse of the orthodontic treatment or as part of normal growth and development.

Determination of the relationships between overbite and other vertical skeletal and dentoalveolar parameters may help clinicians resolve many treatment dilemmas, such as the degree of ideal post-treatment overbite, overtreatment and retention protocols.

The role of soft tissues (lips, tongue, facial musculature) is another very important aspect; however, it is not fully understood and very difficult to evaluate.

1.2 SIGNIFICANCE OF THE PROBLEM

One of the troublesome problems confronting the orthodontist is control of the anterior overbite. The question of interest to the practicing orthodontist is the potential for overbite to self-correct without treatment, or whether minimal overbites have a better probability to self correct than severe overbites. It is also important for planning the retention phase and formulating decisions to overtreat in order to account for potential relapse. The relationships between growth of different parts of the face and overbite have been studied extensively. The results, however, are controversial and inconclusive. Richardson (1969) attributed this controversy to differences in age and gender, the small range of overbite reported in the literature, and the possibility that all open bites or deep overbites are not uniform with the respect to etiologic factors. Popovich (1955) added additional reasons including small sample size, varying malocclusions, age limits of the samples, and varying techniques used (e.g. cephalometrics vs. plaster model studies). Methodological design of the study also plays a role. Most growth studies to date have been based on cross-sectional, longitudinal, or mixed longitudinal designs. *Cross-sectional* studies collect information on one occasion from a different sample of individuals at each point along an age scale. *Longitudinally designed* studies gather information repeatedly from the same sample of individuals over a long period during active growth; while *mixed longitudinal* studies collect data from a sample of individuals at different age levels that are followed for certain period of time, thus it is a combination of cross-sectional and longitudinal designs. Even though longitudinal study designs have some drawbacks, such as small sample size, difficulty in keeping subjects in the study, and long term data collection, it produces the most valuable clinical data.

It is generally accepted that various parts of the head grow at different rates, speeds and directions. The puzzling question is how the changes in the different skeletal and dentoalveolar parameters relate to each other and how dependent these changes are on other parameters. Controversy exists in the literature regarding the correlation of various dental and skeletal factors with respect to overbite. Bishara (1998) found that changes in the skeletal parameters correlated poorly with overbite changes, so that the latter parameter could not be predicted by skeletal growth. Bergerson (1988) similarly concluded that overbite changes are independent of skeletal growth and are more dependent on other variables (eg. specific oral and speech habits, order of exfoliation and eruption of teeth, loss of arch length as a result of extractions and/or decay, breathing habits, and heredity factors).

Richardson (1970) stated that the etiology of abnormal vertical incisor relationship is part skeletal and part dentoalveolar. Naumann (2000) found that dental changes were significantly larger than skeletal changes in the maxilla, whereas skeletal changes were larger in the mandible. It is interesting to know if normal skeletal growth always accompanies normal overbite development and if there is a possibility of predicting overbite from skeletal parameters.

Bergersen (1988) stated that overbite is the "most difficult to predict in a growing child, most difficult to correct orthodontically, and often relapses following orthodontic correction".

In the effort to answer some of the controversial questions and help clinicians predict treatment success of patients with overbite problems, this longitudinal cephalometric study was conducted.

1.3 PURPOSES OF THE STUDY

The purposes of the present study were to understand how overbite correlates with skeletal and dentoalveolar changes taking place elsewhere in the craniofacial skeleton and to identify the differences in these changes between subjects with minimal overbite and deep bite.

1.4 NULL HYPOTHESES

Null Hypothesis # 1: Subjects with vertical growth patterns develop an open bite tendency or open bite during growth.

Null Hypothesis # 2: Subjects with horizontal growth patterns develop a deep bite during growth.

Null Hypothesis # 3: Overbite development is independent of dento-alveolar influences.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 2

LITERATURE REVIEW

2.1 NORMAL GROWTH OF THE FACE IN THE VERTICAL DIMENSION AND ITS RELATIONSHIP TO CEPHALOMETRICS

A great deal of attention has been paid to craniofacial growth and developmental changes of young individuals. Reports on this subject appeared in the literature as early as the beginning of eighteenth century. Pierre Fauchard in 1728 described the development of the deciduous and permanent dentition. John Hunter (1771) in his book on the natural history of the human teeth devoted a chapter to the growth of the jaws. Robert Blake (1801), Joseph Fox (1803), and Delabarre CF (1819) all made an attempt to describe the growth process of the craniofacial skeleton.

The cephalometric technique was first described by Broadbent in 1931 and was developed as a research tool for the purpose of longitudinal study. Presently this technique is used by most orthodontists as a routine procedure before, during, and after orthodontic treatment. Cephalometrics has also yielded a great deal of valuable information in regards to the study of craniofacial growth. Discussion of overall growth processes is beyond this thesis and only a few cephalometric studies will be discussed that pertain to the topic of this thesis. Only growth studies that dealt with untreated normal growing subjects were included in this literature review.

Both skeletal and dentoalveolar growth changes have been studied extensively and have been described in the literature; however, some controversy exists. For example, Bhatia (1971), Boersma et al (1979), Bishara et al (1998), and Naumann, Behrents, & Buschang (2000) concluded that mandibular plane angle (MPA) decreases; however, Adams (1972) showed 5° clockwise rotation of the mandible between 5 and 15 years of age. Brodie (1953), on the other hand, showed that MPA either increased or remained stable between ages 8 and 17 years.

Similarly, documented changes in the palatal plane angle (PPA) are equivocal. The palatal plane angle was found to be stable by Brodie (1953) and Adams (1972) yet increases were found by Bhatia (1971), Boersma et al (1979), and Naumann, Behrents, & Buschang (2000). Brodie did mention, however, that in those cases that did exhibit change, PPA increased, with the greatest change of 5° occurring between 8 and 17 years of age.

Palatal to mandibular plane angle (PP-MP) decreased 3.1° between the ages 4 and 14 years (Bhatia, 1971).

Boersma et al (1979) also demonstrated a decrease of mandibular to occlusal plane angle (MP-OP) between 9 to 14 years of age.

Occlusal plane angle (OPA) was shown to either decrease or stay stable (Brodie, 1953). Isery & Solow (1996) found a 4.5° decrease in this angle between the ages 9 and 25 years.

Y-Axis (N-S-Gn) was found to be stable in the majority of cases (Brodie, 1953). When there was a change, it was an increase.

Lower incisor proclination (LI-MP) was found to increase by Boersma et al (1979) and Naumann, Behrents, & Buschang (2000). However, Ceylan, Baydas, & Bolukbasi (2002) found no change in this angle between the ages 10 and 14 years.

Upper incisor proclination (UI-PP) showed an increase from 6 to 12 years of age and a decrease from 12 to 14 years of age (Boersma et al, 1979). Naumann, Behrents, & Buschang (2000) and Ceylan, Baydas, & Bolukbasi (2002) also reported that the upper incisors became more upright from 10 to 14 years of age.

Brodie (1953) pointed out unpredictable upper and lower incisor angulation changes and that these teeth can become more or less proclined or remain at their original axial inclination.

Ceylan, Baydas, & Bolukbasi (2002) found an increase in interincisal angle (UI-LI) between the ages of 10 and 14 years.

Most authors agree that females complete the most of their growth earlier than males (Snodel, Nanda, & Currier, 1993; Bishara et al, 1998). Another area of agreement is considerable individual variations (Brodie, 1953; Bhatia, 1971).

2.2 WHAT IS NORMAL OVERBITE

Overbite shows considerable variation. According to Horowitz & Hixon (1966) it can range from -2 to 11 mm in the adult dentition, while Kim (1974) reported a range from -11 mm of open bite to 11 mm of positive overbite. Anterior open bite has been associated with temporomandibular diorders (TMD), reduced biting efficiency, and speech problems. Deep overbite can cause direct tissue trauma and it has been associated with a higher rate of periodontal breakdown and dental attrition (Daniels & Richmond, 2000). Normal ranges of overbite must be considered when evaluating patients before, during, or after orthodontic treatment; however, after an extensive literature review on this subject, it is difficult to reach some consensus.

Strang & Thompson (1958) and Engelman (1966) stated that the clear borderline between a normal and an abnormal degree of overbite is not clear and the normal overbite may vary depending on the person's age, their physical make-up, form and design of teeth, race, and the type of the facial skeleton. Engelman argued that the overbite should not be considered abnormal unless function is impeded, abrasion of teeth is induced, or the dental or gingival health is in danger. However, most researches do try to come up with numerical normative for the overbite.

The following ranges of overbite have been defined as “normal” in the literature:

Normal overbite ranges	Authors
15-60% of the clinical crown length of the lower incisor	Moorrees, 1959
20% of the clinical crown length of the lower incisor	Neff, 1949
Lower incisors occlude with the middle 1/3 of upper central incisors	Baume, 1950 Poulton &Aaronson, 1961
Lower incisors occlude with the incisal 1/3 of upper central incisors	Strang & Thompson, 1958
Overlap of up to ½ of the crowns of lower incisors	Foster & Day, 1974
Overlap of up to 1/3 of the crowns of lower incisors but not less than 1 mm	Daniels & Richmond, 2000
Overlap in the middle 1/3 of the crowns of lower incisors	Haynes, 1972
0-3 mm	Popovich, 1955 Brunelle, Bhat, & Lipton, 1996 Freudenthaler, Celar, & Schneider, 2000
0-4 mm	Bjork, 1953
0.5-4 mm	Kim, 1974 Beckmann et al, 1998
1-4 mm	Ceylan & Eröz, 2001
1.5-4 mm	Bjørnaas, Rygh, & Boe, 1994
2-3 mm	Ari-Demirkaya et al, 2002
2-4 mm	Kinaan, 1986 Lawton & Selwyn-Barnett, 1975
2.5-6.5 mm	Prakash & Margolis, 1952

Many authors pointed out gender differences of normal overbite. Most found that males have deeper overbites than females (Herness, Rule, & Williams, 1973; Van der Linden et al, 1979; Sinclair & Little, 1983; Naumann, Behrents, & Buschang, 2000; Ceylan, Baydas, & Bolukbasi, 2002). Moorrees (1959) and Herness, Rule, & Williams (1973) attributed this difference to longer clinical crowns in boys. However, Fleming (1961) noticed that overbite in females is deeper than in males and hypothesized that this difference is due to earlier incisors eruption in girls.

2.3 MEASUREMENT OF OVERBITE

The methods used to measure overbite have varied from clinical and dental cast analysis (Strang, 1934; Diamond, 1944; Neff, 1949; Steadman, 1949; Baume, 1950; Barrow & White, 1952; Poulton & Aaronson, 1961; Haynes, 1972; Foster & Day, 1974; Sinclair & Little, 1983; Kinaan, 1986; Helm & Petersen, 1989) to cephalometric appraisal (Wylie, 1946; Prakash & Margolis, 1952; Bjork, 1953, 1963; Sassouni & Nanda, 1964; Atherton, 1965; Richardson, 1967, 1969, 1970, 1981; Kapoor, 1968; Bhatia, 1971; Nahoum, Horowitz, & Benedicto, 1972; Kim, 1974; Bishara & Jacobsen, 1985; Bergersen, 1988; Snodell, Nanda, & Currier, 1993; Iseri & Solow, 1996; Tsang, Cheung, & Samman, 1997; Beckmann et al, 1998; Naumann, Behrents, & Buschang, 2000; Ceylan & Eroz, 2001; Ceylan, Baydas, & Bolukbasi, 2002) and a combination of both (Popovich, 1955; Fleming, 1966; Isaacson et al, 1971; Adams, 1972; Herness, Rle, & Williams, 1973; Lowe, 1980; Bishara, Peterson, & Bishara, 1984; Bishara, Treder, & Jakobsen, 1994; Bjørnaas, Rygh, & Boe, 1994; Freudenthaler, Celar, & Schneider, 2000; Baydaş et al, 2004). The lack of agreement on the choice of derived methods of measurement of overbite limits the comparison of data. Overbite can be reported in both millimeters or as a percentage. Neff

(1949) strongly suggested overbite measurement as percentage of coverage of the lower incisor by the upper central incisor. He argued that this is the only way to have an accurate representation of overbite regardless of tooth length.

The most commonly used clinical technique is to measure the degree of overbite with the periodontal probe. However, this method is not precise enough for the research purposes. Kinaan (1986) developed a new overbite gauge to use intraorally or on the plaster models. The gauge is calibrated in millimeters and consists of two L-shaped stainless steel sections. Precise overbite measurement can be performed using this gauge. The gauge did not seem to gain too much popularity. Moorrees in 1959 described the technique that is the most widely used by clinicians and researches today. He measured the distance from the incisal edge of the mandibular incisor to the pencil mark, denoting the projection of the incisal edge of maxillary central incisor. The projection was made "with a finely sharpened pencil held in such position that the upper side of the cone produced by sharpening was parallel with the occlusal plane". The same method was used by Poulton & Aaronson (1961) and Herness, Rule, & Williams (1973). A similar technique was used by Haynes (1972), except he estimated Frankfurt Horizontal as the reference plane.

Some researchers suggest measuring overbite as part of the length of the upper central incisor crown (Strang, 1934; Strang & Thompson, 1958); however, most measure it as part of length of the lower incisors.

To measure overbite on cephalograms, most researches measure the linear distance between the incisal tips of upper and lower incisors perpendicular to the reference line. Bjork (1953), Kim (1974), Lowe (1980), Beckmann et al (1998), and Ceylan & Eroz (2001) used occlusal plane as the reference line. Bjork defined occlusal plane as a tangent line from the incisal edge of the upper incisor to the disto-buccal cusp of the upper permanent first molar. Kim (1974) extended occlusal plane from the point of bisection at the incisal overlap to the mesial cusp of the upper first molar. Lowe, Beckmann et al, and Ceylan & Eroz did not specify the definition of the occlusal plane that was used in their studies. Other reference lines, such as palatal plane (Bergersen, 1988), Nasion-Sella plane (Isaacson et al, 1971), Facial plane (N-Pog) (Prakash & Margolis, 1952), and Nasion-Menton plane (Nahoum, Horowitz, & Benedicto, 1972) have been used to measure overbite cephalometrically. Bjørnaas, Rygh, & Boe (1994) measured the overbite as the distance from the incisal edge of the lower incisor to the occlusal plane.

2.4 NORMAL CHANGES IN OVERBITE

Over time overbite changes are small; however, the individual variability is great as has been pointed out by many researchers (Bjork, 1953; Fleming, 1961; Horowitz & Hixon, 1966; Herness, Rule, & Williams, 1973; Richardson & Richardson, 1993; Naumann, Behrents, & Buschang, 2000). Horowitz & Hixon (1966) pointed out that variations can be as much as 5 mm in either direction from the mean. In Bjork's study (1953) it was found that between the ages 12 and 20 years the most extreme reduction in overbite was -5.1 mm, and the greatest increase was 5.0 mm. More recently Naumann, Behrents, & Buschang, (2000) showed 2.4 mm of maximum bite opening and 5.6 mm of maximum bite deepening among the children from 10 to 15 years of age.

Differences in opinion exist in regards to normal changes in overbite over time. In general, however, most studies agree that overbite increases during the transition from mixed to permanent dentiton and then decreases from early permanent dentition to the adulthood (Bjork, 1953; Fleming, 1961; Horowitz & Hixon, 1966; Adams, 1972; Herness, Rule, & Williams, 1973; Van der Linden et al, 1979; Sinclair & Little, 1983; Bergersen, 1988; Naumann, Behrents, & Buschang, 2000; Ceylan, Baydas, & Bolukbasi, 2002). Moorrees (1959) found that overbite decreased from 10 to 11 1/3 and from 16 to 18 years of age.

Bishara et al (1998) found that the most significant increases in overbite occurred between 5 and 10 years of age in both males (x=2.1±1.2 mm) and females (x=1.4±1.7 mm). Between 10 and 15 years of age overbite didn't change in females and increased only slightly (x=0.3±1.3 mm) in males. Between 15 and 25 years of age overbite decreased in males (x=-0.4±0.7 mm) and increased in females (x=0.3±0.8 mm).

Some authors believe that proportionate to the incisor tooth size overbite remains stable after the contact between the incisal edges of lower incisors and the lingual surfaces of the upper incisors is established (Barrow & White, 1952; Moorrees, 1959).

Few studies have been undertaken to evaluate the changes in overbite among subjects with deep or open bite. In Bjork's 1953 study deep overbite cases showed a greater tendency to open than normal overbite cases, whereas individuals with the open bite showed a tendency to close. Again, individual differences were great. The range of variation in overbite was from -2.0 to 11.6 mm at age 12 years and from -4.8 to 8.2 mm at age 20 years.

Helm & Petersen (1989) clinically examined 176 untreated subjects from 13-19 to 33-39 years of age. It was observed that the deep overbites tend to increase with the advancing age and open bites tend to decrease with age. In agreement with Bjork, the authors explained the increase in deep overbite by the unstable incisor occlusion and forward rotation of the mandible.

To better understand the changes in overbite, Bishara et al (1998) divided his sample into three groups based on the magnitude of overbite in the primary dentition (group 1 – least overbite, group 2 – average overbite, and group 3 – most overbite). In 33 out of 35 cases the overbite increased from primary to mixed dentition. Following that, there was no consistent pattern in overbite changes with age. Bishara also tried to create similar groups based on the severity of overbite at age 25 years and retrospectively determine the variation in the original overbite. The only consistent change that he found was that the males with the least amount of overbite also had minimal overbite in the primary dentition.

2.5 DIFFERENCES IN VERTICAL GROWTH IN SUBJECTS WITH OPEN BITES AND DEEP BITES

In reviewing the literature it becomes clear that both dentoalveolar and skeletal factors may play role in determining the degree of anterior overbite. However, the evidence is not conclusive and there is no general agreement as to which factors are the most important.

Study of the relationship between total and lower anterior face height and overbite has been area of attention since early cephalometric studies (Bjork, 1947). Bjork noticed that in persons with reduced lower anterior face height, the overbite was deeper. Since then many other investigators confirmed the negative correlation between the overbite and total face height (Wylie, 1946; Prakash & Margolis, 1952; Hapak, 1964; Subtelny & Sakuda, 1964; Kapoor, 1968; Sassouni, 1969; Richardson, 1969; Bhatia & Leighton, 1971; Loufty, 1973) and lower anterior face height (Wylie, 1946; Popovich, 1955; Hapak, 1964; Atherton, 1964; Subtelny & Sakuda, 1964; Sassouni & Nanda, 1964; Kapoor, 1968; Sassouni, 1969; Richardson, 1969; Bhatia & Leighton, 1971; Loufty, 1973; Nahoum, Horowitz, & Benedicto, 1972; Nielsen, 1991; Beckmann et al, 1998; Fujiki et al, 2004). Most researchers agree that there is no difference in upper anterior face height between subjects with open and deep overbites (Wylie, 1946; Hapak, 1964; Subtelny & Sakuda, 1964;

Kapoor, 1968; Richardson, 1969; Nahoum, Horowitz, Benedicto, 1972). However, few studies reported that this dimension is smaller in open bite subjects (Atherton, 1964).

Many studies have evaluated other skeletal and dentoalveolar parameters and their possible relations to the degree of overbite. Greater disagreement, however, exists. Few studies show definite positive relationships between the ramus height and overbite (Sassouni & Nanda, 1964; Sassouni, 1969; Nahoum, Horowitz, & Benedicto, 1972; Nielsen, 1991; Stuani, Matsumoto, & Stuani, 2000). Other studies show either no relationship at all (Wylie, 1946; Popovich, 1955; Subtelny & Sakuda, 1964; Ceylan & Eröz, 2001; Fujiki et al, 2004), or conclude that a longer ramus significantly correlates with open bite (Diamond, 1944; Fleming, 1961).

Subjects with open bite have steeper mandibular (Hapak, 1964; Subtelny & Sakuda, 1964; Sassouni & Nanda, 1964; Sassouni, 1969; Isaacson et al, 1971; Nahoum, Horowitz, & Benedicto, 1972; Lowe, 1980; Trouten et al, 1983; Nielsen, 1991; Fujiki et al, 2004), occlusal (Subtelny & Sakuda, 1964; Sassouni & Nanda, 1964; Sassouni, 1969; Lowe, 1980; Trouten et al, 1983; Tsang, Cheung, & Samman, 1997), and palatal (Sassouni & Nanda, 1964; Sassouni, 1969; Trouten et al, 1983; Tsang, Cheung, & Samman, 1997) planes, greater palatal to occlusal (Subtelny & Sakuda, 1964), mandibular to occlusal (Bjork, 1947), and palatal to mandibular plane angles (Subtelny & Sakuda, 1964; Bhatia & Leighton, 1971; Nahoum, Horowitz, & Benedicto, 1972; Fujiki et al, 2004), a larger Y-Axis (Hapak, 1964; Subtelny & Sakuda, 1964), larger S-Ar-Go (Richardson, 1969) and gonial (Ar-Go-Me) angles (Sassouni & Nanda, 1964; Richardson, 1969; Sassouni, 1969; Herness, Rule, & Williams, 1973; Nahoum, Horowitz, & Benedicto, 1972; Trouten et al, 1983; Ceylan & Eröz, 2001; Fujiki et al, 2004), a smaller anterior cranial base (N-S) (Richardson, 1969) and ANS-PNS distances (Ceylan & Eröz, 2001), smaller facial (FH/N-Pog) (Subtelny & Sakuda, 1964) and N-Me-Go (Richardson, 1969) angles.

Stuani, Matsumoto, & Stuani (2000) examined thirty 7 to 10 years olds with open bite subjects and compared their vertical cephalometric measurements with those of age matched subjects with normal overbite. They found that the S-Go/N-Me was the only measurement that was statistically smaller in open bite subjects, indicating a smaller posterior face height in this group. MPA, ANS-Me/N-Me, ArGo/GoMe, and PPA did not differ significantly between the two groups, which is in disagreement with many studies. The authors contribute this discrepancy in their results to the presence of oral habits, which was not one of the exclusion criteria for this study, and the early age of the subjects.

Dentoalveolar measurements were also evaluated extensively. Richardson (1970) noted that both upper and lower incisors were longer and more upright in deep overbite subjects. The interincisal angle has been shown to be significantly smaller in open bite subjects by many investigators (Bjork, 1947; Steadman, 1949; Popovich, 1955; Sassouni & Nanda, 1964; Bhatia & Leighton, 1971; Andrews, 1972; Herness, Rule, & Williams, 1973; Lowe, 1980; Beckmann et al, 1998). Most studies attribute this to proclination of both the upper and lower incisors (Bjork, 1947; Baume, 1950; Sassouni & Nanda, 1964; Sassouni, 1969; Andrews, 1972; Herness, Rule, & Williams, 1973; Beckmann et al, 1998). Subtelny & Sakuda (1964) found that LI-MP angle was significantly smaller in open bite subjects, possibly due to the steeper mandibular plane angle in this group; however, there were no differences in the UI-PP angle.

It is generally accepted that after their full emergence, the teeth continue to erupt, accompanied by the growth in height of the alveolar process until the facial growth is complete and at a much reduced rate, for a long duration thereafter. The puzzling yet very controversial question in the literature is whether the eruption process is different in individuals with different degrees of overbite. Both Bjork (1953) and Solow (1980) described the mechanism of dentoalveolar compensation. Solow defined this mechanism as a system which attempts to maintain normal inter-arch relations under varying jaw relationships. Sassouni & Nanda (1964) and Ceylan & Eröz (2001) stated that in subjects with open bite, the total maxillary and mandibular dental heights were greater at both the incisor and molar levels. Richardson (1970) also admitted the possibility of compensatory growth in the basal part of anterior maxilla and mandible (distance from ANS to the root tip of upper incisor and from Menton to the root tip of lower incisor in this study). Wylie (1946) and Trouten et al (1983) also noticed that the distance between the palatal plane and the mandibular plane at the first molar level was significantly larger in the minimal overbite group, when compared to medium and severe overbite groups. Diamond (1944), Sassouni (1969), and Nielsen (1991) all agreed with the influence of excessive or retarded posterior tooth eruption on the anterior overbite. Popovich (1955) partially agreed with this, finding the difference in the maxilla, but not the mandible. In contrast, Nahoum, Horowitz, & Benedicto (1972) found mandibular dentoalveolar height (LM-MP) to be significantly higher in open bite subjects, but found no difference in the upper dentoalveolar vertical compensatory growth. Hapak (1964) confirmed compensatory vertical growth in the lower dentoalveolar area only, which was noticed in open bite subjects. The upper dentoalveolar area was not evaluated in his study. In contrast, Subtelny & Sakuda (1964) showed that the distance from the upper incisal edge to the palatal plane and from the buccal cusp of upper molar to the palatal plane was significantly larger in open bite subjects. However, they did not find any compensatory growth in the mandible. Isaacson et al (1971) hypothesized that the open bite subjects have longer maxillary anterior dental height in comparison with deep bite subjects. Not everyone agrees with this mechanism. For example, Loufty (1973) found that the linear measurements from the upper incisor tip to the palatal plane and from the lower incisor tip to the mandibular plane were significantly smaller in the open bite subjects in comparison with deep bite subjects, refuting the mechanism of dentoalveolar compensation. Kapoor's (1968) findings are in agreement with Loufty's. Atherton (1964) suggested that the vertical development of upper (measured from the upper incisor edge to ANS) and lower (measured from lower incisor edge to lowest point of the symphysis) incisors was not significantly different in open and deep bite individuals. Similarly, Bhatia & Leighton (1971) found no differences in dentoalveolar heights between the two groups; however, authors argued that relative to the lower anterior face height, incisors in the deep overbite group in fact did erupt more than in the reduced overbite group. They state: "A deep overbite is marked by restricted vertical growth while the horizontal growth, the growth of the alveolus and the eruption of the incisors, proceed unimpeded. In a reduced overbite, on the other hand, there does not appear to be a limitation in growth in any of the above directions. A deep overbite results because the incisors continue to erupt to their full potential without making due allowance for the reduced distance they have to travel and, therefore, overshoot the mark. In a reduced overbite, in contrast, the lower face height is increased but there is no attempt on the part of the alveolus to overgrow or incisors to overerupt to compensate for this increased distance." Prakash & Margolis (1952) found that in the excessive overbite cases the lower molar height (LM-MP) was smaller while upper incisor height (UI-SN) was greater. Upper molar height (UM-SN) was only slightly smaller and lower incisors (LI-MP) did not seem to have an effect at all. Sassouni (1969) argued that upper and lower incisors are extruded in both deep and open bite individuals; however, this extrusion is not sufficient to establish the vertical contact between the upper and lower incisors in open bite subjects. Tsang, Cheung, & Samman (1997) found that in open bite subjects the upper anterior dental height (U1-PP) is smaller and upper posterior dental height (U6-PP) is larger. Both Baume (1950) and Kapoor (1968) found that molar height did not contribute to the overbite.

2.6 CORRELATION OF OVERBITE WITH VARIOUS SKELETAL AND DENTOALVEOLAR PARAMETERS

A number of investigators have studied the variations in the degree of overbite concomitant with the degree of change in the dentoalveolar and skeletal components. Not all of the findings are in agreement.

Popovich (1955) evaluated 102 University students between 18 and 25 years of age to study the factors that might alter vertical overbite. He divided his sample into three groups: 1) Class I normal occlusion (overbite 0-3 mm), 2) Class I deep overbite (over 4 mm), and 3) Class II deep overbite (over 4 mm). Twenty six different factors were evaluated clinically and cephalometrically. In the first group Popovich found a clear association of overbite with the vertical cusp heights of posterior teeth (r=0.73) and a negative correlation with the total anterior face height (r=-0.60). In the second group overbite was correlated with the length of the upper incisors (r=0.43). In the third group the overbite had a negative correlation with the ramus height (r=-0.37), total anterior face height (r=-0.33), lower anterior face height (r=-0.52), and the degree of eruption of the upper first molar (r=-0.43). Positive correlations were observed in this group between the overbite and interincisal angle (r=0.73) and the length of the lower incisor (r=0.28).

Fleming (1961) found statistically significant relationships between overbite and some craniofacial dimensions: 1) Upper incisor length (UI-PP) and lower incisor length (LI-MP) were found to hold a significant positive correlation in females only (r=0.25 and r=0.43 respectively), 2) The ramus length was found to have a significant negative correlation to overbite in both sexes (r=-0.24) which supports the work of Diamond (1944), 3) Upper molar length (U6-PP) and lower molar length (L6-PP) had significant negative correlations to the degree of overbite in males only (r=-0.22 and r=-0.24 respectively), and 4) The lower incisor proclination (LI-MP) had negative correlations to overbite in females only (r=-0.53).

Bjork (1953) studied cephalograms of 243 individuals at 12 and 20 years of age longitudinally. He found a significant correlation between overbite and overjet. Starting from 0 mm overbite, the overbite increased when the overjet increased. Moreover, the overbite increased when the overjet decreased, starting from a 0 mm overbite. He also found significant negative correlation between the primary degree of overbite at age 12 years and resultant overbite at age 20 years (r=-0.31). This means that deep bites showed a greater tendency to open than normal overbites, whereas open bites showed a tendency to close. Freeway space showed a significant positive correlation with the degree of overbite (r=0.45).

Steadman (1949) also described in great detail how the overbite depth could change depending on the overjet. He also stressed the importance of bucco-lingual angulation of upper and lower incisors.

Bergersen (1988) found significant relationships between initial overjet at age 9 years and overbite at both 9 and 16 years of age (r=0.48). He found no relations between overbite changes from 9 to 16 years of age or the final resultant overbite at age 16 years and the interincisal angle, MPA, and total anterior face height.

Baydaş et al (2004) studied 137 subjects from 13 to 16 years of age and found that there was a statistically significant positive correlation (r=0.42) between the overbite and curve of Spee. In the deep curve of Spee group (>4 mm) the overbite was 3.3 mm, whereas in the flat curve of Spee group (≤2 mm) the overbite was 1.3 mm.

Herness, Rule, & Williams (1973) longitudinally studied 20 Class I orthodontically untreated children at 5, 7, 9, and 11 years of age. The following angular measurements were recorded: MPA, Ar-Go-Me, UI-PP, LI-MP, UI-LI. The registered linear measurements were as followed: Ba-N, S-N, Ba-A, S-Ar, Ba-Ar, Ar-Go, Go-Pog, N-Me, N-ANS, ANS-Me, N-UM, Me-LM, ANS-UI, ANS-A, A-UI, Me-LI, Me-B, B-LI. The interincisal angle (UI-LI) was the only measurement showing significant correlations with overbite at age 5 (r=0.61), 9 (r=0.66), and 11 (r=0.57) years. However, individual variation was great, and authors questioned the clinical significance of this relationship.

Tsang, Cheung, & Samman (1997) cephalometrically studied 104 subjects 15 to 45 years of age who had an anterior open bite. They divided their sample into 3 groups: 1) mild – anterior open bite of 3.75 mm or less; 2) moderate – anterior open bite between 3.75 and 6.85 mm; 3) severe – anterior open bite greater than 6.85 mm. The relationships between the severity of anterior open bite and vertical skeletal and dentoalveolar parameters were evaluated. Four significant factors were discussed:

1. PP angle. Counterclockwise rotation of PP correlates well with a more severe anterior open bite.

2. OP angle. Maxillary and mandibular occlusal planes were measured separately in this study, reporting that the mandibular OP became steeper with increasing severity of open bite.
3. Upper anterior dental height (UI-PP). Smaller UI-PP distance correlated with more severe anterior open bite.
4. Upper posterior dental height (U6-PP). Smaller U6-PP distance correlated with less severe open bite.

Bishara & Jakobsen in 1998 calculated correlation coefficients (r) of the absolute values of overbite with eight vertical cephalometric measurements (N-ANS, N-Me, N-ANS/N-Me, Ar-Go, S-Go, Ar-Go/S-Go, S-Go/N-Me, and MP-SN) and found no significant correlations between these parameters and overbite at different ages in both males and females. Correlation coefficients of the incremental changes in overbite during each of the four studied growth periods (5 to 10 years, 10 to 15, 15 to 25, and 25 to 45 years of age) and the changes in the mentioned above cephalometric parameters were also calculated. Only a few very weak and not clinically significant correlations were found. Trying to find out if the magnitude of overbite change is influenced by any of the skeletal vertical changes, Bishara divided his sample into two groups: 1) overbite change is 2 mm or greater from 5 to

45 years of age; 2) overbite change is less than 2 mm from 5 to 45 years of age. In both sexes there were no significant differences in any of the vertical skeletal parameters between these groups in all studied growth periods. Bishara & Jakobsen concluded that the normal changes in overbite cannot be accurately predicted from the changes in the vertical cephalometric parameters. He hypothesized that other factors, such as alveolar processes growth, might contribute to the changes in overbite.

2.7 PREDICTION OF OVERBITE

The ability to forecast overbite changes could help clinicians to resolve many treatment dilemmas, such as the degree of ideal posttreatment overbite, overtreatment, and retention protocols. When presented with deep or open bite tendency in a child in the mixed dentition, it would be a valuable clinical guide if one could predict whether growth changes in different parts of dentoalveolar skeleton would likely accentuate or minimize abnormal incisor relationships. After an extensive literature review, however, it was found that that variations, ranges, and individual patterns of overbite changes are great, and most authors agree that overbite changes are unpredictable (Moorrees, 1959; Bergersen, 1988; Herness, Rule, & Williams, 1973, Bishara & Jakobsen, 1998).

Moorrees (1959) found that the mean numbers for overbite in the deciduous dentition at 5-6 years were very similar to the numbers in permanent dentition at 16-18 years; however, some individual observations were made where overbite decreased considerably, going from 100 % overlap of upper and lower incisors in the deciduous dentition to a normal overbite in the permanent dentition. On the other hand, the overbite increased in some children, while in others the changes in overbite were erratic.

Bergersen (1988) also found that overbite at age 8 years and overbite at age 17 years were not significantly different. The conclusion, however, was that that overbite is unpredictable based on individual severity.

2.8 ETIOLOGY OF OVERBITE

To conclude this literature review, a number of skeletal and dentoalveolar factors that have been shown to be associated with the overbite are reviewed.

Factors that have been shown to contribute to the overbite:

Etiologic factor	Author
Heredity	Sassouni & Nanda, 1964 Bergersen, 1988
Pathology: local (e.g. such as supernumerary teeth, cysts, and dilacerations) and skeletal (e.g. cleft palate, cranio-facial dysostosis, condylar hyperplasia, and acromegaly)	Bjork, 1953 Richardson, 1967
Periodontal disease	Poulton & Aaronson, 1961 Bjørnaas, Rygh, & Bøe, 1994
Loss of teeth	Prakash & Margolis, 1952 Bergersen, 1988 Richardson & Richardson, 1993
Relapse of orthodontic treatment	Strang, 1934 Prakash & Margolis, 1952 Strang & Thompson, 1958 Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Bergersen, 1988
Habits (e.g. thumb sucking and mouth breathing)	Strang & Thompson, 1958 Subtelny & Sakuda, 1964 Richardson, 1967 Lawton & Barnett, 1975 Bergersen, 1988 Nielsen, 1991
Anatomic size and physiologic activity of the tongue	Bjork, 1953 Strang & Thompson, 1958 Subtelny & Sakuda, 1964 Sassouni, 1969 Bergersen, 1988 Fujiki et al, 2002
Facial musculature balance	Strang, 1934 Wylie, 1946 Neff, 1949 Brodie, 1953 Bjork, 1953 Strang & Thompson, 1958

	Subtelny & Sakuda, 1964 Sassouni & Nanda, 1964 Sassouni, 1969 Lawton & Barnett, 1975 Lowe, 1980 Nielsen, 1991 Ari-Demirkaya et al, 2004
Disturbances in TMJ	Bjork, 1953 Strang & Thompson, 1958 Moloney, 1987 Ari-Demirkaya et al, 2004
Condylar position	Sassouni, 1969
Condylar growth direction	Bjork, 1953 Nielsen, 1991
Ramus height and inclination	Diamond, 1944 Strang & Thompson, 1958 Fleming, 1961 Sassouni & Nanda, 1964 Kapoor, 1968 Sassouni, 1969 Nahoum, Horowitz, & Benedicto, 1972 Trouten et al, 1983 Nielsen, 1991 Stuani, Matsumoto, & Stuani, 2000
Anatomic characteristics of mandibular symphysis	Sassouni, 1969 Beckmann et al, 1998 Ceylan & Eröz, 2001
Total, upper, and lower face height dimensions	Wylie, 1946 Prakash & Margolis, 1952 Bjork, 1953 Popovich, 1955 Strang & Thompson, 1958 Hapak, 1964 Subtelny & Sakuda, 1964 Sassouni and Nanda, 1964 Atherton, 1965 Richardson, 1967 Kapoor, 1968 Sassouni, 1969 Bhatia & Leighton, 1971 Nahoum, Horowitz, & Benedicto, 1972 Loufty, 1973 Lawton & Barnett, 1975 Trouten et al, 1983 Nielsen, 1991 Beckmann et al, 1998 Fujiki et al, 2002
Rotation of the mandible	Sassouni and Nanda, 1964 Sassouni, 1969 Nielsen, 1991
Maxillary and/or mandibular AP positioning	Wylie, 1946 Baume, 1950 Brodie, 1953 Bjork, 1953 Fleming, 1961

	Kapoor, 1968 Strang & Thompson, 1968 Lawton & Barnett, 1975 Nielsen, 1991
Upper and/or lower arches transverse discrepancy	Strang & Thompson, 1968 Sassouni, 1969
Excessive or inadequate eruption of posterior and/or anterior teeth	Strang, 1934 Diamond, 1944 Steadman, 1949 Baume, 1950 Prakash & Margolis, 1952 Bjork, 1953 Popovich, 1955 Fleming, 1961 Hapak, 1964 Subtelny & Sakuda, 1964 Sassouni & Nanda, 1964 Kapoor, 1968 Strang & Thompson, 1968 Sassouni, 1969 Nahoum, Horowitz, & Benedicto, 1972 Loufty, 1973 Lawton & Barnett, 1975 Trouten et al, 1983 Nielsen, 1991 Tsang, Cheung, & Samman, 1997 Ceylan & Eröz, 2001
Eruption sequence of canines and premolars	Baume, 1950 Bergersen, 1988
Eruption of second and third molars	Sassouni, 1969 Bergersen, 1988
Length of the upper and lower incisors crowns and roots	Barrow & White, 1952 Popovich, 1955 Moorrees, 1959 Herness, Rule, & Williams, 1973
Bucco-lingual angulation of upper and lower incisors	Steadman, 1949 Popovich, 1955 Fleming, 1961 Sassouni & Nanda, 1964 Richardson, 1967 Sassouni, 1969 Isaacson et al, 1971 Herness, Rule, & Williams, 1973 Lowe, 1980 Richardson & Richardson, 1993 Ceylan & Eröz, 2001 Fujiki et al, 2002
Bucco-lingual angulation of posterior teeth	Strang & Thompson, 1968
Mesiodistal width of the teeth	Neff, 1949 Steadman, 1949 Sassouni, 1969
Overjet	Steadman, 1949 Bjork, 1953 Lawton & Barnett, 1975

	Lowe, 1980 Bergersen, 1988
Curve of Spee	Trouten et al, 1983 Baydaş et al, 2004
Dental cusps height	Wylie, 1946 Steadman, 1949 Popovich, 1955
Free-way space	Bjork, 1953

Factors, associated with deep overbite:

Etiologic factor	Author
Heredity	Sassouni & Nanda, 1964 Bergersen, 1988
Pathology: local (e.g. such as supernumerary teeth, cysts, and dilacerations) and skeletal (e.g. cleft palate, cranio-facial dysostosis, condylar hyperplasia, and acromegaly)	Bjork, 1953 Richardson, 1967
Periodontal disease	Poulton & Aaronson, 1961 Bergersen, 1988 Bjørnaas, Rygh, & Boe, 1994
Loss of teeth	Prakash & Margolis, 1952 Bergersen, 1988 Richardson & Richardson, 1993
Relapse of orthodontic treatment	Strang, 1934 Prakash & Margolis, 1952 Strang & Thompson, 1958 Subtelny & Sakuda, 1964 Sassouni & Nanda, 1964 Bergersen, 1988
Facial musculature balance	Strang, 1934 Bjork, 1953 Sassouni and Nanda, 1964 Sassouni, 1969 Lawton & Barnett, 1975 Lowe, 1980 Nielsen, 1991 Ari-Demirkaya et al, 2004
Disturbances in TMJ	Bergersen, 1988 Ari-Demirkaya et al, 2004
Lower anatomical condylar positioning	Sassouni & Nanda, 1964
More upward and forward growth of the condyle	Bjork, 1953 Nielsen, 1991
Condylar flattening	Ari-Demirkaya et al, 2004
Increased ramus height	Sassouni & Nanda, 1964

	Sassouni, 1969 Nielsen, 1991 Stuani, Matsumoto, & Stuani, 2000
Retarded ramus growth	Diamond, 1944 Fleming, 1961
Larger maxillary and mandibular cross-sectional areas	Beckmann et al, 1998
Wider and shorter mandibular symphysis	Sassouni, 1969 Ceylan & Eröz, 2001
Narrower and longer mandibular symphysis	Beckmann et al, 1998
Larger symphysial area	Beckmann et al, 1998
Small gonial angle	Sassouni & Nanda, 1964 Sassouni, 1969 Herness, Rule, & Williams, 1973 Trouten et al, 1983
Small total anterior face height	Wylie, 1946 Prakash & Margolis, 1952 Bjork, 1953 Sassouni & Nanda, 1964 Atherton, 1965 Richardson, 1967 Sassouni, 1969 Lawton & Barnett, 1975 Nielsen, 1991
Small lower anterior face height	Wylie, 1946 Popovich, 1955 Sassouni & Nanda, 1964 Atherton, 1965 Richardson, 1967 Sassouni, 1969 Lawton & Barnett, 1975 Nielsen, 1991 Beckmann et al, 1998
Long upper anterior face height	Atherton, 1965
Counterclockwise rotation of the mandible	Sassouni & Nanda, 1964 Sassouni, 1969 Nielsen, 1991
Posterior positioning of the mandible	Lawton & Barnett, 1975 Nielsen, 1991
Decreased MPA	Wylie, 1946 Bjork, 1953 Sassouni & Nanda, 1964 Hapak, 1964 Subtelny & Sakuda, 1964 Sassouni, 1969 Isaacson et al, 1971 Trouten et al, 1983 Nielsen, 1991
Decreased OPA	Bjork, 1953 Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Sassouni, 1969 Trouten et al, 1983

	Tsang, Cheung, & Samman, 1997
Decreased PPA	Bjork, 1953 Sassouni & Nanda, 1964 Sassouni, 1969 Trouten et al, 1983 Tsang, Cheung, & Samman, 1997
Inadequate molar eruption	Strang, 1934 Diamond, 1944 Wylie, 1946 Steadman, 1949 Prakash & Margolis, 1952 Popovich, 1955 Fleming, 1961 Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Hapak, 1964 Sassouni, 1969 Nahoum, Horowitz, & Benedicto, 1972 Lawton & Barnett, 1975 Trouten et al, 1983 Tsang, Cheung, & Samman, 1997 Ceylan & Eröz, 2001
Excessive eruption of upper and/or lower anterior teeth	Strang, 1934 Diamond, 1944 Steadman, 1949 Prakash & Margolis, 1952 Popovich, 1955 Kapoor, 1968 Sassouni, 1969 Loufty, 1973 Nielsen, 1991 Tsang, Cheung, & Samman, 1997
Inadequate eruption of upper and/or lower anterior teeth	Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Richardson, 1967 Isaacson et al, 1971 Ceylan & Eröz, 2001
Eruption sequence of canines and premolars	Baume, 1950 Bergersen, 1988
Excessively long incisors	Steadman, 1949 Barrow & White, 1952 Popovich, 1955 Moorrees, 1959 Fleming, 1961 Richardson, 1967 Herness, Rule, & Williams, 1973
More upright incisors	Steadman, 1949 Popovich, 1955 Fleming, 1961 Sassouni & Nanda, 1964 Richardson, 1967 Sassouni, 1969 Lawton & Barnett, 1975 Richardson & Richardson, 1993 Beckmann et al, 1998

	Herness, Rule, & Williams, 1998 Ceylan & Eröz, 2001
Lingual inclination of lower posterior teeth	Strang, 1934 Strang & Thompson, 1968
Narrow teeth	Sassouni, 1969
Overjet	Steadman, 1949 Bjork, 1953 Lawton & Barnett, 1975 Bergersen, 1988
Deep curve of Spee	Trouten et al, 1983 Baydaş et al, 2004
Large cusp height of posterior teeth	Wylie, 1946 Steadman, 1949 Popovich, 1955
Larger free-way space	Bjork, 1953

Factors, associated with anterior open bite:

Etiologic factor	Author
Heredity	Sassouni & Nanda, 1964 Bergersen, 1988
Pathology: local (e.g. supernumerary teeth, cysts, and dilacerations) and skeletal (e.g. cleft palate, cranio-facial dysostosis, condylar hyperplasia, and acromegaly)	Bjork, 1953 Richardson, 1967
Relapse of orthodontic treatment	Strang, 1934 Prakash & Margolis, 1952 Strang & Thompson, 1958 Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Bergersen, 1988
Habits (e.g. thumb sucking and mouth breathing)	Strang & Thompson, 1958 Subtelny & Sakuda, 1964 Richardson, 1967 Lawton & Barnett, 1975 Bergersen, 1988 Nielsen, 1991
Anatomic size and physiologic activity of the tongue	Bjork, 1953 Strang & Thompson, 1958 Subtelny & Sakuda, 1964 Sassouni, 1969 Bergersen, 1988 Fujiki et al, 2002
Facial musculature balance	Strang, 1934 Wylie, 1946 Neff, 1949 Brodie, 1953

	Bjork, 1953 Strang & Thompson, 1958 Subtelny & Sakuda, 1964 Sassouni & Nanda, 1964 Sassouni, 1969 Lawton & Barnett, 1975 Lowe, 1980 Nielsen, 1991 Ari-Demirkaya et al, 2004
Disturbances in TMJ	Bjork, 1953 Strang & Thompson, 1958 Moloney, 1987 Ari-Demirkaya et al, 2004
Higher anatomical condylar positioning	Sassouni & Nanda, 1964
Thin condyles	Ari-Demirkaya et al, 2004
More upward and backward growth of the condyle	Bjork, 1953 Nielsen, 1991
Condylar erosion	Ari-Demirkaya et al, 2004
Decreased ramus height	Sassouni & Nanda, 1964 Sassouni, 1969 Nahoum, Horowitz, & Benedicto, 1972 Nielsen, 1991 Stuani, Matsumoto, & Stuani, 2000
Smaller maxillary and mandibular cross-sectional areas	Beckmann et al, 1998
Narrower and longer mandibular symphysis	Sassouni, 1969 Ceylan & Eröz, 2001
Wider and shorter mandibular symphysis	Beckmann et al, 1998
Smaller symphysial area	Beckmann et al, 1998
Large gonial angle	Hapak, 1964 Sassouni & Nanda, 1964 Richardson, 1967 Sassouni, 1969 Nahoum, Horowitz, & Benedicto, 1972 Herness, Rule, & Williams, 1973 Trouten et al, 1983 Ceylan & Eröz; 2001 Fujiki et al, 2002
Long total anterior face height	Wylie, 1946 Prakash & Margolis, 1952 Bjork, 1953 Sassouni & Nanda, 1964 Hapak, 1964 Atherton, 1965 Richardson, 1967 Sassouni, 1969 Lawton & Barnett, 1975 Nielsen, 1991
Long lower anterior face height	Wylie, 1946 Sassouni & Nanda, 1964 Hapak, 1964 Atherton, 1965

	Richardson, 1967 Nahoum, Horowitz, & Benedicto, 1972 Lawton & Barnett, 1975 Nielsen, 1991 Beckmann et al, 1998 Fujiki et al, 2002
Short upper anterior face height	Atherton, 1965
Clockwise rotation of the mandible	Sassouni & Nanda, 1964 Sassouni, 1969 Nielsen, 1991
Increased MPA	Wylie, 1946 Bjork, 1953 Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Hapak, 1964 Sassouni, 1969 Isaacson et al, 1971 Nahoum, Horowitz, & Benedicto, 1972 Lowe, 1980 Trouten et al, 1983 Nielsen, 1991 Fujiki et al, 2002
Increased OPA	Bjork, 1953 Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Sassouni, 1969 Nahoum, Horowitz, & Benedicto, 1972 Lowe, 1980 Trouten et al, 1983 Tsang, Cheung, & Samman, 1997
Increased PPA	Bjork, 1953 Sassouni Nanda, 1964 Sassouni, 1969 Trouten et al, 1983 Tsang, Cheung, & Samman, 1997
Increased PP-MP angle	Subtelny & Sakuda, 1964 Bhatia & Leighton, 1971 Nahoum, Horowitz, & Benedicto, 1972 Fujiki et al, 2002
Increased ANB angle	Lowe, 1980
Excessive molar eruption	Strang, 1934 Diamond, 1944 Wylie, 1946 Prakash & Margolis, 1952 Popovich, 1955 Fleming, 1961 Sassouni & Nanda, 1964 Subtelny & Sakuda, 1964 Hapak, 1964 Strang & Thompson, 1968 Sassouni, 1969 Nahoum, Horowitz, & Benedicto, 1972 Lawton & Barnett, 1975 Trouten et al, 1983 Nielsen, 1991

	Tsang, Cheung, & Samman, 1997 Ceylan & Eröz, 2001
Inadequate eruption of upper and/or lower anterior teeth	Strang, 1934 Steadman, 1949 Strang & Thompson, 1968 Kapoor, 1968 Nahoum, Horowitz, & Benedicto, 1972 Loufty, 1973 Tsang, Cheung, & Samman, 1997
Excessive eruption of upper and/or lower anterior teeth	Hapak, 1964 Subtelny & Sakuda, 1964 Sassouni & Nanda, 1964 Richardson, 1967 Sassouni, 1969 Isaacson et al, 1971 Ceylan & Eröz, 2001
Eruption sequence of canines and premolars	Baume, 1950 Bergersen, 1988
Eruption of second and third molars	Bergersen, 1988
Short incisors length	Steadman, 1949 Barrow & White, 1952 Popovich, 1955 Moorrees, 1959 Fleming, 1961 Richardson, 1967 Herness, Rule, & Williams, 1973
More proclined incisors	Steadman, 1949 Popovich, 1955 Fleming, 1961 Sassouni & Nanda, 1964 Richardson, 1967 Sassouni, 1969 Herness, Rule, & Williams, 1973 Lawton & Barnett, 1975 Lowe, 1980 Richardson & Richardson, 1993 Beckmann et al, 1998 Ceylan & Eröz, 2001 Fujiki et al, 2002
Wide teeth	Sassouni, 1969
Overjet	Steadman, 1949 Bjork, 1953 Lawton & Barnett, 1975 Lowe, 1980 Bergersen, 1988
Flat curve of Spee	Trouten et al, 1983 Baydaş et al, 2004
Inadequate free-way space	Bjork, 1953

CHAPTER 3

MATERIALS AND METHODS

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3.1 SAMPLE SELECTION

The sample was chosen from the archives of the Burlington Growth Center that was established in 1952 at the University of Toronto, Ontario, Canada. The 1,258 existing records of Burlington Growth Center were searched on the basis of the inclusion criteria determined for this research project. A total of 74 subjects were selected (41 females and 33 males). Each subject had a complete set of orthodontic records taken at 9, 12, and 20 years of age. The records included a lateral cephalometric radiograph, set of plaster models, and medical and dental histories. All the subjects were of Northern European descent and at the beginning of the study, were living in the small town of Burlington, outside of Toronto, Ontario, Canada.

The following inclusion criteria were used to select the subjects:

1. Clinically acceptable facial features, determined from the clinical photographs;
2. Orthodontically untreated subjects;
3. Subjects with all permanent teeth erupted at age 20 apart from third molars.

The subjects were excluded from the study, if they had any of the following:

1. Habits (e.g. finger sucking) that persisted after age 5;
2. Developmental syndromes;
3. Mutilated deciduous and/or permanent dentitions;
4. Congenitally missing teeth other than third molars;
5. Space loss due to caries;
6. Significantly delayed eruption patterns;
7. Ectopically erupted second molars;
8. Heavily restored dentitions;
9. Previous orthodontic treatment.

Lateral cephalograms at 9, 12, and 20 years of age were scanned by a single operator using the Epson Expression 1680 scanner (Seiko Epson Corporation, Japan) and subjected to cephalometric analysis using the

Dolphin™ treatment planning software program (Dolphin Imaging and Management Systems, Chatsworth, CA, USA).

Subjects were divided into three groups: 1) Deep overbite (n=22, OB≥4.0 mm), 2) Normal overbite (n=31, OB of 2.2-3.9 mm), and 3) Inadequate overbite (n=21, OB≤2.1 mm). Plaster models taken at age 20 years were used to determine the overbite grouping for each person.

3.2 PLASTER MODEL ANALYSIS

Original maxillary and mandibular alginate impressions of the subjects were taken at the same time as the cephalograms and were then poured in blue stone. The dental casts were carefully checked for missing teeth and large dental restorations which would effect normal contours of the teeth and those subjects were excluded from the study. Two subjects had congenitally missing lower second premolars with the primary second molars still in place at the age of 20 years and one subject had a congenitally missing lower incisor. These subjects were included in the study as it was thought that this would not influence the vertical dimension.

Plaster model measurements were made directly on the plaster models using an electronic Boley gauge (Donated by Ortho-pli Corp, Philadelphia, PA, USA) accurate to 0.05 mm. The following measurements were performed on the plaster models:

Overbite. The incisal edge of the upper right central incisor was projected onto the crown of the opposing lower incisor using a mechanical pencil (Pentel® 2B 0.5mm lead) with the lead extended so that it contacted both the incisal edge of the maxillary incisor and the labial surface of the mandibular incisor and was oriented parallel to the functional occlusal plane. To insure that the measurements were done parallel to the occlusal plane, plaster models articulated in centric occlusion were placed on the table. To insure a flat-leveled surface of the table, a level was used (Johnson Plastic Torpedo Level, Johnson Level & Tool Mfg Co Inc, Mequon, WI, USA). The distance from the projected point to the incisal edge of the mandibular incisor was measured in millimeters with an electronic Boley gauge held parallel to the labial surface of measured incisor. Open bite was measured as the distance between the incisal edge of the right maxillary central incisor and the incisal edge of the mandibular incisor. Care was taken to keep the Boley gauge perpendicular to the occlusal plane.

Overjet. The linear distance from the incisal edge of the maxillary most protruding central incisor to the labial surface of mandibular incisor was measured using an electronic Boley gauge. The plaster models were articulated in centric occlusion and placed on the table with a flat-leveled surface. This measurement was also performed parallel to the occlusal plane and reported in millimeters.

Upper incisor length. The linear distance from the incisal edge of maxillary right central incisor to its gingival margin was measured with the electronic Boley gauge held parallel to the facial surface of the measured incisor and was reported in millimeters.

Lower incisor length. The linear distance from the incisal edge of mandibular right central incisor to its gingival margin was measured with the electronic Boley gauge held parallel to the facial surface of the measured incisor and was reported in millimeters.

Angle classification. Malocclusion was registered based on the anteroposterior relationship of the maxillary and mandibular permanent molars. ***Class I*** – the buccal groove of the mandibular first permanent molar occludes with the mesiobuccal cusp of the maxillary first permanent molar. ***Class II*** – the buccal groove of mandibular first permanent molar occludes distal to the mesiobuccal cusp of the maxillary first permanent molar. The severity of the deviation from the Class I molar relationship was indicated in fractions ("half cusp Class II" or "full cusp Class II"). There were no Class III subjects included in this study.

Eruption stage of second molars. Registered as “+”, if second molars were in occlusal contact at least on one side; registered as “-“, if second molars were not in occlusion.

Twenty three (10.4%) sets of plaster models were re-measured by the same operator 6 days after the first set of measurements was recorded to ensure that initial measurements were reliable.

3.3 CEPHALOMETRIC ANALYSIS

All the cephalograms were obtained on a Keleket radiographic machine in a Thurow cephalostat using a high-kilovoltage technique (Thompson & Popovich, 1977) at University of Toronto. The data collection was started in 1952 and completed in 1971 (Thompson & Popovich, 1977).

Twenty five landmarks were identified on each cephalogram, from which twenty eight various linear and angular measurements were derived.

The following landmarks were identified on each cephalograph:

Sella turcica (*S*), Nasion (*N*), 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: Overbite, Posterior Cranial Base, Lower Posterior Face Height, Total Posterior Face Height, Relative Posterior Cranial Base, Lower Anterior Face Height, Total Anterior Face Height, Relative Lower Anterior Face Height, Anterior to Posterior Face Height, Space available for the upper second molar, Upper Incisor Length, Upper Molar Length, Lower Incisor Length, Lower Molar Length, Mandibular Plane Angle, Palatal Plane Angle, Occlusal Plane Angle, Facial Angle, Y Axis, Facial Axis, Lower Anterior Facial Height, Mandibular Arc, Upper Incisor Proclination, Lower Incisor Proclination, Interincisal Angle, Palatal to Mandibular Plane Angle, Palatal to Occlusal Plane Angle, and Mandibular to Occlusal Plane Angle (Figures 3.3 – 3.27) .

The selection of these measurements was based on the fact that they are widely used by orthodontists to evaluate vertical skeletal and dental relations and their potential relationship to overbite changes.

3.4 DEFINITIONS

3.4.1 Basic definitions

Growth – the age related increase in size or mass, involving changes in amount of living substance, which may be measured in increments of weight or linear change (Daskalogiannakis, 2000). Growth is mostly an anatomic phenomenon (Proffit, 2000).

Development – the process of differentiation and maturation that leads to increase in skill, more comprehensive function and sexual dimorphism in progress towards maturity (Daskalogiannakis, 2000). Development is a physiologic and behavioral phenomenon (Proffit, 2000).

Lateral Cephalometric Radiograph (Cephalogram) – a radiograph of the head taken with the X-ray beam perpendicular to the patient's sagittal plane (Daskalogiannakis, 2000).

Overbite – the degree of vertical overlap of the mandibular incisors by their maxillary antagonists, measured perpendicular to the occlusal plane. It is reported either in millimeters, or as a percentage of the total crown length of the mandibular incisors that is overlapped by the maxillary incisors (Daskalogiannakis, 2000). It is reported in millimeters in this study.

Anterior open bite – a vertical separation of upper and lower anterior teeth when the posterior teeth are in occlusion (Tsang, 1997).

Overjet – the distance between the labial surface of the mandibular incisors and the labial aspect of the incisal edge of the most prominent maxillary incisor, measured parallel to the occlusal plane and reported in millimeters (Daskalogiannakis, 2000).

Angle classification – a classification of malocclusion introduced by E.H. Angle, based on the anteroposterior relationship of the maxillary and mandibular permanent molars (Daskalogiannakis, 2000).

Class I – a malocclusion in which the buccal groove of the mandibular first permanent molar occludes with the mesiobuccal cusp of the maxillary first permanent molar (Daskalogiannakis, 2000).

Class II – a malocclusion in which the buccal groove of mandibular first permanent molar occludes distal to the mesiobuccal cusp of the maxillary first permanent molar. The severity of the deviation from the Class I molar relationship is indicated in fractions ("half cusp Class II" or "full cusp Class II") (Daskalogiannakis, 2000).

3.4.2 Cephalometric landmarks

All the pictures adapted from Jacobson, 1995.

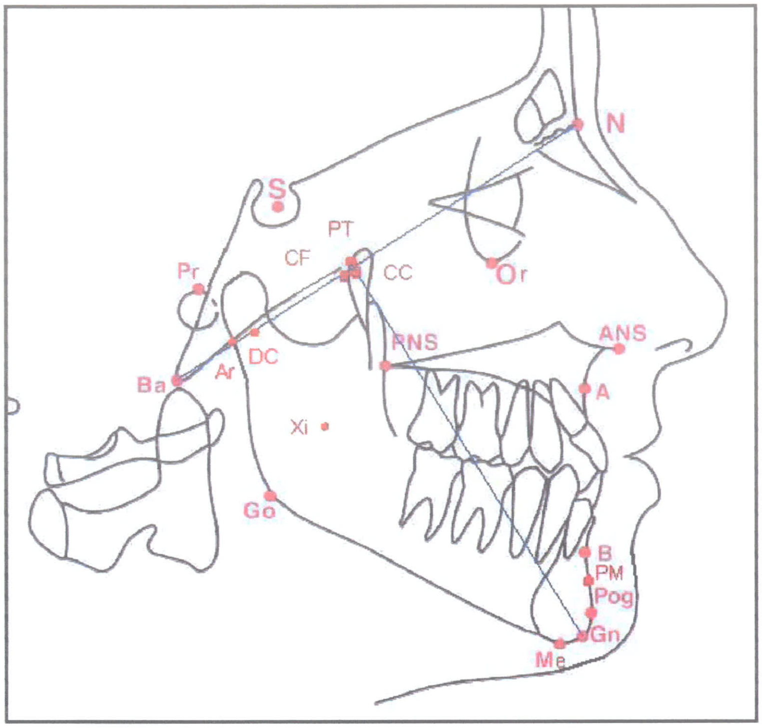


Figure 3.1 Lateral cephalometric analysis points.

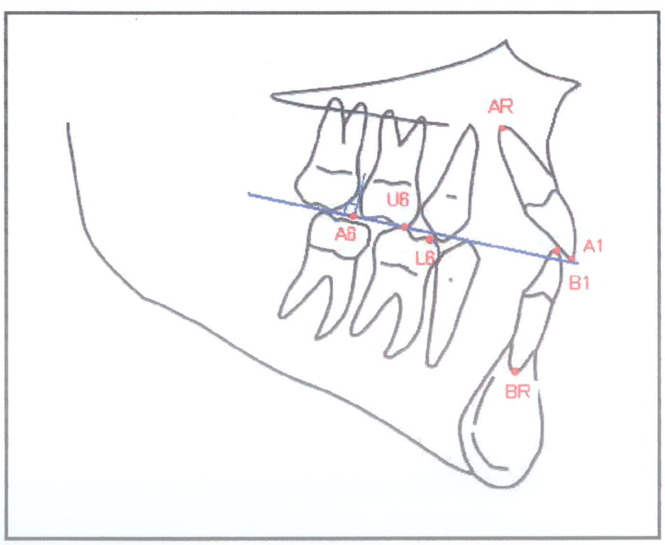


Figure 3.2 Lateral cephalometric analysis points.

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).

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).

3.4.3 Cephalometric linear measurements

Overbite (OB) – distance A1-B1 measured perpendicular to the functional occlusal plane (Downs, 1948). Normal value is 0-4 mm (Bjork, 1953) (Figure 3.3).

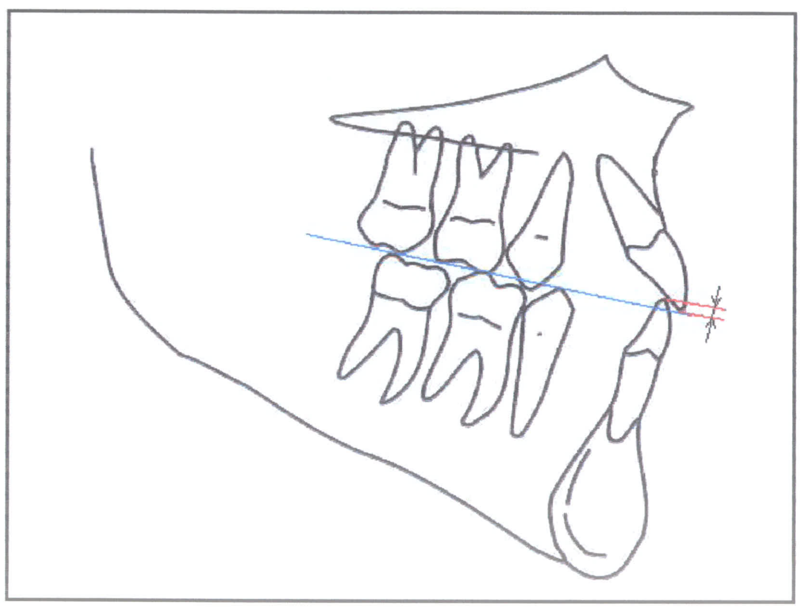


Figure 3.3 Overbite measurement on the lateral cephalogram.

Posterior cranial base (S-AR) – linear distance from Sella to Articulare.

Normal value is 33 mm (SD=3 mm) (Siriwat & Jarabak, 1985) (Figure 3.4).

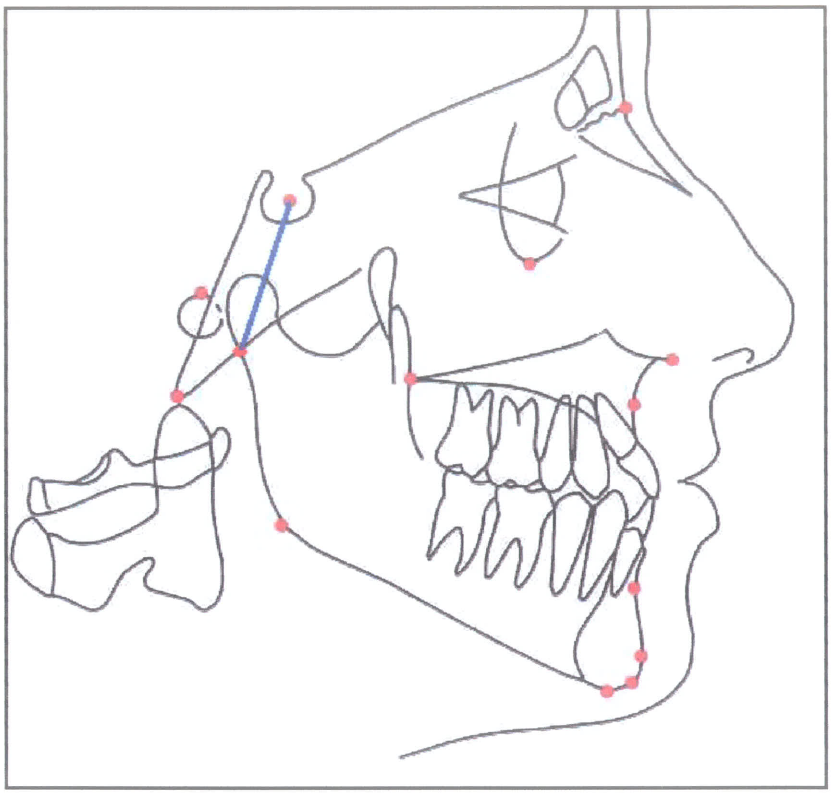


Figure 3.4 Posterior cranial base

Lower Posterior Face Height (Ar-Go) – linear distance from Articulare to constructed Gonion. Normal value is 44 mm (SD=5 mm) (Siriwat & Jarabak, 1985) (Figure 3.5).

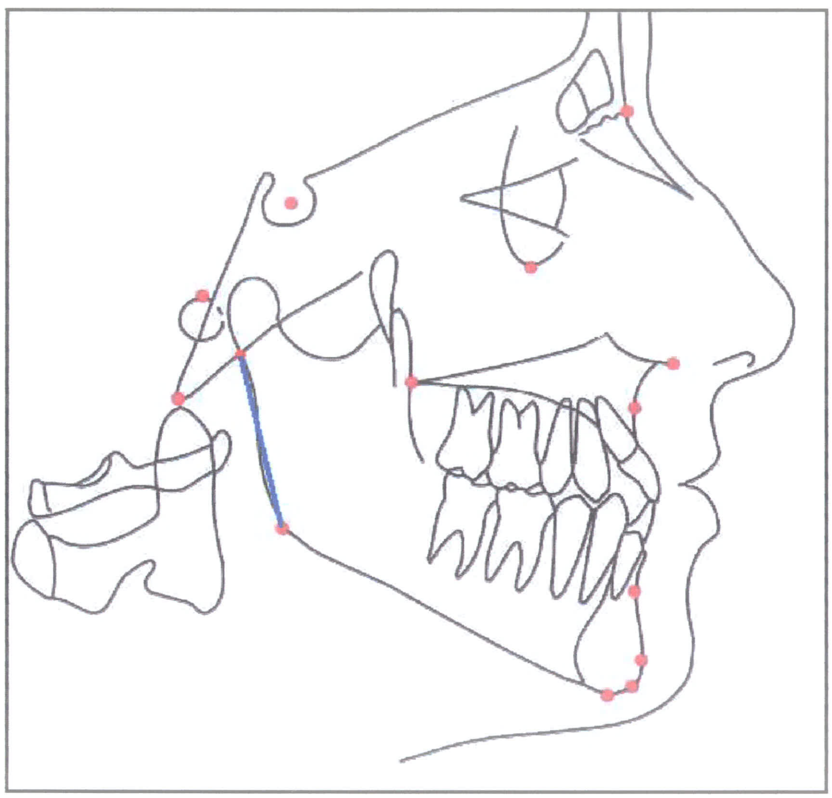


Figure 3.5 Lower posterior face height.

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 3.6).

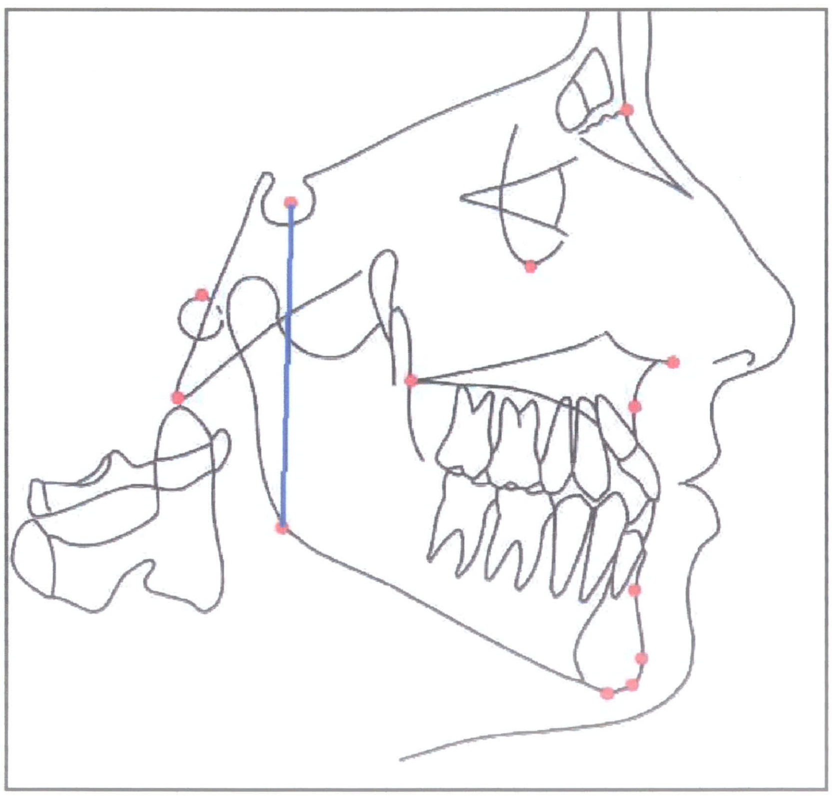


Figure 3.6 Total posterior face height

Relative Posterior Cranial Base (S-Ar/Ar-Go) – proportion of Posterior cranial base to Ramus height. Normal value is 75% (SD=5%) (Siriwat & Jarabak, 1985).

Lower Anterior Face Height (ANS-Me) – distance, measured from Anterior nasal spine to Menton. Normal values depend on the size of the individual. For a child in mixed dentition it should be 60-62 mm, for a medium size person it should be 65-67 mm, and for a large person it varies between 70 and 73 mm (McNamara, 1984) (Figure 3.7).

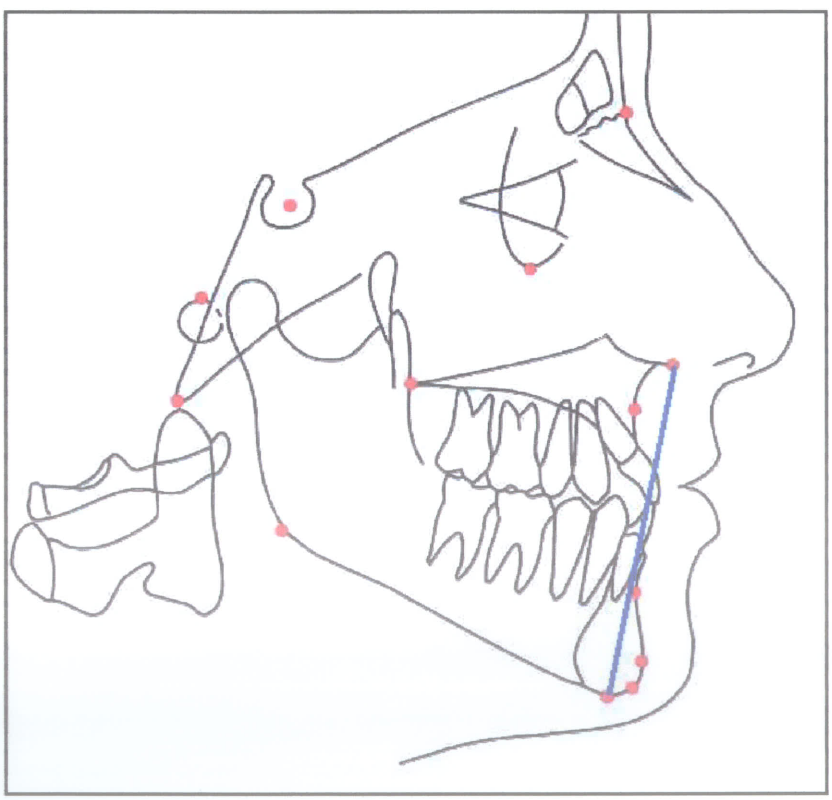


Figure 3.7 Lower anterior face height

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 3.8).

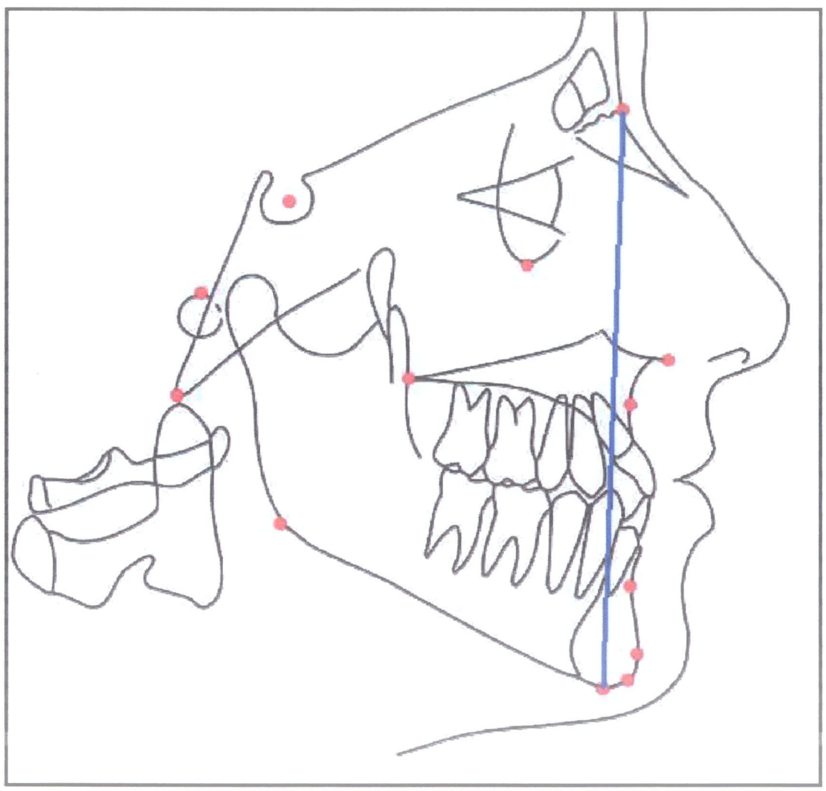


Figure 3.8 Total anterior face height

Relative Lower Anterior Face Height (ANS-Me/N-Me) – proportion of lower anterior face height to total anterior face height. Normal value is 56% (SD=0.1%) (Nanda, 1988).

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%) (Siriwar & Jarabak, 1985).

Space available for the upper second molar (A6-PT) – distance from the distal surface of upper first molar to the PT vertical measured parallel to occlusal plane. Pt vertical is a perpendicular from FH tangent to the distal surface of pterygomaxillary fissure. Normal value should equal the age of the patient plus 3 mm (Ricketts, 1981) (Figure 3.9).

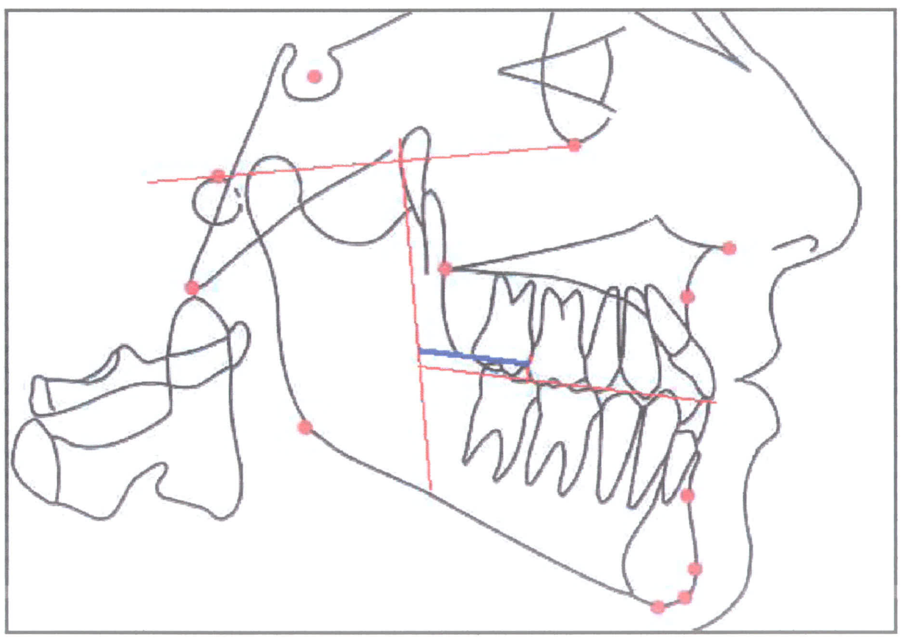


Figure 3.9 Space available for the upper second molars

Upper Incisor Length (UI–PP) – linear measurement from the incisal edge of most protruding upper central incisor to palatal plane, measured perpendicular to ANS-PNS plane. Normal values for an adult: males – 33 mm (SD=3 mm), females – 30 mm (SD=3 mm) (Riolo et al, 1974) (Figure 3.10).

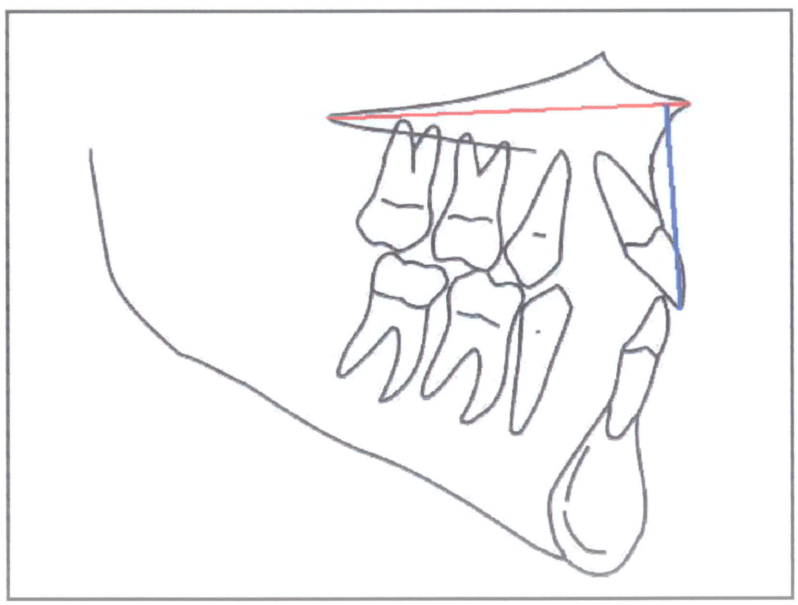


Figure 3.10 Upper incisor length

Lower Incisor Length (LI – MP) – linear measurement from the incisal edge of the most protruding lower incisor to the mandibular plane, measured perpendicular to mandibular plane. Normal adult values: males – 49 mm (SD=3 mm), females – 42 mm (SD=3 mm) (Riolo et al, 1947) (Figure 3.11).

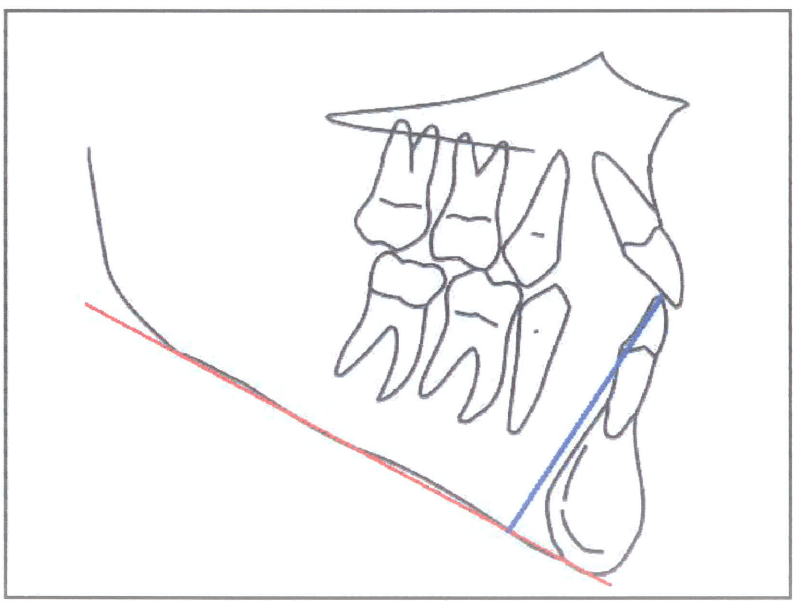


Figure 3.11 Lower incisor length

Upper Molar Length (U6 –PP) – linear distance from the mesial cusp of upper first molar to the palatal plane measured perpendicular to palatal plane. Normal adult values: males – 28 mm (SD=3 mm), females – 25 mm (SD=2 mm) (Riolo et al, 1974) (Figure 3.12).

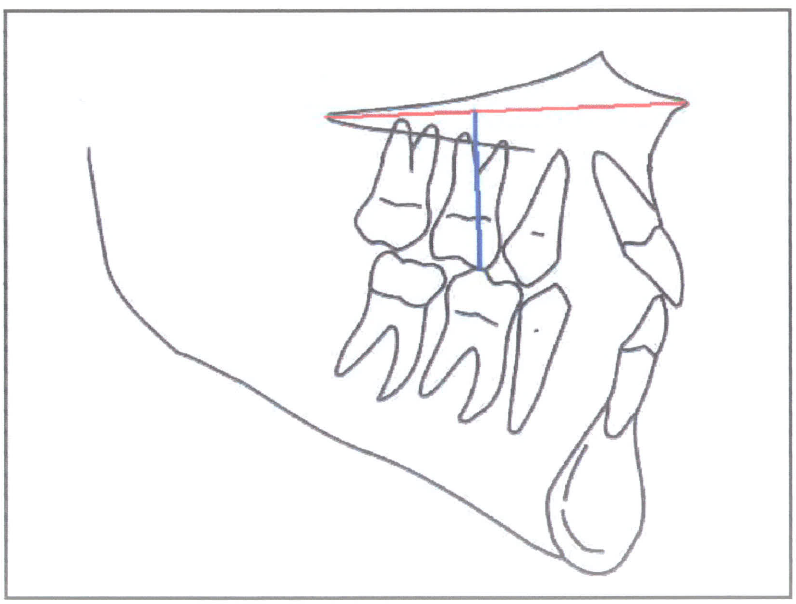


Figure 3.12 Upper molar length

Lower Molar Length (L6 – MP) – linear measurement from the mesial cusp of lower first molar to the mandibular plane measured perpendicular to mandibular plane. Normal adult values: males – 38 mm (SD=3 mm), females – 33 mm (SD=3 mm) (Riolo et al, 1974) (Figure 3.13).

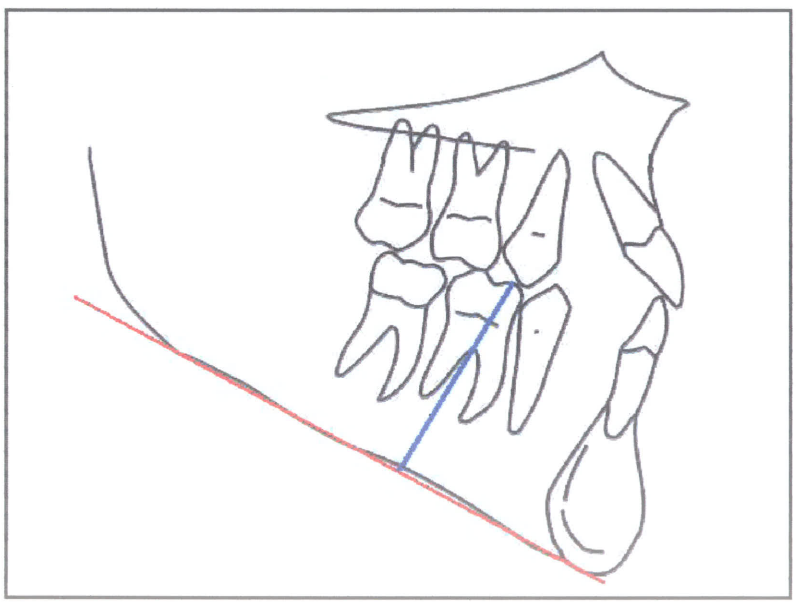


Figure 3.13 Lower molar length

3.4.4 Cephalometric angular measurements

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 21.9° (SD=3.2°) (Downs, 1948). Ricketts (1981) considers 26° (SD=4.5°) to be normal (Figure 3.14).

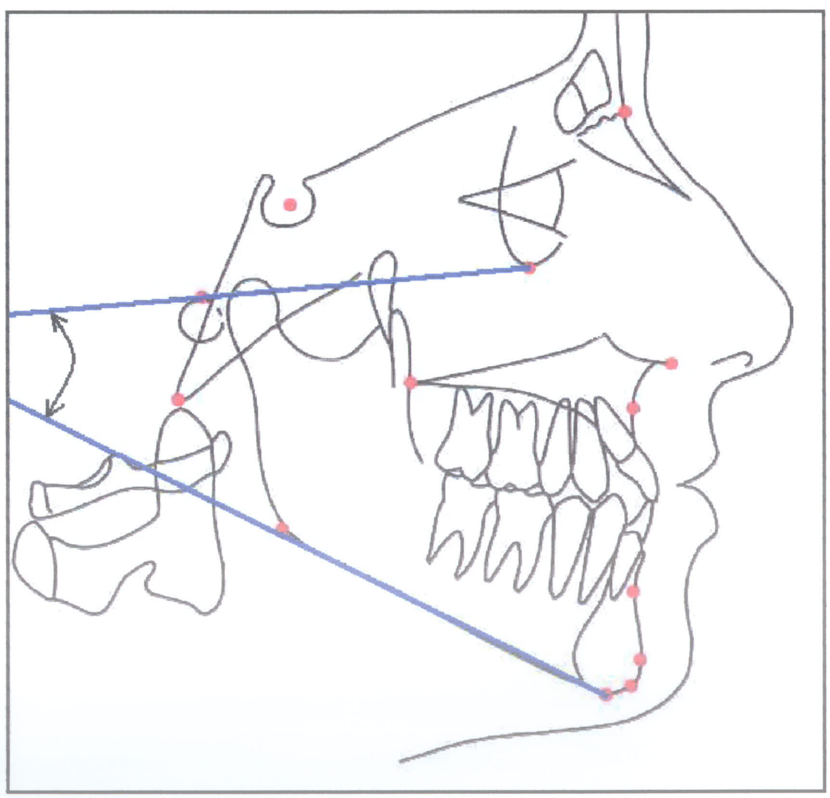


Figure 3.14 Mandibular plane angle

Palatal Plane Angle (PPA) – angle created by palatal plane (PP) and FH. PP extends from ANS to PNS. The normal value for PPA is 0° (SD=2.5°) (Ricketts, 1981) (Figure 3.15).

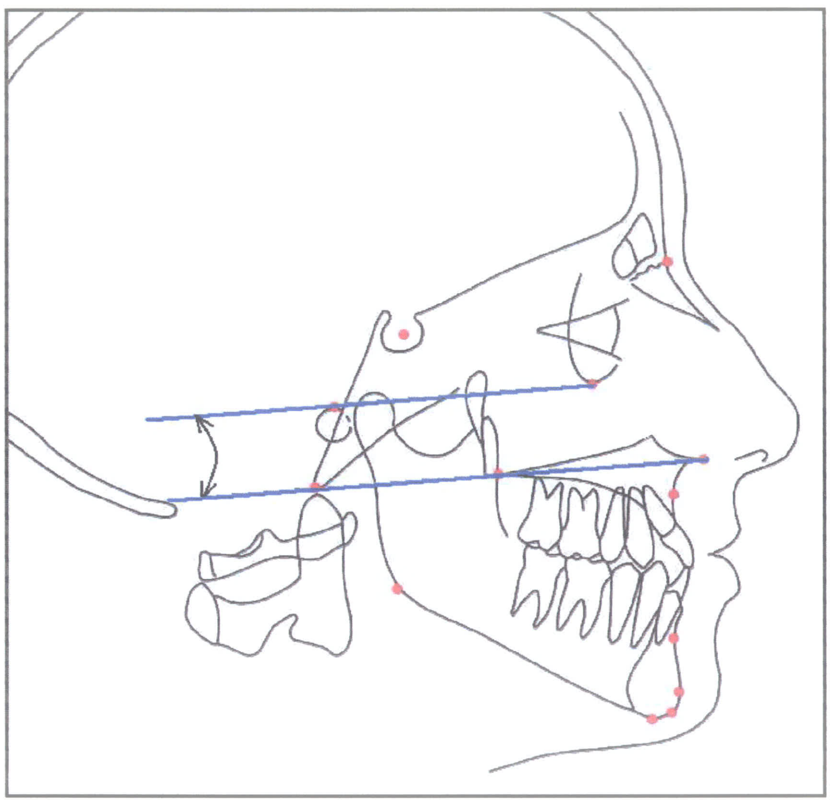


Figure 3.15 Palatal plane angle

Occlusal Plane Angle (OPA) – created by functional occlusal plane (OP) and FH. The functional OP is represented by a line extending through the first molars and premolars. Normal value is 9.3° (SD=3.8°) (Downs, 1948) (Figure 3.16).

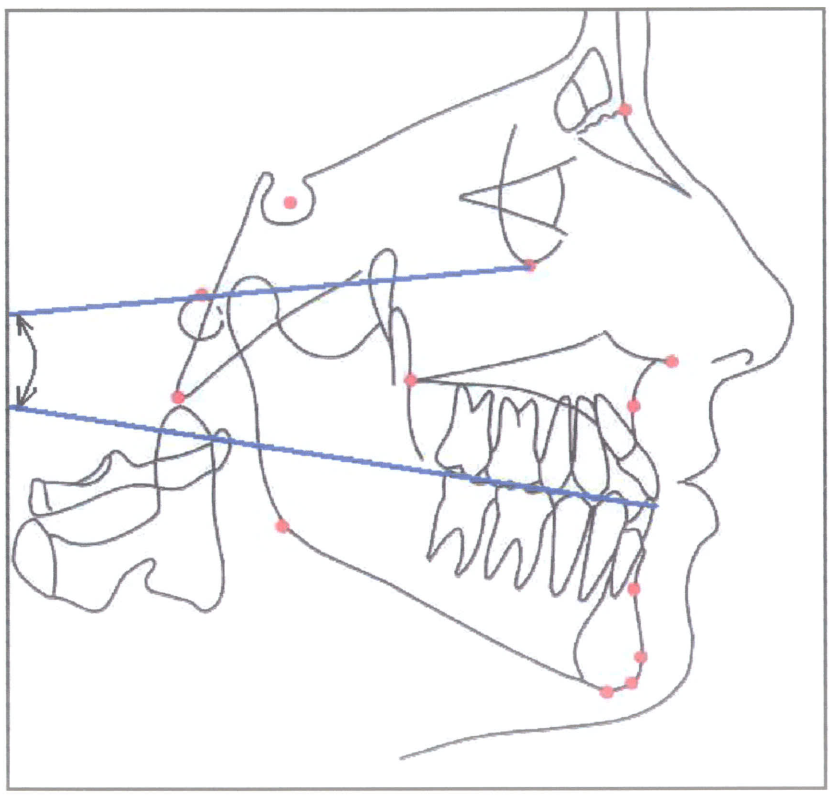


Figure 3.16 Occlusal plane angle

Facial Angle (FH/N-Pog) – the inferior posterior angle formed by the intersection of the Frankfort horizontal and the facial plane (N-Pog). Normal value is 87.8° (SD=3.6°) (Downs, 1948). Ricketts (1981) considers 85° to be the normal for age 9 years, 86° for age 12 years, and 89° for 20 years of age (SD=3°) (Figure 3.17).

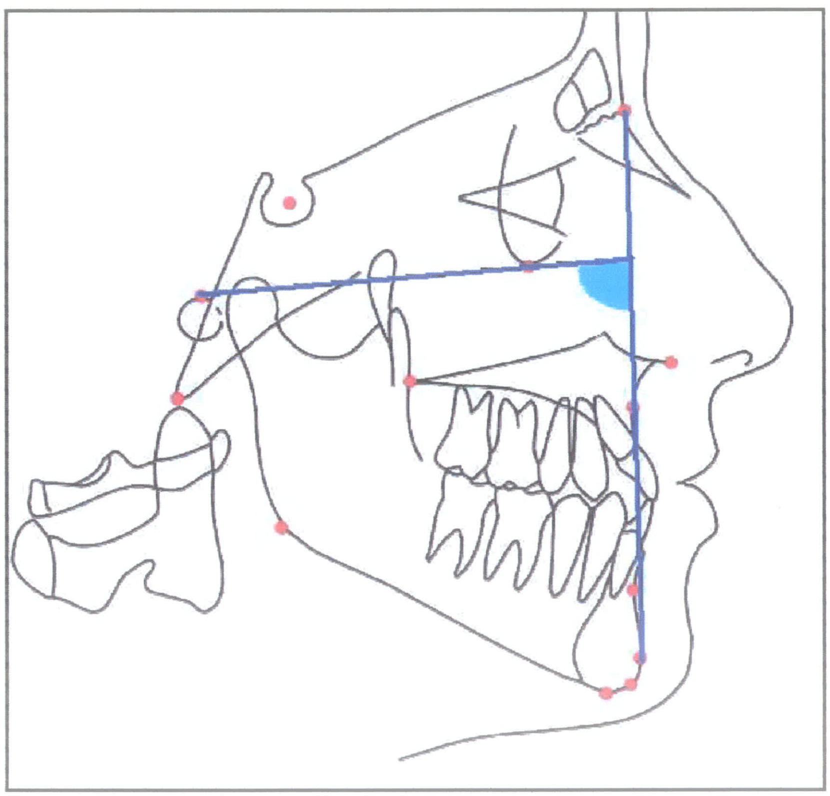


Figure 3.17 Facial angle

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 3.18).

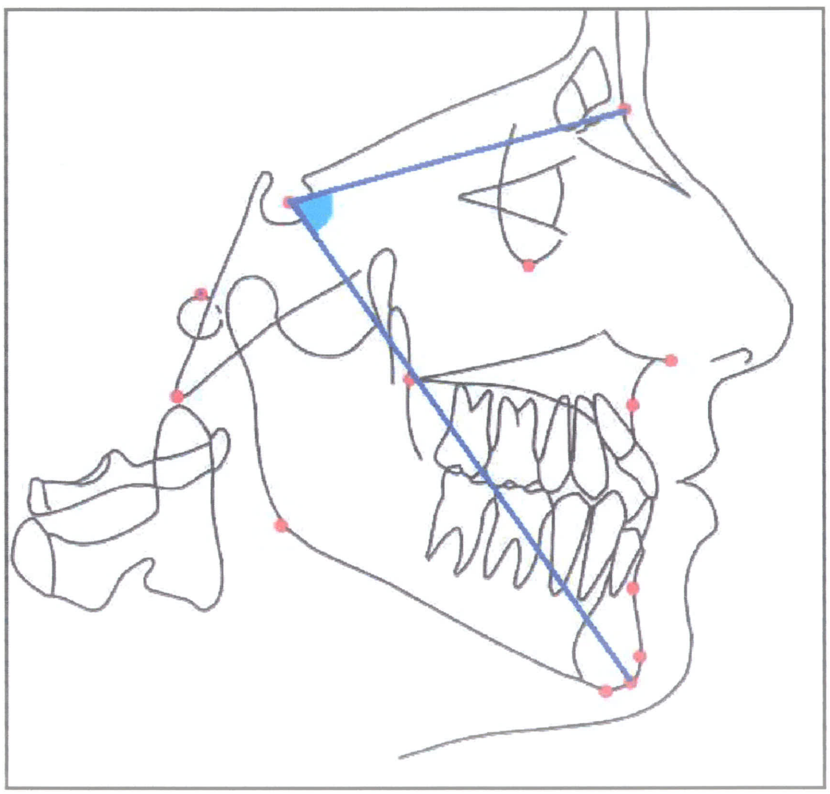


Figure 3.18 Y-Axis

Facial Axis (Ba-N/PT-Gn) – the inferior angle formed by the intersection of the facial (PT-Gn) and cranial (Ba-N line) axes. Normal value is 90° (SD=3.5°) (Ricketts, 1981) (Figure 3.19).

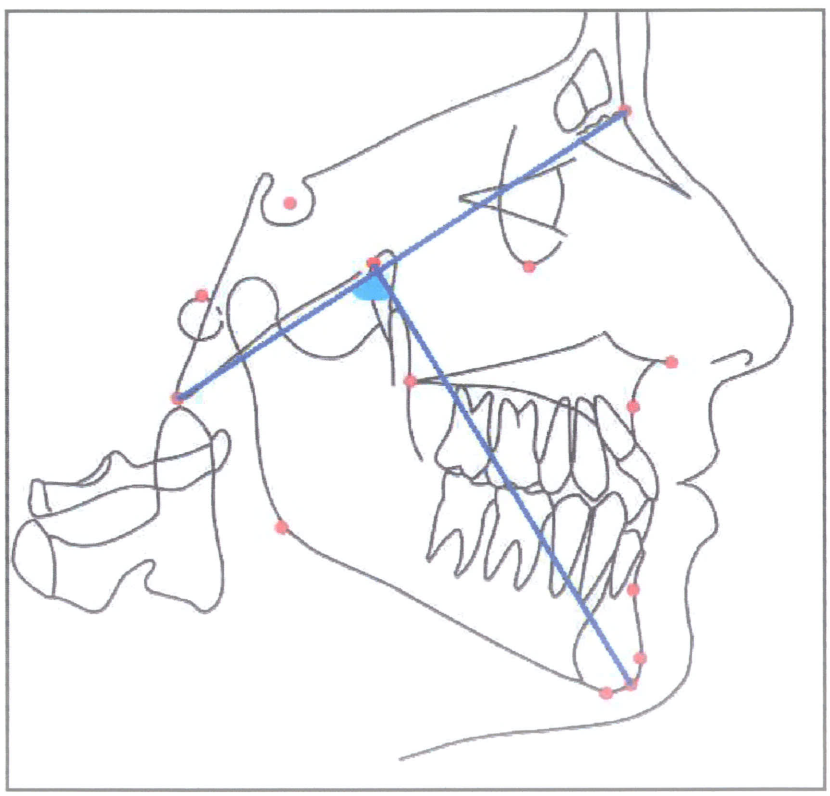


Figure 3.19 Facial Axis

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. The normal value is 46° (SD=3°) (Ricketts, 1981) (Figure 3.20).

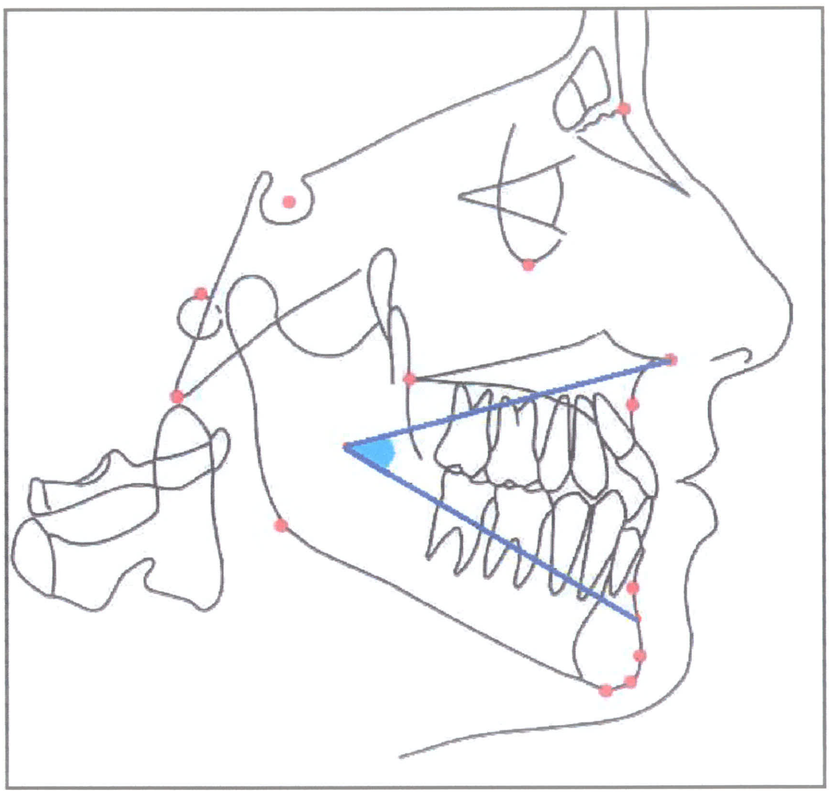


Figure 3.20 Lower anterior facial height

Mandibular Arc (DC-Xi/Xi-PM) – acute angle created by Condylar Axis (extends from DC to Xi) and Corpus Axis (Xi-PM). Normal values for mandibular arc: age 9 – 22.5°, age 12 – 24.4°, age 20 – 29.2°. SD=4° (Ricketts, 1981) (Figure 3.21).

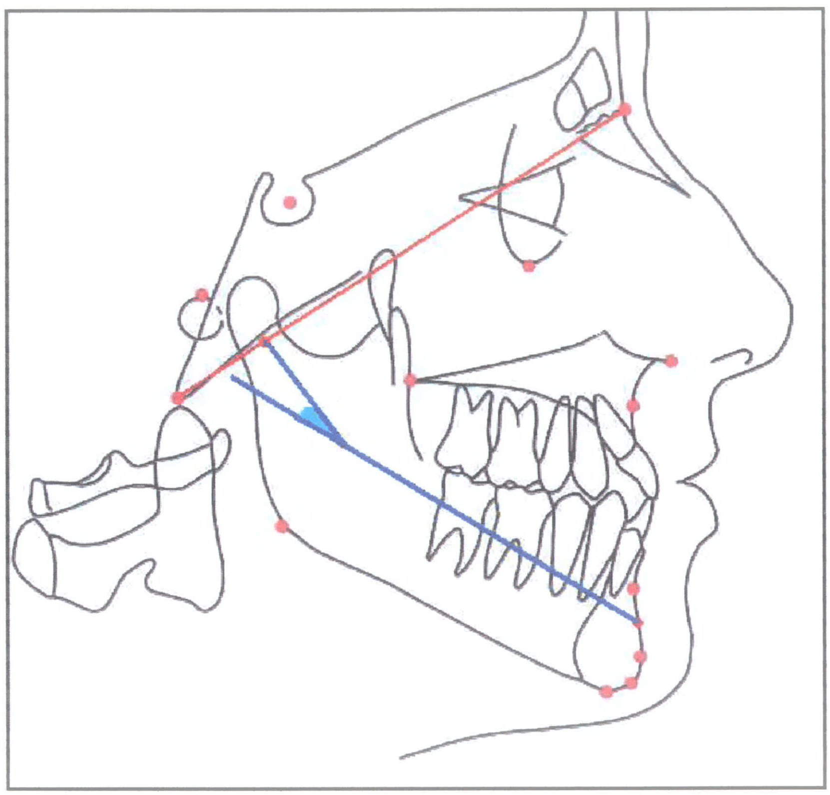


Figure 3.21 Mandibular arc

Upper Incisor Proclination (UI-PP') – angle created by upper incisor line (line from A1 to AR) and palatal plane. Normal value is 110° (SD=5°) (Boersma, van dar Linden & Prahl-Andersen, 1979) (Figure 3.22).

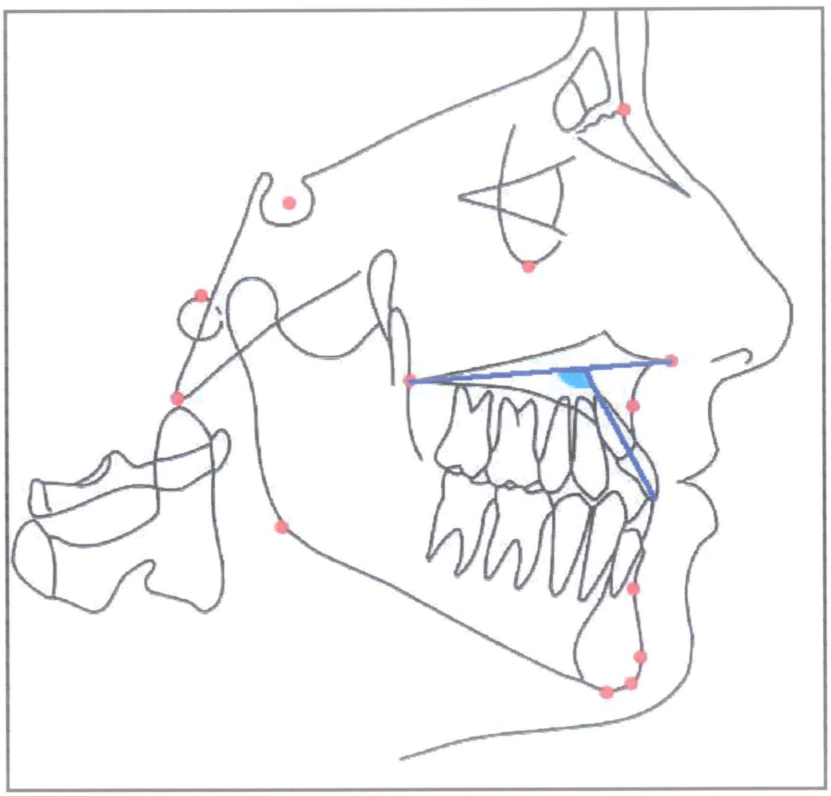


Figure 3.22 Upper incisor proclination

Lower Incisor Proclination (LI-MP') – angle created by lower incisor line (from B1 to BR) and MP. Normal value is 95° (SD=7°) (Downs, 1948) (Figure 3.23).

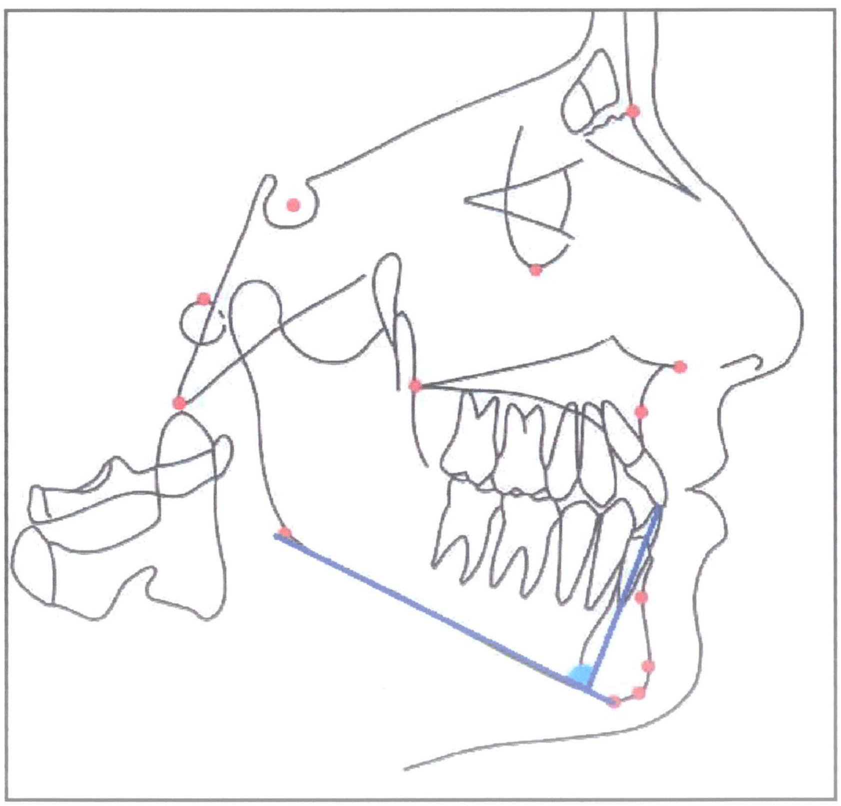


Figure 3.23 Lower incisor proclination

Interincisal angle (UI-LI) – angle formed by upper and lower incisor lines. Incisor lines connect the incisal edges and incisal root tips. Normal value is 135.4° (SD=5.8°) (Downs, 1948). Ricketts (1981) considered the following to be normal: age 9 – 124°, age 12 – 126, age 20 – 129° (SD=5°) (Figure 3.24).

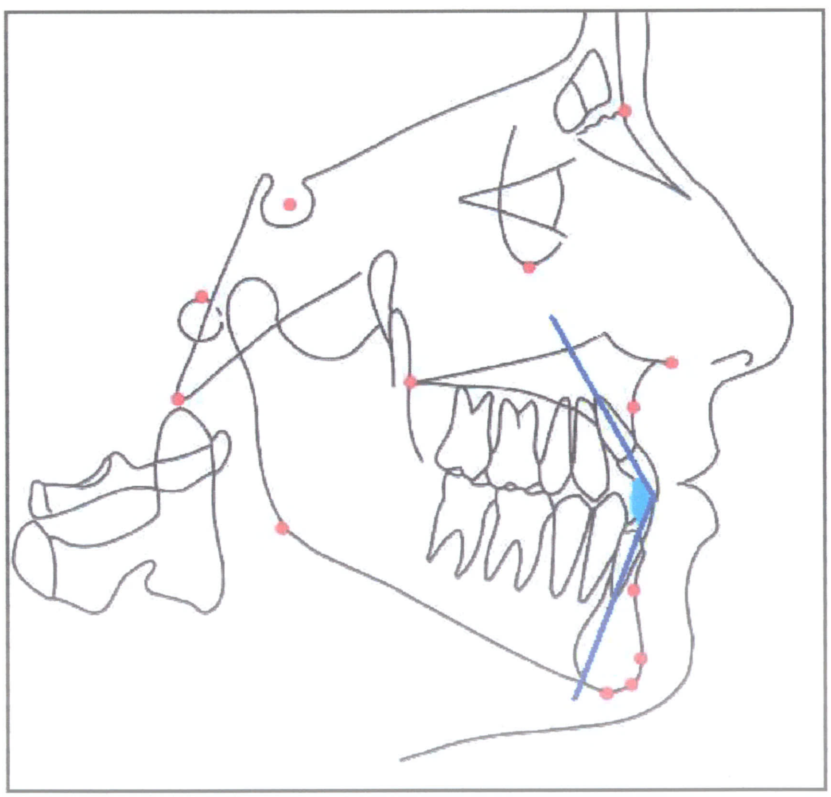


Figure 3.24 Interincisal angle

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 3.25).

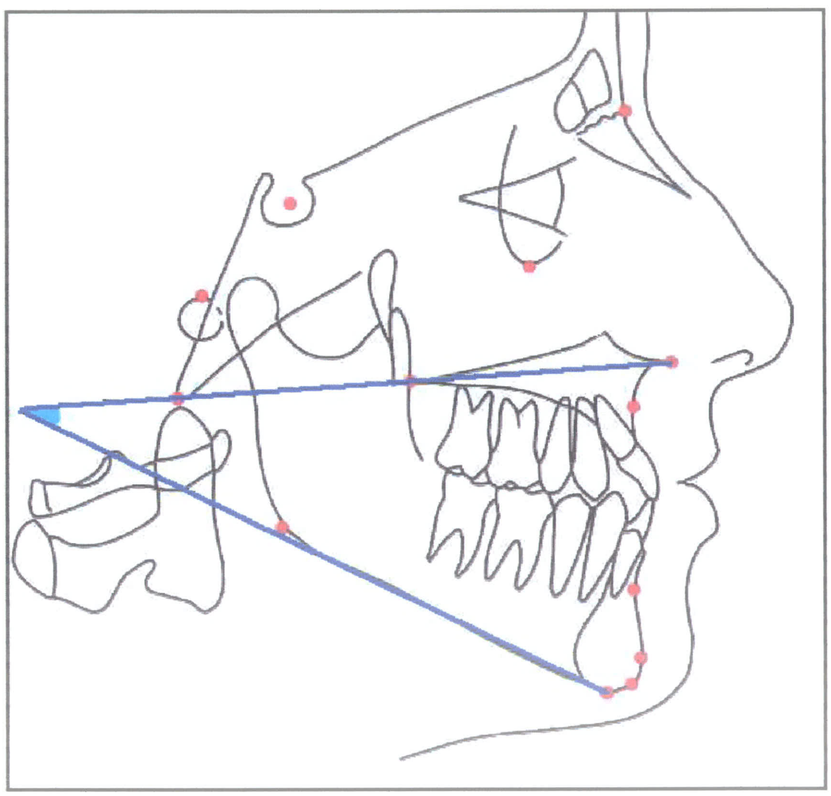


Figure 3.25 Palatal to mandibular plane angle

Palatal/Occlusal plane angle (PP-OP) – angle formed by intersection of palatal and occlusal planes. Normal value is 10° (SD=4°) (Subtelny & Sakuda, 1964) (Figure 3.26).

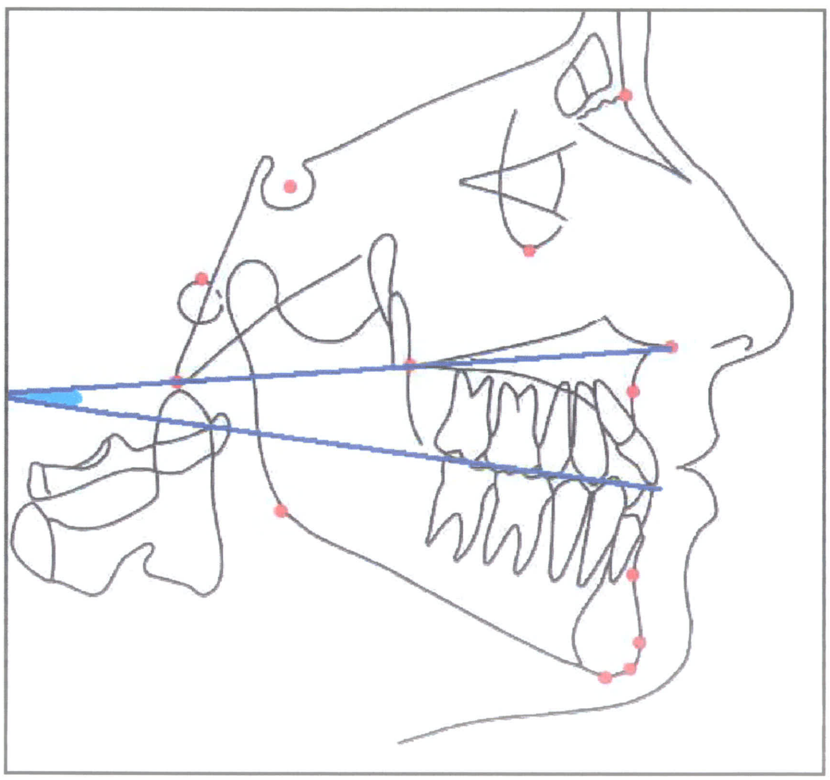


Figure 3.26 Palatal to occlusal plane angle

Mandibular/Occlusal Plane Angle (MP-OP) – angle created by intersection of mandibular and occlusal planes. Normal value is 16° (SD=5°) (Siriwat & Jarabak, 1985) (Figure 3.27).

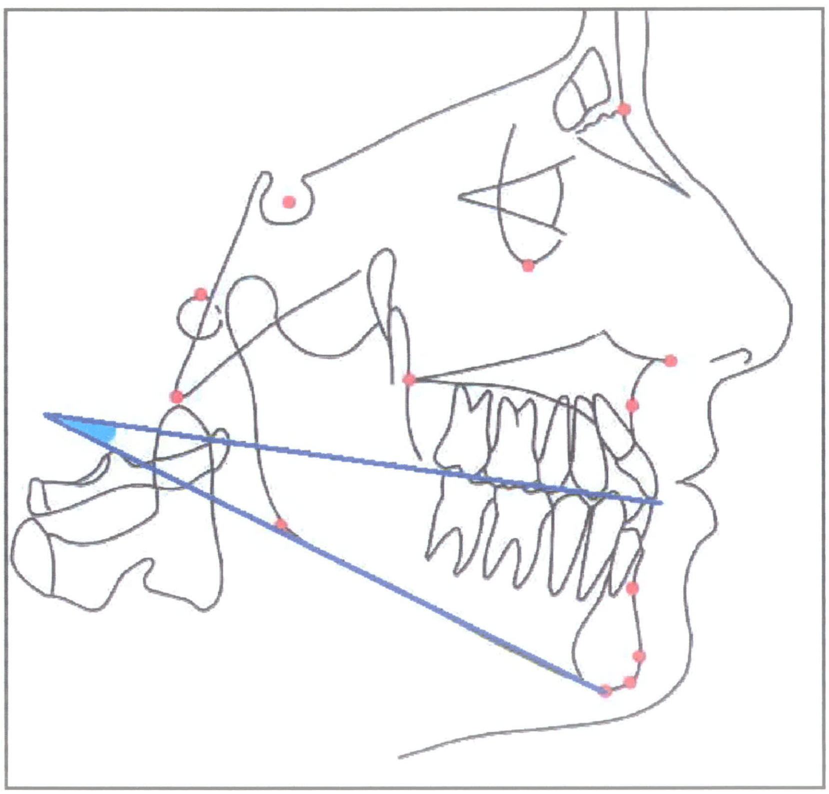


Figure 3.27 Mandibular to Occlusal plane angle

CHAPTER 4

STATISICAL ANALYSIS

CHAPTER 4

STATISICAL ANALYSIS

4.1 RELIABILITY

Calibration of the digitizing software and the electronic Boley gauge was performed in the factory. The lateral cephalographs were checked and standardized by the Burlington Growth Center.

Twenty three (10.4%) sets of plaster models were re-measured by the same operator six days after the first set of measurements was recorded. The paired *t*-test was performed to determine reliability.

The landmarks on each of 222 cephalographs were digitized by one operator. In cases of double image, the midline between both structures was chosen. All the cephalograms belonging to an individual subject were digitized at the same sitting. Twenty three (10.4%) cephalograms were redigitized two weeks after the first set was digitized. The systematic error was assessed by a paired *t*-test to see whether there were significant differences between measurements taken on two separate occasions. The degree of error was also measured between overbite measurements on the plaster models and digitized cephalographs using paired *t*-test.

Twenty three (10.4%) cephalographs were manually traced (Orthopli corp. Cephalometric tracing paper, Philadelphia, PA, USA) and the error was measured between the manually traced and digitized measurements.

To find out if there was a relationship between the linear overbite measurements and percentage of overbite on plaster models at age 20 years, a multiple regression analysis was performed.

4.2 STATISTICAL ANALYSIS

Plaster model and cephalometric measurements were entered into a Microsoft Excel spreadsheet (Microsoft Corp., Redmond WA). Data were analyzed using the NCSS program (Kaysville, Utah, USA). Descriptive statistics reports included the mean, standard deviation, and minimum and maximum values for each parameter measured at each age (9, 12, and 20 years) and the changes in each parameter between the studied ages for both genders.

Paired *t*-tests were used to determine the significant differences in parameters between the three overbite groups (deep vs. normal, normal vs. minimal, and deep vs. minimal) and between the studied ages (9 vs. 12, 12 vs. 20, and 9 vs. 20). Independent *t*-tests were used to determine the significant differences between sexes.

The level of significance was predetermined at the 0.05 level. To measure the strength of relationship between the overbite and cephalometric parameters that showed to be statistically different between the studied groups, the correlation coefficient (r) was calculated.

CHAPTER 5

RESULTS

CHAPTER 5

RESULTS

5.1 CALIBRATION

The reproducibility of measurements was assessed on 10 % of the studied sample by a paired *t*-test on the means of individual variables obtained from: 1. the plaster models measurements on the two separate occasions; 2. the cephalometric measurements on the two separate occasions; 3. manually traced and digitized measurements; and 4. plaster models and digitized overbite 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 5.1 and 5.2.

Multiple regression analysis between the overbite measured on the plaster casts and the percentage of overbite at age 20 years did not show significant differences between these two measurements ($P<0.001$).

Table 5.1 Measurement error for 10% redigitized and 10% manually traced cephalograms for all the variables.

Variable	Redigitized			Manually traced		
	|x|	SD	*t*-test	|x|	SD	*t*-test
OB	0.02	1.93	NS	0.04	0.37	NS
S-Ar	0.09	0.27	NS	0.13	0.50	NS
Ar-Go	0.03	0.54	NS	0.12	0.33	NS
S-Go	0.09	0.48	NS	0.30	0.47	S
S-Ar/Ar-Go	0.15	1.43	NS	0.14	1.33	NS
ANS-Me	0.03	0.37	NS	0.02	0.23	NS
N-Me	0.30	1.50	NS	0.23	1.02	NS
ANS-Me/N-Me	0.18	0.95	NS	0.10	0.62	NS
S-Go/N-Me	0.25	1.19	NS	0.42	0.79	S
A6-PT	0.31	1.11	NS	0.30	0.84	S
UI-PP	0.02	0.37	NS	0.04	0.45	NS
LI-MP	0.04	0.07	NS	0.84	0.61	S
U6-PP	0.08	0.42	NS	0.19	0.44	S
L6-MP	0.04	0.19	NS	0.70	0.43	S
MPA	0.56	0.67	S	0.29	0.79	NS
PPA	0.18	1.53	NS	0.55	0.92	S
OPA	0.61	0.62	S	0.37	0.83	S
FH/N-Pog	0.55	0.85	S	0.37	0.93	S
Y-Axis	0.17	1.01	NS	0.41	0.84	S
Ba-N/PT-Gn	0.31	1.17	NS	0.03	0.92	NS
ANS-Xi-PM	0.03	0.43	NS	0.04	0.23	NS
DC-Xi/Xi-PM	0.71	1.43	S	0.22	0.83	NS
UI-PP'	0.36	1.43	NS	0.17	1.11	NS
LI-MP'	0.30	1.68	NS	0.24	0.70	NS
UI-LI	0.14	1.26	NS	0.19	1.17	NS
PP-MP	0.08	0.77	NS	0.10	0.60	NS
PP-OP	0.08	0.58	NS	0.19	0.79	NS
MP-OP	0.15	0.37	NS	0.01	0.40	NS

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

Table 5.2 Overbite measurement error between plaster models measurements and digitized cephalograms.

Age	|x|	SD	*t*-test	*r*
9	0.48	0.99	S	0.86
12	0.12	1.01	NS	0.84
20	0.08	0.80	NS	0.94

|x| - Mean change; SD – Standart deviation; S – Significant difference; NS – No significant difference

5.2 CHANGES IN CEPHALOMETRIC MEASUREMENTS AND THEIR RELATIONSHIPS TO OVERBITE

The group 1, 2, 3, and overall mean values for all the studied parameters and results of ANOVA and Tukey's analysis are given in Table 5.3. Normal values as presented by Downs (1948), Riolo (1974), Ricketts (1981), McNamara (1984), Siriwat & Jarabak (1985), and Nanda (1988) are also presented in this table.

Table 5.3 Mean values and ANOVA and Tukey's results of all investigated cephalometric measurements.

Variable	Norm. value	Mean	Group 1	Group 2	Group 3	P value (ANOVA)	Tukey's
OB 9 ceph	2.5	2.93	4.46	2.86	1.39	P<0.001	P<0.05 all differ from each other
OB 12 ceph	2.5	3.66	5.47	3.51	1.99	P<0.001	P<0.05 all differ from each other
OB 20 ceph	2.5	3.21	5.73	2.86	1.08	P<0.001	P<0.05 all differ from each other
OJ 9 cast	2.5	3.20	3.51	3.10	3.01	N/S p=0.26	N/S
OJ 12 cast	2.5	3.39	3.81	3.33	3.05	N/S p=0.06	N/S
OJ 20 cast	2.5	2.83	3.39	2.80	2.29	P<0.05	P<0.05 groups 1 and 3 differ from each other
S-Ar/9	31	32.21	31.76	32.20	32.68	N/S p=0.54	N/S
S-Ar/12	33	34.77	34.3	34.58	35.52	N/S p=0.37	N/S
S-Ar/20	37	37.58	37.71	37.14	38.06	N/S p=0.65	N/S
Ar-Go/9	39.5	41.45	41.87	41.04	41.61	N/S P=0.66	N/S
Ar-Go/12	44	45.12	46.12	44.12	45.5	N/S p=0.16	N/S
Ar-Go/20	53	53.35	55.21	51.87	53.50	P<0.05	P<0.05 groups 1 and 2 differ from each other
S-Go/9	67.5	69.89	69.90	69.61	70.28	N/S p=0.85	N/S
S-Go/12	75	75.72	76.28	74.60	76.72	N/S p=0.23	N/S

S-Go/20	85	86.16	87.83	84.42	86.88	N/S p=0.14	N/S
S-Ar/Ar- Go/9	75	78.16	76.33	78.72	79.26	N/S p=0.49	N/S
S-Ar/Ar-Go/12	75	77.60	74.66	78.92	78.78	N/S p=0.20	N/S
S-Ar/Ar-Go/20	75	70.79	68.53	71.95	71.49	N/S p=0.26	N/S
ANS-Me/9	62.6	60.90	60.14	60.74	61.93	N/S p=0.14	N/S
ANS-Me/12	66	64.11	63.17	63.83	65.49	N/S p=0.12	N/S
ANS-Me/20	71.5	70.03	68.72	69.07	72.75	N/S p<0.05	P<0.05 group 1 and 2 differ from group 3
N-Me/9	107.5	105.90	105.04	106.36	106.14	N/S p=0.52	N/S
N-Me/12	115	113.24	112.62	113.11	114.07	N/S p=0.65	N/S
N-Me/20	132	124.07	124.32	123.24	124.98	N/S p=0.67	N/S
ANS-Me/N-Me/9	56	57.53	57.30	57.11	58.35	N/S p=0.13	N/S
ANS-Me/N-Me/12	56	56.62	56.10	56.43	57.43	N/S p=0.14	N/S
ANS-Me/N-Me/20	56	56.43	55.30	56.00	58.17	P<0.05	P<0.05 group 1 and 2 differ from group 3
S-Go/N-Me/9	65	66.04	66.65	65.47	66.23	N/S p=0.50	N/S
S-Go/N-Me/12	65	66.91	67.80	65.99	67.27	N/S p=0.17	N/S
S-Go/N-Me/20	65	69.47	70.70	68.52	69.55	N/S p=0.17	N/S
A6-PT/9	12	11.83	12.06	11.39	12.21	N/S p=0.49	N/S
A6-PT/12	15	16.61	17.22	16.24	16.50	N/S p=0.60	N/S
A6-PT/20	24	23.66	24.79	23.13	23.23	N/S p=0.36	N/S
UI-PP/9	27	26.42	26.65	26.43	26.18	N/S p=0.73	N/S
UI-PP/12	29	28.17	28.19	28.24	28.07	N/S p=0.97	N/S
UI-PP/20	30	29.78	29.68	29.48	30.31	N/S p=0.60	N/S
LI-MP/9	39	33.29	34.01	32.96	32.99	N/S p=0.21	N/S
LI-MP/12	42	35.48	36.39	34.83	35.43	N/S p=0.09	N/S
LI-MP/20	44	38.61	39.79	37.71	38.68	N/S p=0.11	N/S
U6-PP/9	19	17.39	17.07	17.59	17.42	N/S p=0.54	N/S
U6-PP/12	24	20.27	20.18	20.36	20.23	N/S p=0.94	N/S
U6-PP/20	25	24.37	23.82	24.19	25.21	N/S p=0.13	N/S
L6-MP/9	29	26.04	26.13	25.84	26.23	N/S p=0.78	N/S
L6-MP/12	32	27.44	27.58	26.94	28.01	N/S p=0.24	N/S
L6-MP/20	35	31.08	31.36	30.41	31.73	N/S p=0.27	N/S
MPA/9	26	24.34	24.31	24.47	24.19	N/S p=0.97	N/S
MPA/12	25	22.86	22.30	23.34	22.76	N/S p=0.60	N/S
MPA/20	22	19.93	18.79	20.32	20.59	N/S p=0.31	N/S
PPA/9	7.3	4.80	5.16	5.56	3.33	p<0.05	P<0.05 group 2 and 3 differ from each

							other
PPA/12	7.3	5.62	6.13	6.22	4.21	N/S p=0.05	N/S
PPA/20	7.3	6.82	7.65	7.56	4.90	P<0.05	P<0.05 groups 1 and 2 differ from group 3
OPA/9	9.3	9.94	10.53	10.06	9.15	N/S p=0.38	N/S
OPA/12	9.3	7.51	7.36	7.71	7.37	N/S p=0.91	N/S
OPA/20	9.3	4.37	4.03	4.69	4.27	N/S p=0.79	N/S
FH/N-Pog/9	85	85.86	85.05	86.08	86.40	N/S p=0.21	N/S
FH/N-Pog/12	86	87.65	87.29	87.73	87.91	N/S p=0.78	N/S
FH/N-Pog/20	89	90.00	89.56	90.19	90.21	N/S p=0.76	N/S
Y-Axis/9	66	64.60	64.26	64.97	64.41	N/S p=0.64	N/S
Y-Axis/12	66	64.66	64.28	65.05	64.48	N/S p=0.61	N/S
Y-Axis/20	66	64.61	64.53	64.96	64.19	N/S p=0.68	N/S
Ba-N/PT-Gn/9	90	90.52	91.24	89.55	91.16	N/S p=0.09	N/S
Ba-N/PT-Gn/12	90	90.73	92.05	89.67	90.84	p<0.05	P<0.05 groups 1 and 2 differ from each other
Ba-N/PT-Gn/20	90	91.36	92.47	90.23	91.8	N/S p=0.05	N/S
ANS-Xi-PM/9	46	42.49	41.51	42.59	43.37	N/S p=0.09	N/S
ANS-Xi-PM/12	46	41.90	40.67	42.11	42.90	N/S p=0.07	N/S
ANS-Xi-PM/20	46	42.03	40.11	42.03	44.02	p<0.05	P<0.05 groups 1 and 3 differ from each other
DC-Xi/Xi-PM/9	22.5	33.69	32.87	34.11	33.96	N/S p=0.60	N/S
DC-Xi/Xi-PM/12	24.4	35.49	35.32	35.81	35.21	N/S p=0.83	N/S
DC-Xi/Xi-PM/20	29.2	38.70	39.22	38.60	38.30	N/S p=0.78	N/S
UI-PP'/9	112	109.71	108.49	109.54	111.22	N/S p=0.35	N/S
UI-PP'/12	112	110.58	108.63	110.98	112.06	N/S p=0.15	N/S
UI-PP'/20	112	112.71	109.08	113.90	114.81	p<0.05	P<0.05 groups 2 and 3 differ from group 1
LI-MP'/9	95	96.18	96.85	95.41	96.60	N/S p=0.69	N/S
LI-MP'/12	95	96.88	98.15	96.01	96.79	N/S p=0.57	N/S
LI-MP'/20	95	96.44	97.14	96.49	95.62	N/S p=0.84	N/S
UI-LI/9	124	128.19	129.87	129.20	124.98	N/S p=0.17	N/S
UI-LI/12	126	128.03	130.25	128.05	125.69	N/S p=0.26	N/S
UI-LI/20	129	129.54	134.55	127.99	126.52	p<0.05	P<0.05 groups 2 and 3 differ from

							group 1
PP-MP/9	28	25.91	24.79	25.84	27.20	N/S p=0.14	N/S
PP-MP/12	28	24.50	22.97	24.95	25.44	N/S p=0.09	N/S
PP-MP/20	28	21.32	19.26	21.62	23.07	p<0.05	P<0.05 group 1 differ from group 3
PP-OP/9	10	11.51	11.00	11.43	12.17	N/S p=0.43	N/S
PP-OP/12	10	9.15	8.04	9.33	10.04	N/S p=0.06	N/S
PP-OP/20	10	5.76	4.51	5.99	6.74	p<0.05	P<0.05 group 1 differ from group 3
MP-OP/9	15	14.40	13.80	14.41	15.03	N/S p=0.44	N/S
MP-OP/12	16.2	15.36	14.93	15.64	15.41	N/S p=0.70	N/S
MP-OP/20	17.5	15.57	14.76	15.63	16.32	N/S p=0.38	N/S

Descriptive statistics and results of paired *t*-test for incremental changes in various parameters evaluated during three periods of growth – 9 to 12 years, 12 to 20 years, and 9 to 20 years are presented in Table 5.4.

Table 5.4 Descriptive statistics and results of paired *t*-test for incremental changes in various parameters evaluated during three growth periods.

Variable	**Changes from ages 9 to 12 years**			**Changes from ages 12 to 20 years**			**Changes from ages 9 to 20 years**		
	x	**SD**	***t*-test**	**x**	**SD**	***t*-test**	**x**	**SD**	***t*-test**
OB	0.35	0.76	NS	-0.67	0.91	S	-0.32	1.07	NS
S-Ar	2.56	1.67	S	2.81	2.06	S	5.37	2.35	S
Ar-Go	3.67	2.95	S	8.23	4.60	S	11.90	3.84	S
S-Go	5.82	3.09	S	10.44	5.29	S	16.26	4.68	S
S-Ar/Ar-Go	-0.56	6.12	NS	-6.81	6.26	S	-7.37	6.39	S
ANS-Me	3.21	2.01	S	5.92	3.79	S	9.13	3.33	S
N-Me	7.34	3.20	S	10.83	5.36	S	18.17	4.68	S
ANS-Me/N-Me	-0.90	0.98	S	-0.20	1.32	NS	-1.10	1.60	S
S-Go/N-Me	0.86	1.70	S	2.57	2.20	S	3.43	2.64	S
A6-PT	4.78	2.45	S	7.05	3.18	S	11.83	3.43	S
UI-PP	1.75	1.16	S	1.60	1.55	S	3.36	1.76	S
LI-MP	2.19	1.41	S	3.14	2.07	S	5.33	2.12	S

U6-PP	2.88	1.49	S	4.10	1.97	S	6.98	1.92	S
L6-MP	1.40	1.32	S	3.64	2.01	S	5.04	2.04	S
MPA	-1.48	1.89	S	-2.93	2.19	S	-4.41	3.11	S
PPA	0.82	1.61	S	1.21	1.58	S	2.02	2.06	S
OPA	-2.43	2.28	S	-3.14	2.12	S	-5.57	3.12	S
FH/N-Pog	1.79	1.93	S	2.35	1.88	S	4.14	2.50	S
Y-Axis	0.06	1.13	NS	-0.05	1.23	NS	0.01	1.67	NS
Ba-N/PT-Gn	0.20	1.59	NS	0.63	1.79	S	0.83	2.40	S
ANS-Xi-PM	-0.59	1.81	S	0.12	2.06	NS	-0.46	2.62	NS
DC-Xi/Xi-PM	1.80	3.42	S	3.21	3.34	S	5.01	4.28	S
UI-PP'	0.87	3.87	S	2.13	4.13	S	3.00	5.43	S
LI-MP'	0.70	3.19	S	-0.44	3.81	NS	0.25	4.40	NS
UI-LI	-0.16	5.02	NS	1.51	5.81	S	1.36	6.91	S
PP-MP	-1.42	1.90	S	-3.18	2.41	S	-4.59	3.10	S
PP-OP	-2.36	2.32	S	-3.39	2.56	S	-5.75	2.80	S
MP-OP	0.96	1.71	S	0.21	1.95	NS	1.17	2.22	S

x – Mean; SD – Standard deviation; S – Significant change; NS – Not significant change. Positive numbers denote increase in the measurement and the negative numbers – decrease in the measurement between the two ages.

5.2.1 OVERBITE (OB)

Subjects were divided into three groups of deep (group 1), normal (group 2), and minimal overbite (group 3) based on the last available plaster model (age 20). The descriptive statistics for overbite in all three groups are presented in Table 5.5. Incredible variability of overbite changes and ranges of overbite at all ages is evident from this table.

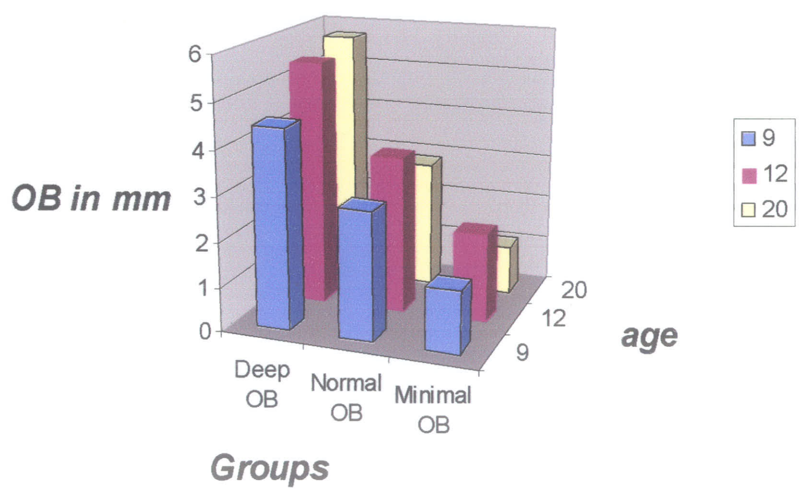
Table 5.5 Descriptive overbite statistics of overbite at 9, 12, and 20 years of age for all three groups.

Overbite group	Age	Mean	SD	SE	Min	Max	Range
1	9	4.46	1.86	0.40	0.2	8.1	7.9
	12	5.47	1.44	0.31	3.6	9.3	5.7
	20	5.73	1.63	0.35	3.7	9.2	5.5
2	9	2.88	1.31	0.24	0.5	5.3	4.8
	12	3.51	0.98	0.18	1.3	5.4	4.1
	20	2.86	0.87	0.16	1.2	4.6	3.4
3	9	1.39	1.23	0.27	-0.5	4.1	4.6
	12	1.99	1.34	0.29	-0.3	5.3	5.6
	20	1.08	0.78	0.17	-0.6	2.4	3.0

Group 1 – deep overbite, group 2 – normal overbite, group 3 – minimal overbite, SD – Standard Deviation, SE – Standard Error, Min – Minimum value, Max – Maximum value

Overbite was found to be significantly different between the groups at all ages (Table 5.3). None of the groups showed statistically significant changes in overbite over time and the changes during both periods of growth (9-12 and 12-20 years) were similar (x=0.68mm) (Table 5.4). For both groups 2 (normal overbite) and 3 (minimal overbite) overbite increased between the ages 9 and 12 and then decreased between the ages 12 and 20. For group 1 the overbite increased in both growth periods (Figure 5.1). This pattern was similar for males and females.

Figure 5.1 Comparison of overbite changes in different age groups



The overbite for 9 and 12 years old females in group 1 was significantly smaller than the overbite for 9 and 12 years old males. This influenced the mean overbite differences between males and females for all three groups, which was also statistically significant. Overbite at age 20 years showed a similar trend but the difference was not significant. This can be seen from the Table 5.6.

Table 5.6 Results of *Overbite* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
OB/9	**2.93**		**4.46**		**2.88**		**1.39**	
	2.50	3.25	2.86	5.38	2.85	2.91	1.49	1.33
OB/12	**3.66**		**5.47**		**3.51**		**1.99**	
	3.28	3.95	4.70	5.91	3.33	3.70	1.76	2.13
OB/20	**3.21**		**5.73**		**2.86**		**1.08**	
	3.01	3.36	5.03	6.13	2.72	3.00	1.54	0.79

5.2.2 POSTERIOR CRANIAL BASE (S-Ar)

The parameter S-Ar increased 2.56 mm between age 9 and 12 years and 2.81 mm between ages 12 and 20 years, which was statistically significant (Table 5.4). This value was not significantly different between the groups (Table 5.3). The mean length of posterior cranial base in 20 years old females was significantly lower than the mean length in 20 years old males in all three groups (Table 5.7).

Table 5.7 Results of *Posterior cranial base* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
S-Ar/9	**32.21**		**31.77**		**32.20**		**32.68**	
	31.84	32.48	31.19	32.10	32.10	32.30	31.99	33.10
S-Ar/12	**34.77**		**34.30**		**34.58**		**35.52**	
	34.42	35.03	34.49	34.19	34.25	34.92	34.66	36.05
S-Ar/20	**37.58**		**37.71**		**37.14**		**38.06**	
	35.90	38.82	36.46	38.43	35.97	38.31	35.20	39.82

5.2.3. LOWER POSTERIOR FACE HEIGHT (Ar-Go)

This value increased 3.67 mm in the first growth period and 8.23 mm in the second growth period (Table 5.4). The ramus height in group 1 was significantly longer ($P<0.05$) than the ramus height in the group 2 in 20 years old subjects. Differences in groups 2 and 3 at age 20 years were not statistically significant, however, this parameter was smaller in group 2 than in group 3. At ages 9 and 12 years there was no specific pattern of differences and the differences were not statistically significant (Table 5.3). At age 20 years the ramus height was significantly larger in males in all three groups (Table 5.8).

Table 5.8 Results of *Lower posterior face height* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
Ar-Go/9	**41.45**		**41.87**		**41.04**		**41.61**	
	41.27	41.59	42.08	41.75	41.15	40.93	40.68	42.19
Ar-Go/12	**45.12**		**46.12**		**44.12**		**45.5**	
	46.07	44.42	46.98	45.64	45.35	42.89	46.53	44.87
Ar-Go/20	**53.35**		**55.21**		**51.87**		**53.51**	
	50.62	55.37	51.55	57.31	49.93	53.81	50.98	55.07

5.2.4 TOTAL POSTERIOR FACE HEIGHT (S-Go)

This value increased in both growth periods (Table 5.4) and the only significant difference found was that in females at age 20 years total posterior face height was significantly smaller than in males in all three groups Tables 5.3 and 5.9).

Table 5.9 Results of *Total posterior face height* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
S-Go/9	**69.89**		**69.91**		**69.61**		**70.28**	
	69.42	70.25	69.48	70.15	69.53	69.70	69.15	70.98
S-G0/12	**75.72**		**76.28**		**74.60**		**76.72**	
	76.16	75.39	77.39	75.65	75.21	73.99	76.73	76.72
S-Go/20	**86.16**		**87.83**		**84.42**		**86.88**	
	81.97	89.25	83.46	90.33	81.33	87.51	81.68	90.09

5.2.5 RELATIVE POSTERIOR CRANIAL BASE (S-Ar/Ar-Go)

This value decreased 0.56% in the first growth period and decreased again 6.81% between the ages 12 and 20 years (Table 5.4). There was no specific pattern observed between the groups. None of the measurements were statistically different (Tables 5.3 and 5.10).

Table 5.10 Results of *Relative posterior cranial base* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
S-Ar/Ar-Go/9	**78.16**		**76.34**		**78.72**		**79.26**	
	77.72	78.48	74.25	77.53	78.25	79.20	80.20	78.68
S-Ar/Ar-Go/12	**77.60**		**74.66**		**78.92**		**78.78**	
	75.27	79.32	73.60	75.27	75.97	81.87	75.61	80.72
S-Ar/Ar-Go/20	**70.79**		**68.53**		**71.95**		**71.49**	
	71.33	70.38	70.71	67.29	72.58	71.31	69.60	72.64

5.2.6 LOWER ANTERIOR FACE HEIGHT (ANS-Me)

This value increased 3.21 mm in the first growth period and 5.92 mm in the second (Table 5.4). The overall mean value for anterior face height in group 3 was significantly higher than the same values in groups 1 and 2 at age 20 years (Table 5.3). The mean value in females was significantly lower than the same value in males at 9 and 20 (but not 12) years of age. There were no statistically significant differences between the groups for female subjects at all ages; however, males showed significantly lower values in group 1 than in group 3 (Table 5.11).

Table 5.11 Results of *Lower anterior face height* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
ANS-Me/9	**60.90**		**60.14**		**60.74**		**61.93**	
	59.72	61.77	59.05	60.76	60.12	61.35	59.64	63.35
ANS/Me/12	**64.11**		**63.17**		**63.83**		**65.49**	
	63.55	64.52	63.28	63.11	63.59	64.08	63.75	66.55
ANS-Me/20	**70.03**		**68.72**		**69.07**		**72.75**	
	66.43	72.68	66.28	70.12	66.56	71.58	66.34	76.70

5.2.7 TOTAL ANTERIOR FACE HEIGHT (N-Me)

This parameter increased 7.34 mm in the first growth period and 10.83 mm in the second (Table 5.4). There were no statistically significant differences between the groups at any ages (Table 5.3). The mean total anterior face height for females was significantly smaller that the same value for males at 20 years of age in all the groups (Table 5.12).

Table 5.12 Results of *Total anterior face height* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
N-Me/9	**105.90**		**105.04**		**106.36**		**106.14**	
	104.65	106.83	101.94	106.81	106.60	106.13	103.69	107.65
N-Me/12	**113.24**		**112.62**		**113.11**		**114.07**	
	112.72	113.62	112.10	112.91	113.50	112.73	111.89	115.41
N-Me/20	**124.07**		**124.32**		**123.24**		**124.98**	
	118.56	128.13	118.20	127.82	119.82	126.66	116.56	130.16

5.2.8 RELATIVE LOWER ANTERIOR FACE HEIGHT (ANS-Me/N-Me)

This value decreased 0.90% in the first growth period and decreased again 0.20% in the second (Table 5.4). The mean value in group 3 is significantly higher than the same values in groups 1 and 2 at age 20 years for males only (Table 5.13). This influenced the overall mean value in this group that also was found to be statistically different from the other two groups (Table 5.3).

Table 5.13 Results of *Relative lower anterior face height* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
ANS-Me/N-Me/9	**57.53**		**57.30**		**57.11**		**58.35**	
	57.09	57.84	57.98	56.91	56.39	57.83	57.54	58.85
ANS-Me/N-Me/12	**56.62**		**56.11**		**56.43**		**57.43**	
	56.39	56.79	56.49	55.89	56.01	56.85	56.99	57.70
ANS-Me/N-Me/20	**56.43**		**55.30**		**56.02**		**58.18**	
	56.02	56.72	56.05	54.87	55.52	56.53	56.94	58.94

5.2.9 ANTERIOR TO POSTERIOR FACE HEIGHT (S-Go/N-Me)

This value showed a statistically significant increase in the first and second growth periods (0.86% and 2.57%, respectively) (Table 5.4). There were no statistically significant differences between the groups for both males and females. Moreover, no specific pattern was found in the changes (Tables 5.3 and 5.14).

Table 5.14 Results of *Anterior to Posterior face height* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
S-Go/N-Me/9	**66.04**		**66.65**		**65.47**		**66.24**	
	66.38	65.80	68.23	65.74	65.23	65.71	66.69	65.96
S-Go/N-Me/12	**66.91**		**67.81**		**65.99**		**67.27**	
	67.59	66.40	69.03	67.11	66.30	65.68	68.58	66.47
S-Go/N-Me/20	**69.47**		**70.70**		**68.52**		**69.55**	
	69.16	69.71	70.59	70.76	67.91	69.13	70.08	69.23

5.2.10 SPACE AVAILABLE FOR THE UPPER SECOND MOLAR (A6-PT)

This parameter increased significantly in both growth periods (4.78 mm between 9 and 12 years of age and 7.05 mm between 12 and 20 years of age) (Table 5.4). The only significant difference observed was that at age 20 years the mean value for females was significantly lower than the same value among males in all three groups (Tables 5.3 and 5.15).

Table 5.15 Results of *Space available for the upper second molar* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
A6-PT/9	**11.83**		**12.06**		**11.39**		**12.21**	
	11.78	11.86	12.19	11.99	10.85	11.93	13.11	11.66
A6-PT/12	**16.61**		**17.22**		**16.24**		**16.50**	
	17.13	16.22	18.56	16.46	16.32	16.15	17.21	16.05
A6-PT/20	**23.66**		**24.79**		**23.13**		**23.23**	
	22.16	24.77	23.95	25.26	21.43	24.84	21.73	24.16

5.2.11 UPPER INCISOR LENGTH (UI-PP)

The distance between the upper incisal edge and palatal plane increased 1.75 mm in the first growth period and again 1.55 mm in the second (Table 5.4). There were no statistically significant differences between the three groups in this measurement (Table 5.3); however, females showed a significantly shorter upper incisor at 9 and 20 (but not 12) years of age (Table 5.16).

Table 5.16 Results of *Upper incisor length* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
UI-PP/9	**26.42**		**26.65**		**26.43**		**26.18**	
	25.73	26.93	25.41	27.35	26.23	26.62	25.10	26.84
UI-PP/12	**28.17**		**28.19**		**28.24**		**28.07**	
	27.62	28.58	27.34	28.67	28.13	28.35	26.94	28.76
UI-PP/20	**29.78**		**29.68**		**29.48**		**30.31**	
	28.74	30.54	28.56	30.31	28.98	29.98	28.48	31.43

5.2.12 LOWER INCISOR LENGTH (LI-MP)

This value increased 2.19 mm between 9 and 12 years of age and 2.07 mm between 12 and 20 years of age (Table 5.4). There were no statistically significant differences between the three overbite groups (Table 5.3); however, at all ages this parameter was smaller among females than among males in all three groups (Table 5.17).

Table 5.17 Results of *Lower incisor length* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
LI-MP/9	**33.29**		**34.01**		**32.96**		**32.99**	
	32.32	34.00	32.46	34.90	32.57	33.34	31.71	33.78
LI-MP/12	**35.48**		**36.39**		**34.83**		**35.44**	
	34.68	36.07	36.06	36.58	34.17	35.49	34.24	36.18
LI-MP/20	**38.61**		**39.79**		**37.71**		**38.68**	
	36.10	40.47	37.84	40.90	35.69	39.72	35.11	40.87

5.2.13 UPPER MOLAR LENGTH (U6-PP)

This distance increased 2.88 mm in the first growth period and 4.10 mm in the second (Table 5.4). There were no statistically significant differences between the groups (Table 5.3); however, at 20 years of age the mean value for upper molar length was significantly lower in females than males in all three groups (Table 5.18).

Table 5.18 Results of *Upper molar length* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
U6-PP/9	**17.39**		**17.07**		**17.59**		**17.42**	
	17.45	17.34	17.21	16.99	17.67	17.51	17.28	17.52
U6-PP/12	**20.27**		**20.18**		**20.36**		**20.23**	
	20.68	19.96	20.61	19.94	20.61	20.10	20.89	19.82
U6-PP/20	**24.37**		**23.82**		**24.19**		**25.21**	
	23.29	25.17	22.65	24.49	23.53	24.85	23.48	26.28

5.2.14 LOWER MOLAR LENGTH (L6-MP)

Lower molar length increased 1.40 mm in the first growth period and 3.64 mm in the second (Table 5.4.). There were no significant differences between the three groups at any age (Table 5.3); however, at 20 years of age females showed a significantly smaller L6-MP measurement than males in all three groups (Table 5.19).

Table 5.19 Results of *Lower molar length* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
L6-MP/9	**26.04**		**26.13**		**25.84**		**26.23**	
	25.59	26.37	25.46	26.51	25.61	26.08	25.69	26.57
L6-MP/12	**27.44**		**27.58**		**26.94**		**28.01**	
	27.08	27.71	27.68	27.53	26.71	27.17	27.18	28.53
L6-MP/20	**31.08**		**31.36**		**30.41**		**31.73**	
	29.09	32.54	29.78	32.26	28.70	32.13	29.15	33.32

5.2.15 MANDIBULAR PLANE ANGLE (MPA)

MPA decreased 1.48° between 9 and 12 years of age and decreased again 2.93° between 12 and 20 years of age (Table 5.4). The only significant difference that was found between the three groups was that males in the minimal overbite group had a significantly steeper MPA in comparison to females at all ages (Tables 5.3 and 5.20).

Table 5.20 Results of *Mandibular plane angle* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
MPA/9	**24.34**		**24.31**		**24.47**		**24.19**	
	23.57	24.91	23.61	24.71	24.21	24.72	22.33	25.34
MPA/12	**22.86**		**22.30**		**23.34**		**22.76**	
	22.07	23.45	22.10	22.41	22.83	23.86	20.60	24.09
MPA/20	**19.93**		**18.79**		**20.32**		**20.59**	
	19.75	20.07	19.56	18.34	20.52	20.11	18.50	21.88

5.2.16 PALATAL PLANE ANGLE (PPA)

This angle increased 0.82° in the first growth period and increased again 1.21° in the second (Table 5.4). At age 9 years this value was significantly smaller in group 3 than in group 2 and at age 20 years the group 3 showed a significantly smaller value than both groups 1 and 2 (Table 5.3). This difference was more pronounced in males than in females (Table 5.21).

Table 5.21 Results of *Palatal plane angle* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
PPA/9	**4.80**		**5.16**		**5.56**		**3.33**	
	5.35	4.39	4.06	5.79	6.35	4.76	4.76	2.45
PPA/12	**5.62**		**6.13**		**6.22**		**4.21**	
	6.26	5.14	5.71	6.36	6.81	5.63	5.78	3.25
PPA/20	**6.82**		**7.65**		**7.56**		**4.90**	
	7.23	6.52	6.51	8.30	7.99	7.13	6.51	3.91

5.2.17 OCCLUSAL PLANE ANGLE (OPA)

This angle decreased 2.43° in the first growth period and 3.14° in the second (Table 5.4). No significant differences or patterns were observed between the groups (Tables 5.3 and 5.22).

Table 5.22 Results of *Occlusal plane angle* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
OPA/9	**9.94**		**10.53**		**10.06**		**9.15**	
	9.56	10.22	9.78	10.96	10.01	10.11	8.51	9.55
OPA/12	**7.51**		**7.36**		**7.71**		**7.37**	
	6.74	8.08	6.64	7.78	7.45	7.97	5.49	8.52
OPA/20	**4.37**		**4.03**		**4.69**		**4.27**	
	4.81	4.05	4.89	3.54	5.08	4.29	4.23	4.3

5.2.18 FACIAL ANGLE (FH/N-Pog)

This angle increased 1.79° between 9 and 12 years of age and 2.35° between 12 and 20 years of age (Table 5.4). There were no statistically significant differences between the groups (Table 5.3). The only significant gender difference was at age 12 years where the facial angle was significantly higher among females than males, which was more pronounced in group 3 (Table 5.23).

Table 5.23 Results of *Facial angle* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
FH/N-Pog/9	**85.86**		**85.05**		**86.08**		**86.40**	
	86.49	85.40	86.36	84.29	86.23	85.93	87.10	85.96
FH/N-Pog/12	**87.65**		**87.29**		**87.74**		**87.91**	
	88.70	86.88	88.83	86.41	88.24	87.23	89.43	86.97
FH/N-Pog/20	**90.00**		**89.56**		**90.19**		**90.21**	
	90.33	89.76	90.44	89.05	89.73	90.64	91.34	89.51

5.2.19 Y-Axis

Y-Axis was found to be the only angle to remain stable in both growth periods in all the groups at all ages (Tables 5.3 and 5.4). It was not shown to be significantly different between the three groups at any ages or between genders (Tables 5.3 and 5.24).

Table 5.24 Results of *Y-Axis* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
Y-Axis/9	**64.60**		**64.26**		**64.97**		**64.41**	
	64.38	64.75	62.26	65.40	65.56	64.38	64.30	64.49
Y-Axis/12	**64.66**		**64.28**		**65.05**		**64.48**	
	64.29	64.92	62.74	65.16	65.29	64.81	63.98	64.79
Y-Axis/20	**64.61**		**64.53**		**64.96**		**64.19**	
	64.35	64.80	62.86	65.48	65.51	64.42	63.68	64.51

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

This angle increased only 0.20° in the first growth period and 0.63° in the second growth period (Table 5.4). At age 12 years the mean value for facial axis in group 1 was significantly higher than in group 2 (Table 5.3). There were no gender differences for this measurement (Table 5.25).

Table 5.25 Results of *Facial Axis* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
Ba-N/PT-Gn/9	**90.52**		**91.24**		**89.55**		**91.16**	
	90.57	90.49	92.45	90.54	89.23	89.87	91.18	91.15
Ba-N/PT-Gn/12	**90.73**		**92.05**		**89.67**		**90.84**	
	90.98	90.54	93.15	91.42	89.57	89.77	91.45	90.46
Ba-N/PT-Gn/20	**91.36**		**92.47**		**90.23**		**91.80**	
	91.27	91.42	92.81	92.27	89.88	90.58	92.34	91.47

5.2.21 LOWER ANTERIOR FACE HEIGHT (ANS-Xi-PM)

This angle decreased 0.59° between ages 9 and 12 and increased 0.12° in the second growth period, showing insignificant overall change of 0.46° between ages 9 and 20 (Table 5.4). At age 20 years the lower anterior face height (ANS-Xi-PM) in group 1 was significantly smaller than the same value in group 3 (Table 5.3). It was more pronounced in males than females (Table 5.26).

Table 5.26 Results of *Lower anterior face height* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
ANS-Xi-PM/9	**42.49**		**41.51**		**42.59**		**43.37**	
	42.03	42.83	41.11	42.73	42.68	42.51	41.73	44.39
ANS-Xi-PM/12	**41.90**		**40.67**		**42.11**		**42.90**	
	41.71	42.05	40.34	40.86	42.43	41.78	41.73	43.62
ANS-Xi-PM/20	**42.03**		**40.11**		**42.03**		**44.02**	
	41.44	42.46	39.83	40.28	42.13	41.93	41.74	45.42

5.2.22 MANDIBULAR ARC (DC-Xi/Xi-PM)

This measurement increased 1.80° in the first growth period and 3.21° in the second growth period (Table 5.4). There were no significant differences between the three groups among males and females (Tables 5.3 and 5.27).

Table 5.27 Results of *Mandibular arc changes* in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
DC-Xi/Xi-PM/9	**33.69**		**32.87**		**34.11**		**33.96**	
	34.81	32.86	33.85	32.31	34.16	34.06	37.00	32.09
DC-Xi/Xi-PM/12	**35.49**		**35.32**		**35.81**		**35.21**	
	36.42	34.80	35.94	34.96	36.05	35.57	37.60	33.74
DC-Xi/Xi-PM/20	**38.70**		**39.22**		**38.60**		**38.30**	
	39.03	38.46	38.38	39.70	38.65	38.55	40.40	37.01

5.2.23 UPPER INCISOR PROCLINATION (UI-PP')

Upper incisors became 0.87° more proclined in the first growth period and 2.13° in the second growth period (Table 5.4). In the deep overbite group the upper incisors are more upright in comparison with the minimal overbite group at age 20 years only (Table 5.3). This was true for both males and females (Table 5.28).

Table 5.28 Results of *Upper incisor proclination* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
UI-PP'/9	**109.71**		**108.49**		**109.54**		**111.22**	
	111.10	108.68	111.64	106.69	109.71	109.38	113.19	110.01
UI-PP'/12	**110.58**		**108.63**		**110.98**		**112.06**	
	111.75	109.72	111.18	107.17	110.60	111.36	114.49	110.57
UI-PP'/20	**112.71**		**109.08**		**113.90**		**114.81**	
	113.37	112.23	109.59	108.79	113.45	114.36	117.01	113.46

5.2.24 LOWER INCISOR PROCLINATION (LI-MP')

Lower incisors proclined 0.70° in the first growth period and uprighted again 0.44° in the second growth period, showing an overall change of only 0.25° between 9 and 20 years of age (Table 5.4). There were no significant differences between the three groups (Table 5.3) and the only gender differences were obvious in group 3 in which females had more proclined lower incisors than males (Table 5.29).

Table 5.29 Results of *Lower incisor proclination* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
LI-MP'/9	**96.18**		**96.85**		**95.41**		**96.60**	
	97.08	95.52	97.33	96.58	95.40	95.41	99.98	94.52
LI-MP'/12	**96.88**		**98.15**		**96.01**		**96.79**	
	96.78	96.95	96.79	98.93	95.24	96.78	99.68	95.01
LI-MP'/20	**96.44**		**97.14**		**96.49**		**95.62**	
	97.40	95.72	97.21	97.09	96.68	96.31	98.95	93.58

5.2.25 INTERINCISAL ANGLE (UI-LI)

This angle increased only 1.36° between 9 and 20 years of age (Table 5.4). At age 20 years the interincisal angle in group 1 was significantly larger than in groups 2 and 3 for both males and females (Tables 5.3 and 5.30). In group 3 this measurement was much higher in males than females (Table 5.30).

Table 5.30 Results of *Interincisal angle* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
UI-LI/9	**128.19**		**129.87**		**129.2**		**124.98**	
	126.97	129.09	127.14	131.43	129.48	128.92	122.09	126.76
UI-LI/12	**128.03**		**130.25**		**128.05**		**125.69**	
	128.11	127.97	129.96	130.41	129.74	126.35	123.21	127.21
UI-LI/20	**129.54**		**134.55**		**127.99**		**126.52**	
	128.17	130.56	133.29	135.26	127.99	128	123.39	128.45

5.2.26 PALATAL TO MANDIBULAR PLANE ANGLE (PP-MP)

This angle decreased 1.42° between ages 9 and 12 and again 3.18° between ages 12 and 20 (Table 5.4). At age 20 years PP-MP value was significantly lower in the deep overbite group in comparison with the minimal overbite group (Table 5.3). In group 3 this angle was significantly smaller in females than males at all ages (Table 5.31).

Table 5.31 Results of *Palatal to Mandibular plane angle* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
PP-MP/9	**25.91**		**24.79**		**25.84**		**27.20**	
	24.86	26.69	23.90	25.30	25.41	26.27	24.78	28.69
PP-MP/12	**24.50**		**22.97**		**24.95**		**25.44**	
	23.35	25.35	22.08	23.49	24.41	25.49	22.61	27.19
PP-MP/20	**21.32**		**19.26**		**21.62**		**23.07**	
	21.07	21.51	19.94	18.86	21.89	21.34	20.66	24.55

5.2.27 PALATAL TO OCCLUSAL PLANE ANGLE (PP-OP)

This angle decreased 2.36° in the first growth period and 3.39° in the second growth period (Table 5.4). At ages 12 and 20 years the PP-OP angle was significantly smaller in the deep overbite group in comparison with the minimal overbite group (Table 5.3). Both genders showed similar patterns (Table 5.32).

Table 5.32 Results of *Palatal to Occlusal plane angle* changes in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
PP-OP/9	**11.51**		**11.00**		**11.43**		**12.17**	
	10.43	12.01	10.05	11.54	11.20	11.65	10.95	12.92
PP-OP/12	**9.15**		**8.04**		**9.33**		**10.04**	
	8.01	9.98	6.60	8.86	9.05	9.61	7.49	11.62
PP-OP/20	**5.76**		**4.51**		**5.99**		**6.74**	
	6.12	5.49	5.25	4.09	6.45	5.53	6.39	6.95

5.2.28 MANDIBULAR TO OCCLUSAL PLANE ANGLE (MP-OP)

This angle increased 0.96° between 9 and 12 years of age and 0.21° between 12 and 20 years of age. This angle was significantly smaller in group 1 than in group 3 in males only (Tables 5.3 and 5.33).

Table 5.33 Results of *Mandibular to Occlusal plane angle changes* in different periods of growth

Variable	Mean		Group 1		Group 2		Group 3	
	F	M	F	M	F	M	F	M
MP-OP/9	**14.40**		**13.80**		**14.41**		**15.03**	
	14.01	14.69	13.84	13.77	14.21	14.61	13.81	15.78
MP-OP/12	**15.36**		**14.93**		**15.64**		**15.41**	
	15.34	15.37	15.46	14.63	15.37	15.91	15.15	15.56
MP-OP/20	**15.57**		**14.76**		**15.63**		**16.32**	
	14.95	16.03	14.68	14.81	15.45	15.82	14.29	17.58

5.3 RELATIONSHIP BETWEEN OVERBITE AND THE ERUPTION STAGE OF THE SECOND PERMANENT MOLARS.

As seen from Table 5.34, the overbite was deeper in the subjects where the second molars were not in occlusion. However, the differences were not statistically significant. There were also no significant differences between the genders.

Table 5.34 ANOVA and Tukey's Results based on variables by eruption of 7's groupings

Variable	Mean		7's in occlusion		7's not in occlusion	
	F	M	F	M	F	M
OB/20-cast	**3.11**		**2.93**		**3.29**	
	2.97	3.22	2.94	2.92	3.02	3.42
OB/12-cast	**3.79**		**3.49**		**4.07**	
	3.61	3.91	3.57	3.40	3.68	4.25
OB/9-cast	**3.44**		**3.24**		**3.62**	
	3.23	3.59	3.25	3.23	3.19	3.83
OB/9-ceph	**2.93**		**2.51**		**3.31**	
	2.50	3.25	2.38	2.66	2.68	3.60
OB/12-ceph	**3.66**		**3.48**		**3.84**	
	3.28	3.95	3.33	3.65	3.19	4.14
OB/20-ceph	**3.21**		**3.08**		**3.33**	
	3.01	3.36	3.07	3.09	2.91	3.52

5.4 CORRELATION OF OVERBITE WITH SOME CEPHALOMETRIC PARAMETERS THAT WERE FOUND TO HAVE SIGNIFICANT RELATIONSHIPS WITH OVERBITE

Multiple regression analysis revealed few significant correlations:

1. Overbite at age 20 years was significantly correlated with overbite at age 9 years (r=0.74) and overbite at age 12 years (r=0.88).
2. Relative anterior face height (ANS-Me/N-Me) had a significant negative correlation with overbite at ages 9 (r=-0.38), 12 (r=-0.48), and 20 (r=-0.41) years.
3. Lower anterior facial height (ANS-Xi-PM) had a strong negative correlation with overbite at ages 12 and 20 years (r=-0.44 and –0.41 respectively), with much weaker correlation coefficient at age 9 years (r=-0.26).
4. Upper incisor proclination (UI-PP') was negatively correlated to overbite at age 9,12 (r=-0.39 for both) and 20 (r=-0.45) years.

No other significant correlations were found.

CHAPTER 6

DISCUSSION

CHAPTER 6

DISCUSSION

6.1 OVERVIEW

Overbite is a crucial clinical dimension and better understanding of the normal overbite changes as well as related craniofacial and dentoalveolar parameters, over prolonged periods of time, may help orthodontists in more accurate diagnosis and treatment planning. It is generally accepted that various components of the head grow at different rates and according to different patterns; however, significant controversy exists in the literature in regards to how growth processes in different parts of the facial skeleton relate to overbite and to each other. Strong relationships were found between certain cephalometric parameters by some authors, only to be refuted by others (Diamond, 1944; Wylie, 1946; Bjork, 1947; Steadman, 1949; Baume, 1950; Popovich, 1955; Fleming, 1961; Hapak, 1964; Atherton, 1964; Subtelny & Sakuda, 1964; Sassouni & Nanda, 1964; Kapoor, 1968; Sassouni, 1969; Richardson, 1969; Bhatia & Leighton, 1971; Isaacson et al, 1971; Nahoum, Horowitz, & Benedicto, 1972; Andrews, 1972; Herness, Rule, & Williams, 1973; Loufty, 1973; Lowe, 1980; Trouten et al, 1983; Nielsen, 1991; Tsang, Cheung, & Samman, 1997; Beckmann et al, 1998; Bishara & Jakobsen, 1998; Stuani, Matsumoto, & Stuani, 2000; Ceylan & Eröz, 2001; Fujiki et al, 2004; Baydaş et al, 2004).

Anterior open bite and deep overbite are two of the common clinical problems which confront orthodontists. Between the ages 9 and 20 years orthodontic treatment is most frequently proposed and applied. When presented with deep or open bite tendency in a child of 9 years of age, it would be a valuable clinical guide, if the orthodontist could predict whether growth changes in different parts of dentoalveolar skeleton would likely accentuate or minimize the abnormal incisor relationships at a later age.

In general, there seems to be a lack of uniformity of scientific opinion on the dental and skeletal factors that may be associated with variations in the vertical relationship of the incisors. For this reason, it was decided to evaluate the changes in overbite and its relation to other dentoalveolar and skeletal parameters between the ages 9 and 20 years.

6.2 OVERBITE CHANGES AND ITS VARIABILITY

The results of this investigation confirm previous studies which demonstrated an increase in mean overbite from the mixed to early permanent dentition and a gradual decrease from that point into adulthood (Bjork, 1953; Fleming, 1961; Horowitz & Hixon, 1966; Adams, 1972; Herness, Rule, & Williams, 1973; Van der Linden et al, 1979; Sinclair & Little, 1983; Bergersen, 1988; Naumann, Behrents, & Buschang, 2000; Ceylan, Baydas, & Bolukbasi, 2002). In this study, both normal and minimal overbite groups demonstrated this pattern; however, in the deep overbite group the overbite continued to increase in both growth periods. This could be partially explained by a larger overjet in deep overbite group, supporting the hypothesis of Steadman (1949), Bjork (1953), Helm & Petersen (1989), Nielsen (1991), Bergersen (1998), and Tsang, Cheung, & Samman (1997), who hypothesized that when the overjet is increased and there is no contact between the lingual surface of upper incisors and incisal edges of lower incisors, upper and/or lower incisors tend to overerupt leading to an increase in overbite. In the present study the overjet was greater in deep overbite group at all studied ages; however, the difference was statistically significant only at age 20 years (Table 5.3). This finding is not supported by Lowe (1980) who found that overjet was greater in open bite subjects in comparison with those that did not have an open bite.

Fleming (1961) noted that overbite in females was deeper than in males. He contributed this to earlier incisor eruption in females. Results from the present study agree with the majority of the other reviewed literature (Herness, Rule, & Williams, 1973; Van der Linden et al, 1979; Sinclair & Little, 1983; Brunelle, Bhat, & Lipton, 1996; Naumann, Behrents, & Buschang, 2000; Ceylan, Baydas, & Bolukbasi, 2002), showing that males had deeper overbite than females (Table 5.6). This was evident in all studied age groups; however, only at ages 9 and 12 years was this difference statistically significant. An explanation for deeper overbite in males was first offered by Moorrees (1959) and later supported by Herness, Rule, & Williams (1973). They suggested that males have greater clinical crown heights than females, contributing to deeper overbite.

Over time, the mean overbite changes were found to be small; however, the individual variability was large (Table 5.5) and has been pointed out previously by many researchers (Bjork, 1953; Fleming, 1961; Horowitz & Hixon, 1966; Herness, Rule, & Williams, 1973; Bergersen, 1988; Richardson & Richardson, 1993; Bishara & Jakobsen, 1998; Naumann, Behrents, & Buschang, 2000). The range was the greatest in the deep overbite group at all ages.

6.3 RELATIONSHIPS OF OVERBITE WITH VARIOUS SKELETAL AND DENTOALVEOLAR CEPHALOMETRIC PARAMETERS

The results showed statistically significant differences in only a few skeletal and dentoalveolar parameters between the subjects with deep, normal and minimal overbite.

Total (N-Me), lower anterior face heights (ANS-Me & ANS-Xi-PM) and relative lower anterior face height (ANS-Me/N-Me)

In the present study N-Me and ANS-Me measurements increased in both growth periods, which can be expected due to growth. However, the ANS-Xi-PM measurement remained stable, suggesting that the difference between the groups in ANS-Me measurement exists mainly due to the increased distance between PM and Me points in open bite tendency subjects. General agreement exists that N-Me and ANS-Me measurements are greater in open bite individuals (Wylie, 1946; Prakash & Margolis, 1952; Popovich, 1955; Hapak, 1964; Subtelny & Sakuda, 1964; Atherton, 1964; Kapoor, 1968; Sassouni, 1969; Richardson, 1969; Bhatia & Leighton, 1971; Loufty, 1973; Nahoum, Horowitz, & Benedicto, 1972; Nielsen, 1991; Beckmann et al, 1998; Fujiki et al, 2004). In the present study this was found to be true only for ANS-Me measurement for males at all studied ages. This reflects on the

ANS-Me/N-Me measurement that was significantly higher in male subjects with open bite tendency. This is in contrast with one study (Stuani, Matsumoto & Stuani, 2000) that found no differences between the studied groups. Similarly, ANS-Xi-PM was shown to be statistically smaller in males with deep overbite when compared with males with open bite tendency in al age groups. No published research evaluating the differences in ANS-Xi-PM between deep and open bite subjects was found. There were no statistically significant differences in total (N-Me) and lower (ANS-Me) anterior face heights and relative lower anterior face height (ANS-Me/N-Me) between the groups in female subjects.

Posterior cranial base (S-Ar), total (S-Go) and lower (Ar-Go) posterior face heights, relative posterior cranial base (S-Ar/Ar-Go) and anterior to posterior face heights (S-Go/N-Me)

As expected, due to growth, S-Ar, S-Go and Ar-Go measurements increased in both growth periods. The S-Ar/Ar-Go measurement decreased between the ages of 9 and 20 years, suggesting that there is relatively more growth in lower posterior face height than in the posterior cranial base. The S-Go/N-Me measurement increased, showing that there is relatively more growth in posterior than anterior lower face height. There were no significant differences in the S-Ar measurement in both males and females, which is in agreement with Subtelny & Sakuda (1964), Richardson (1969), and Herness, Rule, & Williams (1973). Wylie (1946), Popovich (1955), Subtelny & Sakuda (1964), Richardson (1969), Herness, Rule, & Williams (1973), Ceylan & Eroz (2001), and Fujiki et al (2004) also found no differences in Ar-Go between deep and open bite subjects. However, our study showed that the deep overbite subjects have longer lower posterior height than the subjects with normal overbite. This difference existed only at age 20 years. There were no statistically significant differences in this parameter between the subjects with deep and open tendency overbite. This, at least partially, is in agreement with Sassouni & Nanda (1964), Sassouni (1969), Nahoum, Horowitz & Benedicto (1972), Nielsen (1991) and Stuani, Matsumoto, & Stuani (2000), who found positive relations between the overbite and lower posterior face height.

The S-Go and S-Ar/Ar-Go measurements did not show any statistically significant differences between the groups for both genders.

Mandibular plane angle (MPA)

Many researches agree that the MPA is steeper in subjects with open bite (Hapak, 1964; Subtelny & Sakuda, 1964; Sassouni & Nanda, 1964; Sassouni, 1969; Isaacson et al, 1971; Nahoum, Horowitz, & Benedicto, 1972; Lowe, 1980; Trouten et al, 1983; Nielsen, 1991; Fujiki et al, 2004). In the present study it was found that this trend exists only in males at age 12 and 20 years. The overall mean values and values for females show no differences between the groups, which is in agreement with Herness, Rule, & Williams (1973) and Stuani, Matsumoto, & Stuani (2000).

Much more disagreement exists in the changes of MPA with time. Results of the present study agree with Bhatia (1971), Boersma, van der Linden & Prahl-Andersen (1979), Bishara & Jacobsen (1998), and Naumann, Behrents, & Buschang (2000), which concluded that mandibular plane angle decreased. In contrast, Adams (1972) showed an increase in MPA and Brodie (1953) showed that MPA either increased or remained stable.

Palatal plane angle (PPA)

No statistically significant differences between the groups were found at age 9 and 12 years. However, at age 20 years PPA was smaller in the open bite tendency group, which is in disagreement with Sassouni & Nanda (1964), Sassouni (1969), Trouten et al (1983) and Tsang, Cheung, & Samman (1997), who found PPA to be steeper in open bite subjects. Disagreement also exists with Subtelny & Sakuda (1964), Nahoum, Horowitz, & Benedicto (1972), Lowe (1980) and Stuani, Matsumoto, & Stuani (2000), who concluded that there were no statistically significant differences in PPA between deep and open bite subjects.

The PPA was found to be stable by Brodie (1953) and Adams (1972); however, the findings of this study are in agreement with Bhatia (1971), Boersma, van der Linden & Prahl-Andersen (1979) and Naumann, Behrents, & Buschang (2000), who found an increase in this angle over time.

Occlusal plane angle (OPA)

OPA decreased during both growth periods, which is in agreement with Brodie (1953) and Isery & Solow (1996). Subtelny & Sakuda (1964), Sassouni & Nanda (1964), Sassouni (1969), Lowe (1980), Trouten et al (1983) and Tsang, Cheung, & Samman (1997) found that OPA was significantly lower in deep overbite subjects; however, the present study found no significant differences in OPA between the groups in both genders.

Palatal to mandibular (PP-MP), palatal to occlusal (PP-OP) and mandibular to occlusal (MP-OP) plane angles

Both PP-MP and PP-OP measurements decreased with age in the present study, which is in agreement with Bhatia (1971). MP-OP showed an increase with time, which is the opposite of what Boersma, van der Linden & Prahl-

Andersen (1979) found. PP-MP and PP-OP measurements were statistically smaller in the deep overbite group when compared to the open bite tendency group at age 20 years only. This was true for both genders. The same finding was repeated by Subtelny & Sakuda (1964), Bhatia & Leighton (1971), Nahoum, Horowitz, & Benedicto (1972) and Fujiki et al (2004). The MP-OP angle was found to be smaller in the deep overbite group than in the open bite tendency group in males only. Bjork (1947) found a similar trend, while Lowe (1980) did not find statistically significant differences between open bite and normal subjects.

Y-Axis, facial angle (FH/N-Pog), facial axis (Ba-N/PT-Gn), mandibular arc (DC-Xi/Xi-PM)

Y-Axis was very stable between 9 and 20 years of age in all three groups for both genders. Our study is in agreement with the results of Fujiki et al (2004), showing no statistically significant differences between the groups. However, Hapak (1964) and Subtelny & Sakuda (1964) concluded that Y-Axis was larger in subjects with open bite.

Facial angle and mandibular arc increased significantly in both growth periods and showed no differences between the groups. Rickets (1981) said that the facial axis angle does not change significantly with growth (Change

0°±1.5° each 5 years). He calls this angle "the most consistent growth axis of any of those proposed and studied thus far". This is in agreement with the present study. Subtelny & Sakuda (1964) found that the FH/N-Pog measurement was smaller in open bite subjects. No studies comparing Ba-N/PT-Gn and DC-Xi/Xi-PM measurements in deep and open bite subjects were found.

Upper (UI-PP) and lower (LI-MP) incisor and molar (U6-PP and L6-MP) lengths and space available for upper second molar (A6-PT)

These measurements increased overtime and did not show statistically significant differences between any of the groups for both genders. Much controversy exists in the literature on this subject (Diamond, 1944; Wylie, 1946; Baume, 1950; Prakash & Margolis, 1952; Bjork, 1953; Popovich, 1955; Sassouni & Nanda, 1964; Subtelny & Sakuda, 1964; Hapak, 1964; Kapoor, 1968; Sassouni, 1969; Richardson, 1970; Isaacson et al, 1971; Nahoum, Horowitz, & Benedicto, 1972; Loufty, 1973; Solow, 1980; Trouten et al, 1983; Tsang, Cheung, & Samman, 1997; Ceylan & Eröz, 2001); however, the present study is in agreement with studies of Atherton (1964) and Bhatia & Leighton (1971). There was no literature found on the relationship between overbite and A6-PT measurement.

Upper (UI-PP') and lower (LI-MP') incisor proclination and interincisal angle (UI-LI)

UI-PP' and UI-LI angles increased with time; however, LI-MP' angle remained stable. Literature on the changes of upper and lower incisor proclination is extremely controversial and ranges from a decrease to an increase in all three angles (Boersma, van der Linden, & Prahl-Andersen, 1979; Naumann, Behrents, & Buschang, 2000; Ceylan, Baydas, & Bolukbasi, 2002). Brodie (1953) pointed out unpredictable upper and lower incisor angulation changes and that these teeth can become more or less proclined or remain at their original axial inclination.

No differences were found between the groups in LI-MP' measurement; however, at 20 years of age upper incisors were more upright in the deep overbite group when compared with the open bite tendency group. This was true for both males and females. Similarly, at age 20 years interincisal angle was larger in the deep overbite group, indicating more upright incisors in this group. There is a general agreement in the literature that interincisal angle is smaller in open bite subjects (Bjork, 1947; Steadman, 1949; Popovich, 1955; Sassouni & Nanda, 1964; Bhatia & Leighton, 1971; Andrews, 1972; Herness, Rule, & Williams, 1973; Lowe, 1980; Beckmann et al, 1998); however, significant disagreement exists in regards to the contribution of upper and/or lower incisors to this difference (Bjork, 1947; Baume, 1950; Sassouni & Nanda, 1964; Subtelny & Sakuda, 1964; Sassouni, 1969; Andrews, 1972; Herness, Rule & Williams, 1973; Beckmann et al, 1998). In his famous article "The six keys to normal occlusion" (1972), Andrews mentioned that upper and lower incisor inclinations are complimentary and both can significantly affect overbite. He states that if the anterior teeth are too upright, overeruption results, leading to deep overbite.

As expected, values of posterior cranial base (S-Ar), total (S-Go) and lower (Ar-Go) posterior face heights, total (N-Me) and lower (ANS-Me) anterior face heights, space available for the upper second molars (A6-PT), and upper (UI-PP) and lower (LI-MP) incisor and molar (U6-PP & L6-MP) lengths were significantly smaller in females than males at age 20 years in all three overbite groups.

6.4 RELATIONSHIP BETWEEN OVERBITE AND ERUPTION STAGE OF SECOND MOLARS

This study showed that subjects whose second molars were not in occlusion at age 12 years, had deeper overbite, though this was not statistically significant. A similar trend was seen at ages 9 and 20 years in both males and females, from which it can be concluded that there is no difference in overbite depth or changes in overbite between the subjects with second molars in occlusion at age 12 years and subjects with the second molars not in occlusion at age 12 years. It has been suggested by Bergersen (1988) that erupting second and third molars elevate the first molars, thus increasing the distance between the jaws and decreasing overbite. Richardson & Richardson (1993) disagreed with this explanation of the mechanism of overbite changes. They compared 33 orthodontically untreated subjects that had their four permanent second molars extracted with 33 untreated controls. The cephalograms were taken just before extraction and again 5 or more years later. The following measurements were evaluated: overbite, overjet, ANS-Me (mm), UI-PP (°), LI-MP (°), UI-LI (°), PP-MP (°), and antero-posterior positions of upper and lower first molars. There was an average increase in overbite of 0.7 mm in the extraction group compared to an average decrease of -0.8 mm in the non-extraction group. Upper incisors retroclined in the extraction group (-1.3°) and proclined in the control group (0.9°). The extraction group showed a significantly greater increase in UI-LI angle (3.6°), compared with the non-extraction group (1.4°). The ANS-Me dimension increased in both groups, the extraction group increasing less (3.2 mm) than the non-extraction group (5.2 mm). The non-extraction group showed slight distal movement of the upper and lower molars (-0.9 mm, -0.5 mm), compared to the mesial movement in the non-extraction group (0.8 mm, 1.4 mm). The authors also pointed out incredible individual variability in overbite changes. This study suggests that extraction of second molars promotes the overbite increase. The authors disagree with this explanation of the mechanism of overbite changes as suggested by Bergersen (1988) because in their study they did not find that the PP-MP angle and the ANS-Me distance changes were significantly different between the extraction and non-extraction groups. Moreover, after eruption of third molars there was no overbite decrease noted. It was suggested that the mechanism responsible for overbite reduction is distal movement of the dentition with retroclination of the incisors and an increase in interincisal angle.

The results of our study are in agreement with Richardson & Richardson (1993) refuting role of second molar eruption on overbite changes.

6.5 CORRELATION OF OVERBITE WITH VARIOUS SKELETAL AND DENTOALVEOLAR PARAMETERS

According to Horowitz and Hixon (1966), if the correlation coefficient (r) is greater than 0.7 or 0.8, it can be considered clinically significant for prediction purposes. The only clinically significant correlation that was found was between the overbite at ages 20 and 9 (r=0.74) and ages 20 and 12 (r=0.88) years. Bjork (1953) also found a correlation between the overbite at age 12 and 20 years; although, much weaker (r=0.31). The only other clinically significant correlation that was found in the literature was a correlation between the overbite and the interincisal angle (Popovich, 1955; Herness, Rule, & Williams, 1973).

6.6 PREDICTION OF OVERBITE

There were no statistically significant differences found between the overbite at 9 and 20 years of age in this study. Moreover, statistically and clinically significant correlations were found between overbite at 20 and 9 years of age. Few significant trends were found between the overbite and other skeletal and dentoalveolar cephalometric parameters; however, these trends were found only at age 20 years and cannot be used for predictive purposes. Individual variations in overbite and other skeletal and dentoalveolar parameters and their changes are a persistent phenomenon in this and most, if not all, longitudinal growth studies. The data presented in this thesis provides some information on the general trend of overbite changes and its relations to vertical cephalometric parameters. However, it is the authors' opinion that it cannot be used to predict changes in overbite in any one person.

6.7 NULL HYPOTHESIS DEDUCTIONS

Null Hypothesis # 1: Subjects with vertical growth patterns develop an open bite tendency or open bite during growth.

This statement was **rejected** as the only relationships that were found between the overbite and other vertical skeletal parameters existed at age 20 years only. At age 9 and 12 years great variability in overbite and growth patterns existed among the studied subjects.

Null Hypothesis # 2: Subjects with horizontal growth patterns develop a deep bite during growth.

This statement was **rejected** as no specific growth pattern was noticed in the deep overbite group at age 9 and/or 12 years.

Null Hypothesis # 3: Overbite development is independent of dentoalveolar influences.

This statement was **accepted** as no differences in any dentoalveolar parameters were found between the groups at ages 9 and 12 years.

CHAPTER 7

CONCLUSIONS

CHAPTER 7

CONCLUSIONS

7.1 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.

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 deep overbite group had only 22 subjects, the normal overbite group only 31 subjects and the open bite tendency group only 21 subjects represented.

The second limitation was that this study did not include subjects past the age of 20 years. Bjork (1963), Behrents (1985) and Bishara, Treder, & Jakobsen (1994) all concluded that few facial parameters continue to change past age 20 years. Because of increasing numbers of adults seeking orthodontic treatment, a better understanding of overbite changes in early and “mid” adulthood would probably further assist clinicians in the possibility of better predicting this important clinical dimension further into adulthood.

Another limitation is that only subjects of Northern European descent were included in this study. Therefore, the conclusions can not be applied to other ethnic groups.

The last and probably the most important limitation of this study is that these results cannot be applied to the extreme growth patterns. The deepest overbite at age 20 years was 9.2 mm and an open bite of 0.6 mm was the most extreme case in the open bite tendency group. Longitudinal data collection of the subjects with extreme skeletal and dental characteristics will probably be even more difficult, as most of these patients normally receive some form of orthodontic treatment, which would make them unsuitable for inclusion in a longitudinal growth study.

7.2 CONCLUDING REMARKS

The following conclusions can be drawn from the present study:

1. In subjects with normal overbite or open bite tendency, the overbite increases from the mixed to the early permanent dentition and then gradually decreases from that point into adulthood. In subjects with a deep overbite, the bite continues to increase over time. This increase in overbite is probably related to increased overjet in the deep overbite group.
2. Males have deeper overbites than females.
3. The eruption stage of permanent second molars does not play a role in overbite changes.
4. Based on initial overbite and other skeletal and dentoalveolar parameters, overbite changes cannot be accuratelly predicted at age 9 and/or 12 years due to incredible individual variability.

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