Arch Circumference Changes in Vertical vs Horizontal Growers from the Mixed to the Permanent Dentition

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ABSTRACT

The association between growth direction and occlusion has been studied in the past with various conclusions being reported in the literature. In an effort to explore the contribution of skeletal growth direction in the progressive alteration of dental arch space requirements from the mixed to the permanent dentition, the change in arch length discrepancy was evaluated in terms of facial skeletal growth direction.

A sample of 65 subjects, including 34 vertical and 31 horizontal growers were identified from the Growth Study material housed at the Oregon Health Sciences University using the facial axis angle of Ricketts. Mandibular models of the mixed and permanent dentition stages of dental development were selected for these subjects based on predetermined criteria. Cranial base angles and y-axis angles were also measured along with the facial axis angles on the lateral cephalometric radiographs of each subject at both the mixed and permanent dentition stages.

Although no cause and effect relationships between growth direction and arch circumference changes from the mixed to the permanent dentitions could be made based on the observations of this study, a trend was seen towards increases in arch circumference and decreases in crowding with a more horizontal growth direction. The facial axis angle was found to remain relatively stable with growth in both the vertical and horizontal groups, with mean changes from the mixed to the permanent dentitions of -0.1 ± 2.2 and 0.7 ± 2.0 degrees respectively. The y-axis also showed little change with growth, in both vertical and horizontal groups, with mean changes of 0.4 ± 2.0 and 0.0 ± 2.3 degrees respectively.

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INTRODUCTION

The transitional dentition is a dynamic entity characterized by growth and change, including the growth of the jaws and of the facial skeleton and the development of the teeth and their eruptive patterns. One area that has been examined over the years, with varying conclusions, has been the association between growth direction and occlusion.

Today orthodontics, like medicine, is characterized by concerned efforts aimed at establishing preventative measures. Public opinion is now largely oriented towards preventative and interceptive procedures. This attitude which stresses prevention has obviously placed considerable demands on the orthodontist.

Orthodontic diagnosis might be facilitated if the relationship between occlusion and growth direction were better understood.
A knowledge of how spacing or crowding is modified by facial growth direction from the mixed to the permanent dentition would permit a more accurate analysis of the potential for improvement or deterioration of tooth space requirements in a young patient. This knowledge may aid in extraction decisions as one would have more precise knowledge of the amount of crowding or spacing to be expected when the dentition is complete. This is particularly true in the lower arch, as it is the

foundation on which the occlusion will be built.

In an effort to explore the contribution of skeletal growth direction in the progressive alteration of dental arch space requirements from the mixed to the permanent dentition, the change in arch length discrepancy (arch circumference minus tooth size) was evaluated in terms of facial skeletal growth direction. Different facial growth directions may have differing effects on changes in arch length discrepancies. It is possible that a vertical growth direction may be more favorable than a horizontal growth direction for increase in the alveolar arch perimeter. Therefore, more favorable arch length changes might be anticipated in vertical growers as more space is provided for the erupting teeth.

The purpose of this present work was to test the hypothesis that vertical facial growers will have an increase in alveolar arch circumference which may allow for a more favorable arch length change from the mixed to the permanent dentition.

LITERATURE REVIEW

In 1968, the following observation was made by Hixon [1] :

" Many alterations in treatment concepts have grown from increased clinical experience and a greater fund of biologic theory, much of which was the result of long term observation of treated and untreated cases. One consequence of these studies has been greater acceptance of the concept that the size and shape of the dental arch are not only subservient to facial growth and to muscle action, but in a more complicated manner than theorized earlier."

An understanding of the relationship that exists between the variation in facial growth and occlusion can be obtained from the implant studies of Bjork [2] which began in 1951 and grew to include a sample of 110 Danish children of both sexes from ages 4 to 24 . By means of Vitallium implants inserted into the bones, fixed landmarks were obtained that permitted radiographic description of the location, direction, and magnitude of bone changes. From these longitudinal studies Bjork [3,4] in 1963, and in greater detail in 1972, portrayed some characteristics of growth changes in the dentition associated with vertical and horizontal mandibular growth. He showed that labially inclined mandibular incisors and mesially inclined first molars are peculiar to predominant vertical growth and that changes with age were in the same direction. Lingually inclined mandibular incisors and upright first molars are peculiar to predominant horizontal growth, and changes with age are in the same direction.

In a case in which the condylar growth was in a markedly horizontal direction it appears that the mandible is thrust into the labial musculature, thus uprighting the incisors. In the dentition, arch length is reduced not by mesial movement of the molars but by lingual movement of the incisors. There is an increase in anterior crowding and a decrease in the bicanine diameter. In contrast, in a case of condylar growth in the vertical direction, the bone at the gonial angle is resorbed as the mandible is thrust into the sling formed by the masseter and internal pterygoid muscles. The teeth drift mesially and the incisors tip labially while bicanine diameter increases.

In 1952, Downs [5] studied the relationship between facial patterns and patterns of mandibular growth. The findings of these studies indicate that patterns of mandibular growth tend to vary with facial type. Class II cases tend to grow more vertically, and Class I cases tend to grow more horizontally.

In 1965, Schudy [6] studied the rotation of the mandible resulting from growth and its implications in orthodontic treatment. His studies led him to the following conclusions:

1) The facial angle is influenced by vertical as well as horizontal growth.

2) Clockwise rotation is a result of more vertical growth at the molar. area than at the mandibular condyles. Extremes may cause open bites.

3) Counterclockwise rotation is a result of more condylar growth than vertical growth at the molars. Extremes may cause closed bites.

4) The size of the gonial angle affects the amount of rotation.

5) The degree of facial divergence has an effect upon the degree of rotation of the mandible.

In 1966, Fisk [7] studied the changes which occur in the lower arch between 9 and 16 years. His sample consisted of 20 male subjects whose occlusion had developed normally by the age of 16 years. He found that during normal development neither the future arch perimeter, tooth irregularity, nor spacing/crowding at age 16 could be predicted with accuracy from dimensions measured at 9 years. He believed that a prediction of arch form, final tooth position, and the available space is possible only if the relationship between the skeletal growth pattern and development of the dentition is known.

In 1969, Bjork [8] suggested that extreme degrees of mandibular growth could result in increased crowding. When the mandible rotated upward and forward, the paths of eruption of all the teeth were displaced in a mesial direction, resulting in what he called "packing" of the lower incisor segment. In extreme downward and backward rotation, the lower incisors become retroclined through their functional relationship with the upper incisors. The posterior teeth are not guided distally in their eruption, and crowding develops anteriorly. In general, the more extreme the rotation of the mandible during growth, the greater the clinical problems it presents. He felt that it is important to predict such rotations at an early stage, as extreme rotation greatly influences the paths of eruption of the teeth. This has a bearing on orthodontic tooth movement, and must be taken into account in planning treatment, as there is a risk of extreme migration after extractions, and secure anchorage is needed. In the case of pronounced forward rotation, there is a risk of a deep bite developing. Bjork advises delaying extractions until the beginning of the puberal growth spurt, even when some other form of treatment has been introduced earlier.

In 1971, Hasund and Sivertsen [9] investigated whether there was any relationship between the space conditions of the lower anterior teeth and the facial type. Their results were based on cephalometric headplates and plaster models of 165 Norwegian individuals. They found that the conditions of space in the anterior region show no relationship with the degree of prognathism in men. For women there is a tendency to a greater lack of space in the retrognathic than in the prognathic face.

In 1973, Sanin and Savara [10] developed a hypothetical model to explain the development and self-correction of crowding of the mandibular incisors. They proposed that the self-correction, development, increase, or decrease of crowding of the mandibular incisors is, in part, a function of the relationship among tooth size, arch width, axial inclination of the teeth, and direction of mandibular growth. Their sample consisted of 150 children, participants in the Child Study Clinic of the University of Oregon Dental School. Their results indicated that a most favorable relationship concerning the prognosis of a given incisor alignment would be that of labially inclined incisors with upright or distally inclined first molars. This relationship would tend to result in proper incisor alignment in subjects with average arch width and large tooth size or average tooth size and a narrow arch.

A clinical implication of this relationship occurs in subjects with premature extraction of deciduous teeth in which space maintainers are unnecessary as they would interfere with the process of disto-occlusal growth of the first molars and the labio-incisal growth of the incisors. It seems that in a number of cases the axial inclination of the molars and the incisors is a sign of direction of mandibular growth and that direction of growth is a major contributor to the development of crowding.

In 1975, Lundstrom [11] investigated the significance of a horizontal or vertical growth pattern on changes in incisor inclination, overjet, overbite and crowding. His study was based on profile radiographs of 25 pairs of twins covering a growth period of about eleven years, extending from the age of 12-15 years to 23-26 years. Results obtained indicated correlations that may be significant subject to confirmation on a larger sample. Vertical growth of gnathion is combined with a tendency towards forward tilting of the lower incisors and less marked backward tilting of the upper incisors, while more horizontal growth is associated with movement in the opposite direction. Vertical growth of gnathion is combined with an opening of the angle between the anterior skull base and the mandibular plane, while more horizontal growth is associated with changes in the opposite direction. No cause and effect relationship between increase of lower crowding and the growth direction of the anterior part of the mandible was demonstrated from these observations.

In 1976, Sakunda [12] investigated the changes in crowding in both upper and lower dental arches during adolescence and their relation to the growth of the facial skeleton. They concluded that the specific pattern of growth during adolescence and the specific type of skeleton at the beginning of adolescence are important etiologic factors of secondary crowding. They claimed that increased lower arch crowding was associated with a downwardly directed growth pattern. However, Richardson [13] found only a very tenuous connection between downward growth and increased crowding.

In 1977, Christie [14] characterized cephalometric patterns of adults with normal occlusion. His findings indicated that people with normal occlusion tend to have more brachyfacial than dolichofacial patterns. Many of the norms varied significantly with the different facial patterns. Therefore, when treating a patient, the norms used should reflect differences associated with the various facial patterns and sex. He felt that this would enable treatment with fewer extractions with the confidence that the teeth and bony structure will remain stable. The key norms used by clinicians in setting treatment objectives should be reassessed to determine whether they are affected by varying facial structures.

In 1977, Hunter [15] studied the dynamics of mandibular arch perimeter change from mixed to permanent dentition in untreated samples. He found that the greater the crowding at age 9 years, the less the arch perimeter change at age 14 or 16 years, especially for the mandibular dentition with crowding in excess of 2.2 mm. Molar relationship, overbite, overjet, curve of spee and tooth size appeared to have no clinically useful relationship with arch perimeter. A severely crowded mandibular dentition appears to involve more labial tipping of incisors from mixed to permanent dentition than is found in a spaced dentition. Since labial tipping of mandibular incisors occurred during the transition from mixed to permanent dentition in these untreated subjects, the sanctity of mandibular incisor angulation may be questioned.

In 1977, Moyers and Wainwright [16] studied skeletal contributions to occlusal development. They reviewed three concepts which have been used in understanding the role of the craniofacial skeleton in occlusal development:

1) Craniofacial morphology determines occlusal relations, meaning that specific craniofacial types have typical occlusal categories.
2) Craniofacial growth accounts for most of the variability seen in occlusal relationships, which would include "vertical vs horizontal growers".
3) Variations in dental morphology produce the variations in occlusal relationships.

A new approach was presented in which occlusal relationships alter through time in identifiable patterns of change which can be understood by analyzing variable skeletal morphology, combinations of change in craniofacial growth, dental morphology and dental development. It was felt that much emphasis should be placed upon the role of built-in feed-back responses in the guidance of occlusal development. This would support the rationale for early orthodontic therapy with an emphasis on altering the conditions which determine the pattern of occlusal development rather than altering the occlusion directly.

In 1982, Latham [17] studied facial growth correlations with changes in arch perimeter/tooth size proportions from six to fourteen years. He found that there appeared to be a weak relationship between changes in arch perimeter/tooth size and facial growth direction. The relationship was stronger in the maxilla and attained statistical significance. In the maxilla the more vertical the facial growth direction the more arch perimeter-tooth size tended to increase.

Leighton and Hunter, [18] in 1982, concluded from their selected sample that mandibular dentitions with crowding exist in a specific morphologic structure characterized by a downward growth direction and relatively deficient growth. In 1986, Richardson [13] of Northern Ireland studied the relationship between dental crowding and facial morphology in 51 individuals over the first five years of their permanent dentition. She concluded that some morphological features in the early permanent dentition may predispose an individual to increased crowding of the lower arch, but the pattern of association is variable and unclear. Furthermore, downwardly-directed mandibular growth or treatment change and forward mandibular rotation are among the factors which may contribute to late crowding of the anterior part of the lower arch.

In 1994, Richardson [19] studied the role of differential horizontal growth on late lower arch crowding. Her sample consisted of casts of 85 subjects, recorded soon after eruption of second permanent molars and followed for 3 or 4 years. No significant differences in amount or direction of growth were found between the maxillary and mandibular teeth or jaws. Increased lower arch crowding was weakly associated with differential horizontal growth of the teeth and jaws. Reduced horizontal growth and greater vertical as opposed to horizontal growth of the maxilla and teeth, and increased growth of the mandibular base were to some extent related to the crowding increase.

In 1988, Miethke [20] studied correlations between lower incisor crowding, lower incisor position and lateral craniofacial morphology on a sample of 100 untreated subjects. He found no correlation between lower incisor crowding and skeletal morphology nor lower incisor position.

Keeling [21] studied the relationship between occlusion and craniofacial morphology using data from 164 children in the early permanent dentition. The results published in 1989 suggested that combinations of certain occlusal characteristics may be associated with specific skeletal types; however, a generalized statement of this concept could not be supported. In studying the effects of mandibular growth on the dental occlusion and profile Isaacson [22], in 1977, found that as the direction of the condylar vector becomes less perpendicular to the occlusal plane it becomes more effective at converting vertical growth to anteroposterior changes in the dentition.

MATERIALS AND METHODS

A sample of 65 subjects (34 males, 31 females) was selected from the Longitudinal Child Study material housed by the Oregon Health Sciences University Orthodontic Department. Dental casts of the mandibular arches were selected at two stages of dental development. (figure 1) The mandibular arch was chosen as mandibular incisor crowding is one of the most common and recognized features of maloccusion. Dental casts of four hundred and nine subjects were screened in selecting this sample. In Stage I, the only permanent teeth erupted were the four incisors and both first molars. The lateral incisors were at the same occlusal level as the central incisors or differed by no more than one fourth of their crown length. In Stage II, all permanent teeth anterior to and including the first molars were erupted and in occlusion.

Study casts that met criteria for inclusion in the sample showed no loss of deciduous molar or canine teeth at Stage I and had received no prior orthodontic treatment. Subjects with congenitally missing teeth or evidence of arch circumference loss due to caries were not included. In Stage II, all deciduous teeth had been replaced by their permanent successors. The mode age at Stage I was 9 years with a range from 7 to 10 years, and at Stage II the mode age was 13 years with a range from 12 to 15 years.

(table 1) According to Angle's classification, 51 were Class I, 14 were Class II, and none were Class III.

Dental Cast Measurements

The mandibular study casts of each subject at each of the two stages were scanned and the Molecular Analyst software was used in measuring the digitized pictures. This method allowed for measurements of arch circumference and tooth size to be more standardized than using the brass wire technique. All teeth mesial to the first permanent molars were measured from contact point to contact point and the sum was calculated to determine total tooth size at each stage. The first permanent molars were not included in the measurement as they are present at both stages, and remeasurement from one stage to the other may increase the measurement error. Arch circumference was also measured and arch length discrepancy was calculated using arch circumference minus tooth size and the change in arch length discrepancy from Stage I to Stage II was also calculated. These measurements were correlated with facial growth direction to determine whether a statistical correlation exists between arch circumference changes and facial growth direction from the mixed to the permanent dentitions.

Lateral Headfilm Measurements

The angle on the lateral headfilms chosen to relate the position of the mandibular symphysis to the cranial base and to indicate the general direction of facial growth (horizontal, average, vertical) was the facial axis angle of Ricketts.[23] The facial axis angle is the angle formed by a line constructed from the posterosuperior aspect of the pterygomaxillary fissure (PTM) to gnathion relative to the cranial base, which is represented by a line joining basion to nasion. In a balanced face, the facial axis angle is perpendicular, or 90 degrees to the basion-nasion line.

According to Ricketts,[24] the mean facial axis angle for the general population is 90 degrees with a standard deviation of 3 degrees, and on average, does not change with growth (change of 0.0 $\pm$ 1.5 degrees for each five years). It has been statistically verified to be the most consistent growth axis of any of those proposed and studied.[23,24]

In this study subjects with facial axis angles of 87 degrees or less were classified as vertical growers and those with facial axis angles of 93 degrees or greater were classified as horizontal growers. Those with facial axis angles between 87 and 93 degrees were classified as average growers in terms of facial growth direction and were not included in the sample. Two hundred sixteen lateral cephalometric radiographs were traced and measured in selecting this sample. Thirty-four vertical growers were identified (17 male, 17 female), and thirty-one horizontal growers were identified (17 male, 14 female). Forty-three of the subjects were identified as average growers and were not included in the study sample.

In addition to the facial axis angle, the cranial base angle of nasion-sella-basion (described by Bjork[25] in1955 and Scott[26] in1958), and the y-axis angle of nasion-sella-gnathion were measured on the lateral headfilms. (figure 2) In this study gnathion was constructed using the intersection of the nasion-pogonion line with the mandibular plane. Angular measurements were taken at both stages to determine their reliability in assessing facial growth direction and to see if they had any correlation with changes in arch length discrepancy from the mixed to the permanent dentitions.

Measurement Error

To verify the error of the method of measurement, 20 plaster casts (10 horizontal and 10 vertical) were randomly chosen and remeasured and Dahlberg's formula $\sqrt{\Sigma D^2/2N}$ was calculated, where D is the difference between the repeated measures and N is the number of repeated measurements.

RESULTS

Data tables showing measurements and calculations for each of the subgroups studied can be found under "Data tables for subgroups showing measurements of dental models and lateral headfilms at Stages I & II." (tables 2 - 5)

Descriptive Statistics

Summary statistics for horizontal and vertical growers, as well as male and female subgroups, can be found in the Appendix under "Descriptive statistics by subgroup for lateral headfilm and dental cast measurements." (appendix A)

Dental Cast Measurements

For the vertical growers, the mean decrease in arch circumference from the mixed to the permanent dentition of the mandibular arch was found to be 4.01 ± 1.94 mm with an increase in crowding from the mixed to the permanent dentition in the mandibular arch of 0.52 ± 2.56 mm.

In the horizontal growers, the mean decrease in arch circumference was found to be 4.44 ± 2.2 mm with a mean increase in crowding of 0.19 ± 2.08 mm. When t-tests were applied to these means, the differences between horizontal and vertical groups were not found to be statistically significant. (appendix B)

Cephalometric Measurements

Descriptive statistics for cephalometric measurements and changes in cephalometric measurements from Stage I to Stage II can be found in the Appendix. (appendix C & D)

Facial axis angle

In the vertical group, the mean facial axis angle at Stage I was 85.5 degrees with a standard deviation of 2.1 degrees and a range from 82 to 90 degrees. At Stage II, the mean facial axis angle was 85.4 degrees with a standard deviation of 1.9 degrees and a range of 81 to 88 degrees. Therefore, in the vertical group, there was a mean decrease in facial axis angle from Stage I to Stage II of 0.1 degrees with a standard deviation of 2.2 degrees.

In the horizontal group, the mean facial axis angle at Stage I was 93.4 degrees with a standard deviation of 1.8 degrees and a range from 90 to 98 degrees. At Stage II, the mean facial axis angle was 94.0 degrees with a standard deviation of 2.2 degrees and a range of 90 to 101 degrees. Therefore, in the horizontal group, there was a mean increase in facial axis angle from Stage I to Stage II of 0.7 degrees with a standard deviation of 2.0 degrees. These mean changes in facial axis angles from the mixed to the permanent dentitions were similar to those found by Ricketts,[24] who reported mean changes of 0.0 $\pm$ 1.5 degrees for each five years.

Cranial base angle

The cranial base angle remained relatively stable from Stage I to Stage II, in both vertical and horizontal groups, with mean changes of 0.2 ± 2.8 and 0.6 ± 3.7 degrees respectively. The cranial base angles were similar in all groups at both stages with a mean for the entire sample of 130.4 ± 4.4 degrees and a range of 120 to 141 degrees. These findings are similar to those found by Bjork,[25] who reported mean cranial base angles at age 12 years of 130.8 ± 4.2 degrees for a sample of 243 subjects with a mean change between ages 12 and 20 years of 0.7 ± 0.13 degrees.

Y-axis angle

In the vertical group, the mean y-axis angle at Stage I was 69.4 ± 2.6 degrees with a range of 64.5 to 76 degrees. At Stage II, the mean y-axis angle was 70.0 ± 2.6 degrees with a range of 65 to 77 degrees. Therefore, in the vertical group, there was a mean increase in the y-axis angle from Stage I to Stage II of 0.4 ± 2.0 degrees.

In the horizontal group, the mean y-axis angle at both stages was 63.8 ± 3.0 degrees with a range from 58 to 73 degrees. Therefore, in the horizontal group, there was a mean change in the y-axis angle from Stage I to Stage II of 0.0 ± 2.3 degrees. The mean y-axis for the entire sample combined was 66.8 ± 4.03 degrees with a range of 58 to 77 degrees, which are similar to values published in 1971 by Moore,[27] who reported a mean value for "Y" Axis-SN of 66 degrees with a range of 60 to 72 degrees.

Correlations

Correlations were calculated for both vertical and horizontal groups to see if any relationship existed between the angles measured on the lateral cephalometric radiograph and measurements calculated from the plaster models. Groups were subdivided into males and females to determine whether gender specific correlations existed. These results can be seen in their entirety under "Correlations between cephalometric angles and arch circumference measurements" in the Appendix. (appendix E) Degrees of freedom were calculated from the N of each group and values of significance were determined using t-tables for levels of significance (two-tailed tests).[28]

Correlations were found to be statistically significant but not clinically predictive, as a rule of thumb, an r value of 0.8 is the dividing line for use in clinical prediction,[29] as this will account for 64 % of the variation and the area of uncertainty amounts to 36% of the variation. Values that were found to be statistically significant at $p = .05$ are denoted with an asterisk (*) and those that were found to be statistically significant at $p = .01$ are denoted with a double asterisk (**).

In the vertical group for combined males and females, a low

negative correlation was found between the facial axis angle and the change in arch circumference (r= -.31 *) from Stage I to Stage II. This finding suggests a trend in vertical growers for decreases in arch circumference from the mixed to the permanent dentitions in individuals with increasing facial axis angles. A low negative correlation (r= -.25 *) was also found between the cranial base angle and changes in arch circumference from Stage I to Stage II, suggesting decreases in arch circumference from the mixed to the permanent dentitions with increases in the cranial base angle.

In the male vertical group, a positive correlation (r= .45 **) was found between facial axis angle and arch circumference. This finding would imply that in male vertical growers as the facial axis angle increases there may also be an increase in the arch circumference.

The male vertical group also showed a low negative correlation (r= -.42 *) between the cranial base angle and change in arch circumference from Stage I to Stage II, suggesting a slight trend towards decreases in arch circumference from the mixed to the permanent dentition with increases in the cranial base angle.

In the female vertical group, a low negative correlation (r= -.41 *) was found between facial axis angle and change in arch circumference from Stage I to Stage II, suggesting a slight trend towards decreases in arch circumference changes from the mixed to the permanent dentition with increases in the facial axis angle. This group also showed a positive correlation (r= .57 **) between facial axis angle and the change in arch circumference minus tooth size from Stage I to Stage II. This would suggest decreases in crowding from the mixed to the permanent dentition with increases in the facial axis angle in female vertical growers.

A low positive correlation (r= .33*) was found between the cranial base angle and arch circumference minus tooth size, suggesting that decreases in crowding may be seen with increases in the cranial base angle. A low positive correlation (r= .34 *) was also found between the y-axis and the change in arch circumference from Stage I to Stage II, suggesting that the arch circumference may increase from the mixed to the permanent dentition with increases in the y-axis. A low negative correlation (r= -.30) was found between the y-axis and arch circumference, suggesting decreases in arch circumference with increases in the y-axis.

No significant correlations were found in the horizontal group with males and females combined, nor in the male horizontal group alone. In the female horizontal, group a low positive correlation (r= .45 *) was found between the facial axis angle and arch circumference minus tooth size, suggesting that crowding may decrease with increases in the facial axis angle. A low negative correlation (r= -.33) was found for the y-axis when correlated with arch circumference, and a negative correlation (r= -.49 **) was found between y-axis and arch circumference minus tooth size. These findings suggest a trend towards decreases in arch circumference and subsequent increases in crowding with increases in the y-axis.

A positive correlation (r= .38 **) was found between the facial axis angle and arch circumference minus tooth size when the entire sample was correlated combining vertical and horizontal groups, suggesting a trend for decreases in crowding with increases in the facial axis angle. For the entire sample combined, there was a negative correlation (r= -.81 **) between the facial axis angle and the y-axis. This correlation can be explained by the fact that both the facial axis angle and the y-axis angle are based on angles involving the mandibular symphysis. The correlation is negative as the facial axis angle measures a posterior-inferior angle and the y-axis angle measures an anterior-superior angle. (figure 2) A positive correlation (r= .44 **) between the y--axis and the cranial base angle was found for the entire sample and there was no correlation found between the cranial base angle and the facial axis angle.

<u>Measurement Error</u>

The standard error of measure calculated using Dahlberg's formula was found to be 0.33 mm for arch circumference measurements and 1.71 mm for tooth size measurements with a subsequent measurement error of 1.71 mm for arch circumference minus tooth size calculations.

DISCUSSION

This present study raises a number of questions concerning the clinical significance of growth in the treatment of malocclusion. Throughout the history of orthodontics, the clinician has been interested in the growth and development of the bones of the skull, and there have been numerous claims concerning the significance of this growth.

In the analysis of the transitional dentition of the growing child, a difficult problem is encountered in predicting the alignment and stability of the permanent teeth because future increments in the size of the dental arches and the differences in crown size of the deciduous and permanent teeth must be considered.

This present study was undertaken in an attempt to shed some light on these issues, and to determine if relationships existed between growth direction and arch circumference changes from the mixed to the permanent dentitions. The facial axis angle of Ricketts was chosen in determining growth direction based on claims by Ricketts that it remained stable throughout growth and was a good indicator of growth direction. The facial axis angle was found to remain relatively stable with growth in both the vertical and horizontal groups, with mean changes from the mixed to the permanent dentitions of -0.1 ± 2.2 and 0.7 ± 2.0 degrees respectively.

This would indicate that the facial axis angle is a reliable angle to use as a reference angle in determining growth direction.

In retrospect, it may also be interesting to study the mandibular plane angle and its relationship to crowding and changes in crowding, as past studies have shown interesting results. Sakunda [12] found a correlation between an increase in lower incisor crowding and high mandibular plane angles, and Leighton and Hunter [18] found that severely crowded subjects had larger mandibular plane and occlusal plane angles to sella-nasion than others.

The y-axis angle, when measured from the sella-nasion line, was also found to be a reliable reference angle with changes from the mixed to the permanent dentitions of only 0.4 ± 2.0 degrees in the vertical group and 0.0 ± 2.3 degrees in the horizontal group. These findings are similar to values calculated from growth prediction tables in the University of Connecticut cephalometric analysis, [30] where the mean cumulative change in y-axis measurements from developmental ages of 9 to 13 years was calculated to be 0.16 ± 3.1 degrees for males and females combined.

In 1958, Moorrees [31] reported the findings of a longitudinal study of dental development between 3 and 18 years of age. He found that the arch circumference in the mandible is 3.4 and 4.5 mm smaller in the average male and female, respectively, at eighteen years of age than at five years of age. The findings of this study were similar to those found by Moorrees with mean arch circumference decreases from the mixed to the permanent dentitions in the mandibular arch of 4.21 mm for the entire sample.

Clinically, this average arch circumference decrease of approximately 4 mm that occurs during the posterior exchange from the mixed to the permanent dentitions can be attributed to average leeway spaces of 2 mm per side, indicating differences between the primary molars and primary canines with the permanent premolars and permanent canines.[32,33]

The thought that individuals with a more horizontal direction of growth may experience more arch circumference decreases (with subsequent increases in crowding) from the mixed to the permanent dentions due to a mesial migration of the dentition into the musculature resulting in uprighting of the incisors and closure of the leeway spaces was not supported by this study.

Although correlations that were significant at both the $p = .05$ and $p = .01$ levels were found, the highest correlation of $r = 0.57$ ** accounts for only 33 % of the variance which is not enough to be considered clinically predictive. This is not a suprising finding considering the individual variation found in any given sample and the small increments of measure that were studied.

When considering correlations that were found to be significant at the $p = .01$ level, a trend towards increases in arch circumference and decreases in crowding may be seen with increases in facial axis angles and decreases in the y-axis angle. Since as facial axis angles increase and y-axis angles decrease, individuals are considered to be more horizontal in their growth tendencies,[24,34] this finding is the opposite of that which was hypothesized. The finding of a mean decrease in crowding from the mixed to the permanent dentition in the mandibular arch of 0.19 mm of the horizontal growers and a mean increase in crowding of 0.52 mm in the vertical growers also tends to reveal this trend.

This finding of a trend towards crowding and increases in crowding with vertical growth can be supported with the findings of others in the literature. In 1976, Sakunda[12] also found that increased lower arch crowding was associated with a downwardly directed growth pattern. In 1982, Leighton and Hunter[18] found that crowded mandibular dentitions seemed to be characterized by a downward growth direction, and Richardson[13,19] cited downwardly-directed mandibular growth or treatment change as a possible factor which may contribute to mandibular crowding.

SUMMARY AND CONCLUSIONS

Vertical and Horizontal growers were identified from the Growth Study material housed at the Oregon Health Sciences University using the facial axis angle of Ricketts. Mandibular models of the mixed and permanent dentition stages of dental development were selected for these subjects based on predetermined criteria. Cranial base angles and y-axis angles were also measured along with the facial axis angles on the lateral cephalometric radiographs of each subject at both the mixed and permanent dentition stages.

All teeth mesial to the first permanent molars were measured from contact point to contact point and the sum was calculated and subtracted from the measured arch circumference. Changes from the mixed to the permanent dentition in arch circumference and arch circumference minus tooth size were calculated. These measurements were correlated with the cephalometric measurements in both the horizontal and vertical groups to determine if any relationships existed between growth direction and arch circumference changes. Due to the possibility of gender differences, horizontal and vertical groups were subdivided according to gender and correlations for cephalometric and model measurements were recalculated.

The most significant correlation found was in the female vertical group, where a positive correlation (r= 0.57 **) was found between facial axis angle and change in arch circumference minus tooth size from Stage I to Stage II. This finding suggests that with increases in the facial axis angle decreases in crowding from the mixed to the permanent may also be seen. Combined with the positive correlation (r= -.45**) found between the facial axis angle and arch circumference, and the negative correlation (r= - .49 **) found between the y-axis angle and arch circumference minus tooth size, a trend may be seen towards increases in arch circumference and decreases in crowding with a more horizontal growth direction. Although no cause and effect relationships between growth direction and arch circumference changes from the mixed to the permanent dentitions can be made based on the observations of this study, it is possible that this trend and the correlations found may be significant subject to confirmation on a larger sample. All other correlations were found to be low and not clinically predictive.

In conclusion, the following observations were made based on the results of this study :

1) The facial axis angle remained relatively stable from the mixed to the permanent dentitions with changes in vertical and horizontal groups of -0.1 ± 2.2 and 0.7 ± 2.0 degrees respectively.

2) The y-axis angle also remained relatively stable from the mixed to the permanent dentitions with changes in vertical and horizontal groups of

0.4 ± 2.0 and 0.0 ± 2.3 degrees respectively.

3) The cranial base angle did not demonstrate any significant change from the mixed to the permanent dentitions with mean changes of 0.2 ± 2.8 and 0.6 ± 3.7 degrees in vertical and horizontal groups respectively.

4) Mean arch circumference decreases from the mixed to the permanent dentitions in the mandibular arch of 4.21 ± 2.06 mm were found for the entire sample combined.

5) A mean increase in crowding in the mandibular arch from the mixed to the permanent dentition of 0.52 ± 2.56 mm was found in the vertical growers and a mean decrease in crowding of 0.19 ± 2.08 mm was found in the horizontal growers.

6) A trend was seen towards decreases in arch circumference and increases in crowding with a more vertical growth direction.

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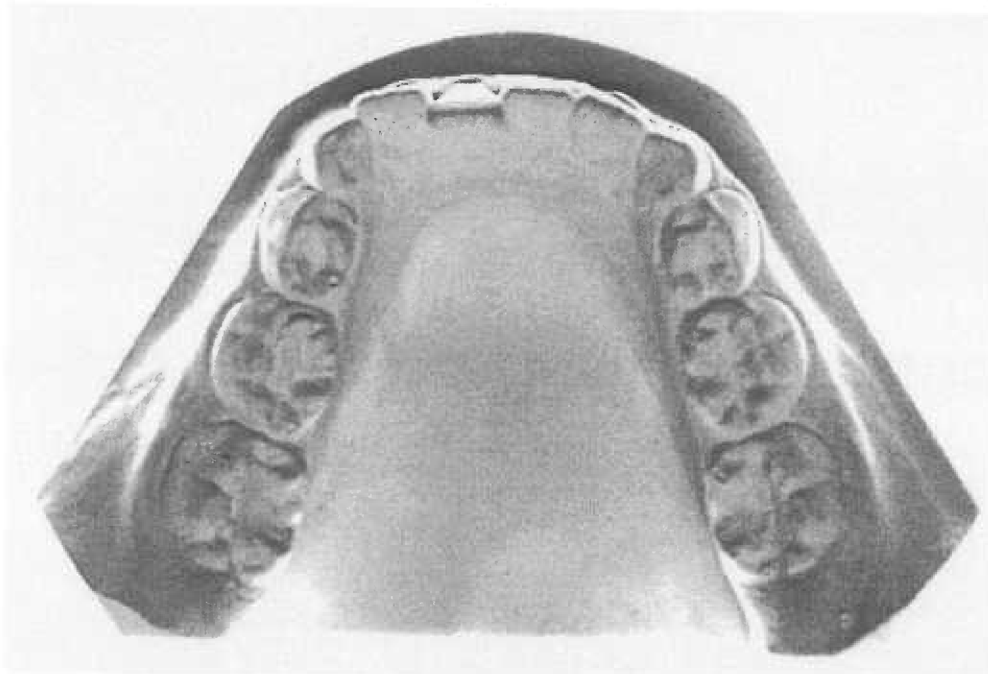
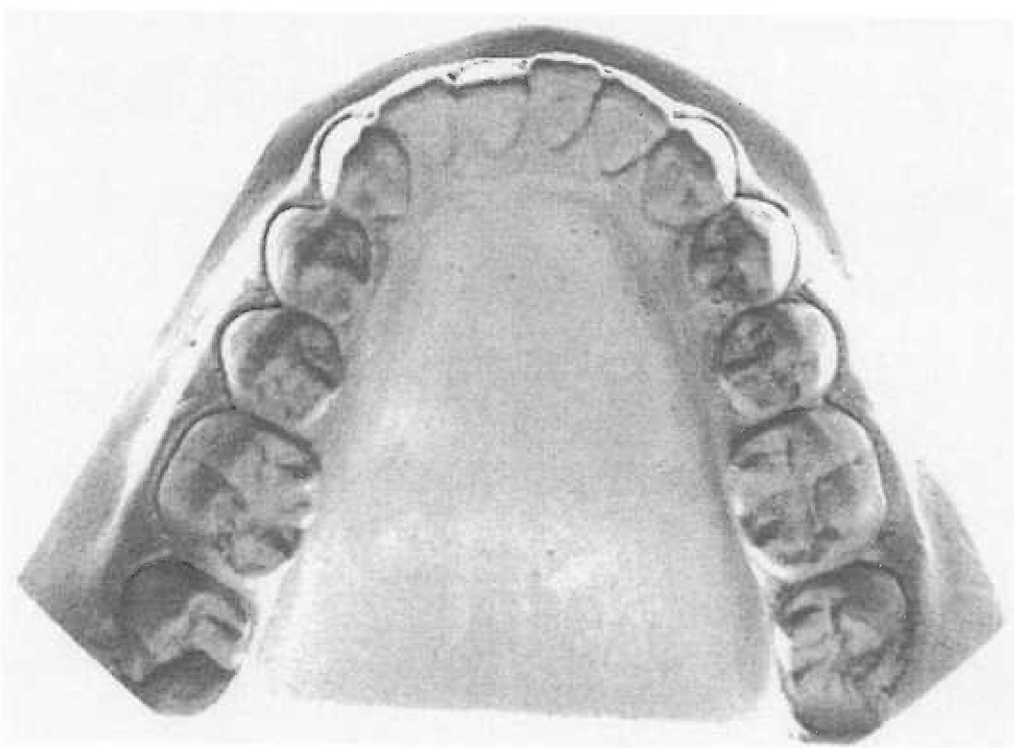
FIGURES

Figure 1 -Occlusal views of models showing stages of dental development used in this study

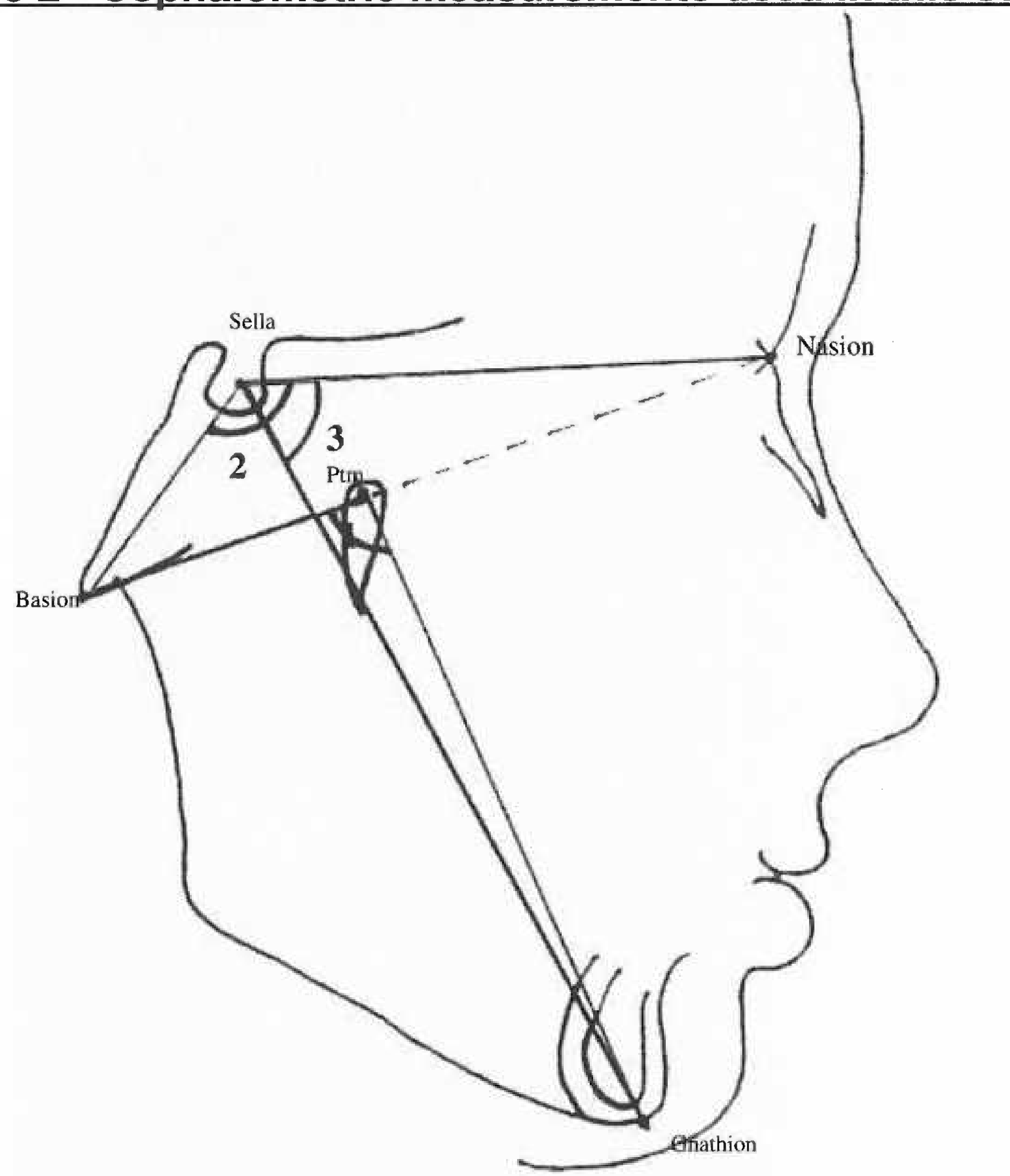


Stage I- Mixed dentition



Stage II -Permanent dentition

<u>**Figure 2 - Cephalometric measurements used in this study**</u>



1- Facial axis angle - the posterior-inferior angle of intersection of lines Basion / Nasion and Ptm / Gnathion

2- Cranial base angle - Basion-Sella -Nasion

3- Y-axis angle - Nasion - Sella - Gnathion

LEGEND

V - Vertical group

H - Horizontal group

I - Stage I (mixed dentition)

II - Stage II (permanent dentition)

AC - Arch circumference

Delta AC - Change in arch circumference from Stage I to Stage II

TS - total of tooth sizes

Delta TS - Change in total tooth size from Stage I to Stage II

AC-TS - Arch circumference minus tooth size

Delta AC-TS - Change in arch circumference minus tooth size from Stage I to Stage II

Facial axis - Facial axis angle of Ricketts (posterior-inferior angle at intersection of lines connecting nasion-basion and ptgerygomaxillary fissure -gnathion)

Delta facial axis - Change in the facial axis angle from Stage I to Stage II

Cranial base - Cranial base angle (angle formed by lines connecting nasion-sella-basion)

Delta cranial base - Change in the cranial base angle from Stage I to Stage II

Y-axis - Y-axis angle (angle formed by lines connecting nasion-sella-gnathion)

Delta y-axis - Change in the y-axis angle from Stage I to Stage II

TABLES

Table 1 - Ages in years of subjects at Stages I & II

	Stage I	Stage II
Mean	8.74	13.50
Median	9	13.25
Mode	**9**	**13**
Standard Deviation	0.81	0.65
Range	3	3
Minimum	**7**	**12**
Maximum	**10**	**15**
Count	65	65

Table 2 - Data table for vertical male subgroup showing measurements of dental models and lateral headfilms at Stages I & II

Subject	AC	Delta AC	TS	Delta TS	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
V10-I	72.9		72.31		0.62		89	131	69
V10-II	67.2	-5.73	67.17	-5.14	0.03	-0.59	87	132	71
V11-I	75.4		74.36		1.07		87	135	70
V11-II	69.2	-6.2	68.98	-5.38	0.25	-0.82			
V12-I	75.2		69.92		5.26		87	131	67
V12-II	72	-3.21	71.25	1.33	0.72	-4.54			
V14-I	74.6		74.94		-0.36		86	132	70
V14-II	72.1	-2.52	72.51	-2.43	-0.45	-0.09	84	128	69
V15-I	71.4		74.46		-3.1		86	132	70
V15-II	70.6	-0.77	72.92	-1.54	-2.33	0.77	84	128	69
V16-I	74.1		74.26		-0.12		82	126	69
V16-II	71.8	-2.39	69.32	-4.94	2.43	2.55			
V17-I	69.1		68.66		0.44		83	134	71
V17-II	64.1	-4.96	64.04	-4.62	0.1	-0.34	84	128	70
V2-I	71.1		70.72		0.4		85	128	70
V2-II	70.7	-0.43	68.13	-2.59	2.56	2.16	87	129	70
V20-I	68.1		70.29		-2.24		85	136	73
V20-II	64.1	-3.94	64.67	-5.62	-0.56	1.68	82	136	72
V22-I	76.8		76.75		0.07		87	138	71
V22-II	71.6	-5.2	69.8	-6.95	1.82	1.75	87	136	71
V23-I	73.4		71.4		1.95		83	138	76
V23-II	68.7	-4.66	68.99	-2.41	-0.3	-2.25	84	139	77
V25-I	70.5		72.47		-2		83	128	71
V25-II	65.7	-4.82	67.54	-4.93	-1.89	0.11	81	128	72
V27-I	70.2		71.74		-1.57		82	122	69
V27-II	69.1	-1.12	70.45	-1.29	-1.4	0.17	82	124	70
V3-I	74.9		68.49		6.36		85	130	71
V3-II	74.3	-0.59	63.45	-5.04	10.81	4.45	86	128	71
V30-I	75.2		78.02		-2.83		86	127	67
V30-II	67.6	-7.57	73.92	-4.1	-6.3	-3.47	87	128	68
V5-I	70.4		72.09		-1.71		85	125	68
V5-II	68.6	-1.74	71.83	-0.26	-3.19	-1.48	83	126	69

Table 3 - Data table for vertical female subgroup showing measurements of dental models and lateral headfilms at Stages I & II

Subject	AC	Delta AC	TS	Delta TS	AC-TS	Delta AC-TS	Facial Axis	Cranial base	Y-axis
V1-I	69.7		73		-3.32		83.5	131	64.5
V1-II	66.4	-3.32	69.2	-3.82	-2.82	0.5	87	134	67
V13-I	73.1		77.8		-4.62		87	131	69
V13-II	68.5	-4.65	70.3	-7.46	-1.81	2.81	86	130	68
V18-I	75.2		77.8		-2.66		87	128	66
V18-II	70.6	-4.58	70.4	-7.4	0.16	2.82	88	130	70
V19-I	70.3		70.3		0.04		83	134	73
V19-II	64.5	-5.82	65.2	-5.11	-0.67	-0.71	86	140	73
V21-I	68.7		64.3		4.38		87	137	72
V21-II	62.9	-5.81	56	-8.37	6.94	2.56	88	134	69
V24-I	70.1		67.9		2.2		87	130	68
V24-II	65.4	-4.73	67	-0.95	-1.58	-3.78	84	134	72
V26-I	66.9		67.8		-0.92		83	125	70
V26-II	62.6	-4.23	62.6	-5.16	0.01	0.93	87	125	68
V28-I	65.6		65.2		0.42		90	134	68
V28-II	61.7	-3.92	62.3	-2.91	-0.59	-1.01	86	135	72
V29-I	69.6		68.1		1.47		86	125	65
V29-II	65.9	-3.69	67.4	-0.78	-1.44	-2.91			
V31-I	66		65.9		0.09		86	135	70
V31-II	58.6	-7.47	66.8	0.83	-8.21	-8.3			
V32-I	65.7		67.2		-1.48		86	132	69
V32-II	59.9	-5.86	62	-5.18	-2.16	-0.68			
V33-I	66.6		67.4		-0.71		87	126	67
V33-II	64.5	-2.16	65.5	-1.87	-1	-0.29	86	128	70
V34-I	65.1		66.2		-1.16		83	120	68
V34-II	59	-6.11	63	-3.25	-4.02	-2.86	87	122	65
V4-I	71		69.4		1.65		89	132	66
V4-II	65.2	-5.81	63.9	-5.54	1.38	-0.27	87	132	65
V6-I	68.1		67.8		0.29		86.5	129	68
V6-II	66.7	-1.36	66.5	-1.3	0.23	-0.06	86	134	70
V7-I	63.4		63.2		0.23		84	135	75
V7-II	61.2	-2.23	61.3	-1.89	-0.11	-0.34	84	132	74
V8-I	63.4		63.4		-0.04		83	127	70
V8-II	58.1	-5.27	62	-1.37	-3.94	-3.9			
V9-I	73.5		74.5		-1		87	127	68
V9-II	69.9	-3.59	73.2	-1.23	-3.36	-2.36	86	125	67

Table 4 - Data table for horizontal male subgroup showing measurements of dental models and lateral headfilms at Stages I & II

Subject	AC	Delta AC	TS	Delta TS	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
H1-I	75.23		75		0.25		96	124	62
H1-II	69.61	-5.62	69	-5.91	0.54	0.29	97	123	60
H10-I	69.37		67		2.22		92	134	67
H10-II	64.36	-5.01	63	-3.66	0.87	-1.35	96	131	63
H13-I	71.32		66		5.2		93	133	66
H13-II	68.1	-3.22	66	0.17	1.81	-3.39	92	134	66
H14-I	67.4		68		-0.3		93	127	62
H14-II	60.7	-6.7	66	-2.15	-4.85	-4.55	93	129	64
H15-I	78.36		79		-0.86		91	136	67
H15-II	74.28	-4.08	74	-4.98	0.04	0.9	94	135	66
H16-I	73.12		70		2.72		93	125	62
H16-II	70.91	-2.21	66	-4.08	4.59	1.87			
H17-I	68.09		70		-1.9		91	132	67
H17-II	66.37	-1.72	66	-4.17	0.55	2.45	93	126	63
H2-I	68.47		67		1.31		92	125	62
H2-II	61.74	-6.73	61	-6.29	0.87	-0.44	94	124	61
H20-I	69.67		66		3.29		93	128	64
H20-II	63.37	-6.3	59	-7.8	4.79	1.5	91	136	66
H24-I	71.74		65		6.4		96	128	60
H24-II	66.55	-5.19	62	-3.49	4.7	-1.7	97	124	59
H26-I	71.9		66		5.87		94	128	64
H26-II	70.18	-1.72	62	-4.36	8.51	2.64	93	129	65
H31-I	70.01		67		2.67		95	126	60
H31-II	64.58	-5.43	63	-4.03	1.27	-1.4	95	126	60
H4-I	66.42		62		4.61		92	133	66
H4-II	62.08	-4.34	58	-3.72	3.99	-0.62	93	135	66
H5-I	72.01		70		2.49		92	130	64
H5-II	68.18	-3.83	66	-3.45	2.11	-0.38	93	129	61
H6-I	67.44		70		-2.74		93.5	137	68
H6-II	63.08	-4.36	64	-6.03	-1.07	1.67			
H7-I	71.82		70		1.95		93	125	63
H7-II	65.01	-6.81	63	-6.83	1.97	0.02	93	127	65
H9-I	67.17		66		1.64		93	130	65
H9-II	69.87	2.7	68	2.35	1.99	0.35	96	131	63

Table 5 - Data table for horizontal female subgroup showing measurements of dental models and lateral headfilms at Stages I & II

Subject	AC	Delta AC	TS	Delta TS	AC-TS	Delta Ac-TS	Facial axis	Cranial base	Y-axis
H11-I	68		69		-0.53		93.5	133	66
H11-II	65	-3.31	62	-6.18	2.34	2.87	93	137	68
H12-I	67		66		0.84		95	130	62
H12-II	60	-7.17	60	-5.97	-0.36	-1.2	92.5	135	66.5
H18-I	68		69		-1.39		93	131	64
H18-II	63	-4.5	65	-3.81	-2.08	-0.69	93	128	62
H19-I	74		74		-0.36		93	133	64
H19-II	66	-7.93	68	-6.6	-1.69	-1.33	92	128	64
H21-I	67		68		-0.54		94	124	62
H21-II	65	-2.3	63	-4.47	1.63	2.17	90	128	65
H22-I	71		70		0.63		97	129	60.
H22-II	67	-3.8	64	-5.51	2.34	1.71			
H23-I	71		69		2.39		93	133	63
H23-II	65	-6.38	63	-5.08	1.09	-1.3	95	135	64
H25-I	69		64		4.93		93	127	60
H25-II	63	-5.3	61	-2.78	2.41	-2.52	92	131	65
H27-I	70		68		2		96	134	63
H27-II	68	-2.48	63	-4.7	4.22	2.22	101	140	60
H28-I	63		63		-0.19		90	131	67
H28-II	58	-4.68	53	-10.57	5.7	5.89	93	129	65
H29-I	70		65		5.12		98	125	58
H29-II	67	-2.97	63	-2.13	4.28	-0.84	97	123	58
H3-I	68		68		0.59		94	127	63
H3-II	61	-6.92	60	-7.36	1.03	0.44	95	135	64
H30-I	74		73		0.9		93	134	64
H30-II	68	-6.41	67	-5.96	0.45	-0.45	95	134	65
H8-I	67		69		-1.62		91	141	72
H8-II	64	-2.78	65	-3.71	-0.69	0.93	93	136	73

APPENDIX

Appendix A - Descriptive statistics by subgroup for lateral headfilm and dental cast measurements

VERTICAL- males and females

N=68

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Mean	**68.44**	**-4.01**	**-0.35**	**-0.52**	**85.4**	**130.4**	**69.6**
Standard Error	0.54	0.33	0.35	0.44	0.3	0.6	0.3
Median	68.89	-4.41	-0.33	-0.31	86	130	70
Mode	#N/A	-5.81	0.23	#N/A	87	128	70
Standard Deviation	**4.46**	**1.94**	**2.86**	**2.56**	**2**	**4.5**	**2.6**
Sample Variance	19.87	3.78	8.21	6.53	4	20.1	6.6
Kurtosis	-0.40	-0.75	3.72	1.36	-0.6	-0.5	0.6
Skewness	-0.33	0.24	0.93	-0.71	-0.2	0.0	0.4
Range	18.72	7.14	19.02	12.75	9	20	12.5
Minimum	58.10	-7.57	-8.21	-8.30	81	120	64.5
Maximum	76.82	-0.43	10.81	4.45	90	140	77

VERTICAL MALES

N=32

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Mean	**70.95**	**-3.49**	**0.14**	**0.00**	**84.8**	**130.4**	**70.4**
Standard Error	0.58	0.55	0.55	0.57	0.4	0.8	0.4
Median	70.91	-3.58	-0.05	0.01	85	129	70
Mode	#N/A	#N/A	#N/A	#N/A	87	128	70
Standard Deviation	**3.26**	**2.21**	**3.11**	**2.29**	**2.1**	**4.5**	**2.2**
Sample Variance	10.64	4.90	9.68	5.24	4.2	20.2	4.9
Kurtosis	-0.36	-1.09	3.95	0.20	-0.9	-0.7	2.8
Skewness	-0.29	-0.12	1.37	-0.17	0.0	0.3	1.3
Range	12.71	7.14	17.11	8.99	8	17	10
Minimum	64.11	-7.57	-6.30	-4.54	81	122	67
Maximum	76.82	-0.43	10.81	4.45	89	139	77

VERTICAL FEMALES

N=36

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Mean	**66.21**	**-4.48**	**-0.78**	**-0.99**	**86**	**130.4**	**69**
Standard Error	0.70	0.37	0.43	0.65	0.3	0.8	0.5
Median	65.98	-4.62	-0.69	-0.51	86	131	68.5
Mode	#N/A	-5.81	-1.00	#N/A	87	134	68
Standard Deviation	**4.21**	**1.59**	**2.59**	**2.75**	**1.8**	**4.5**	**2.7**
Sample Variance	17.72	2.52	6.73	7.57	3.1	20.6	7.5
Kurtosis	-0.35	-0.28	2.74	1.67	-0.2	-0.2	-0.4
Skewness	-0.02	0.26	0.14	-0.91	-0.2	-0.3	0.4
Range	17.05	6.11	15.15	11.12	7	20	10.5
Minimum	58.10	-7.47	-8.21	-8.30	83	120	64.5
Maximum	75.15	-1.36	6.94	2.82	90	140	75

Appendix A (continued)

HORIZONTAL - males and females

N=62

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Mean	**67.65**	**-4.44**	**1.63**	**0.19**	**93.7**	**130.4**	**63.8**
Standard Error	0.50	0.39	0.32	0.37	0.3	0.6	0.4
Median	67.58	-4.50	1.47	0.02	93	130	64
Mode	#N/A	-1.72	2.34	#N/A	93	128	64
Standard Deviation	**3.97**	**2.20**	**2.50**	**2.08**	**2.0**	**4.4**	**3.0**
Sample Variance	15.77	4.82	6.24	4.34	4.2	19.5	8.9
Kurtosis	0.13	2.19	0.24	0.97	1.8	-0.7	1.1
Skewness	0.05	1.02	0.23	0.25	1.0	0.2	0.5
Range	20.14	10.63	13.36	10.44	11	18	15
Minimum	58.22	-7.93	-4.85	-4.55	90	123	58
Maximum	78.36	2.70	8.51	5.89	101	141	73

HORIZONTAL MALES

N=34

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Mean	**68.49**	**-4.15**	**1.99**	**-0.13**	**93.5**	**129.4**	**63.7**
Standard Error	0.69	0.59	0.47	0.48	0.3	0.7	0.4
Median	68.33	-4.36	1.96	0.02	93	129	64
Mode	#N/A	-1.72	#N/A	#N/A	93	124	66
Standard Deviation	**4.02**	**2.42**	**2.72**	**1.97**	**1.7**	**4.1**	**2.5**
Sample Variance	16.12	5.88	7.42	3.87	2.8	17	6.2
Kurtosis	-0.01	2.82	0.59	0.27	-0.4	-1.1	-1.1
Skewness	0.12	1.44	-0.04	-0.67	0.6	0.3	-0.2
Range	17.66	9.51	13.36	7.19	6	14	9
Minimum	60.70	-6.81	-4.85	-4.55	91	123	59
Maximum	78.36	2.70	8.51	2.64	97	137	68

HORIZONTAL FEMALES

N=28

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Mean	**66.63**	**-4.78**	1.19	**0.56**	**93.9**	**131.5**	**64**
Standard Error	0.71	0.51	0.41	0.60	0.5	0.9	0.7
Median	67.04	-4.59	0.87	-0.01	93	131	64
Mode	#N/A	#N/A	2.34	#N/A	93	134	64
Standard Deviation	**3.74**	**1.91**	**2.16**	**2.23**	**2.4**	**4.6**	**3.5**
Sample Variance	13.97	3.66	4.67	4.98	5.8	20.7	12.3
Kurtosis	0.26	-1.44	-0.47	1.00	1.8	-0.4	1.3
Skewness	-0.17	-0.23	0.56	0.97	1.0	0.1	0.7
Range	15.75	5.63	7.78	8.41	11	18	15
Minimum	58.22	-7.93	-2.08	-2.52	90	123	58
Maximum	73.97	-2.30	5.70	5.89	101	141	73

ENTIRE SAMPLE

N=130

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Mean	**68.06**	**-4.21**	**0.60**	**-0.19**	**89.5**	**130.4**	**66.8**
Standard Error	0.37	0.26	0.25	0.29	0.4	0.4	0.4
Median	68.10	-4.50	0.25	-0.29	89.5	130	67
Mode	69.61	-1.72	0.25	#N/A	93	128	70
Standard Deviation	**4.23**	**2.06**	**2.86**	**2.35**	**4.6**	**4.4**	**4.0**
Sample Variance	17.93	4.25	8.19	5.53	21.2	19.7	16.2
Kurtosis	-0.29	0.65	1.36	1.51	-1.1	-0.6	-0.5
Skewness	-0.15	0.62	0.43	-0.47	0.1	0.1	0.0
Range	20.26	10.63	19.02	14.19	20	21	19
Minimum	58.10	-7.93	-8.21	-8.30	81	120	58
Maximum	78.36	2.70	10.81	5.89	101	141	77

Appendix B - T-tests

Arch Circumference changes from the mixed to the permanent dentitions in Vertical (V) and Horizontal (H) groups

t-Test: Two-Sample Assuming Unequal Variances

	Delta AC (H)	Delta AC (V)
Mean	**-4.44**	**-4.01**
Variance	4.82	3.78
Observations	31	34
Hypothesized Mean Difference	0	
df	60	
t Stat	-0.82	
P(T<=t) one-tail	0.21	
t Critical one-tail	1.67	
P(T<=t) two-tail	**0.42**	
t Critical two-tail	2.00	

AC-TS changes in Horizontal (H) and Vertical (V) groups from the mixed to the permanent dentitions

t-Test: Two-Sample Assuming Unequal Variances

	Delta AC-TS (H)	Delta AC-TS (V)
Mean	**0.19**	**-0.52**
Variance	4.34	6.53
Observations	31	34
Hypothesized Mean Difference	0	
df	62	
t Stat	1.23	
P(T<=t) one-tail	0.11	
t Critical one-tail	1.67	
P(T<=t) two-tail	**0.22**	
t Critical two-tail	2.00	

Appendix C - Descriptive statistics for cephalometric measurements of vertical and horizontal groups at Stages I & II

Horizontal Stage I

	Facial Axis	Cranial base	Y-axis
Mean	**93.4**	**130.1**	**63.8**
Standard Error	0.3	0.8	0.5
Median	93	130	64
Mode	93	133	62
Standard Deviation	**1.8**	**4.2**	**2.9**
Sample Variance	3.3	17.8	8.5
Kurtosis	0.4	-0.1	0.8
Skewness	0.6	0.5	0.5
Range	8	17	14
Minimum	90	124	58
Maximum	98	141	72

Horizontal Stage II

	Facial Axis	Cranial base	Y-axis
Mean	**94**	**130.6**	**63.8**
Standard Error	0.4	0.9	0.6
Median	93	130	64
Mode	93	135	65
Standard Deviation	**2.3**	**4.7**	**3.1**
Sample Variance	5.1	22.1	9.6
Kurtosis	2.2	-1.0	1.7
Skewness	1.1	0.0	0.5
Range	11	17	15
Minimum	90	123	58
Maximum	101	140	73

Vertical Stage I

	Facial Axis	Cranial base	Y-axis
Mean	**85.5**	**130.3**	**69.4**
Standard Error	0.4	0.8	0.4
Median	86	131	69
Mode	87	131	70
Standard Deviation	**2.1**	**4.5**	**2.6**
Sample Variance	4.3	20.1	6.6
Kurtosis	-0.7	-0.4	0.6
Skewness	0.1	-0.2	0.5
Range	8	18	11.5
Minimum	82	120	64.5
Maximum	90	138	76

Vertical Stage II

	Facial Axis	Cranial base	Y-axis
Mean	**85.4**	**130.6**	**70**
Standard Error	0.4	0.9	0.5
Median	86	130	70
Mode	87	128	70
Standard Deviation	**1.9**	**4.6**	**2.6**
Sample Variance	3.7	20.8	6.8
Kurtosis	-0.4	-0.5	1.1
Skewness	-0.7	0.2	0.4
Range	7	18	12
Minimum	81	122	65
Maximum	88	140	77

Appendix D - Changes in cephalometric measurements from the mixed to the permanent dentitions in vertical and horizontal groups

VERTICAL

	Delta Facial axis	Delta Cranial base	Delta Y-axis
Mean	**-0.1**	**0.2**	**0.4**
Standard Error	0.4	0.5	0.4
Median	0.0	1.0	0.0
Mode	1.0	1.0	-1.0
Standard Deviation	**2.2**	**2.8**	**2.0**
Sample Variance	4.8	7.9	3.9
Kurtosis	-0.6	0.0	-0.5
Skewness	0.3	-0.1	0.3
Range	8	12	7
Minimum	-4	-6	-3
Maximum	4	6	4

HORZONTAL

	Delta Facial axis	Delta Cranial base	Delta Y-axis
Mean	**0.7**	**0.6**	**0.0**
Standard Error	0.4	0.7	0.4
Median	1.0	0.5	0.0
Mode	1.0	-1.0	1.0
Standard Deviation	**2.0**	**3.7**	**2.3**
Sample Variance	4.1	14.0	5.3
Kurtosis	0.0	-0.4	-0.2
Skewness	-0.1	0.3	0.2
Range	9	14	9
Minimum	-4	-6	-4
Maximum	5	8	5

Appendix E - Correlations between cephalometric angles and arch circumference measurements

Bold - statistically significant at p = .05
Bold / Underline - statistically significant at p = .01

VERTICAL males and females

N=68

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Facial axis	0.10	**-0.31**	0.20	0.18	1		
Cranial base	0.02	**-0.25**	0.23	0.05	0.21	1	
Y-axis	-0.09	0.11	0.19	0.00	**-0.39**	**0.57**	1

VERTICAL MALES

N=32

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Facial axis	**0.45**	-0.19	0.23	0.09	1		
Cranial base	0.1	**-0.42**	0.16	-0.01	0.28	1	
Y-axis	-0.22	-0.18	0.15	-0.01	-0.27	**0.67**	1

VERTICAL FEMALES

N=36

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Facial axis	0.19	**-0.41**	0.25	**0.57**	1		
Cranial base	-0.04	0.00	**0.33**	0.13	0.15	1	
Y-axis	-0.30	**0.34**	0.21	-0.05	**-0.39**	**0.54**	1

HORIZONTAL -males and females

N=62

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Facial axis	0.02	0.12	0.09	-0.10	1		
Cranial base	0.01	0.20	-0.06	0.00	**-0.51**	1	
Y-axis	0.06	0.12	-0.13	0.13	**-0.69**	**0.84**	1

HORIZONTAL MALES

N=34

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Facial axis	0.02	0.12	0.09	-0.10	1		
Cranial base	0.01	0.20	-0.06	0.00	**-0.51**	1	
Y-axis	0.06	0.12	-0.13	0.13	**-0.69**	**0.84**	1

HORIZONTAL FEMALES

N=28

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Facial axis	0.28	0.20	**0.45**	0.050	1		
Cranial base	-0.04	-0.02	-0.21	0.145	-0.01	1	
Y-axis	-0.33	-0.02	**-0.49**	0.159	**-0.63**	**0.61**	1

ENTIRE SAMPLE

N=130

	AC	Delta AC	AC-TS	Delta AC-TS	Facial axis	Cranial base	Y-axis
Facial axis	-0.08	-0.18	**0.38**	0.03	1		
Cranial base	-0.02	-0.08	0.05	0.10	0.00	1	
Y-axis	0.02	0.17	-0.27	0.07	**-0.81**	**0.44**	1