C-axis: A growth vector for the maxilla

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Abstract: Based on M-point, defined as the center of the largest circle that is tangent to the superior, anterior, and palatal outlines of the maxilla in the sagittal view, a growth axis and its direction are described for each gender from age 7.4 to 18.75 years. Growth increments along the C-axis, defined by sella–M-point, are described by regression formulas with correlation coefficients of 0.618 for females and 0.669 for males. The vector (direction) of the growth axis, defined by the angle S–M–C-axis, increases in females from 42.21 degrees at 7.4 years to 44.47 degrees at 18.75 years, with a standard deviation of 3.55 degrees. In males, it increases from a mean of 41.69 degrees at 7.6 years to 45.55 degrees at 18.6 years, with a standard deviation of 2.74 degrees. This is based on 172 serial lateral cephalograms of 20 females and 174 serial lateral cephalograms of 19 males. The C-axis incremental growth change and its vector offer a means of quantifying complex maxillary growth in the sagittal plane via cephalometric measurements relative to and coordinated with other craniofacial structures.

Key words: M-point, C-axis, maxillary growth vector, Maxillary growth increment

Cephalometric analysis is important in orthodontics because it helps the clinician understand the factors that may contribute to malocclusion, evaluate factors that may relate to a patient's facial esthetics, evaluate treatment effects, and forecast and understand changes associated with growth and development.

While investigators[1-11] have described the manner in which the maxilla is altered during growth, no anatomic area viewed in the sagittal plane had been determined to be a suitable point of reference within the maxilla until Nanda and Merill[12] proposed M-point, a constructed point representing the center of the largest circle that is tangent to the superior, anterior, and palatal surfaces of the maxilla as seen in the sagittal plane (Figure 1). While a complicated process of remodeling maintains the general shape and proportions of the maxilla, a geometrically defined point within the maxillary complex would permit a description of the natural loci of this complex in relation to other craniofacial structures during growth and development, rather than the imprecise "downward and forward migration" often used in describing maxillary growth.

The purpose of this investigation was to study the natural changes in position of M-point in relation to the anterior cranial base (S-N) using polar coordinates in combination with the palatal plane (ANS-PNS); the objective was to provide a quantitative description of the "anterior and downward migration" of the maxilla associated with skeletal growth. It is worth noting that the Y-axis (S-Gn), a generalized expression of the direction of growth of the mandible, is used in cephalometric analysis by many clinicians,[13-15] while others[16,17] have questioned the value of this axis in orthodontic diagnosis.

Materials and methods

Annual serial lateral cephalograms of 19 males and 20 females from 7.4 to 18.75 years of age were selected from the Mooseheart Growth Study, Chicago, Illinois. The subjects were selected on the basis of acceptable quality radiographs with the subject's head oriented to Frankfort horizontal, display of clinically acceptable occlusion, teeth in full occlusion, no absent teeth except through normal exfoliation, and no history of orthodontic intervention.

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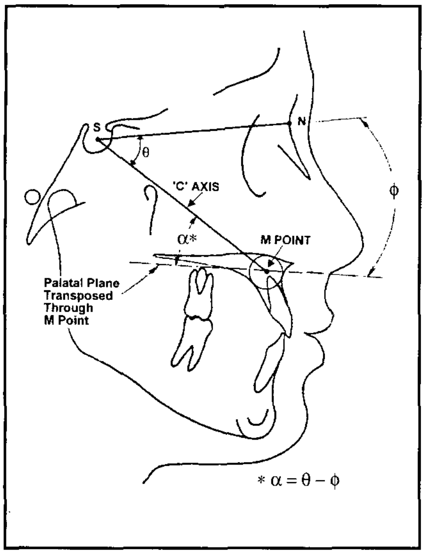

Figure 1
The relationship of C-axis (S–M-point) to SN, and to palatal plane (ANS-PNS)

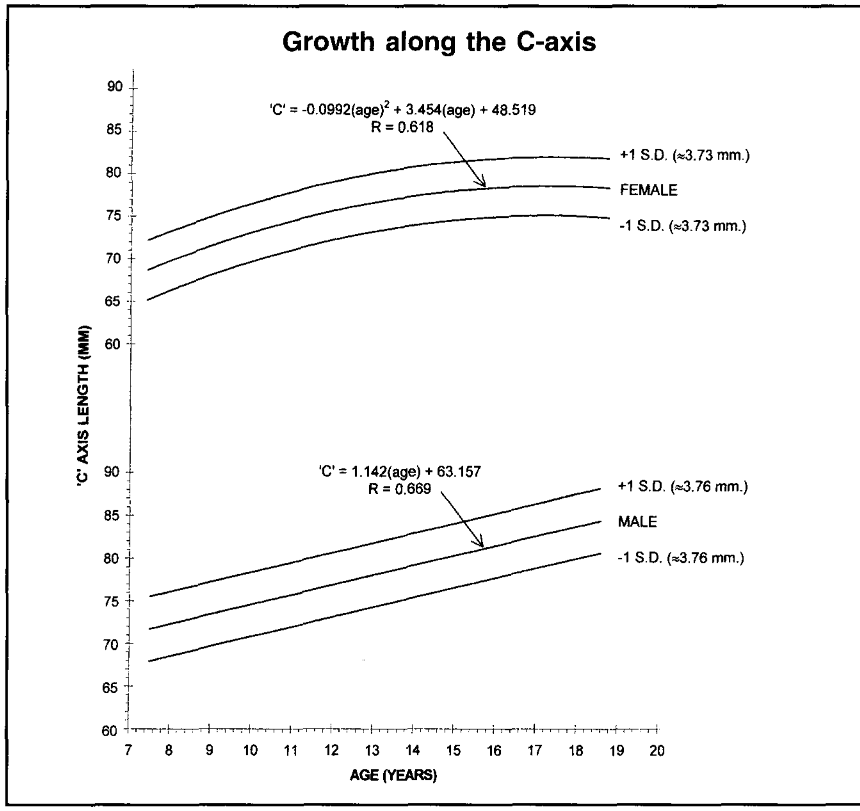

Figure 2
Chronological growth along the C-axis

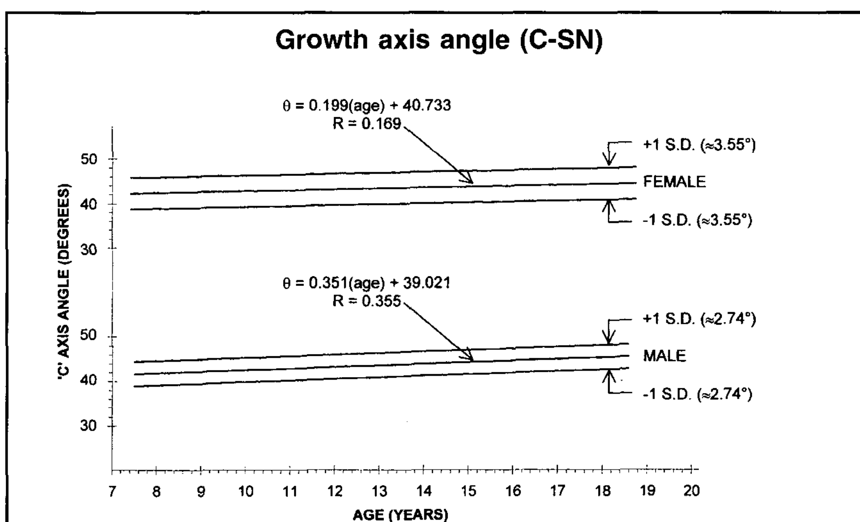

Figure 3
Growth axis angle (C-axis–SN) vs. chronological age

Cephalometric points and reference planes were identified on each cephalogram and marked on overlaid acetate tracing paper. These points and planes are illustrated in Figure 1. Each acetate tracing was subsequently digitized using Dentofacial Planner 7.01 (Dentofacial Inc, Toronto, Canada). Thirty lateral cephalograms were randomly chosen from the entire sample of 346 radiographs and the pertinent points and planes re-digitized to evaluate intra- and interexaminer error. (Two examiners were involved in digitization of the cephalometric landmarks.) The variations in cephalometric landmark coordinates were determined to be no more than 0.025%.

M-point was determined using a specially designed transparent template containing a number of circles whose diameter increased in 1 millimeter increments. Each of the centers was identified by a pinhole in the template. The best fit circle that was tangent to the superior, anterior, and palatal surfaces of the maxilla in each sagittal cephalogram was selected. The selected circle center was then transferred to the tracing through the pinhole for subsequent digitization. The line from sella (S) to M-point is defined as the C-axis.

Since the original Mooseheart Growth Study radiographs were taken at differing object-to-film distances, the films in this study were normalized to a 90 mm midsagittal plane-film distance using the formula:

Corrected measurement value = 0.065 [90-(mid-sagittal plane film distance)] + measured value

Results

The C-axis linear (S–M-point) and angular (SN–SM-point) values obtained for each gender are shown graphically in Figures 2 and 3.

Discussion

The C-axis in males increased linearly and continually at a mean rate of 1.14 mm per year from ages 7.4 to 18.75. This is based on the slope of a linear regression formula where C-axis length in millimeters = 1.142 (age in years) + 63.157, with a correlation coefficient (R) of 0.669, while the C-axis length in females is characterized by a second order regression formula where C-axis length in millimeters = -0.099 (age in years)^2 + 3.454 (age in years) + 48.519, having a correlation coefficient (R) of 0.618. This regression formula suggests that, on average, growth along the C-axis tends to cease at age 16 in females. A two-sample *t*-test comparing males with females revealed a statistically significant decrease in female growth velocity along the C-axis commencing at age 14 ($p<0.10$). The mean velocity (slope) in the years preceding this age is 1.31 mm per year, not significantly different than that of males in the same age range.

The mean growth axis angle (C-axis–SN) for both males and females generally tends to increase throughout the age range studied. The total mean angular increase for males and females is relatively small: 3.98 degrees and 2.25 degrees, respectively. When a linear regression formula is developed for males (θ = 0.351 [age in years] + 39.021) a low correlation coefficient (R) of 0.355 is obtained. For females, the regression formula (θ = 0.199 [age in years] + 40.733) has a correlation coefficient (R) of 0.169. The standard deviations for males and females are 2.74 degrees and 3.55 degrees, respectively. No statistically significant difference in the growth axis angle could be shown between genders ($p<0.10$). The low correlation coefficients imply little correlation between the magnitude of the angle and the subject's age for the age range studied. A review of the original measurements reveals that some subjects have a growth axis angle that increases slightly with age, while others decrease slightly with age, and some oscillate between small increases and small decreases. This variation in the data likely accounts for the low vector correlation coefficients.

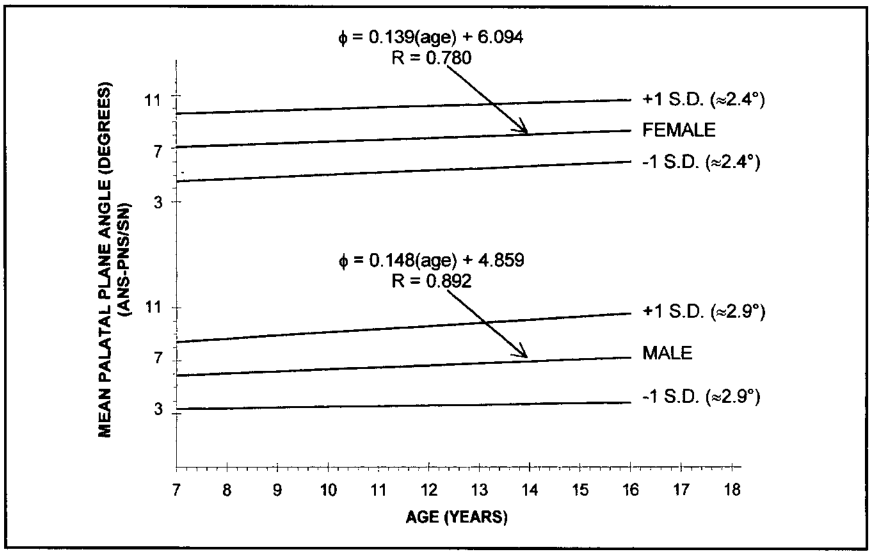

Figure 4
Angular relationship of palatal plane (ANS-PNS) to SN for each gender from age 7 through 16, from University of Michigan Growth Study [16]

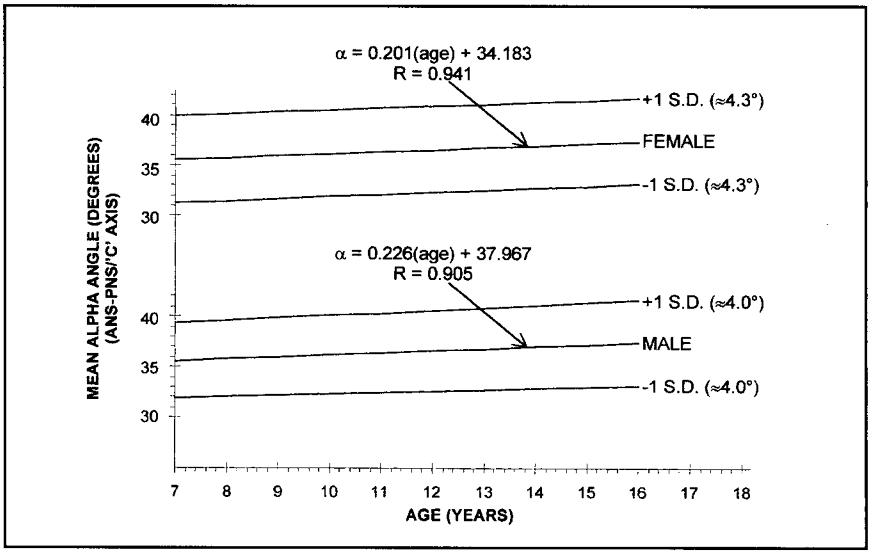

Figure 5
Relationship of palatal plane (ANS-PNS) to C-axis (S–M-point) for ages 7 through 16

Conclusion

The C-axis, defined by sella–M-point, permits the quantification of a complex maxillary growth process in cephalometric terms relative to various craniofacial structures in the sagittal plane. This has been done from 7.4 to 18.75 years of age for each gender. The C-axis angle regression formulas appear to be independent of gender within the chronological ages studied. Growth increments along the C-axis, however, are related to gender. Up to age 14, males and females display average yearly growth increments of 1.14 mm and 1.31 mm per year, respectively. The difference is not statistically significant. After age 14, growth increments in females tend to diminish, and at a mean chronological age of 16, growth ceases; in males, growth along the C-axis continues linearly throughout the age range studied.

A single point (M-point) cannot by itself summarize the growth of the dentomaxillary complex in the sagittal plane. However, when associated with the palatal plane (ANS-PNS), the downward and forward migration is more accurately described than previously possible.

Figure 4 is a graphic representation of the relationship of ANS-PNS to anterior cranial base (S-N) from age 7 through 16, derived from the University of Michigan Growth Study.[16] Since the C-axis vector is related to S-N, the palatal plane is geometrically related to the C-axis: ([ANS-PNS]/C-axis angle = [C-axis/S-N] angle – [ANS-PNS]/S-N angle). See Figure 1. The relationship of the palatal plane angle to the C-axis for each gender from age 7 through 16 is shown in Figure 5. The regression equation for females is: (ANS-PNS)/C-axis angle = α = 0.201 (age) + 34.183, (R) = 0.941; the equation for the male is: α = 0.226 (age) + 37.967, (R) = 0.905. In females, the angular relationship between palatal plane and the C-axis tends to increase from 35.4 degrees at age 6 to 37.4 degrees at age 16, while in the male it increases from 39.3 degrees to 41.6 degrees. These changes tend to "flatten" the palatal plane somewhat with respect to the C-axis during growth and development. The gender difference is not statistically significant ($p<0.10$).

It is interesting to note that in both males and females, the C-axis vector (angle) tends to increase through the age range studied and, as noted, this tends to "steepen" M-point relative to SN (an increase of 3.98 degrees in males and 2.25 degrees in females). Simultaneously, however, the palatal plane/C-axis angle (α) increases 2.30 degrees on average in males, and 2.00 degrees on average in females. These angular changes tend to offset each other.

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