Longitudinal Evaluation of Growth Changes in Class II Division 1 Subjects

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Longitudinal records from the Ohio State University Growth Study were used to compare the skeletal growth changes between Class II division 1 and Class I female subjects between ages 7 and 14. Tensor analysis was used to determine the yearly growth rate and direction. No significant difference was found in cranial base dimension between the Class I and Class II subjects. In Class II subjects, the maxilla (S-N-A) was found to be normally related to the cranial base. However, mandibular position (S-N-B and S-N-Pog) was found to be significantly more retrusive in Class II when compared with Class I subjects. Mandibular length (Ar-Gn) and corpus length (Go-Gn) were found to be shorter in Class II subjects. The ratio of PFH to AFH was found to be smaller in Class II subjects. This is particularly apparent during the pubertal growth period. The y-axis and mandibular plane angle were more open in Class II subjects which also contributed to the retrusive position of the mandible. Maxillo-mandibular difference (A-N-B) between Class I and II subjects was present at age 7 and persisted through puberty, maintaining a greater angle of convexity (A-N-Pg) in Class II subjects. These results suggest that Class II malocclusion can be detected early. The majority of the Class II cases showed mandibular skeletal retrusion or a combination of horizontal and vertical abnormalities of the mandible rather than maxillary protrusion. These skeletal differences remain through puberty without orthodontic intervention. Individual variations were found within each type of malocclusion. (Semin Orthod 1997;3:222-231.)

The treatment philosophy employed in the correction of the Class II malocclusion is governed by the clinician's concept of the Class II problem, the possibilities of tooth movement, and the relationship of growth to treatment. Concepts of the etiology of the Class II malocclusion has undergone change since the days of Edward Angle. It has been pointed out by many investigators[1-7] that a Class II molar relationship occurs in a variety of skeletal and dental configurations. Cross sectional studies[8-21] (Table 1) have shown that components of Class II malocclusion can be categorized into four main groups: anterior position of the maxilla; anterior position of the maxillary dentition; mandibular skeletal retrusion in absolute size or relative position; and excessive or deficient vertical development. The majority of Class II patients showed either mandibular skeletal retrusion or a combination of horizontal and vertical abnormalities of the mandible.[20] Although cross-sectional studies can identify the etiology of Class II malocclusion by comparing Class II individuals with normal subjects or existing cephalometric standards, longitudinal growth data may help answer some of the more commonly asked clinical questions: What are the growth changes with age in Class II individuals? How early can one detect Class II growth problems? What components of Class II malocclusion express during pubertal growth?

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Table 1. Cross-Sectional Studies on the Etiologies and Components of Class II Malocclusion

Source	*Sample Population*			*Findings*
	Size	*Age*	*Sex*	
Drelich, 1948	48	9 to 24	M-F	Max skeletal protrusion Max dentoalveolar protrusion Mand skeletal retrusion Decreased PFH/AFH
Nelson and Higley, 1948	250	10 to 14	M-F	Mand skeletal retrusion
Renfroe, 1948	95			Max skeletal retrusion Max dentoalveolar protrusion Mand skeletal retrusion
Gilmore, 1950	128	16 to 42	M-F	Mand skeletal retrusion
Craig, 1951	70	12	M-F	Max skeletal retrusion Max dentoalveolar protrusion Mand skeletal retrusion
Riedel, 1952	114	7 to 36	M-F	Max dentoalveolar protrusion Mandibular skeletal retrusion
Blair, 1954	100	10 to 14	M-F	Mandibular skeletal retrusion
Altemus, 1955	40	Avg 12	F	Max skeletal protrusion Max dentoalveolar protrusion Mand dentoalveolar retrusion
Henry 1957	130			Max skeletal retrusion Mand skeletal retrusion Increased AFH
Hunter, 1967	75	10 to 11	M-F	Max dentoalveolar protrusion Mand skeletal retrusion Mand dentoalveolar retrusion Increased AFH
Rothstein, 1971	608	8 to 15	M-F	Max skeletal protrusion Max dentoalveolar protrusion
Hitchcock, 1973	149	7 to 28	M-F	Max dentoalveolar protrusion Mand skeletal retrusion Mand dentoalveolar retrusion
McNamara, 1981	277	8 to 10	M-F	Various combination of skeletal and dental components
Carter, 1987	30	12 to 17	M-F	Mandibular skeletal retrusion

Is there individual variability in growth from subject to subject? Longitudinal growth records of Caucasians are available from several growth studies in the United States.[22-27] However, few studies have compared growth changes between Class I and II subjects.

Coben,[28] in an article titled the "Biology of Class II treatment" stated "the greatest potential of cephalometrics has not been fully recognized or utilized. This potential lies in an understanding of rates and directions of growth within the craniofacial complex, of the manner by which growth affects the spatial relationship of the arches, and the way this growth may be modified or utilized in our treatment procedure." We now understand that it is no longer acceptable to rely on the "constancy of growth pattern" concept of Broadbent[29] and Brodie,[30] and that increments of facial growth are not uniform in neither direction nor rate. An understanding of the longitudinal growth changes in Class II patients will help in formulating visualized treatment objectives, predicting growth during juvenile and adolescent periods, as well as determining the optimal time to intercept a Class II malocclusion.

The tensor analysis has been used by many investigators to calculate growth rates and directions using cephalometric data.[31-34] The tensor method requires the construction of triangles from sets of three cephalometric landmarks. These triangles are observed in matched pairs, such as initial and final, and pretreatment and posttreatment. For example, the landmarks sella, nasion, and "A point" (SNA) could be used to construct pairs of triangles (Fig 1). Inside the first triangle, a circle which touches the three sides can be drawn. Inside the circle, all diameters have the same length. With growth and treatment, the distances between the landmarks increase disproportionately, changing the shape of the triangle formed by the landmarks. This shape change, from the first triangle to the second, enlarges the diameters of the original circle by differing amounts, depending on the direction of the diameter measured. The effect

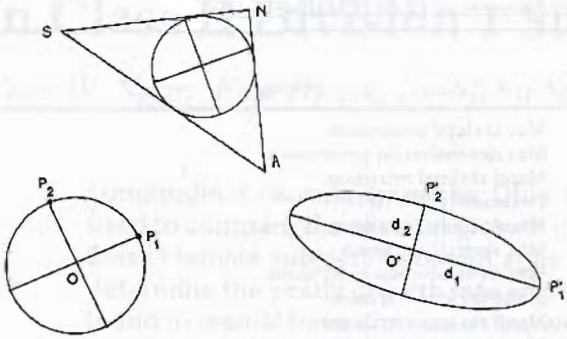

Figure 1. The tensor method requires the construction of triangles from sets of three cephalometric landmarks (eg, S-N-A). Inside the triangle, a circle which touches the three sides can be drawn. With growth and treatment, the distances between the landmarks increase disproportionately, changing the shape of the triangle. This effect distorts the dimensions of the circle or transforms it into an exact ellipse with two axes, d_1 and d_2. In growth terms, this represents maximum and minimum growth rates during growth or treatment.

of this change in the dimensions of the circle is to distort or transform the circle into an exact ellipse. The ellipse has two axes (d_1 and d_2) that are at 90° to one another. Maximum dilation or the largest rate of growth occurs in the direction of the long axis d_1, and minimum dilation or the smallest rate of growth occurs along the short axis d_2. The direction of maximum or minimum strain can also be calculated to orient clinicians to the growth changes with time. The theory on tensor analysis has been tested rigorously using a mathematical model.[32,33] The fact that its calculation does not depend on any reference landmarks enables it to analyze growth changes accurately.

The purpose of this study was to compare, using longitudinal growth records, the skeletal changes between Class I and Class II division 1 female subjects between 7 and 14 years of age. A tensor analysis was used to evaluate the growth rates and directions of these two groups of subjects.

Methods and Materials

Lateral cephalometric radiographs from the Ohio State University Longitudinal Growth Study were used in this study. Participants in the growth study between 1963 to 1975 had orthodontic records taken annually from age 5 through 17. All subjects were Caucasian; 97% were of northern European ancestry. None of the subjects had undergone orthodontic therapy.

The sample group consisted of forty females for whom serial radiographs were available between 7 to 14 years of age. Subjects were divided into two groups: 20 subjects with a Class II division 1 malocclusion (Class II molar relationship and an ANB > 4°) and 20 subjects with a Class I molar relationship and a good skeletal pattern. Cephalometric landmark identifications and constructed lines were established as shown in Figure 2. All radiographs were traced and digitized using a Texas Instrument digitizer and all analyses were performed on an IBM PC using Oliceph Orthodontic Software.

Tensor Analysis

Tensor analysis was performed on triangles formed by joining three skeletal landmarks as shown in Figure 1. Strain ellipses were computed on an IBM personal computer[32] and expressed in terms of maximum and minimum dilations for each triangle. These dilations describe the yearly rates of skeletal change along the two axes which lie at 90° to each other within the three skeletal landmarks. For example, a maximum

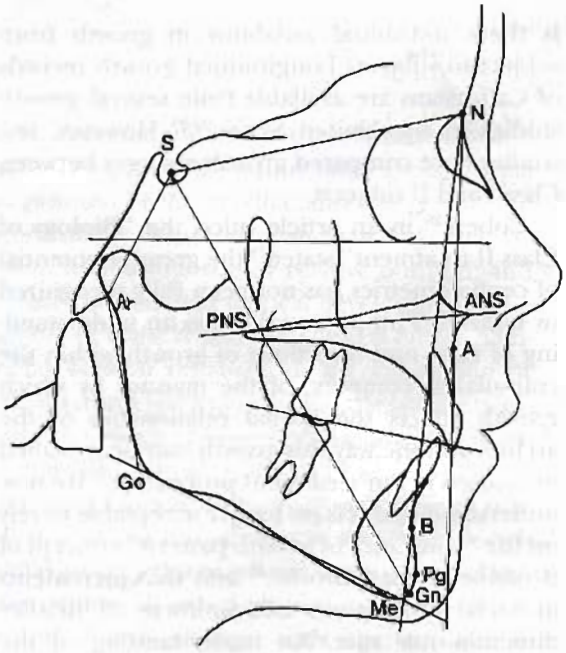

Figure 2. Cephalometric landmarks used to construct the linear and angular measurements analyzed in this study.

dilation factor of 1.00 represents no change from the original form, whereas a maximum dilation factor of 1.02 represents 2% increase in size from the original form. Angles with reference to a line formed by the first two cephalometric landmarks were calculated in an attempt to illustrate the directions of maximum and minimum growth changes.

Reliability in Measurement

The landmarks on each cephalogram were located by one investigator and checked by another. When possible, the set of cephalometric landmarks belonging to an individual were located at the same sitting. Two investigators independently measured each parameter on each cephalogram twice. Permissible intrainvestigator and interinvestigator disagreements were predetermined and limited to 0.5° and 0.5 mm. When disagreements were greater than these limits, two new measurements were taken and the three in closest agreement were averaged.

Errors in Measurement

Lateral cephalograms were selected at random, traced and superimposed with measurements recorded at 2-week intervals. The size of the combined method error (ME) in locating, superimposing, and measuring the changes in the different landmarks was calculated by the Dahlberg formula $ME = \sqrt{\Sigma d^2/2n}$, in which d is the difference between two registrations of a pair and n is the number of double registrations.[35] Any difference obtained between the duplicated tracing should describe the magnitude of error involved. The combined standard error of the landmark location, superimposition, and measurement did not exceed 0.8 mm for any of the vertical and horizontal dimensions registered.

Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) to assess significant differences between age groups and classes of subjects. Significant differences between groups were further analyzed using multiple comparison tests such as the Tukey's or Scheffe's tests. The levels of significance used were $P < .05$, $P < .01$, and $P < .001$.

Results

Growth Changes

For cranial base measurements (Fig 3), anterior cranial base (S-N) and posterior cranial base (S-Ar) were found to increase with age in both samples ($P < .001$). Analysis of variance showed no significant differences between Class I and II samples for S-N, S-Ar, saddle angle (N-S-Ar), and articular angle (S-Ar-Go) (Table 2).

For horizontal growth changes (Fig 4), no significant difference was found between Class I and Class II samples for the measurement S-N-A. However, there was a trend showing a decrease in S-N-A measurement with age in Class II subjects and an increase in Class I subjects, particularly during the pubertal growth period. Significant differences were found in mandibular measurements S-N-B and S-N-Pog between the Class I and II samples ($P < .05$). Both measurements were found to increase with age for Class I subjects and decrease with age for Class II subjects during

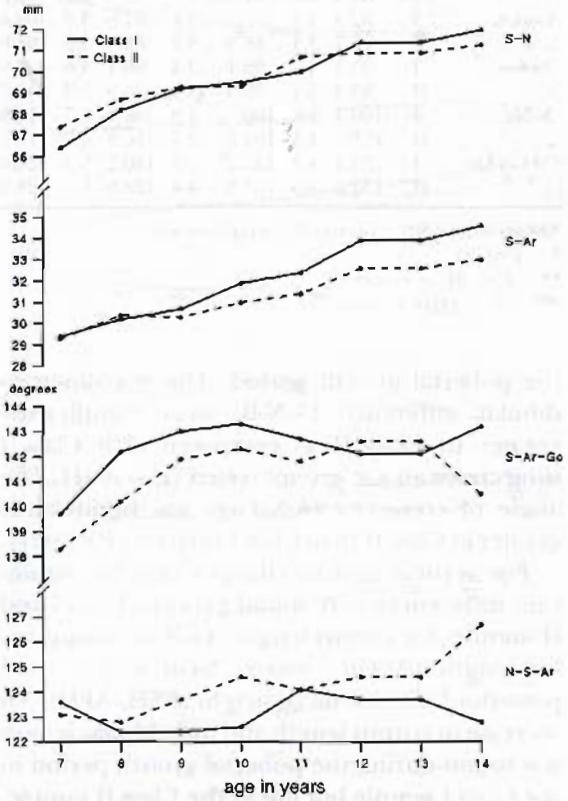

Figure 3. Incremental curves for four cranial base measurements between ages 7 and 14 in Class I and Class II subjects.

Table 2. Cephalometric Growth Changes Between Ages 7 and 14 in 20 Class II Division 1 Subjects and 20 Class I Subjects and Comparison Between the Two Classes

		Age 7		*8*		*9*		*10*		*11*		*12*		*13*		*14*		*Significance*	
Variable	*Class*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Class*	*Age*
S-Ar	I	29.4	2.8	30.2	2.2	30.7	2.9	31.9	2.4	32.4	2.8	33.9	2.2	33.9	2.5	34.6	2	NS	***
	II	29.3	2	30.4	1.9	30.3	2.3	31	2.5	31.4	2.4	32.6	2.4	32.6	1	33	1.9		
S-N	I	66.4	2.6	68.2	2.4	69.2	2.2	69.5	2.7	70	3.1	71.4	3.8	71.4	3.4	72	2.8	NS	***
	II	67.4	2.2	68.7	2.7	69.3	2.8	69.3	3.3	70.7	2.4	70.9	3.5	70.9	3.7	71.3	3.6		
N-S-Ar	I	123.6	9.7	122.4	6.4	122.4	8.4	122.6	6.9	124.1	6.6	123.7	6.7	123.7	7.2	122.8	7.9	NS	NS
	II	123.1	5.5	122.8	5.1	123.7	4.1	124.6	5.8	124.1	5.6	124.6	5.1	124.6	4.2	126.7	5.2		
S-Ar-Go	I	139.7	8.8	142.2	6.3	143	6.8	143.3	5.6	142.7	6.4	142.1	6.2	142.1	6.1	143.1	7.7	NS	NS
	II	138.3	4.5	140.2	5.2	141.9	4.6	142.3	5.9	141.8	7.1	142.6	6.8	142.6	6	140.5	7.3		
A-N-B	I	4.4	2.6	2.5	3.1	2.7	2.7	2.8	2.5	2.9	2.2	2.5	2.6	2.5	2.4	2.2	2.1	***	NS
	II	6.7	2.2	5.8	2.2	5.8	1.6	5.4	1.5	5.5	1.8	5.2	2	5.2	1.8	4.8	1.4		
S-N-Pog	I	75.5	4.6	76.4	3.3	76.2	4.3	76.2	3.9	76.7	3.5	79.3	3.9	79.3	3.4	80.7	4.4	*	NS
	II	76.8	3.1	76.6	3.2	76.3	3.1	75.3	3.5	76.5	3.5	75.5	4.6	75.5	4.1	75.3	3.9		
S-N-B	I	75.6	4.2	75.9	3.2	75.6	4	75.5	3.6	75.8	3.4	78.2	3.9	78.2	2.7	79.4	3.3	***	NS
	II	76.2	3.2	75.7	3.3	75.3	3.2	74.4	3.4	75.6	3.5	74.6	4.5	74.6	4.1	73.9	4.2		
S-N-A	I	79.9	5.9	78.4	4.6	78.2	5.5	78.3	3.9	78.8	3.9	80.7	4.4	80.7	3.4	81.6	5	NS	NS
	II	81.6	6.2	80.5	5.6	80.5	3.3	79.4	3.9	80.2	3.7	79.5	4.2	79.5	3.2	78.5	3.7		
A-N-Pog	I	4.5	2.9	2	3.4	2.1	3.3	2.2	2.6	2.1	2.6	1.4	3.1	1.4	3	0.8	2.2	***	*
	II	6.1	2.7	4.9	2.6	4.2	2.2	4.2	2.3	4.1	2.4	4	2.4	4	2.4	3.3	1.8		
MP Angle	I	37.6	4.4	36.2	4.2	35.6	5.1	35.7	3.2	35.5	4	33.6	4.6	33.6	4.8	31.9	4.6	NS	NS
	II	34.6	4.5	35.2	5.2	34.7	3.7	36.9	5.6	34.7	4.4	36.8	5.9	36.8	6.9	37.4	4.2		
N-ANS	I	46	2.7	47.9	2.6	48.8	3.2	50.5	2.6	51.2	3.6	53.2	3.9	53.2	5.2	53.6	5.4	NS	***
	II	45.3	3	46.9	3	48.2	3	50.1	2.8	51.2	2.8	53.8	3.2	53.8	2.7	54.7	4.1		
Y-Axis	I	58	2.5	57.7	2.5	58	2.8	59.3	2.3	58.1	2.68	57.4	2.6	57.4	2.9	56.6	1.8	*	NS
	II	58.6	4.1	58.3	3.9	57.9	3.5	58.9	3.9	58.6	4.3	59.8	4.8	59.8	4.7	59.6	4.9		
PFH/AFH	I	59.2	2.9	60.5	2.9	60.6	3.4	60.7	2.1	60.7	2.9	62.7	3	62.7	3.3	63.7	2.6	*	*
	II	61.5	2.8	61./2	3.1	60.7	2.1	59.8	3.2	61.3	2.8	61.1	3.5	61.1	4.2	60.5	2.8		
Go-Gn	I	62.9	4.8	65.7	3.8	67.6	3.9	69.4	2.6	70.8	2.9	74.9	3	74.9	4.1	78.6	2.4	***	***
	II	63.7	3.1	65.9	3.2	68.4	3.2	68.6	3.2	70	3.2	71.3	3.3	71.3	3.7	72.8	3.1		
Ar-Gn	I	91.1	4.7	95.1	3.4	96.7	3.6	98.9	3.6	100.1	2.6	107.5	2.9	107.5	3.3	110.8	1.8	***	***
	II	93.3	3.2	95.3	3.1	96.9	3.3	97.2	4.5	99.8	4.7	101.8	4.9	101.8	4.6	103.4	5		
N-Me	I	103.1	5.6	106	4.9	108.1	3.7	110.9	3.4	111.3	5.4	116.5	5.8	116.5	8	119.5	8.3	NS	***
	II	102	4.5	104.9	4.7	106.8	4.5	10.1	4.8	111	4.7	115.1	5.7	115.1	5.7	118.7	7.3		
Ar-Go-Gn	I	133.2	4.2	131.2	5.1	130.2	5.3	129.6	4.4	128.8	5.2	128.9	6.3	128.9	3.6	126.3	1.9	NS	***
	II	132.6	4.5	131.5	4.4	128.5	5	128.9	4.9	128.2	4.6	128.5	3.7	128.5	4.8	128.4	1.8		

Abbreviation: NS = no significant difference.
* = $P < .05$.
** = $P < .01$.
*** = $P < .001$.

the pubertal growth period. The maxillo-mandibular difference (A-N-B) were significantly greater in Class II as compared with Class I subjects for all age groups tested ($P < .001$). The angle of convexity (A-N-Pog) was significantly greater in Class II than Class I subjects ($P < .001$).

For vertical growth changes (Fig 5), significant differences were found between Class I and II samples for corpus length (Go-Gn), mandibular length (Ar-Gn), y-axis (S-Gn to FH) and posterior/anterior facial height (PFH/AFH). An increase in corpus length and mandibular length was found during the pubertal growth period in the Class I sample but not in the Class II sample. The y-axis and the mandibular plane angle were found to decrease during the pubertal growth period in Class I sample but increase in Class II subjects. The upper facial height (N-ANS) and total facial height (N-Me) increased at about the same extent in both classes. The PFH/AFH ratio, on the other hand, was found to increase in the Class I sample during the pubertal growth period but remained relatively constant in the Class II sample. In both samples, significant differences were found with age for Ar-Gn, gonial angle (Ar-Go-Gn), upper facial height (N-ANS), total facial height (N-Me), and PFH/AFH.

Growth Rates and Directions

Cranial base changes (triangle N-S-Ar). Maximum dilation each year varied between 1% and 5% or a dilation factor of 1.00 to 1.05 (Figs 6 through 8). The largest growth changes oc-

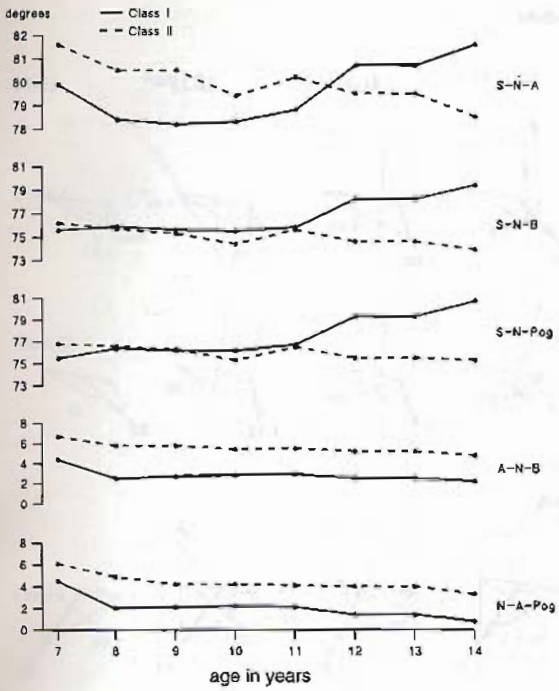

Figure 4. Incremental curves for five horizontal growth measurements between ages 7 and 14 in Class I and Class II subjects.

curred between 12 to 13 years. For both samples, maximum growth occurred in a downward and backward direction with reference to S-N, coincident with active growth at the spheno-occipital synchondrosis that was active through puberty.

Maxillary growth with reference to SN (triangle S-N-A). Maximum dilation each year varied between 1% and 6% or a dilation factor of 1.00 to 1.06. The largest growth changes occurred between 7 to 8 and 12 to 13 years. In Class I subjects, maximum dilation occurred in a downward and forward direction with reference to S-N. In Class II subjects, it occurred in a downward and backward direction.

Mandibular growth with reference to SN (triangles S-N-Pog and S-N-Menton). Maximum dilation each year varied between 1% and 4% or a dilation factor of 1.00 to 1.04. The largest horizontal (S-N-Pog) and vertical changes (S-N-Menton) occurred between 12 to 13 years in Class I subjects. In Class II subjects, relatively smaller growth was found during this period. The direction of maximal growth was downward and forward in Class I subjects, and downward and backward in Class II subjects.

Mandibular body and ramal growth with reference to Sella (triangles S-Go-Gn and S-Ar-Go). For the body of the mandible (S-Go-Gn), maximum growth each year varied between 1% and 7% or a dilation factor of 1.00 to 1.07. Yearly growth rate was larger in Class I when compared with Class II subjects. Direction of maximum growth varied year to year between forward and upward and forward and downward growth with reference to S-Go. For mandibular ramal growth (S-Ar-Go), maximum growth each year varied between 1% and 8% or a dilation factor of 1.00 to 1.08. Direction of maximum growth varied year to year between downward and downward and forward growth with reference to S-Ar.

Discussion

Previous studies have reported on the influence of cranial base morphology and dimension on the position of the mandible.[36-37] Enlow stated

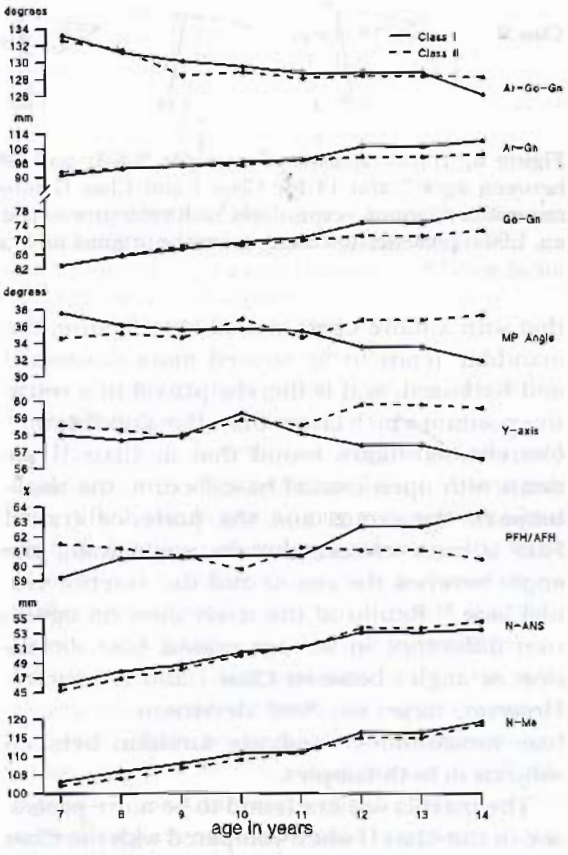

Figure 5. Incremental curves for eight vertical growth measurements between ages 7 and 14 in Class I and Class II subjects.

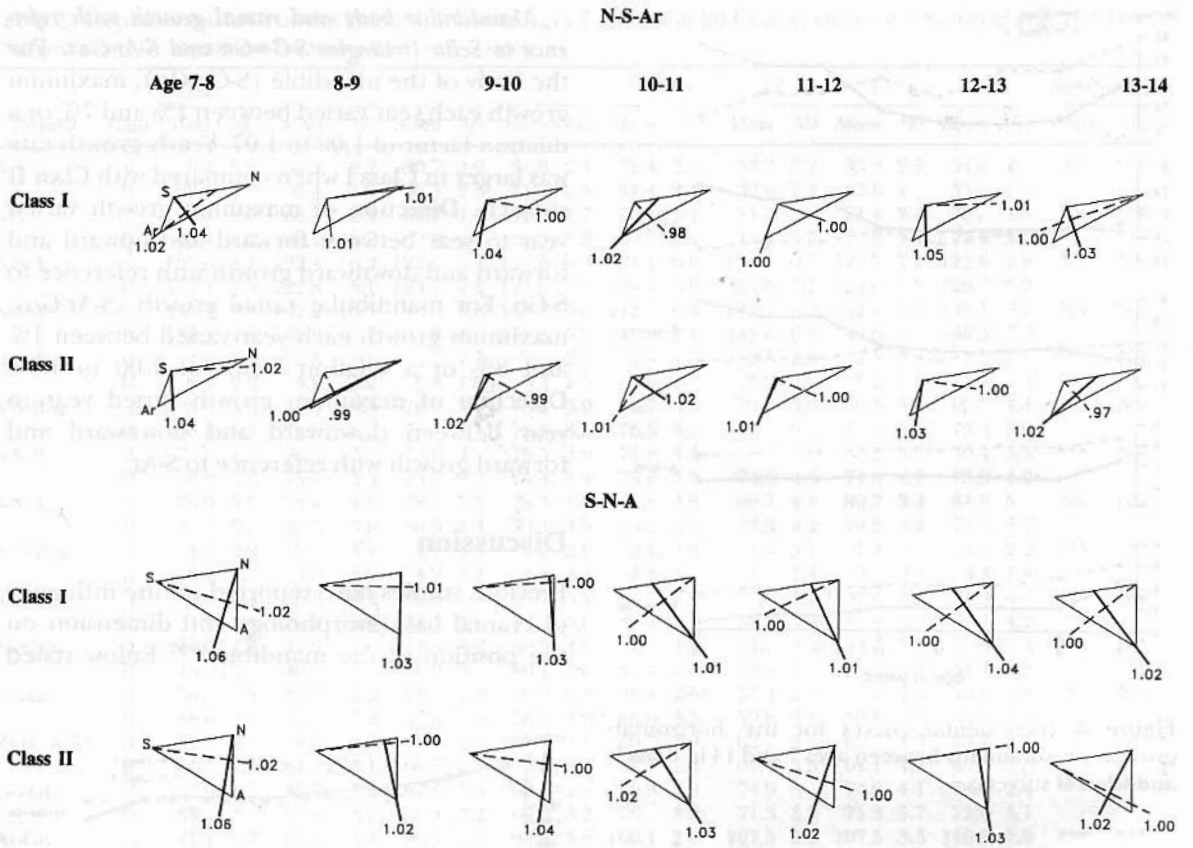

Figure 6. Tensor analysis of triangles N-S-Ar and S-N-A showing the direction and amount of growth yearly between ages 7 and 14 for Class I and Class II subjects. The solid and dotted lines indicate maximum and minimum dilations, respectively, with reference to the first two landmarks. The numbers indicate dilation factor; eg, 1.00 represents no change from the original form and 1.02 represents 2% increase in size.

that with a more open cranial base flexure, the mandible tends to be rotated more downward and backward, and is thereby placed in a retrusive position which favors Class II malocclusion.[36] Correlation studies found that in Class II patients with open cranial base flexure, the angle between the ramus and the posterior cranial base is more closed, thereby maintaining the angle between the ramus and the anterior cranial base.[37] Results of this study show no significant difference in average cranial base dimension or angles between Class I and II samples. However, large standard deviations in cranial base measurements indicate variation between subjects in both samples.

The maxilla was not found to be more protrusive in the Class II when compared with the Class I sample. In fact, there was a decrease in maxillary prognathism in Class II subjects during the pubertal growth period. This has been pointed out by Oppenheim[38] as long ago as in 1928 that Class II was not caused by excessive forward growth of the maxilla. Subsequent studies with the aid of cephalometric radiographs also confirmed that the maxilla was found to be on average normally related to the cranial base.[10,11,13,14,16,17,19] Mandibular growth, on the other hand, showed differences between the two Classes of malocclusion. In the Class II sample, mandibular length (Ar-Gn) and corpus length (Go-Gn) were found to be shorter and the ratio of PFH to AFH was found to be smaller when compared with the Class I sample. This was particularly apparent during the pubertal growth period. Between ages 12 and 13, an increase in mandibular length was seen in Class I but not Class II subjects. Vertically, the PFH increased relative to the AFH in Class I subjects and the mandibular plane angle closed on average about 1.1° per year. In Class II subjects, the PFH relative

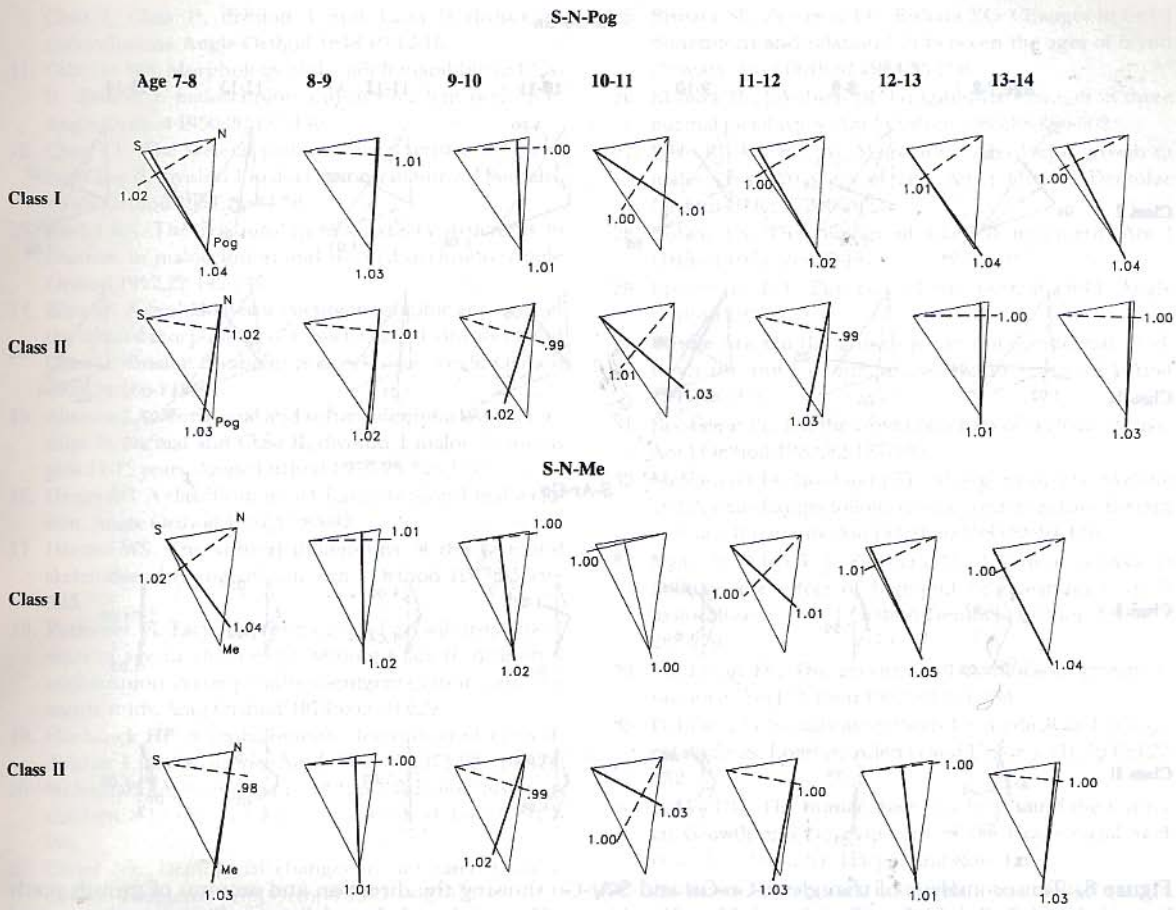

Figure 7. Tensor analysis of triangles S-N-Pog and S-N-Me showing the direction and amount of growth yearly between ages 7 and 14 for Class I and Class II subjects. The solid and dotted lines indicate maximum and minimum dilations, respectively, with reference to the first two landmarks. The numbers indicate dilation factor; eg, 1.00 represents no change from the original form and 1.02 represent 2% increase in size.

to the AFH decreased with age and the mandibular plane angle maintained relatively larger than in Class I subjects. These vertical changes contributed to the more retrusive mandibular position (S-N-B and S-N-Pog) in Class II subjects. These findings are in agreement with many of the growth studies[8-21] which reported that the majority of Class II cases showed mandibular skeletal retrusion or a combination of horizontal and vertical abnormalities of the mandible rather than maxillary protrusion.

The maxillo-mandibular skeletal difference (A-N-B) was found to be significantly greater in the Class II sample at age 7 and did not improve with age. These skeletal differences maintained a greater degree of facial convexity in the Class II subjects. These results suggest that the Class II skeletal growth pattern is established early and maintained through puberty unless altered by orthodontic intervention.

The tensor analysis confirmed that the rates and directions of growth varied from year to year. The difference in growth rate between the Class I and II samples was not apparent in this study. However, the difference in growth direction was quite obvious. Mandibular growth rate in Class II subjects was smaller during the pubertal growth period and the direction was in general more downward and backward in the Class II division 1 subjects. These findings are in agreement with those reported by Foley and Mamandras[39] who employed conventional cephalometric analysis as well as Battagel[40] who used a tensor analysis. Both studies showed significant differences in the direction and amount of growth between prepubertal and late adolescent subjects.

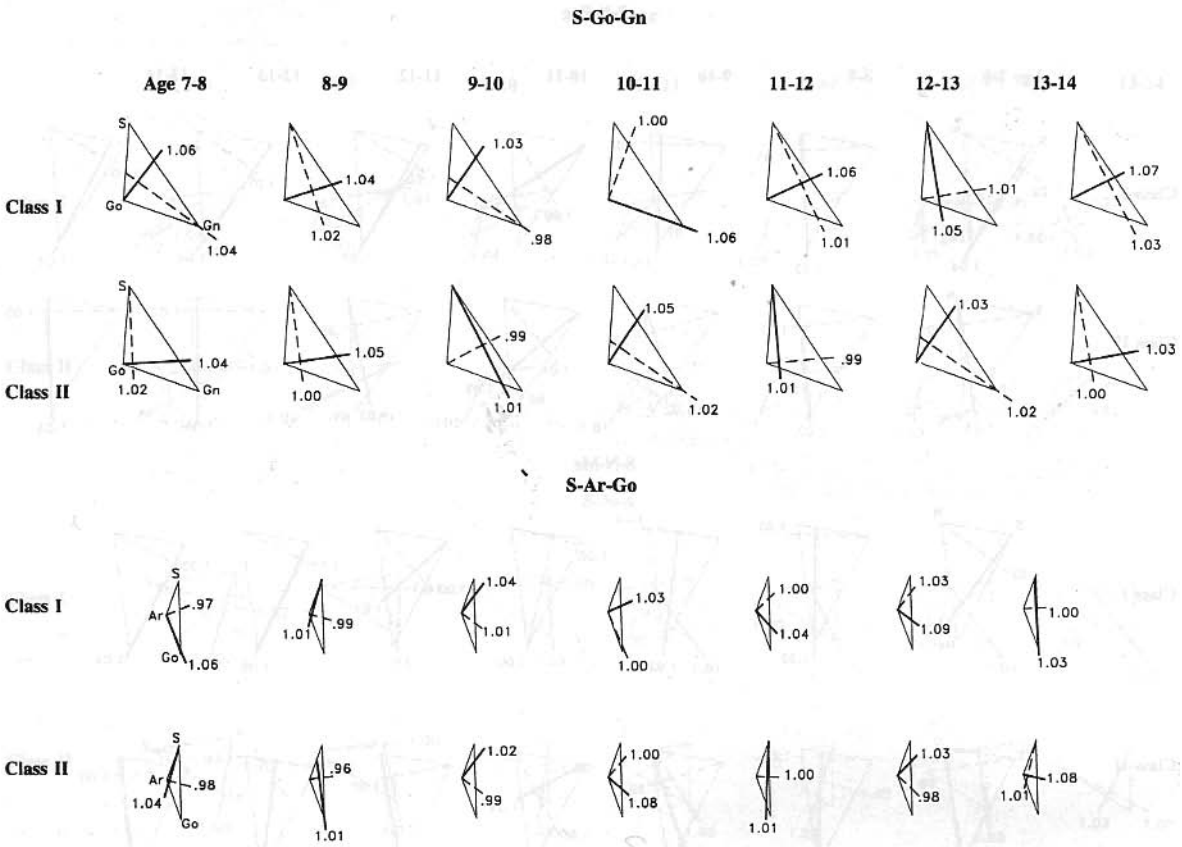

Figure 8. Tensor analysis of triangles S-Go-Gn and S-Ar-Go showing the direction and amount of growth yearly between ages 7 and 14 for Class I and Class II subjects. The solid and dotted lines indicate maximum and minimum dilations, respectively, with reference to the first two landmarks. The numbers indicate dilation factor, eg, 1.00 represents no change from the original form and 1.02 represent 2% increase in size.

Finally, clinicians should be cautioned that mean values are presented in this article. Conclusions drawn from the examination of the mean data should be tempered with an understanding of individual variation. Growth evaluations with treatment should be performed on an individual basis by superimposition of cephalometric radiographs taken 1 or 2 years apart.

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