A Serial Investigation of Facial and Statural Growth in Seven to Twelve Year Old Children*

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This study concerns a serial roentgenographic assessment of dimensional changes in the facial skeleton and their relationships to growth in stature. An essential feature of analyzing facial skeletal growth in its pattern of development involves establishing rates of individual dimensional change and observing the interrelation of these rates of change during a time period. Serial roentgenographic investigations by Brodie[3,5] and Nanda[18] gave evidence of a relationship existing between growth of the facial skeleton and statural growth. These investigations demonstrated a need for further definition of timing in facial growth rates and, more specifically, the relationship between growth in stature and facial skeletal growth. The aim of the investigation is an attempt to answer three specific questions as applied to the age group included in this analysis:

1. Can the rate of facial and statural growth be considered approximately constant (linear increments) when observed from individual growth rate slopes?
2. Based on the preceding statistical determination of growth rate linearity, how does the relationship of statural to facial skeletal growth compare on an individual basis, i.e., do average annual statural growth rates correspond to average annual facial skeletal growth rates?
3. Assuming the validity of the above statistical evaluations, is there a possibility of growth rate prediction?

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Review of the Literature

Before roentgenographic cephalometrics became a workable research tool, anthropometric investigations by Hellman,[11,12,13] Todd[28,29] and Krogman[15,16] described the process of facial growth. Group averages were taken at progressive stages of occlusal development and age levels as a means of plotting growth changes. These investigations revealed that the courses of facial and statural growth were not regular and that variation in the rate of growth of different facial dimensions produced changes in proportionality. They felt that, in general, facial growth in its incremental and proportional development followed the growth pattern of the entire body.

Scammon[24] and Tanner[26,27] suggested that the rate of statural growth could be graphed and the velocity calculated with some precision. Palmer and Reed[20] showed that a short series of repeated measurements may be made to yield reliable growth information when applied to the individual. The results suggested a fundamental characteristic of linear progression during a time period. Garn[9] and Bayley[1] reported that growth differences among children were rather constant and the same rank-order was maintained over fairly long periods of time. Bayley stated, "Most children mature and grow at much the same rate although differing greatly in size." In this regard, Salzmann[23] felt that the maintenance of an adequate rate of growth was more significant than the actual height attained or the degree of correlation to a normal.

Roentgenographic cephalometric studies by Broadbent[2] and Brodie revealed an orderly and progressive pattern of proportional increase in growth. This contradicted the previous concepts of growth discontinuity and corroborated the view that a study of dead material was largely a measure of defective growth. Brodie plotted the growth of facial skeletal dimensions which revealed a group of curves typical of general growth. However, specific statistical description of dimensional changes betwen the facial skeleton and stature was not mentioned. He concluded that when growth was analyzed, one should determine the relative individual variation of parts, growth increments, and gradients. Growth in skeletal bigonial width was studied by Newman and Meredith.[19] Their data indicated that increase in bigonial width was correlated with other transverse facial skeletal dimensions and with dimensions of the body in a transverse direction. The results of this study agreed closely with Woods[30] who also reported the course of growth regular with no fluctuations other than could be accounted for by random error. Nanda analyzed individual facial skeletal dimensions by use of percentage incremental growth curves. When these curves were contrasted with the percentage incremental curve of statural growth, the facial skeletal curves were found generally comparable. The dimensional changes maintained their relative positions in each individual case. Burstone[7] agreed with Nanda's study suggesting a close relationship between peak velocity in stature and certain facial structures. He also supported previously stated opinions suggesting that average growth rates were not reliable when predicting individual incremental addition. He stated that the hypothesis of concurrent facial and statural changes had not been adequately tested and merited consideration as an aid in growth prediction. Johnston et al.[14] compared skeletal maturation, cephalofacial development and chronologic age and found that certain facial skeletal parameters were related to maturation. However, Rose[22] found chronologic age and carpal rank ineffective guides to the growth and development of facial areas; in his investigation stature was demonstrated as the best indication of facial development.

Materials and Methods

The cases used in this investigation were selected from the files of a serial growth study conducted at the University of Minnesota. Twenty-five cases were chosen, fourteen males and eleven females. The children ranged in age at the beginning of record collection from six years and nine months to eight years and ten months, thus approximating the period of the changing dentition. Standardized head roentgenograms, statural determinations, and impressions for study models were taken on all subjects at annual intervals for four years.

Five criteria for the acceptance of cases were determined:

1. Developing normal occlusion as observed from study models of each child.
2. No previous orthodontic treatment.
3. An age span which fell within the indicated seventh to eighth year at the beginning of record collection.
4. Teeth in centric relation in all head roentgenograms.

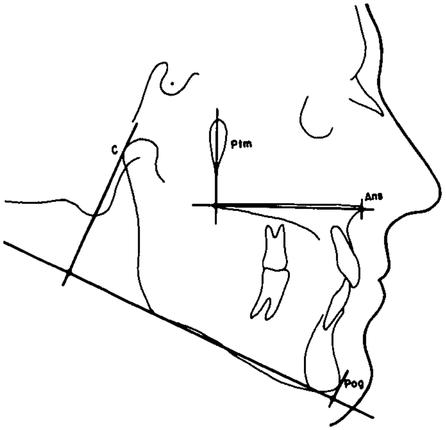

Fig. 1 The method used in this study to measure anteroposterior facial skeletal dimensions from a standardized head x-ray tracing.

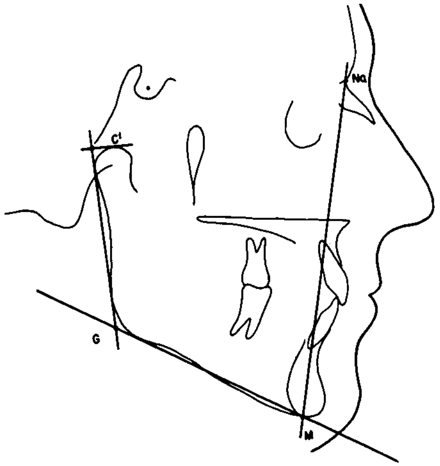

Fig. 2 The method used to measure vertical facial skeletal dimensions.

5. Adequate case records indicating the absence of previous severe ill health or the presence of any pathology.

The determination of a skeletal pattern was not undertaken prior to case acceptance obviating bias on the part of the observer. The individual variation in normal growth of these children was the primary consideration without regard to an average pattern.

All roentgenograms used in this investigation were taken in normal lateralis with a Broadbent-Bolton cephalometer. Four parameters located in the facial skeleton were chosen for assessment and were measured to the nearest one-half millimeter. Two of these were located in an anteroposterior direction and two in a vertical direction.

Total maxillary length was measured by a perpendicular constructed from the center of the pterygomaxillary fissure (Ptm) to the most anterior tip of the anterior nasal spine (ANS) along the palatal plane (Fig. 1). Total mandibular length was measured on the mandibular plane from a perpendicular constructed from the most posterior point on the mandibular condyle (point C) to the most anterior point on the outline of symphysis mandibularis (Pog) (Fig. 1). Total ramus height was measured by a perpendicular constructed from the most superior point on the mandibular condylar outline (point C′) and the intersection of the mandibular plane with a line tangent to the posterior border of the ramus (Fig. 2). Total anterior facial height was determined by the distance from nasion (Na) to mention (M) (Fig. 2).

The majority of roentgenograms presented adequate visualization and, with care in tracing, the decision to use total mandibular condylar morphology appeared justified. This concept is in agreement with Speidel and Stoner[25] who felt that one should record the over-all morphology of a structure when attempting to describe its growth.

Standing height was recorded at the time of taking roentgenograms. A fixed wall scale ruled in tenths of a centimeter and a sliding triangular device placed perpendicular to the scale were used to record this measurement. The children were measured in stocking feet with their heels placed together and against the wall. The Frankfort plane of each child was aligned parallel to the floor during all recordings thereby producing uniformity.

The data in this study were analyzed using regression analysis.[8] In a regression analysis the frequency distribution of one variable is considered while a second variable is held fixed. In the present study the fixed or independent variable is time in yearly intervals and the dependent variable is the observed dimension (statural or facial). The independent variable is designated as t (time) and the dependent variable as y (observed measurement). In the present application of this theory, the computed curve is assumed to be a straight or approximately straight line for the range of t values. If there is linear regression, and the rate of growth is constant over the specified time period, the b value (growth rate estimate) can be computed. On the basis of serial records the growth rate estimate was determined for each individual.

An estimate of the relationship between the statural growth rate (b_1) and the growth rates of the observed facial skeletal dimensions (b_2, b_3, b_4, b_5) during the indicated time period was obtained. This was done by computing the Pearson product moment correlation coefficients between the average annual statural growth rate and the growth rates of the facial skeletal dimensions.

Although the growth rates are approximately linear, deviations from linearity occasionally may be observed. These are due to minor alterations from a constant growth rate over the period of observations and to technical errors in obtaining the data. For this reason it is necessary to obtain some measure of the degree of linearity exhibited by the data. Such a measure can be obtained by comparing actual measurements with the best fitting straight line for any set of data.[8] This measure is denoted by $S_{y.t}$.

Results

Table I gives the values for average annual growth rates of observed measurements and also shows the computed average male and female rates and the mean sex difference. Twice the standard error of measurement for average annual rates is denoted after the positive and negative signs. The mean sex difference is given as the difference between average growth rates plus or minus two times the standard error of difference. A measure of the encountered sex difference is determined by this method. No significant sex difference was observed for any of the dimensions considered. An analysis of this table also indicates that a relatively high degree of individual variation existed in the sample.

The degree of relationship between the average annual rates of statural growth and the average annual growth rates of the four facial skeletal dimensions is determined by computing the Pearson product moment correlation coefficients (r_1, r_2, r_3, r_4). Table II gives these correlation coefficients for males and females separately and also the pooled correlation coefficients. The correlations are all positive values. It can be seen that the average annual growth rates of mandibular components (r_1, r_4) show a relatively higher degree of correlation to statural growth than the maxillary components (r_2, r_3).

Table III gives the values for variation from a constant growth rate (linear increments). These values express alterations in constant growth rate and deviations due to technical error as computed by the principle of least squares.[8] They are denoted by the symbol $S_{y.t}$. Figure 3 demonstrates the best-fitted straight lines ($S_{y.t}$) for two of the individuals chosen at random. The regression analysis for all five parameters for these individuals shows the growth rate estimate (b) in each case.

Table I

Computed values for the estimated average growth rates (*b*) of observed measurements showing average male slopes, average female slopes, and mean sex difference.

Case Number	Age Range (years & months)	Stature b_1	Mandibular Length b_2	Maxillary Length b_3	Total Facial Height b_4	Ramus Height b_5
		Cm.	mm.	mm.	mm.	mm.
101	7-10 to 11-1	5.06	2.08	0.92	1.83	0.70
102	8-2 to 11-2	5.35	1.75	1.40	2.65	2.10
103	9-7 to 12-6	4.66	1.50	0.64	1.19	0.70
104	9 to 12	4.85	2.30	0.85	2.15	1.20
105	7 to 10-1	6.51	4.22	1.55	2.81	3.10
106	8-1 to 11-1	4.93	2.05	1.20	2.55	1.25
107	6-9 to 9-8	6.82	2.27	0.51	2.47	1.76
108	9-11 to 12-10	8.24	2.89	1.96	3.72	2.07
109	8-4 to 11-4	5.38	2.30	0.65	2.30	1.00
110	8-1 to 11-1	6.19	2.10	0.65	2.20	2.15
111	8 to 10-11	4.33	2.27	1.03	3.39	1.65
112	8-11 to 11-9	4.58	1.36	1.04	1.67	1.46
113	8-7 to 11-8	5.65	1.55	0.81	2.01	1.81
114	8-10 to 11-10	4.61	1.40	0.90	1.21	0.65
Average Male Slope		5.50 ± .58	2.14 ± .39	1.01 ± .22	2.30 ± .39	1.54 ± .27
115	8-1 to 11-2	6.58	1.61	0.97	2.91	1.60
116	8 to 11	4.12	1.30	0.65	2.00	0.50
117	7 to 9-10	5.21	1,72	0.90	2.59	1.37
118	7-8 to 10-8	6.47	2.86	1.69	2.23	1.70
119	8 to 11	5.46	1.03	0.82	2.27	1.03
120	8 to 11	5.46	1.94	0.66	1.10	0.92
121	7 to 10	5.22	1.95	1.00	1.65	1.00
122	7 to 10	5.46	1.60	0.80	1.85	1.10
123	8 to 10-10	7.47	3.40	1.03	2.00	1.83
124	9-10 to 12-10	7.15	3.02	1.36	2.24	2.15
125	8-2 to 11-2	5.43	1.65	1.30	2.70	0.90
Average Female Slope		5.82 ± .59	2.01 ± .46	1.02 ± .18	2.14 ± .29	1.28 ± .26
Mean Sex Difference		.13 ± .82	.13 ± .60	.01 ± .89	.16 ± .99	.26 ± .37

Table II

Values of the Pearson product moment correlation coefficients (r) giving an estimate of the relationship between the statural growth rate and the growth rates of facial skeletal dimensions.

Males

r_1—(b_1-b_2)	0.578
r_2—(b_1-b_3)	0.458
r_3—(b_1-b_4)	0.570
r_4—(b_1-b_5)	0.605

Females

r_1—(b_1-b_2)	0.805
r_2—(b_1-b_3)	0.562
r_3—(b_1-b_4)	0.206
r_4—(b_1-b_5)	0.926

Total

r_1—(b_1-b_2)	0.645
r_2—(b_1-b_3)	0.489
r_3—(b_1-b_4)	0.419
r_4—(b_1-b_5)	0.647

Table III

Values for the estimates of degree of linearity ($^{S}y.t$) for observed measurements showing deviation due to minor alteration in constant growth rate and to technical error.

Case Number	Stature y_1	Mandibular Length y_2	Maxillary Length y_3	Total Facial Height y_4	Ramus Height y_5
Males					
	Cm.	mm.	mm.	mm.	mm.
101	0.156	0.430	0.036	0.046	0.311
102	0.130	0.216	0.112	0.097	0.296
103	0.077	0.360	0.094	0.165	0.176
104	0.360	0.362	0.097	0.097	0.079
105	0.324	0.468	0.151	0.313	0.503
106	0.456	0.383	0.079	0.290	0.484
107	0.249	0.458	0.014	0.143	0.159
108	0.941	0.582	0.228	0.346	0.318
109	0.236	0.193	0.097	0.194	0.000
110	0.410	0.296	0.097	0.194	0.444
111	0.407	0.458	0.026	0.256	0.175
112	0.110	0.054	0.023	0.132	0.215
113	0.092	0.422	0.302	0.296	0.104
114	0.129	0.167	0.162	0.154	0.075
Females					
115	0.211	0.236	0.028	0.056	0.063
116	0.512	0.194	0.097	0.000	0.000
117	0.488	0.508	0.124	0.242	0.246
118	0.272	0.333	0.150	0.157	0.325
119	0.121	0.057	0.046	0.126	0.057
120	0.353	0.284	0.113	0.321	0.285
121	0.048	0.291	0.000	0.097	0.000
122	0.302	0.387	0.079	0.097	0.387
123	0.906	0.345	0.070	0.363	0.277
124	0.387	0.331	0.301	0.154	0.501
125	0.195	0.097	0.079	0.079	0.158

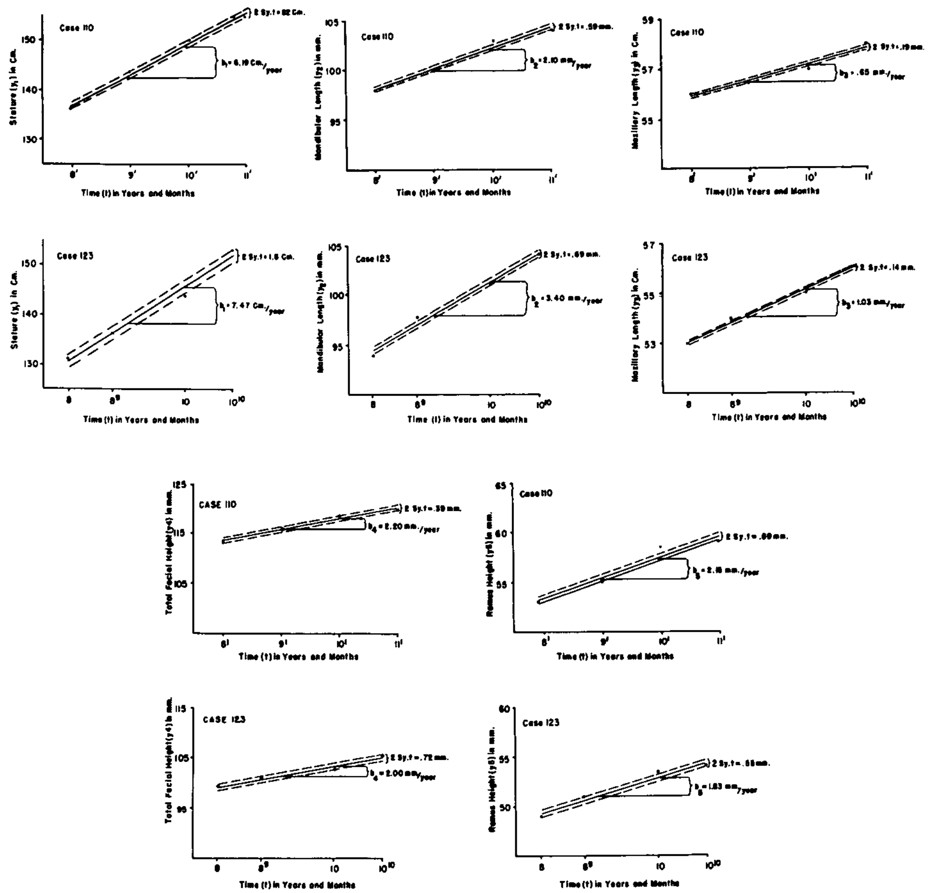

Fig. 3 Computed growth rate slopes for one male (110) and one female (123) illustrating the best fitting straight line for estimates of the average annual increase of observed measurements (b). Also illustrated is the band containing ninety-five per cent of deviations due to alterations in constant growth rate and to technical error ($^2Sy.t$).

The results of the investigation indicate that, over the age interval covered by this study, close approximation to a constant rate of growth occurs. From this information a method of prediction of facial skeletal dimensions could be obtained. An increased number of samples would allow an estimation of the reliability of such a prediction method. It is emphasized that the results of this study apply only to those individuals who meet the criteria of selection as outlined. The results cannot be construed as applying to all children.

Discussion

Previous investigations analyzing growth data by cross-sectional methods have reported facial and statural growth in relation to population norms. They showed the status of an individual relative to the population observed. However, these cross-sectional methods have condensed individual variation into group averages and the rate and direction of individual growth cannot be described. This investigation supports the findings of Brodie, Nanda, Newman and Meredith, and Burstone who reported that the individual must be studied in order to reach definite conclusions regarding the constancy of growth. This investigation has suggested that central tendency studies are not the answer to a description of individual growth aspects. Brodie[6] concurred with this concept when he stated the conclusion that females demonstrate an increase in growth rate earlier than males may rest on statistical averages of groups of children but do not necessarily hold true when applied to the individual. In this regard it is interesting to note that this study showed no significant sex difference for any observed dimensional change. This suggests that the female growth rates may not demonstrate an increase over that of male growth rates during the period studied. This observation supports the findings of Johnston et al.[14] who reported that sex differences were not statistically significant when percentage of completed facial growth was computed against chronologic and skeletal age. However, the time period of this investigation, terminating at twelve years of age, may not have been sufficient to reveal a difference in growth rates due to differences in sexual maturity.

The results of this investigation indicate that close approximation to a constant rate of growth occurs in this sample over the relatively short time period of seven to twelve years of age. The assumption of linear regression of growth rate on chronologic age, therefore, appears valid. The results are in agreement with the findings of Palmer and Reed[20] who also observed short-term linearity in the rate of statural growth. This linearity in growth rate may not hold true either preceding or following the indicated age span. No attempt was made to project any of the findings of this study into age groups other than those reported. Furthermore, the full growth cycle from infancy to adulthood follows a curvilinear rather than rectilinear path when graphed. The hypothesis of a constant growth rate (linear increments) is considered as applying only to this limited period of growth.

An analysis of Tables I and III indicates that a relatively high degree of individual variation exists in the sample. However, it can be seen by comparing these tables that the average growth rates between individuals and the degree of linearity achieved tend to parallel each other. This suggests that differences in the rate of growth between individuals remains constant. This observation is in agreement with the findings of Garn, Nanda, Bayley and Johnston et al.

The observed growth rate linearity also suggests a steady, synchronous process of development existing in the sample studied. It is evident from an analysis of the data that fluctuations occur in the growth rates of selected dimensions. A description of fluctuations in the rate of growth by analysis of percentage increment curves has been reported by Gray and Aryes, Meredith, Nanda and Bayley. These curves showed periods of slower and more rapid growth. The findings of this study agree with Gray and Aryes' criticism of percentage increment curves as not representative of relative rates of growth. Deviations in the rates of growth observed in this investigation are due to minor alterations from a constant rate of growth and to technical errors in obtaining the data. It is difficult by the present procedures to separate these entities and describe them individually. They necessarily must be reported as a single source of error. Even so, these deviations are of a minor degree and were not as large as some investigations have indicated.

An attempt to determine the relationship of statural growth to facial skeletal growth indicated that a positive correlation exists. This correlation exists because the parameters are all linear during the age-span studied. They are not identical, however. Therefore, prognostication of the increment of growth of any parameter may be feasible based upon the growth rate slope of that particular parameter. The findings substantiate those of Rose, Nanda, and Johnston et al. that stature bears a close relation to facial growth. A positive correlation also supports Burstone's statement that much of what is currently known about growth in stature may be applicable to the region of the skull. He said, "Any information that the clinician may obtain concerning stature growth may be helpful in the prediction of the onset of the peak velocity in the face."

Growth rates of maxillary components when compared to mandibular components did not show as great a correlation with the statural growth rate. This finding may be due to the influence on maxillary growth of the cranial base and nasal septum. Nanda noted that growth of the sella-nasion dimension differed from growth observed in dimensions of the facial skeleton. He interpreted this growth between sella and nasion as demonstrating a composite pattern of neural and general body growth. The lower correlation of the rate of maxillary growth and statural growth when compared with the rate of mandibular growth and statural growth as found in this study give support to the above findings of Nanda.

The observed linearity in individual growth rates indicates that a valid method for the prediction of facial measurements may be practicable. This would substantiate the prediction study of Ricketts[21] and support Tanner's observation that, "The decided advantage of taking measurements on a single child is shown by fitting a curve to that individual's measurements." It should be understood that a prediction must be formulated by individual assessment. A series of measurements is necessary to increase the reliability of such an estimation. A growth prediction based on an average curve for the total sample would not be possible since the band resulting from deviations due to alteration in constant growth rate and technical error would be too wide. The parameters of this band would contain the variation of all individuals observed. Therefore, at the present time, accuracy in the estimation of growth rates can be obtained only by individual assessment.

Summary and Conclusions

An assumption of linearity in the growth rates of certain facial parameters and body stature was statistically tested on fourteen male and eleven female children ranging in age from six years and nine months to twelve years and ten months. All individuals demonstrated a negative medical history, normal dental development, and neither required nor received any orthodontic treatment. Four annual lateral head roentgenograms and statural determinations were recorded for each individual. The roentgenograms were traced and the facial skeletal dimensions chosen for assessment were: mandibular length, maxillary length, total anterior facial height, and ramus height.

Statistical computation of data was analyzed using the theories of linear regression and correlation. Tables and graphs developed by these statistical methods were presented to describe the growth of selected individuals. The relationship between the rate of statural growth and the growth rates of the four facial skeletal dimensions was determined. The possibility of a growth rate prediction was discussed based on an analysis of individual data. The results of this investigation applied only to those individuals who met the criteria of case selection.

Linearity in the rate of growth as reported by this study may not hold true either preceding or following the indicated age span. No attempt was made to project the findings of this study into age groups other than those reported. The hypothesis of a constant growth rate was considered applicable only to this limited period of growth. Similarly, no attempt was made to examine the clinical application of the findings of this investigation. Such an application must await further supporting studies utilizing an increased number of samples.

An analysis of the data over the age interval covered by this study has led to the following conclusions:

1. All individuals demonstrated a close approximation to linearity in the growth rates of statural and facial skeletal dimensions studied.
2. This approximation to growth rate linearity indicates that a method of prediction of facial dimensions could be obtained from information concerning the degree of alteration in a constant growth rate among individuals.
3. The reliability of this prediction method could be estimated by subsequent studies.
4. No significant sex difference was observed for any of the dimensional changes considered.
5. A relatively high degree of variation between individuals existed in the sample.
6. A positive correlation was found for the relationship between the statural growth rate and the growth rates of four facial skeletal dimensions.
7. Prognostication of the amount of growth of any parameter is most accurately obtained from the linear growth rate curve of that particular parameter.

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