The Male Adolescent Facial Growth Spurt: Its Prediction and Relation to Skeletal Maturation

EARL O. BERGERSEN, D.D.S., M.S.D.*

INTRODUCTION

There has been considerable interest in recent years concerning the adolescent growth spurt and the influence it exerts on facial structures. The study of the spurt started in 1759 when Gueneau de Montbeillard[1] began an 18-year study on his son to determine yearly increments of growth. The adolescent spurt has since been recognized as an extremely active period of accelerated growth.

The principle of skeletal maturation and its estimate dates back to 1908 when Crampton[2] first described it. Later it was developed by Todd[3] and Greulich and Pyle[4] into the present technique of using hand radiographs in determining the state of maturity. Current research which relates the face to skeletal development and maturation dates back to Spier[5] who was the first to associate tooth eruption with growth in stature. From this original study numerous avenues of research have developed to test the relationship of (a) tooth eruption with skeletal maturation and/or growth in stature (Woodrow and Lowell,[6] Abernathy,[7] Cattell,[8] Becks,[9], Sutow, Terasaki and Ohwada,[10] Björk,[11] Lamons and Gray,[12] Meredith,[13] Bambha and Van Natta,[14] Lewis and Garn,[15] Björk and Helm[16]), (b) root formation or crown calcification with skeletal maturation (Demisch and Wartmann,[17] Hotz, Boulanger and Weisshaupt,[18] Lewis and Garn,[15] Green[19]). Other researchers investigated a combination of (c) eruption, root formation, genetic, nutritional, crowding and spacing, type of malocclusion, maturity and their interrelations (Brauer and Bahador[20] Björk,[11] Gleiser and Hunt,[21] Stein, Kelley and Wood,[22] Lewis and Garn,[15] Lauterstein,[23] Grøn,[24] Garn, Lewis and Kerewsky[25]). Most of the studies above showed varying degrees of nonassociation to good correlation with skeletal growth and maturity, which probably indicates that skeletal maturation plays some part in the development of the dentition. The majority of these studies agree that dental maturation is not as accurate an estimate of skeletal maturation as the use of a roentgenogram of the hand and wrist.

Recent studies that have shown a high degree of association of facial growth with general body growth (stature, standing height, shoulder width, etc.) are Bushra,[26] Lindegard,[27] Nanda,[28] Bambha,[29] Hunter,[30] Singh, Savara and Miller.[31] Other studies which showed a low degree of association are Howells,[32] Rose,[33] Meredith,[34] Savara,[35] and Hixon.[36] Those investigations attributing a high degree of association of the adolescent facial growth peak to a similar peak in standing height are: Hunter,[30] Singh, Savara and Newman,[37] Fukuhara and Matsumoto,[38] while Nanda[28] and Bambha[29] have stated that the peak of facial growth, although closely associated with the stature peak, usually occurs at a slightly later time.

Predictions of facial growth or morphology, based either on other facial dimensions or body dimensions that have exhibited only mild success, have

* Assistant Professor, Department of Orthodontics, Northwestern University Dental School. Read before the Midwestern Component of the Angle Society, Chicago, Illinois, January 1972.

been described by Johnston,[39] Meredith,[34] Singh, Savara and Miller[40,31] Maj and Luzi,[41] Pike,[42] Tracy, Savara and Brant,[43] Bergersen,[44] Singh, Savara and Newman,[37] Hixon,[36] Björk,[45] and Eckler.[46] Ricketts,[47,48,49] and Ricketts, Bench, Hilgers and Schulhof[50] indicate a "high degree" of success in the prediction of facial growth from existing means of facial dimensions and their growth. No detailed prediction parameters, however, have been presented for comparison.

Another approach to the possibility of predicting facial growth and/or ultimate facial size is to compare the inherited characteristics between siblings and parents. This approach has been investigated by Wasson,[51] Stein, Kelley and Wood,[22] and Hunter, Balbach and Lamphiear,[52] all with very marginal success.

The relations of facial growth and dimensions have been compared with the state of skeletal maturation as evidenced from skeletal age (wrist and hand roentgenogram) or menarche by Hunter,[30] Bambha and Van Natta,[53] Moreschi,[54] Greene,[55] and Johnston, Hufham, Moreschi and Terry.[56] Hunter,[30] Moreschi,[54] and Johnston, et al.[56] indicated generally that the best correlations of facial growth with skeletal age involved measurements of the mandibular body (Go-Gn and Art-Gn). Singh, Savara and Miller,[31] and Hunter, Balbach and Lamphiear[52] also found that the length of the mandible was highly correlated with other body measurements and appeared to be the most consistently inherited characteristic (for father-son, father-daughter) of several measured facial dimensions. Of interest is that both Hunter, and Bambha and Van Natta found a significant correlation between the skeletal age (from the hand-wrist roentgenogram) and the peak of adolescent facial growth, particularly in the male, which indicates a predictive quality of the skeletal age in determining the time of greatest growth. The correlations were not as meaningful for the female samples in both studies, as they were for the males.

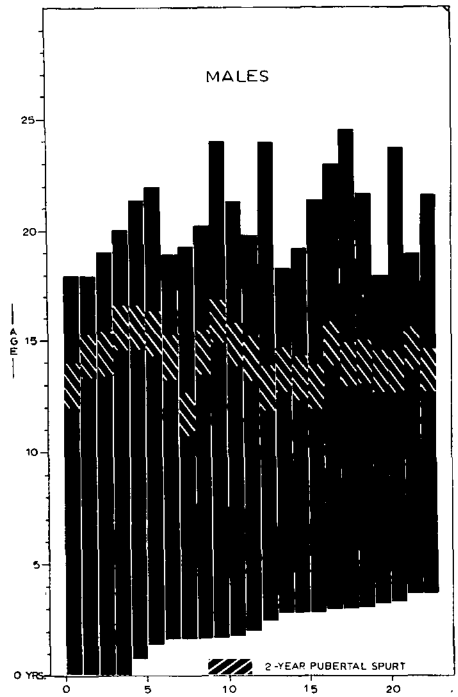


Fig. 1

Since it is quite evident from the literature that the maturation level of the individual is strongly associated with the fluctuations of growth in standing height and the face, particularly of the mandible, it was felt that an analysis of the growth spurts of several areas of the face and their relationship to skeletal maturity might produce knowledge leading to a method of adolescent spurt prediction in the face.

Materials & Methods

Serial cephalometric radiographs of twenty-three healthy white males were obtained from the Child Research Council at the University of Colorado Medical School (Fig. 1). The individuals of this study were primarily of

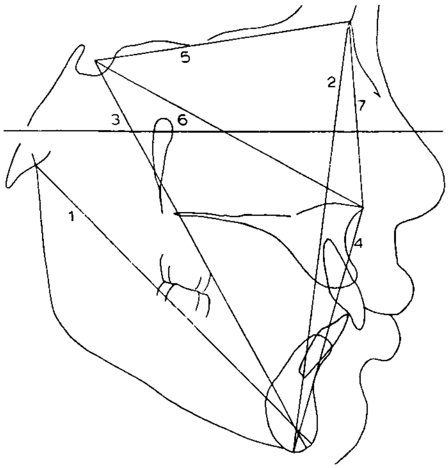


Fig. 2

North European ancestry and were of an upper middle socioeconomic class of Denver, Colorado; however, willingness on the part of the parents to allow their children to take part in the study was the greatest criterion of selection. There were four sets of paired siblings in the sample while all others were non-related. Tracings of these radiographs were made from the age range of approximately one month to 24.4 years of age. Seven measurements, which were constructed on the tracings as shown in Figure 2, consisted of:

(1) Articulare-gnathion (Art-Gn)
(2) Nasion-menton (N-Me)
(3) Sella-gnathion (S-Gn)
(4) Anterior nasal spine-menton (Ans-Me)
(5) Sella-nasion (S-N)
(6) Sella-anterior nasal spine (S-Ans)
(7) Nasion-anterior nasal spine (N-Ans)

All millimetric measurements were calculated to the nearest one-fourth millimeter and corrected for enlargement.

All standing height data, as well as the calculations of skeletal-age determinations of the sample, were obtained from the Child Research Council. The skeletal age calculations were made independently by Hansman and Maresh[57] utilizing the Greulich and Pyle[4] technique. The wrist roentgenograms and standing height data were collected at six-month intervals starting at birth, while the cephalograms were usually taken at yearly intervals (nine-months following each birthday) up to approximately seventeen years of age, after which the films were taken at each birthday. Details of the technique and the research program at the Child Research Council have been previously reviewed by Waldo[58] and Washburn.[59]

All cephalometric and standing height measurements were plotted and interpolations were then made from time-series analyses to convert all figures to yearly intervals (Fig. 3). The increments of growth in millimeters per year were then plotted to determine the rate or velocity of growth from three years of age to adulthood, as well as the timing of the adolescent growth spurt as seen in Figure 4. The beginning of the largest two-year spurt during puberty was determined for each measurement in every subject and the age of this beginning spurt was noted.

Any calculation of the length of the adolescent growth spurt is dependent on the placement of the base or average growth line. Since the spurt onset and termination is represented by the intersections of their growth lines with this variable base line, their estimation also tends to become quite variable. The major inherent problem causing this variation is one of accurately determining a base line in a constantly changing curve. Bambha[29] gave a range for the length of the male facial growth spurt from 1.37 to 4.10 years, while in body height the range varied from 1.05 to 3.90 years with means of 2.57 years in the face and 2.60 years in height. Hunter[30] gave a range of 1.5 to 3.5 years with a mean spurt length of 2.66 years in the male. The onset

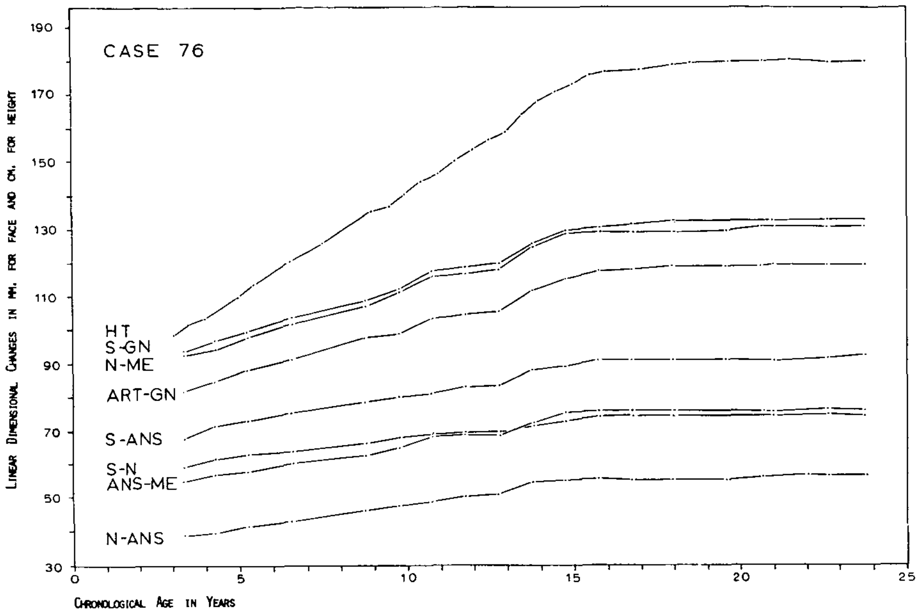

CASE 76
Linear Dimensional Changes in mm. for Face and cm. for Height
190
170
150
130
110
90
70
50
30
HT
S-GN
N-ME
ART-GN
S-ANS
S-N
ANS-ME
N-ANS
0
5
10
15
20
25
Chronological Age in Years

Fig. 3

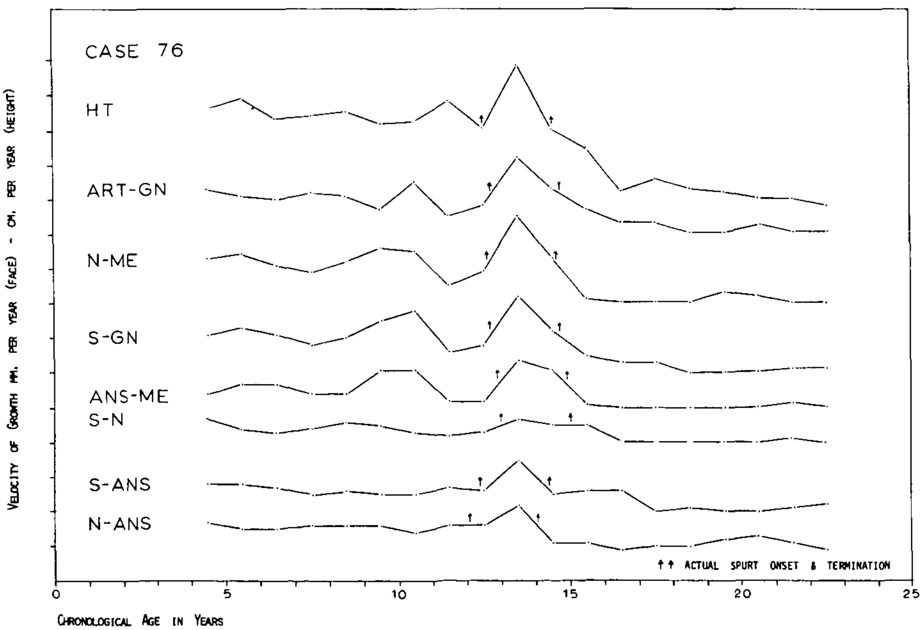

CASE 76
Velocity of Growth mm. per Year (Face) - cm. per Year (Height)
HT
ART-GN
N-ME
S-GN
ANS-ME
S-N
S-ANS
N-ANS
↑↑ ACTUAL SPURT ONSET & TERMINATION
0
5
10
15
20
25
Chronological Age in Years

Fig. 4

and termination vary considerably between individuals depending on the rate of growth and the presence of accessory spurts preceding and following the adolescent spurt. Since the mean length of the spurt for most studies is approximately 2.5 years, it was felt that a more meaningful technique to predict the onset of the growth spurt for the orthodontist would be an estimate of the two-year period of greatest growth in adolescence. Any other determination of the onset and termination of the spurt based on that period of growth exceeding the average growth over a period of several years would have excessive variation as evidenced from the above studies of Bambha and Hunter. This two-year period of greatest adolescent growth will be termed the adolescent or pubertal growth spurt in this study.

If the velocity of the spurt did not exceed the previous year by more than 0.75 millimeters, the onset and termination of the spurt was marked as being questionable. Growth curves representing dimensional-age changes (Figure 3) and velocity changes (Figure 4) were not smoothed because smoothed growth graphs mute or muffle velocity changes and diminish the frequent alterations in growth rates. It was felt that to diminish an infrequent gross measurement error by smoothing growth curves would result in great distortion of the frequent high and low variations in growth due to the rounding off of these normal peaks.

Increments of growth were then calculated forwards and backwards from the onset of the adolescent spurt on a chronological yearly basis to compare growth rates as a function of the spurt onset. Interpolations of the skeletal ages for each of the adolescent spurt onsets were calculated and the chronological age at each skeletal age from eight years to fourteen were calculated. These were estimated by plotting chronological age as an independent variable and skeletal age as a dependent variable, similar to Figure 3. Calculations of skeletal age were then possible at any chronological age.

All calculations for skeletal and chronological ages were converted to the decimal system for ease of statistical analysis.

Means of similar dimensions were utilized only when statistical tests denoted nonsignificant differences between these variables. The statistical tests of correlation coefficients (r), "t" tests of differences ("t"), standard deviations (S.D.), and standard error of estimates (Sy) used in this investigation are those adapted from Snedecor[60] and Arkin and Colton.[61]

Discussion

The adolescent or pubertal growth spurt of seven facial dimensions and standing height was analyzed longitudinally on twenty-three males to ascertain the relationship of these spurts, if any, with skeletal maturity as evidenced by the wrist radiograph. The practical significance of this possible relationship would be to enable the practicing orthodontist to predict an oncoming facial adolescent growth spurt, thereby enabling him to successfully time orthodontic treatment with this spurt. As mentioned previously, the two-year period of greatest intensity of growth during adolescence has, for practical purposes, been termed the adolescent spurt and has been divided into two categories for study. The first is (a) the timing, first occurrence or onset of this spurt, while the second is (b) the intensity or amount of growth per year. These two factors, along with their possible relationship with standing height, skeletal maturity expressed by skeletal age determinations from hand radiographs, and the first appearance of the metacarpal ses-

TABLE I
VARIATIONS IN THE INITIATION OF THE 2-YEAR PUBERTAL SPURT*
Means, S.D., and Ranges

	CA at Initiation of Spurt	SA at Initiation of Spurt	
Height	12.98 ± 0.88	12.42 ± 0.42	±
	11.80 — 14.68	11.33 — 13.17	—
Art.-Gnath.	13.15 ± 1.08	12.66 ± 0.45	±
	10.19 — 15.40	11.79 — 13.50	—
Nasion-Menton	13.14 ± 1.04	12.63 ± 0.45	±
	10.20 — 14.68	11.79 — 13.71	—
Sella-Gnath.	13.14 ± 1.02	12.64 ± 0.36	±
	10.37 — 15.23	11.79 — 13.23	—
Mean of Height Art-Gn N-Me S-Gn	13.11 ± 0.97	12.59 ± 0.35	±
	10.66 — 14.86	11.69 — 13.21	—
Ans-Menton	13.19 ± 1.16		±
	10.00 — 14.80	—	—
Sella-Nasion	13.30 ± 1.24		±
	10.18 — 15.00	—	—
Sella-ANS	13.18 ± 1.14		±
	10.70 — 15.60	—	—
Nasion-ANS	13.01 ± 1.10		±
	11.10 — 15.20	—	—
First Metacarpal Sesamoid	13.70 ± 1.16		±
	11.50 — 16.00	—	—

*The 2-year pubertal spurt represents the 2-year period of greatest intensity of linear growth during adolescence.

amoid at the metacarpophalangeal joint of the first digit, were studied.

Onset of the Pubertal Spurt

In the sample of twenty-three males the chronological age of first occurrence of the adolescent spurt among the four significant areas of concern (standing height, articulare-gnathion, nasion-menton, and sella-gnathion) varied between three and five years, as indicated in Table I. Since there was no significant difference between the times of spurt occurrence of any of these areas (Table II, Items 1-6), an average of the four was calculated which indicated that chronologically the initiation of the spurt varied from 10.66 to 14.86 years of age, or a mean range of 4.2 years (Fig. 1). When the same mean was established for *skeletal ages* of all the individuals in the study, the range of variation was from 11.69 to 13.21 or 1.52 years. Individual variations indicate that the majority of the larger differences between chronological and skeletal ages of the spurt onset occur in retarded and accelerated maturing individuals (as estimated from the Greulich and Pyle atlas). Although there is no significant difference between the chronological and skeletal ages of the spurt onset in normally-maturing individuals (Table II, Item 7), a significant difference (Item 8) does exist when similar comparisons are made between chronological and skeletal ages in the retarded and accelerated individuals, which is in agreement with the findings of Bambha and Van Natta and Hunter. Their studies indicate that skeletal age rather than chronological age is a more accurate indicator of the timing of the spurt for those individuals with accelerated or retarded skeletal maturation. The variation of the mean skeletal age of the spurt onset for height, Art-Gn, N-Me, and S-Gn is almost one third that of the spurt onset calculated from the chronological age, as indicated by the standard deviations in Table I. In other words, if one were to estimate the adolescent spurt onset from the mean chronological age of its first appear-

SUMMARY OF STATISTICAL COMPUTATIONS

Item	COMPARED MEASUREMENTS	N	d.f.	Test	Result
1.	CA at Ht. Spurt Onset:	23	44	t	0.575^{ns}
	CA at Art-Gn Spurt Onset:	23	21	r	0.868^{**}
2.	CA at Ht. Spurt Onset:	23	44	t	0.560^{ns}
	CA at N-Me Spurt Onset:	23	21	r	0.855^{**}
3.	CA at Ht. Spurt Onset:	23	44	t	0.555^{ns}
	CA at S-Gn Spurt Onset:	23	21	r	0.899^{**}
4.	CA at N-Me Spurt Onset:	23	44	t	0.013^{ns}
	CA at S-Gn Spurt Onset:	23			
5.	CA at Art-Gn Spurt Onset:	23	44	t	0.034^{ns}
	CA at N-Me Spurt Onset:	23			
6.	CA at Art-Gn Spurt Onset:	23	44	t	0.047^{ns}
	CA at S-Gn Spurt Onset:	23			
7.	CA at Mean Spurt Onset^{+} of Normal Matur. Indiv.:	15	28	t	1.294^{ns}
	SA at Mean Spurt Onset^{+} of Normal Matur. Indiv.:	15			
8.	CA at Mean Spurt Onset^{+} of Ret. & Accel. Matur. Indiv.:	8	14	t	3.755^{**}
	SA at Mean Spurt Onset^{+} of Ret. & Accel. Matur. Indiv.:	8			
9.	CA at Mean Spurt Onset^{+} of Normal Matur. Indiv.:	15	20	t	3.587^{**}
	CA at Mean Spurt Onset^{+} of Retard. Matur. Indiv.:	7			
10.	SA at Mean Spurt Onset^{+} of Normal Matur. Indiv.:	15	20	t	0.107^{ns}
	SA at Mean Spurt Onset^{+} of Retard. Matur. Indiv.:	7			
11.	CA at Mean Facial Spurt Onset^{++}:	23	44	t	0.010^{ns}
	CA at Predicted Mean Facial Spurt Onset^{++} at SA 9-0:	23	21	r	0.851^{**}
12.	CA at 1st Appear. Metacarp. Ses.:	23	44	t	0.728^{ns}
	CA at Ht. Spurt Onset:	23	21	r	0.840^{**}
13.	CA at 1st Appear. Metacarp. Ses.:	23	44	t	1.609^{ns}
	CA at Art-Gn Spurt Onset:	23	21	r	0.898^{**}
14.	CA at 1st Appear. Metacarp. Ses.:	23	44	t	1.662^{ns}
	CA at N-Me Spurt Onset:	23	21	r	0.873^{**}
15.	CA at 1st Appear. Metacarp. Ses.:	23	44	t	1.635^{ns}
	CA at S-Gn Spurt Onset:	23	21	r	0.915^{**}

ns Not significant.
** The confidence level of "P" (probability) is less than 1%.
\+ Mean Spurt Onset of Ht., Art-Gn, N-Me, and S-Gn.
++ Mean Facial Spurt Onset of Art-Gn, N-Me, and S-Gn.

TABLE II

ance in this study (13.11 years) to within one year on either side of the mean, the prediction would be in error 35% of the time. On the other hand, if one were to calculate the spurt onset from the mean skeletal age of its first appearance in this sample, all predictions would fall within the limits of accuracy of plus or minus one year. Although the individuals who have retarded or accelerated skeletal maturations account for approximately 30% of the sample in this study, this same retarded and accelerated group accounts for 57% of the prediction errors beyond one year of accuracy when using the mean chronological spurt onset age as the means of prediction. Therefore, the use of a mean derived from the chronological ages to predict the growth spurt produces a high degree of inaccuracy due to the inability to predict the skeletally-immature or accelerated individual. Further substantiation of this is evident in the fact that there is a significant difference between the chronological ages of the first appearance of the pubertal spurt between retarded and normally-developing individuals (Table II, Item 9), while no such difference exists (Item 10) between the same individuals whose age is calculated according to a skeletal maturation scale. Therefore, although the comparison sample sizes are rather small, it would tend to indicate that skeletal maturity has an influence on the time of the spurt. In other words, those individuals whose skeletal maturity is retarded have their adolescent growth spurt at a later chronological age than those who are maturing at a normal rate. Since there was only one skeletally-accelerated individual in the study, no similar statistical comparison between the accelerated and normally-maturing individuals could be made.

The fact that there was no significant difference between the chronological and skeletal ages of the spurt onset of the normally-maturing individuals may be due to the possible weighted nature of the sample used in this study in favor of retarded maturation, or the Denver population may have a significantly different rate of maturation than the Cleveland children represented in the atlas used for maturation indexing of the sample. Reports of variation from the Cleveland sample have been made from other areas, as reported by Johnston.[62] A further possibility for the discrepancy may be due to the presence of a skeletal maturity adolescent spurt, as suggested by Hewitt and Acheson.[63]

Four additional facial areas were studied, namely, anterior nasal spine-menton (Ans-Me), sella nasion (S-N), sella-anterior nasal spine (S-Ans), and nasion-anterior nasal spine (N-Ans). These areas have relatively small yearly increments of growth so that often the spurt onset is not great enough in intensity to be distinguished from the remainder of the growth record. Therefore, unless the growth spurt exceeded the preceding or following periods of incremental growth by at least 0.75 millimeter, it was considered unreliable and so marked on the record for that individual. The measurements for height, N-Me, and S-Gn had no questionable estimates of the timing of the growth spurt for all individuals in the study, while Art-Gn had 13% (3), Ans-Me had 30% (7), S-N had 82.6% (19), S-Ans had 34.8% (8), and N-Ans had 65.2% (15). As a result, the estimates regarding the timing and intensity of the pubertal spurts for these latter four measurements were considered unreliable and are presented in Table I only as a matter of interest.

The average skeletal age of the first occurrence of the spurt for all four of the more reliable areas (height, Art-Gn, N-Me and S-Gn) was 12.59 years of age, while the average chronological age was 13.11 years. The sample distribution of this study appears to be weighted to the retarded side of the skeletal maturity scale, evidenced by the five-month difference in the above figures, as previously mentioned. The discrepancy is also evident from an analysis of the wrist films of the twenty-three individuals studied indicating that 30% (7) were determined to be retarded while only 4.5% (1) were accelerated. While the variation in the skeletal ages of the spurt onset was, as previously stated, considerably less than the variation for the chronological ages of this onset (1/3 the amount), a variation of 1.52 years was still evident. One would think that there would be relatively no variation in the skeletal ages at the initiation of the spurt. Hansman and Maresh,[57] in a sample of thirty-six females, experienced similar variation in the occurrence of menarche since skeletally-accelerated girls tend to have their menarche at an earlier skeletal age. They felt that it probably was due to the existence of factors which stimulate maturity.

In the current study no such relationship appeared to exist; however, the sample size was 64% of the size of the above study. In other words, there was no significant statistical difference in the skeletal age of the beginning of the spurt between retarded and normally-developing individuals (Table II, Item 10). No comparison was possible between the accelerated and normally-developing individuals due to the small sample size of the accelerated group. As a result, the above finding would tend to indicate that the rate of individual maturity as a single entity is not related to the skeletal age at which the pubertal growth spurt begins. However, as stated previously, it does appear to be related to the chronological age at which the spurt begins.

Naturally, it is possible that other unknown factors, as well as the inherent errors of the skeletal age determinations and the calculations of determining the timing of the spurts, all may have their influences in producing the previously noted variations in the skeletal ages of first appearances of the growth spurt. Possibly three of the most significant factors in producing variability in spurt onset calculations for both the skeletal and chronological age determinations are (a) the frequency of the raw data measurements, (b) the selection of the particular interval of measurement for plotting velocity, and (c) the interpolation of missing data. A random selection of 25% (6 cases) of the individuals in this study was used to demonstrate the effect of these three factors in producing this variability. Ideally, measurements of facial growth should be obtained monthly or at least on a quarterly basis to obtain the most accurate measure of growth velocity. Measurements of height should ideally be made even more frequently. Many factors affect growth on a month-to-month basis and one, for example, is the seasonal effect. Tanner[64] states that growth in stature is two to two and a half times more intense during March, April and May than it is during September, October and November. Height calculations in the present study were measured every six months and were plotted on that same basis, as shown in Figure 3, however, for growth velocity calculations, the data were plotted on a yearly basis (Fig. 4) to coordinate with the yearly records of the face, since they were only available on a yearly basis. The semiannual height data were taken at random times during the year to coordinate with chronological age; therefore, seasonal effects would have a random effect on the group but would affect individual variation. To test the effect of frequency of measurements on the spurt onset, the velocity of growth was plotted for the random sample on a six-month basis while those used in the body of this study were plotted on a yearly basis. The mean alteration in the spurt onset was 0.146 years (2 months) or 10% of the variation in spurt onset between a yearly and semi-annual basis of raw data collection. The range of this alteration was 0.007 to 0.3 years. In other words, one individual's spurt onset was affected 3.5 months. The cephalometric records were taken on a yearly basis starting at the ninth month between birthdays until the individual was approximately seventeen years of age; after this the records were usually taken on the anniversary of the birth date. Therefore, in order to coordinate the height and facial data, considerable interpolation of the facial data was necessary to bring it to a yearly basis which would correspond to the height data. The velocity of the facial growth was plotted for the random sample for Art-Gn on a ninth-month basis between birthdays to test both the possible variation caused by the selection of a particular interval of measurement for plotting velocity (ninth month vs. even years) and by the interpolation of data. The mean alteration caused by this change in technique was 0.130 years (1.5 months) or 9% of the variation of spurt onset on a skeletal age basis. The range of variation was from 0.04 to 0.31 years. Therefore, three of the factors affecting the determination of the spurt onset tested above could cause 19% variation in the skeletal age spurt onset calculations. The peak of growth is most subject to the variation caused by the particular selection of the interval of measurement in plotting velocity, whether it be on a ninth-month or twelfth-month basis or whatever. As a result, the peak of growth will be identical to the same month selected for the measurement interval as seen in Figure 4. For that reason the time of the peak of growth was not analyzed since it was felt that its location would probably be the most variable of all data analyzed in this study.

Prediction of the Pubertal Growth Spurt

There is no significant difference between the time of occurrence of the adolescent spurt for body height, articulare-gnathion, nasion-menton and sella-gnathion (Table II, Items 1-6). There is, however, a significant correlation between the spurt onset of standing height and the other three facial dimensions (Table II, Items 1-3). In other words, the onset of the adolescent spurt is the same for all four of the above dimensions. This is in agreement with Hunter, Singh, Savara and Newman, and Fukuhara and Matsumoto who found that the peak year of adolescent growth was significantly correlated with the same dimension in standing height. Nanda and Bambha both state that the peak of growth of the face usually occurs after the same peak in body height, however, subjecting Bambha's results to a statistical test indicates an insignificant difference ("t" = 0.281) between the time of the peak of growth of the face and body height in his sample of twenty-five males. Nanda's sample of ten males is found in Bambha's sample, therefore, his results would probably show a similar result. Eight of the individuals in the present study, which were also used in Bambha's sample, indicate an average peak of facial growth of 0.97 years (0.82 years for standing height) after the onset of the spurt in the present study. Seventy-five per cent of the peaks (63% for standing height) occurred during the first year while 25% occurred during the second year of the spurt in this study.

Since all dimensions (standing height, articulare-gnathion, nasion-menton, and sella gnathion) had spurt

PREDICTION TABLE FOR THE BEGINNING OF THE MALE PUBERTAL GROWTH SPURT IN THE FACE

SA	8-0	8-6	9-0	9-6	10-0	10-6	11-0	11-6	12-0	12-6	13-0	13-6	14-0
Rate of Prediction 67%	± 7 mo.	7 mo.	7 mo.	6 mo.	7 mo.	6 mo.	6 mo.	5 mo.	6 mo.	5 mo.	5 mo.	5 mo.	5 mo.
95%	±15 mo.	13 mo.	14 mo.	13 mo.	13 mo.	12 mo.	11 mo.	11 mo.	12 mo.	10 mo.	9 mo.	9 mo.	10 mo.
CA													
6-0	10-3												
6-3	10-6												
6-6	10-9	10-3											
6-9	11-0	10-7											
7-0	11-4	10-10	10-3										
7-3	11-7	11-1	10-6										
7-6	11-10	11-4	10-10	10-1									
7-9	12-1	11-8	11-1	10-5									
8-0	12-4	11-11	11-4	10-8	10-4								
8-3	12-8	12-2	11.8	11-0	10-7								
8-6	12-11	12-5	11-11	11-4	10-11	10-4							
8-9	13-2	12-8	12-2	11-7	11-2	10-7							
9-0	13.5	13-0	12-6	11-11	11-5	10-11	10-5						
9-3	13-9	13-3	12-9	12-2	11-9	11-2	10-8						
9-6	14-0	13-6	13-0	12-6	12-0	11-6	10-11	10-4					
9-9	14-3	13-9	13-4	12-10	12-4	11-9	11-3	10-7					
10-0	14-6	14-0	13-7	13-1	12-7	12-1	11-6	10-11	10-5				
10-3	14-9	14-4	13-10	13-5	12-11	12-4	11-10	11-2	10-9				
10-6	15-1	14-7	14-2	13-9	13-2	12-8	12-1	11-6	11-0	10-4			
10-9	15-4	14-10	14-5	14-0	13-5	13-0	12-5	11-9	11-3	10-7			
11-0	15-7	15-1	14-9	14-4	13-9	13-3	12-8	12-1	11-7	10-10	10-4		
11-3	15-10	15-4	15-0	14-8	14-0	13-7	13-0	12-5	11-10	11-2	10-7		
11-6		15-8	15-3	14-11	14-4	13-10	13-3	12-8	12-1	11-5	10-11	10-5	
11-9		15-11	15-7	15-3	14-7	14-2	13-7	13-0	12-5	11-9	11-2	10-8	
12-0			15-10	15-6	14-11	14-5	13-10	13-3	12-8	12-0	11-5	10-11	10-7
12-3			16-1	15-10	15-2	14-9	14-2	13-7	12-11	12-3	11-9	11-3	10-10
12-6				16-2	15-6	15-1	14-5.	13-10	13-3	12-7	12-0	11-6	11-1
12-9				16-5	15-9	15-4	14-9	14-2	13-6	12-10	12-4	11-9	11-4
13-0					16-0	15-8	15-0	14-6	13-9	13-2	12-7	12-1	11-8
13-3					16-4	15-11	15-4	14-9	14-1	13-5	12-10	12-4	11-11
13-6						16-3	15-7	15-1	14-4	13-8	13-2	12-8	12-2
13-9						16-6	15-10	15-4	14-7	14-0	13-5	12-11	12-5
14-0							16-2	15-8	14-11	14-3	13-8	13-2	12-9
14-3							16-5	15-11	15-2	14-7	14-0	13-6	13-0
14-6								16-3	15-5	14-10	14-3	13-9	13-3
14-9								16-7	15-9	15-2	14-6	14-0	13-6
15-0									16-0	15-5	14-10	14-4	13-9
15-3									16-3	15-8	15-1	14-7	14-1
15-6										16-0	15-4	14-10	14-4
15-9										16-3	15-8	15-2	14-7
16-0											15-11	15-5	14-10
16-3											16-2	15-9	15-2
16-6												16-0	15-5
16-9												16-3	15-8
17-0													15-11
17-3													16-3
r	0.802**	0.839**	0.850**	0.853**	0.868**	0.080**	0.891**	0.899**	0.881**	0.918**	0.931**	0.928**	0.907**
Sy	0.608	0.562	0.576	0.537	0.543	0.491	0.469	0.452	0.488	0.410	0.378	0.384	0.436

** The confidence level of "P" (probability) is less than 1%.

TABLE III

onsets at the same time (insignificant differences), a mean spurt onset was established for each individual for the three facial dimensions, articulare-gnathion, nasion-menton, and sella-gnathion. The ability to predict this spurt was tested for thirteen different skeletal age levels with correlation coefficients and standard error of estimate calculations. As a result of these findings Table III was constructed to show the degree of prediction accuracy: the predicted chronological age at which the adolescent spurt will start (when knowing the chronological age at any skeletal age from 8 - 14 in six-month intervals), the correlation coefficients, and the standard error of estimates.

To predict the oncoming two-year spurt of greatest adolescent growth, the skeletal age is obtained from Greulich and Pyle's atlas.[4] This skeletal age calculation is then located on the first horizontal scale (SA) in Table III, which gives these ages in six-month intervals. The chronological age of the child at the time of the hand radiograph is then located on the first vertical scale (CA), and the predicted onset of the two years of greatest intensity of adolescent growth, stated in chronological years and months, is obtained in the chart. For example, if the individual is 11 years of age, chronologically, and the hand radiograph indicates a skeletal age of 11.5 years of age, the predicted growth onset in the face will occur at 12 years and 1 month ± 5 months chronologically in 67% of the population and ± 11 months in 95% of the population. The correlation coefficient between the chronological age at 11.5 skeletal years of age and the corresponding onset of the adolescent spurt is 0.899, which accounts for approximately 81% of all variation (0.899^2); the standard error of estimate is 0.452, which represents 67% of the population with a prediction rate of ± 0.452 years and 0.904 years (0.452 x 2) in 95% of all individuals.

The prediction of the oncoming adolescent spurt in the face is more accurate for retarded and accelerated maturing individuals than for those maturing normally due to higher variation reductions. This is significant to the orthodontist since the onset of growth spurts in retarded and accelerated cases are those most difficult to predict. The amounts of variation reduction for the prediction rates of the skeletally accelerated and retarded maturing individuals are found in Table IV. These predictions reduce the variation from 61% to 75% over and above that obtained by using the mean chronological age of the spurt onset. The variation reduction is highest and the prediction is most efficient one and one-half years prior to the onset of the spurt. These variation reduction percentages for facial growth predictions are considerably higher than most other of the more efficient prediction studies in the literature.

A practical example of the efficiency of skeletal age to predict the adolescent spurt can be seen in Figures 5 and 6. In Figure 5 is seen the prediction of the growth spurt by a chronological mean of its occurrence, while Figure 6 shows the prediction using the figures in Table III and a skeletal age determination with the use of a wrist roentgenogram. The two individuals (cases 11 and 108) in the upper segments of Figures 5 and 6 are skeletally retarded, while the middle segment is normal (case 76) and the two lower cases (125 and 5) are accelerated. The mean chronological age of the initiation and termination of the two-year period of greatest pubertal growth is represented by the vertical lines at 13.15 and 15.15 years in Figure 5. The beginning of the spurts for the skeletally-retarded cases (#11 and #108) oc-

TABLE IV

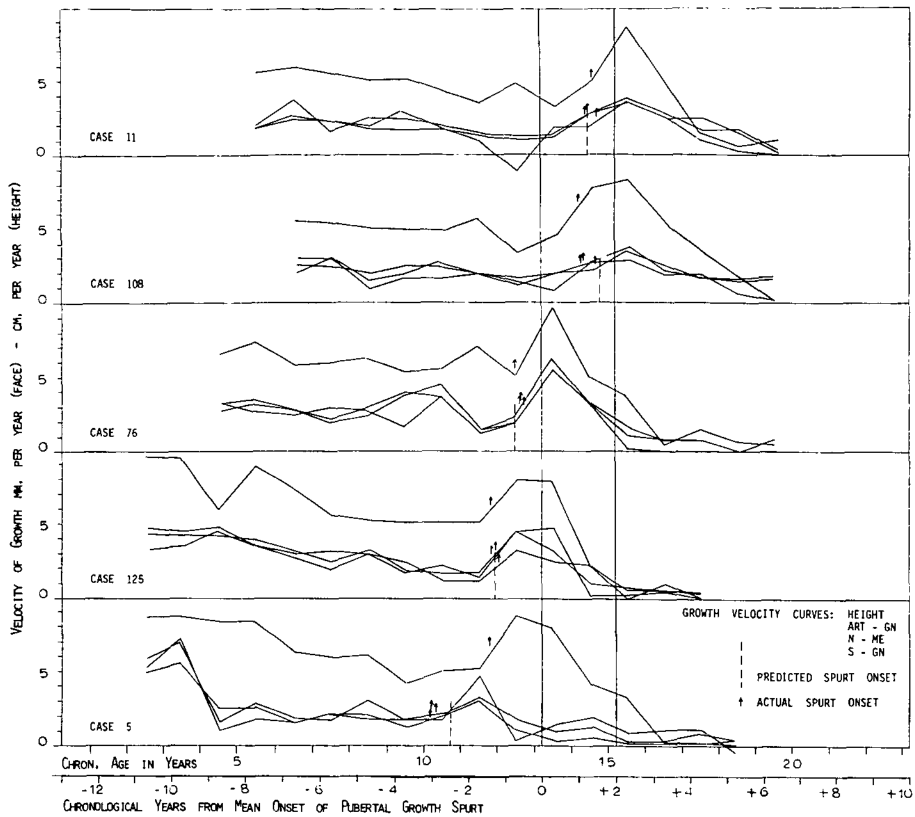
PERCENTAGE EFFICIENCY OF PREDICTION (VARIATION REDUCTION)* OF ADOLESCENT SPURT ONSET OVER ESTIMATES FROM ARITHMETIC MEAN**

SKELETAL AGE

Group	8-0	8-6	9-0	9-6	10-0	10-6	11-0	11-6	12-0	12-6	13-0	13-6	14-0
Retarded & Accelerated Maturation N = 8 S.D. = 1.399 C.A. Onset	63.4	62.5	64.6	67.3	57.5	65.4	72.6	75.2	73.2	74.8	70.6	68.6	60.9
Normal, Retarded & Accelerated Maturation N = 23 S.D. = 1.032 C.A. Onset	41.0	45.5	44.2	47.9	47.4	52.3	54.5	56.1	52.7	60.3	65.3	62.7	57.7
Sy Ret. & Accel.	.511	.524	.496	.457	.595	.484	.383	.346	.375	.353	.412	.439	.547
Sy N, Ret. & Accel.	.608	.562	.576	.537	.542	.491	.469	.452	.488	.409	.377	.384	.436

* Based on Comparison $\frac{(S.D.\ C.A.) - (Sy)}{(S.D.\ C.A.)} \times 100$

** Mean C.A. at Onset = 13.15 Years

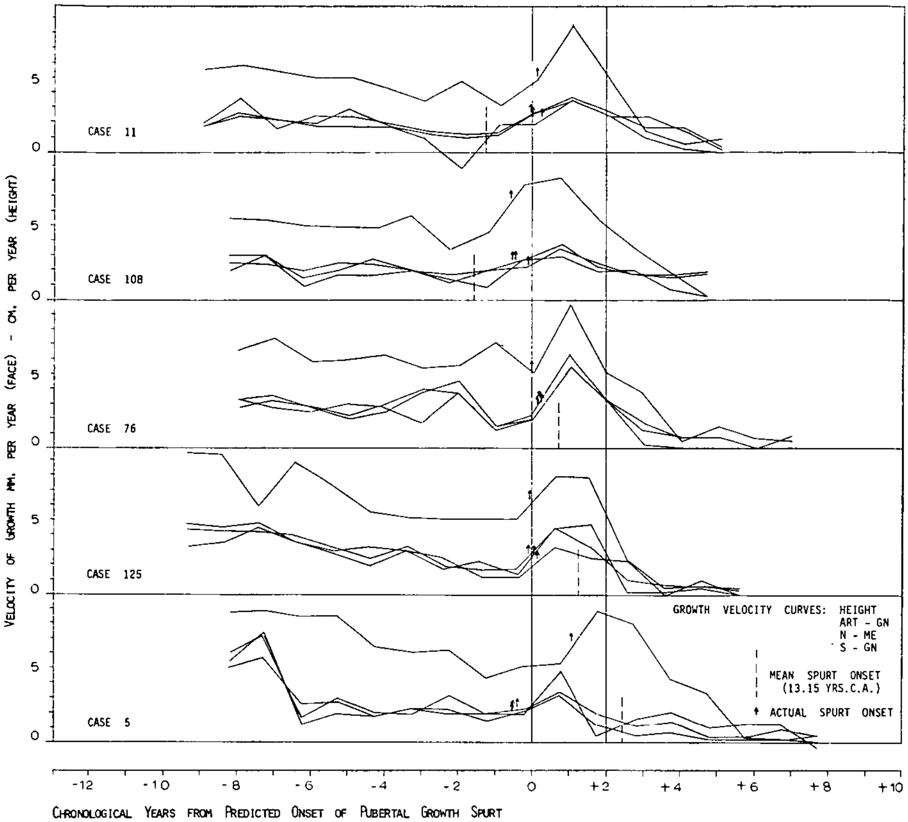


GROWTH VELOCITY CURVES AND THE MEAN ONSET OF THE PUBERTAL SPURT

Fig. 5

curs at least one year following the estimated onset of the spurt according to the chronological mean. In Figure 6, on the other hand, the actual spurt starts within a few months from the skeletally-estimated age of onset. This illustrates that skeletal age more accurately estimates the spurt onset than a mean derived from chronological age. The accelerated cases #125 and #5 in Figure 5 show similar tendencies in that the actual spurt onsets precede the mean chronological estimate of the spurt onset by at least one year or more while in Figure 6 the estimated skeletal onset and the actual onset are within a few months from one another. The normal skeletally-maturing case #76 (represented in Figures 5 and 6) shows that the variation between the actual onset and the estimated onset, be it chronological or skeletal, is quite similar. This similarity substantiates the insignificant differences existing between the skeletal and chronological onsets of the spurt in the normally-maturing individuals.

The deviations between the estimates of the onset of the spurt through the use of skeletal age assessments and the actual occurrence of the spurt at skeletal age 9-0 had a range of 0.005 to 1.115 years, while the mean deviation was 0.46 years. Statistically, there is no difference between the actual onset and the predicted onset (Table II,



GROWTH VELOCITY CURVES AND THE PREDICTED ONSET OF THE PUBERTAL SPURT

Fig. 6

Item 11), and there is a significant correlation between the measures (Table II, Item 11).

The metacarpal sesamoid, which is seen in the hand radiograph medial to the head of the first metacarpal in the tendon of the adductor pollicis is often used as an indicator of the adolescent growth spurt. Its time of occurrence was tested as to its possible correlation with the presence of an adolescent spurt. The time of first occurrence of the metacarpal sesamoid in the hand radiograph was shown to be highly correlated with the initiation of the two-year adolescent spurt in height, Art-Gn, N-Me, and S-Gn (Table II, Items 12-15). Although the mean age of first occurrence of the metacarpal sesamoid follows the first occurrence of the adolescent spurt in the four abovementioned skeletal measurements by seven months, this difference is not statistically significant (Table II, Items 12-15). As a result it is possible to predict when the adolescent spurt will start by the presence of the metacarpal sesamoid. However, since its first appearance coincides with the beginning of the spurt its predictive value is limited. As a result an orthodontist could utilize the appearance of the metacarpal sesamoid to indicate the onset of maximum growth; it would be more useful to precede treatment with a hand radiograph utilizing the skeletal age as a predicting determiner of

TABLE V

MEAN YEARLY INTENSITY OF GROWTH (MALE)

		3rd. yr. Prior to Spurt	2nd. yr. Prior to Spurt	1st. yr. Prior to Spurt	1st. yr. of Spurt	2nd. yr. of Spurt	1st. yr. After End of Spurt
Height cm.	Mean, S.D.	5.18 ± 0.90	5.15 ± 0.86	5.47 ± 0.63	8.07 ± 0.94	8.49 ± 1.21	4.27 ± 1.15
	Range	4.0 - 7.5	3.4 - 6.8	4.4 - 6.8	6.4 - 9.9	5.5 -11.3	1.4 - 5.9
Articulare-Gnathion mm.		1.92 ± 0.82	1.54 ± 0.55	2.04 ± 0.47	3.81 ± 0.84	3.25 ± 0.60	2.05 ± 0.58
		1.0 - 4.5	0.5 - 2.75	0.75 - 2.75	2.5 - 6.25	2.5 - 4.75	1.0 - 3.25
Nasion-Menton mm.		1.79 ± 0.87	1.70 ± 0.76	1.90 ± 0.81	3.64 ± 1.15	3.45 ± 0.89	1.61 ± 0.64
		0.25 - 4.75	0 - 3.25	0.75 - 4.75	0.5 - 6.0	2.25 - 5.25	0.25 - 2.75
Sella-Gnathion mm.		2.18 ± 0.89	1.99 ± 0.50	2.16 ± 0.50	4.05 ± 0.72	3.83 ± 0.64	2.10 ± 0.48
		1.0 - 5.75	1.0 - 3.0	1.0 - 3.0	2.75 - 5.75	3.0 - 5.25	1.0 - 2.75

growth up to at least five years prior to the spurt onset.

Intensity of Adolescent Growth

The intensity or velocity of growth was studied during the first and second year of the adolescent spurt, as well as the three years preceding the onset of the spurt and one year following the end of the two-year spurt. Averages of these rates of growth are found in Table V. The most obvious change in growth rate takes place between the first year prior to the spurt and the first year of the adolescent spurt and is substantiated statistically, by the "t" test, (Table VI) for all of the measurements represented in Table V (height, Art-Gn, N-Me, and S-Gn). Statistically, therefore, there is a definite alteration in growth rate at the beginning of the adolescent spurt which continues for approximately two years. After that there is a significant tapering off in the year following the end of the two-year spurt (Table VI). The facial growth during the year before the spurt starts and during the year following the end of the spurt is approximately one-half the rate of the growth during the spurt.

The growth (height and facial) during the first year of the adolescent spurt was statistically the same as the second year of the spurt with considerable individual variation with means

TABLE VI

SUMMARY OF STATISTICAL COMPUTATIONS REGARDING INTENSITY OF GROWTH

("t") Test

	3rd Yr. Prior to Spurt vs. 2nd Yr. Prior to Spurt	2nd Yr. Prior to Spurt vs. 1st Yr. Prior to Spurt	1st Yr. Prior to Spurt vs. 1st Yr. Spurt	1st Yr. Spurt vs. 2nd Yr. Spurt	2nd Yr. Spurt vs. 1st Yr. After Spurt
Ht.	0.121	1.392	10.789*	1.266	11.873*
Art-Gn	1.800	3.226*	7.605*	1.601	6.755*
N-Me	0.398	0.875	5.821*	0.633	7.884*
S-Gn	0.894	1.153	10.152*	1.109	10.112*

* Significant at the 1% level.
Degrees of freedom 44.

for the facial growth varying from 3.25 to 4.05 millimeters per year, while for height it was between 8.07 to 8.49 centimeters per year. In the years preceding the spurt it appears that the growth velocity slows down from the third to the second year prior to the spurt onset, while from the second to the first year prior to the spurt there is a gradual increase. Statistical analysis of the data, however, disproves any differences in the rates of growth of the three years prior to the spurt with one single exception, which is between the second and first years prior to the spurt of Art-Gn where there is a definite increase in growth (Table VI). The mean intensity of growth during these three years prior to the spurt onset varied between 1.54 to 2.18 millimeters per year in the face and between 5.15 to 5.47 centimeters per year in height. The mean growth velocity during the year following the end of the spurt varied from 1.61 to 2.10 millimeters per year in the face and was 4.27 centimeters per year for standing height.

The transition of the rate of growth from the three years prior to the spurt onset to the two years of the adolescent spurt is quite severe in the face compared to that present for standing height. The growth in the face three years prior to the spurt is only 76 to 80% that of the growth during the two-year spurt, while in height it represents 95%. The growth during each year of the facial spurt is approximately 81% more than the amount present in the year prior to the spurt, while in standing height it is only about 51% more than the year prior to the onset of the adolescent spurt. Following the second year of the facial spurt, facial growth decreases 55%, while in skeletal height the mean decrease is 50%. Clinically, this is extremely meaningful to the orthodontist. Orthodontic treatment, if it is dependent on facial growth, would be greatly benefited if it could be properly timed to coincide with the two years of most intense growth during adolescence. As a result of this study the greatest period of adolescent growth can be coordinated with the initiation of orthodontic treatment through proper prediction with the aid of a skeletal maturation estimate.

Summary and Conclusions

This investigation relates skeletal maturity, as estimated from hand radiographs, to the facial adolescent growth spurt represented by the two years of most concentrated growth. The sample consists of semiannual hand-film and standing-height data and yearly lateral cephalometric radiographs on twenty-three males from birth to full maturity. Seven linear facial dimensions involving the anterior cranial base length, upper face height and depth, lower face height and depth, total face height, and the "Y" axis were measured, corrected for enlargement, and plotted for velocity of growth on a yearly basis from three years of age to adulthood. Standing height was plotted in the same manner, and the onset and termination of the adolescent growth spurt was calculated for all measurements. A technique for the prediction of the adolescent growth spurt was presented and statistical analyses were used to test the relationship between the velocity and timing of facial growth to skeletal maturation estimates represented by skeletal age determinations and the appearance of the metacarpal sesamoid.

As a result of this investigation, the following conclusions can be made:

1. A significant correlation exists between the onset of the male adolescent spurt of all facial dimensions studied and standing height.

2. No significant difference exists between the onset of the male adolescent spurt, represented by total face height,

the "Y" axis, mandibular length, and standing height.

3. The skeletal age estimate of the male adolescent spurt onset has one-third (36%) the variation of the chronological age estimate and is a more accurate indicator of the timing of the spurt than is chronological age.

4. Skeletal maturation is significantly correlated with the onset of the male adolescent growth spurt in the face from at least five years prior to the onset through one year following the onset of the spurt.

5. Prediction tables, utilizing the hand-film index of skeletal maturity, are presented which eliminate up to 75% of the variation when compared with estimates of the adolescent spurt utilizing chronological age.

6. The metacarpal sesamoid is significantly correlated with the onset of the male adolescent growth spurt in the face and in standing height.

7. There is a significant increase in growth at the time of the adolescent spurt onset, and a significant decrease following the two year spurt in the face and in standing height.

8. There is no difference in the intensity of growth between the two years of the adolescent spurt in the face and in standing height.

950 Linden Avenue
Winnetka, Illinois 60093

REFERENCES

1. Montbeillard, P. G., from Scammon, R. E.: The first seriatim study of human growth, *Am. J. Phys. Anthrop.*, 10: 329-36, 1927,
2. Crampton, C. W.: Physiological age, a fundamental principle, *Amer. Phys. Educ. Rev.*, 13: No. 3-6, 1908, reprinted *Child Dev.*, 15: 1-52, 1944
3. Todd, T. W.: *Atlas of Skeletal Maturation* (Part I. Hand), London, 1937, Kimpton.
4. Greulich, W. W., and Pyle, S. I.: *Radiographic Atlas of Skeletal Development of the Hand and Wrist*, Ed. 2, Stanford, Calif., Stanford University Press, 19 9.
5. Spier, L.: Physiological age: the relation of dentition to body growth, *Dent. Cosmos*, 60: 899-905, 1918.
6. Woodrow, H. and Lowell, F.: Anatomic age and its relation to intelligence, *Pedagogical Seminary*, 29: 1, 1922.
7. Abernathy, E. M.: Correlations in physical and mental growth, *J. Educ. Psychol.*, 16: 458, 539, 1925.
8. Cattell, P.: *The Dentition as a Measure of Maturity*, Cambridge, 1928, Harvard University Press.
9. Becks, H.: Orthodontic prognosis: evaluation of routine dentofacial examination to determine "good or poor risks," *Am. J. Orthod.*, 25: 610, 1939.
10. Sutow, W., Terasaki, T., and Ohwada, K.: Comparison of skeletal maturation with dental status in Japanese children, *Pediatrics*, 14: 327-333, 1954.
11. Björk, A.: Bite development and body build, *Dent. Record*, 75: 8-19, 1955.
12. Lamons, F. F., and Gray, S. W.: A study of relationship between tooth eruption age, skeletal development age, and chronological age in sixty-one Atlanta children, *Am. J. Orthod.*, 44: 687-691, 1958.
13. Meredith, H. V.: Relation between the eruption of selected mandibular permanent teeth and the circumpuberal acceleration in stature, *J. Dent. Child.*, 26: 75-78, 1959
14. Bambha, J. K., and Van Natta, P.: A longitudinal study of occlusion and tooth eruption in relation to skeletal maturation, *Am. J. Orthod.*, 45: 847-855, 1959.
15. Lewis, A. B., and Garn, S. M.: The relationship between tooth formation and other maturational factors, *Angle Orthod.*, 30: 70-77, 1960.
16. Björk, A., and Helm, D.: Prediction of the age of maximum puberal growth in body height, *Angle Orthod.*, 37: 134-143, 1967.
17. Demisch, A., and Wartmann, P.: Calcification of the mandibular third molar and its relation to skeletal and chronological age in children, *Child Develop.*, 27: 459-473, 1956.
18. Hotz, R., Boulanger, G., and Weisshaupt, H.: Calcification time of permanent teeth in relation to chronological and skeletal age in children, *Helvet, Odont, Acta*, 3: 4-9, 1959.
19. Green, L. J.: The interrelationships among height, weight and chronological, dental and skeletal ages, *Angle Orthod.*, 31: 189-193, 1961.
20. Brauer, J. C., and Bahador, M. A.: Variations in calcification and eruption of the deciduous and the permanent teeth, *J.A.D.A.*, 29: 1373, 1942.
21. Gleiser, I., and Hunt, E. E.: The

permanent mandibular first molar: its calcification, eruption, and decay, *Am. J. Phys. Anthrop.*, N. S., 13: 253, 1955.
22. Stein, K. F., Kelley, T. J., and Wood, E.: Influence of heredity in the etiology of malocclusion, *Am. J. Orthod.*, 42: 125-141, 1956.
23. Lauterstein, A. M.: A cross-sectional study in dental development and skeletal age, *J.A.D.A.*, 62: 161-167, 1961.
24. Grøn, A. M.: Prediction of tooth emergence, *J. Dent. Res.*, 41: 573-585, 1962.
25. Garn, S. M., Lewis, A. B., and Kerewsky, R. S.: Genetic, nutritional and maturational correlates of dental development, *J. Dent. Res.*, 44: 228-243, Suppl. to No. 1, 1963.
26. Bushra, E.: Correlations between certain craniofacial measurement, trunk, length, and stature, *Human Biol.*, 21: 246-256, 1949.
27. Lindegard, B.: Variations in human body build, *Acta Psychiatrica et Neurolog.*, Suppl. 86: 1-163, 1953.
28. Nanda, R. S.: The rates of growth of several components measured from serial cephalometric roentgenograms, *Am. J. Orthod.*, 41: 658-673, 1955.
29. Bambha, J. K.: Longitudinal cephalometric roentgenographic study of face and cranium in relation to body height, *J.A.D.A.*, 63: 776-799, 1961.
30. Hunter, C. J.: The correlation of facial growth with body height and skeletal maturation at adolescence, *Angle Orthod.*, 36: 44-54, 1966.
31. Singh, I. J., Savara, B. S., and Miller, P. A.: Interrelations of skeletal measurements of the face and body in preadolescent and adolescent girls, *Growth*, 31: 119-131, 1967.
32. Howells, W. W.: A factorial study of constitutional type, *Am. J. Phys. Anthrop.*, N. S. 10: 91-118, 1952.
33. Rose, G. J.: A quantitative study of the facial areas from the profile roentgenograms and the relationships to body measurements, *Am. J. Orthod.*, 39: 59-61, (abstr.) 1953.
34. Meredith, H. V.: Childhood interrelations of anatomic growth rates, *Growth*, 26: 23-39, 1962.
35. Savara, B. S.: Growth of mandible and physique in girls, *Intern. Assoc. Dent. Res.*, 41: 98, (abstr.), 1963.
36. Hixon, E. H.: Prediction of facial growth, *Europ. Orthod. Soc. Trans.*, 44: 127-139, 1968.
37. Singh, I. J., Savara, B. S., and Newman, M. T.: Growth in the skeletal and non-skeletal components of head width from 9-14 years of age, *Human Biol.*, 39: 182-191, 1967.
38. Fukuhara, T., and Matsumoto, M.: A longitudinal study of facial growth in relation to general body height during adolescence. *Bull. of Tokyo Med. and Dent. Univ.*, 15: 161-170, 1968.
39. Johnston, L. E.: A statistical evaluation of cephalometric prediction, *Angle Orthod.*, 38: 284-304, 1968.
40. Singh, I. J., Savara, B. S., and Miller, P. A.: Interrelations of face dimensions to selected body measurements in preadolescent and adolescent girls, *J. Dent. Res.*, 43: 820-821, Suppl., 1964.
41. Maj, G., and Luzi, C.: Longitudinal study of mandibular growth between nine and thirteen years as a basis for an attempt of its prediction, *Angle Orthod.*, 34: 220-230, 1964.
42. Pike, J. B.: A serial investigation of facial and statural growth in 7 to 12 year old children, *Am. J. Orthod.*, 50: 469-570, (abstr.), 1964.
43. Tracy, W. E., Savara, B. S., and Brant, J. W.: Relation of height, width and depth of the mandible, *Angle Orthod.*, 35: 269-277, 1965.
44. Bergersen, E. O.: The directions of facial growth from infancy to adulthood, *Angle Orthod.*, 36: 18-43, 1966.
45. Björk, A.: Prediction of mandibular growth rotation, *Am. J. Orthod.*, 55: 585-599, 1969.
46. Eckler, G. S.: A multivariate approach to the cephalometric prediction of skeletal facial growth, M. S. thesis, *Northwestern University*, Chicago, Illinois, 1969.
47. Ricketts, R. M.: Planning treatment on the basis of the facial pattern and an estimate of its growth, *Angle Orthod.*, 27: 14-37, 1957.
48. ————: Cephalometric synthesis, *Am. J. Orthod.*, 46: 647-673, 1960.
49. ————: Cephalometric analysis and synthesis, *Angle Orthod.*, 31: 141-156, 1961.
50. Ricketts, R. M., Bench, R. W., Hilgers, J. J., and Schulhof, R.: An overview of computerized cephalometrics, *Am. J. Orthod.*, 61: 1-28, 1972.
51. Wasson, J. L.: Evaluation of a method of predicting craniofacial growth that compares cephalometric roentgenograms of children and parents, *Am. J. Orthod.*, 49: 864, (abstr.), 1963.
52. Hunter, W. S., Balbach, D. R., and Lamphiear, D. E.: The heritability of attained growth in the human face, *Am. J. Orthod.*, 58: 128-134, 1970.
53. Bambha, J. K., and Van Natta, P.: Longitudinal study of facial growth in relation to skeletal maturation

during adolescence, *Am. J. Orthod.*, 49: 481-493, 1963.
54. Moreschi, A. F.: Facial growth in relation to chronological age and to skeletal age, *Am. J. Orthod.*, 50: 630, (abstr.), 1964.
55. Greene, A. G.: A roentgenographic cephalometric appraisal of girls at menarche, *Am. J. Orthod.*, 50: 629, (abstr.), 1964.
56. Johnston, F. E., Hufham, H. P. Jr., Moreschi, A. F., and Terry, G. P.: Skeletal maturation and cephalofacial development, *Angle Orthod.*, 35: 1-11, 1965.
57. Hansman, C. F., and Maresh, M. M.: A longitudinal study of skeletal maturation, *Am. J. Diseases of Child.*, 101: 305-321, 1961.
58. Waldo, C. W.: Orthodontic research as a component part of a balanced longitudinal study of 100 children, *Intern. J. Orthod.*, 22: 659-673, 1936.
59. Washburn, A. H.: Annual report of the director to the board of control of the child research council, Denver, Colorado, 1954.
60. Snedecor, G. W.: *Statistical Methods*, ed. 5, Ames, 1956, Iowa State College Press.
61. Arkin, H., and Colton, R. R.: *Statistical Methods*, ed. 4, New York, 1958, Barnes and Noble, Inc.
62. Johnston, F. E.: Skeletal age and its prediction in Philadelphia children, *Human Biology*, 35: 192-201, 1963.
63. Hewitt, D., and Acheson, R .M.: Some aspects of skeletal development through adolescence, *Am. J. Phys. Anthrop.*, 19: 321-344, 1961.
64. Tanner, J. M.: *Growth at Adolescence*, ed. 2, Oxford, 1962, Blackwell Scientific Publications.