Growth of the Mandible During Pubescence

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We are grateful for financial support through grant DE-05160 from the National Institute of Health, Bethesda, Maryland.

Spurts in mandibular growth were analyzed in 67 subjects. They were found to occur 1.5 to 2 years earlier in girls, but are larger in boys. Mean relationships show patterns in relation to chronological age, peak height velocity and bone age, with wide individual variations.

There is an ongoing interest in pubertal growth spurts within the craniofacial complex because of their possible effects in orthodontic treatment. This interest has led to studies of the associations among the timing of pubertal spurts in the mandible, growth in stature, and changes that occur during skeletal maturation.[1-4]

While there is some evidence that spurts in the craniofacial area are synchronous with peak height velocity,[5-7] few analyses have been made of serial records of individuals, so little is known about the distributions of differences in timing. The present study was undertaken to analyze the relationship between the magnitude and timing of pubertal spurts in the mandible, ages at peak height velocity and at menarche, and levels of skeletal maturity within individuals.

REVIEW OF LITERATURE

Several previous studies[5,8-14] leave no doubt that pubertal spurts in the major dimensions of the mandible do

occur. Some believe that they do not always occur, but others claim or infer that these spurts occur in all children.[5,8,10,14] Bambha[9] reported that they tend to occur earlier in girls than in boys, and that this difference in timing is greater for the initial rise in velocity than for the maximum rate. He also found that they last longer in boys than in girls.

The annual increments in the length from condylion to pogonion have been found to decrease slightly before pubescence in boys, followed by a rise that reaches the maximum rate at a mean age of about 13.5 years.[13-15] Girls follow a similar pattern, but the spurts are smaller and occur an average of about 1.6 years earlier.[5,12,15]

A small prepubescent decrease in the rate of increase of sella-gnathion has also been described.[9]

There are also small prepubertal decreases in annual increments for ramus height in both sexes. In boys this is followed by a period of constant growth before the pubescent spurt.[12,13] The mean age for maximum rate of growth in ramus height in girls is about 12 years; in boys it occurs at about 13 years and is more pronounced.[12,13,16] Similar findings have been reported for sella-gonion, a measurement that is partially dependent on ramus height.[8,9]

Annual increments in mandibular body length from gonion to pogonion also decrease before the pubescent spurts occur, with maximum rates of growth for girls at about 12 and for boys at about 14 years.[8,12,13]

In summary, for each major mandibular dimension there is a slight prepubescent decrease in rate of growth, followed by a rapid rise. There is convincing evidence that these spurts tend to occur later in boys than in girls, and may be larger in boys.

The timing of pubescent spurts in mandibular growth is closely associated with the peak velocity of growth in height.[16] These spurts were reported in some studies to occur about six months after peak height velocity, [8,9,17] but others report the timing to be almost synchronous or not significantly different.[5,6,14]

Some have noted that pubertal spurts in mandibular growth are more closely related to skeletal age than to chronological age in boys, but not in girls;[11,16] others have found a closer relationship with skeletal age than with chronological age in both sexes.[6,14]

Material and Methods

The present data were derived from participants in the Fels Longitudinal Study who were selected from the total sample because suitable sets of serial data were available for them. These normal white children (34 boys; 33 girls) live in southwestern Ohio and were generally of middle socioeconomic status. Measurements were made on 990 cephalometric radiographs taken within one month of each birthday from at least 7 to 18 years of age. These radiographic series extend from not less than four years before to four years after peak height velocity (PHV) in 54 of the 67 children. In the remaining 13 children, the radiographs cover the period from at least two years before to two years after PHV, except for one boy whose final radiograph at the age of 18 years was still only 21 months after PHV. Some series were not complete, but at least four annual radiographs were taken for each child during the age range from three years before to three years after PHV.

Each radiograph was traced by one

person and measured by another, using an electronic digitizer to record the location of points articulare (Ar), gonion (Go) and gnathion (Gn) to the nearest 0.1 mm. Comparisons between comparable data measured with the digitizer and with calipers showed few mean absolute differences for age- and sex-specific groups exceeding 0.2 mm. Correlation coefficients were 0.97 or more for each group, and 0.99 for all ages combined (N for radiographs = 539 boys; 515 girls).

Articulare is defined as the point of intersection of the images of the posterior margin of the ramus of the mandible with that of the inferior border of the basisphenoid bone.

Gonion is the point of intersection of the mandibular border with the bisection of the angle formed by the projections of lines representing the mandibular plane and the posterior border of the ramus. The line representing the mandibular plane is drawn tangent to the lower border of the symphysis and the most inferior point in the gonial region. The posterior border of the ramus is represented by the tangent to the lower posterior border that passes through Ar.

Gnathion is the point of intersection of the symphysis with the bisector of the angle formed by projections of the mandibular plane and facial line. The facial line is drawn from nasion tangent to the anterior margin of the symphysis.

All measurements were corrected for radiographic enlargement.

Spurts in Ar-Go, Ar-Gn and Go-Gn were recorded by inspecting *unsmoothed* plots of annual increments (mm/year). A spurt was defined as an annual increment exceeding the immediately preceding annual increment by at least 1 mm. The same criterion was applied to boys and girls because the sex differences in the prepubertal rates of elongation of these variables are not significant. By this criterion, a spurt represents an increase in growth rate of at least 50 percent of the *median* rate for the year preceding the spurt. This was also found in earlier studies of the cranial base.[18,19]

Age at a spurt was recorded at the midpoint of the interval for which it was observed, so all spurts were entered and plotted at half-birthdays.

With this definition of a spurt, it is possible for one individual to have two or more "pubertal spurts," so analyses were made of first pubertal spurts and of maximum pubertal spurts that were found within two years of peak height velocity (PHV).

When a radiograph was missing from a series, the two-year increment was not apportioned between the two annual intervals in an effort to identify a spurt. In some children, however, it was possible to determine that a spurt could not have occurred no matter how the two-year increment was apportioned, so these were recorded as not having experienced a spurt. In others, the increment exceeded the *total* increment during the preceding two-year interval by at least 1 mm, so a spurt was recorded. A few annual increments showed small negative values which were obviously artifacts; the increments immediately following these were considered to be spurts only if they were at least 1 mm/year greater than the preceding increment after adjustment for the preceding negative increment.

Other relevant data were also available for these children. Stature was measured at six-month intervals to the nearest millimeter, with a mean inter-observer difference of 2mm (s.d. 2mm). The midpoint of the annual interval

with the largest increment in stature was recorded as age at PHV. When two equal consecutive increments were the largest, the whole-year midpoint of the combined interval was recorded as PHV. No two equal nonconsecutive increments were the largest.

Several measures of maturity were available. Greulich-Pyle (GP) skeletal ages[20] were recorded for semiannual radiographs of the hand-wrist. These skeletal ages are the means of bone-specific values obtained after interpolating between the standards to the nearest 3 months when this appeared appropriate. The mean interobserver error for these assessments is 0.4 years (s.d. = 0.3 years; N = 90).

Assessments of skeletal maturity based on annual knee radiographs, using the Roche-Wainer-Thissen (RWT) method[21] were also made. The mean interobserver error for these assessments is 0.2 years (s.d. = 0.2 years; N = 18). The age at onset of ossification of the ulnar sesamoid of the first metacarpophalangeal joint was noted as the midpoint of the interval between the last radiograph in which this bone is not ossified and the first radiograph in which it is seen.

Age at menarche was obtained from six-monthly inquiry at appropriate ages.

The means and standard deviations for stature and for these maturational variables are close to those for larger samples of U.S. children[22-25] (Table 1).

It was necessary to estimate mandibular dimensions at ages other than those at which they were measured for some analyses; for example, to calculate annual increments in relation to age at menarche. This was done by fitting a high-term Fourier function to the observed data and interpolating values at the appropriate chronological ages.[26]

Findings

Spurts occurred during the pubertal period as defined by peak height velocity (PHV ± 2 years) for each dimension in most children of either sex. There were such spurts in all three dimensions for 22 boys and 9 girls, and they were usually synchronous.

None were observed in 1 boy and 3 girls, although all showed evidence of spurts not so closely related to peak height velocity. The boy showed earlier spurts in Ar-Gn and Go-Gn. Two of the 3 girls had spurts in either

TABLE 1

Growth and Maturity Measures in 34 Boys and 33 Girls

Measure	*Boys*		*Girls*	
	Mean	*S.D.*	*Mean*	*S.D.*
Stature at 13 years (cm)	157.0	8.2	156.3	6.0
Age at peak height velocity (yrs)	13.8	1.0	11.8	1.1
Greulich-Pyle skeletal age at chronological age 13 (yrs)	13.0	0.7	13.3	0.9
Roche-Wainer-Thissen skeletal age at chronological age 13 (yrs)	13.4	1.0	13.5	1.0
Age at menarche (yrs)	—	—	13.0	1.2
Age at ossification of ulnar sesamoid (yrs)	12.4	1.4	10.6	1.0

Go-Gn and Ar-Go or in Ar-Go and Ar-Gn that were too late to be considered pubertal. No spurts were found at any observed age in the third girl, but there were large increments for Ar-Go and Ar-Gn during the first annual interval (12-13 years) that might have qualified as spurts had earlier data been available.

In each sex, pubertal spurts in excess of 1mm were most common for the larger dimensions Ar-Gn and Go-Gn, and more common in boys for all three dimensions (Table 2). Multiple pubertal spurts in the same dimension followed the same pattern.

First spurts occur later in boys than in girls. The mean difference is 1.9 years for Go-Gn, 1.7 years for Ar-Go and 1.5 years for Ar-Gn.

The mean increment at the spurt and the amount of the spurt (increase over the previous increment) were both larger in boys for each length. Sex differences in the increments at the time of the spurt were 22% for Go-Gn, 30% for Ar-Go, and 12% for Ar-Gn. The spurt in each of those lengths was about 33% larger in the boys.

Thirty-one of the 67 children showed spurts in all three lengths. Correlations between the increments at the time of the spurt for pairs of dimensions in these subjects were all positive, and all except that between Ar-Go and Go-Gn were regarded as statistically significant. Most coefficients were about 0.3, except for those between Ar-Gn and Go-Gn and between Ar-Go and Ar-Gn, which were about twice as large.

Where *multiple* spurts occurred, the largest usually appeared later, with findings similar to those for first pubertal spurts. At the time of maximum spurt, both the growth increments and the spurts tended to be later and larger in boys. The percentage sex differences between the means for the three dimensions ranged from 25% to 33% for the growth increments and from 35% to 41% for the spurts. The increments at the time of maximum spurt and the magnitude of the spurts were both larger for Ar-Gn than for either Go-Gn or Ar-Go.

The mean increments for each dimension decreased before the first pubertal spurt. The means for annual

TABLE 2

The Prevalence and Magnitude of First Pubertal Spurts in Mandibular Dimensions.

		Age (years)		*Increment at Spurt (mm/year)*		*Spurt Magnitude (mm)*	
	N	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Ar-Go							
Boys	25	13.54	1.72	3.17	0.92	2.52	0.93
Girls	18	11.83	1.28	2.44	0.81	1.87	0.74
Ar-Gn							
Boys	29	13.09	1.35	3.26	1.47	2.50	1.35
Girls	20	11.55	1.57	2.90	1.32	1.89	0.94
Go-Gn							
Boys	30	13.17	1.40	2.84	1.24	2.19	1.19
Girls	22	11.32	1.82	2.32	0.81	1.64	0.73

A spurt is the difference between successive annual increments; see text for details.

increments one year before the first pubertal spurts were smallest for Ar-Go, but during the spurts the smallest mean increment was found for Go-Gn (Table 3).

One year after the first pubertal spurts, Go-Gn still showed the smallest mean increment in the boys, but Ar-Go was slightly lower in the girls.

All annual increments tended to be larger in boys than in girls during and after the first pubertal spurts.

Relationship with Age at Peak Height Velocity (PHV)

First pubertal spurts tend to occur several months before PHV for each dimension in both sexes (Table 4), with more frequent occurrence before PHV in boys. They may occur as late as the third year after PHV. The standard deviations of about one year reflect the variability in this timing.

Annual increments in relation to PHV are shown for the 10th, 50th and 90th percentiles in Fig. 1. This presentation of the data removes most but not all of the sex differences in the timing of spurts in relation to chronological age.

The largest increments in Ar-Go occur one year after PHV at each percentile level, except at the 90th percentile level for girls, where the maximum increment tends to coincide with PHV. The decelerations in Ar-Go growth before PHV were less

TABLE 3

Mean Annual Increments (mm/year) Before, During and After First Pubertal Spurts

	One Year Before		*During*		*One Year After*	
	Boys	*Girls*	*Boys*	*Girls*	*Boys*	*Girls*
Ar-Go	0.2	0.4	3.2	2.4	1.8	1.0
Ar-Gn	0.5	0.9	3.3	2.9	2.6	2.3
Go-Gn	0.5	0.6	2.8	2.3	1.2	1.1

TABLE 4

Timing of First Pubertal Spurt in Relation to Peak Height Velocity (PHV), Ossification of the Ulnar Sesamoid (US), and Menarche (M).

	Relation to PHV			*Relation to US*			*Relation to M*		
	N	*Mean (years)*	*S.D.*	*N*	*Mean (years)*	*S.D.*	*N*	*Mean (years)*	*S.D.*
Ar-Go									
Boys	25	—.2	.8	25	+1.3	1.1	—	——	—
Girls	18	—.3	.8	18	+1.3	1.3	18	−1.1	.9
Ar-Gn									
Boys	29	—.7	1.2	28	+ .8	1.4	—	——	—
Girls	20	—.4	.8	20	+ .8	1.0	20	—1.5	.8
Go-Gn									
Boys	30	—.7	1.0	30	+ .9	1.6	—	——	—
Girls	22	—.4	1.4	22	+ .8	1.6	22	—1.8	1.5

— = before; + = after

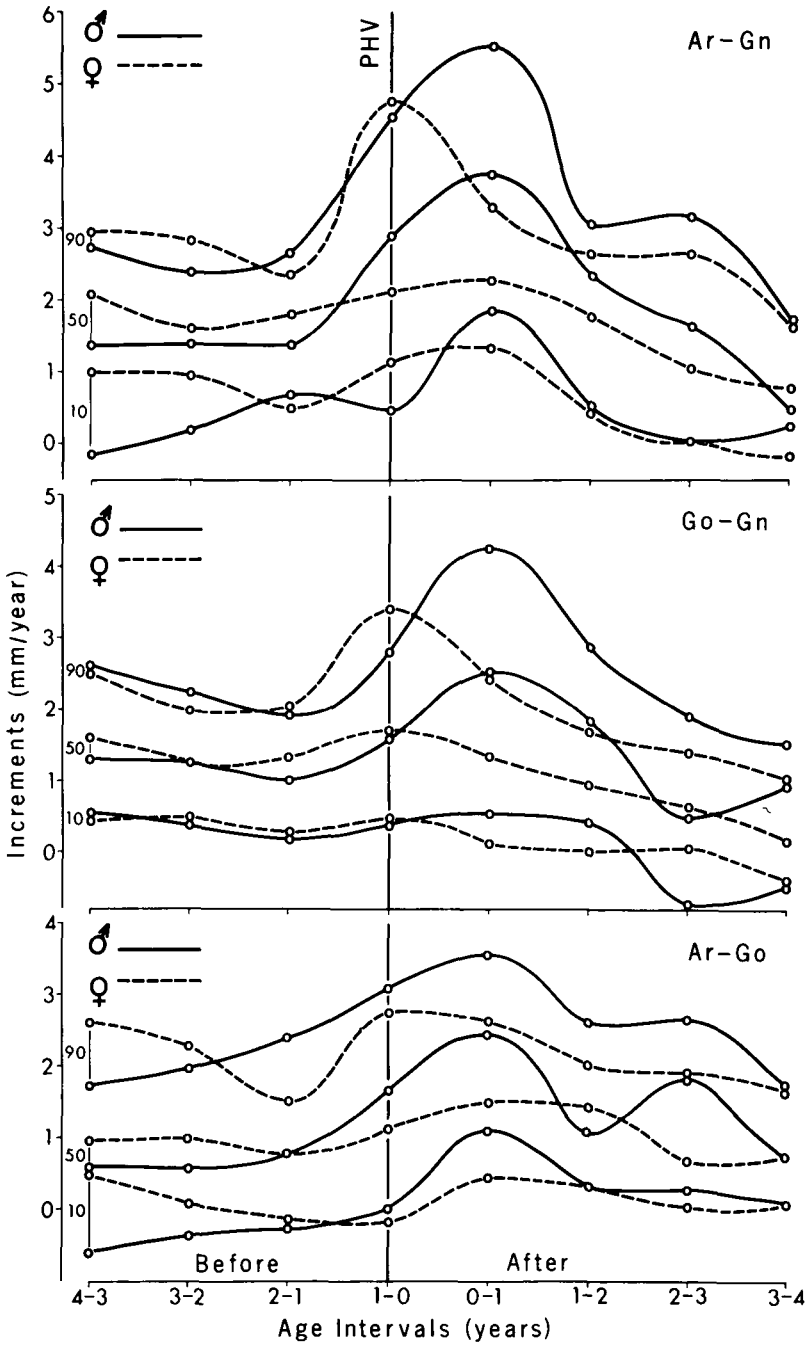

Fig. 1 Tenth, fiftieth and ninetieth percentiles for annual increments in Ar-Gn, Go-Gn and Ar-Go in relation to peak height velocity (PHV).

marked in boys, but the levels were similar both before and after.

Before PHV, the percentiles for increments in Ar-Gn were similar for the two sexes. After PHV, the values were considerably larger for boys at all but the 10th percentile level. Maximum annual increments were found about one year after PHV, except for the 90th percentile in girls, where it coincided with PHV.

The annual increments for Go-Gn were also generally similar in boys and girls, but the largest average increments occur about one year after PHV in the boys and near PHV in the girls.

Relationship with Ossification of the Ulnar Sesamoid (US)

First pubertal spurts tended to occur about one year after US for all three dimensions (Table 4). Spurts before US were unusual (Ar-Gn, boys = 7, girls = 3; Ar-Go, boys = 0, girls = 3; Go-Gn, boys = 6, girls = 4). Boys with large spurts in all three dimensions tend to be later in ulnar sesamoid ossification than those with spurts in only one dimension, but there is an opposite tendency in girls. The variability of timing of spurts, as measured by the standard deviations, is greater in relation to US than in relation to PHV.

Figure 2 shows selected percentiles for average annual increments of three mandibular dimensions in relation to US. Decelerations before US and increases after were typical, but a few deviations will be noted.

Relationship with Menarche (M)

Menarche tends to occur considerably later than first pubertal spurts (Table 4 and Fig. 3), with Go-Gn tending to be the earliest and Ar-Go the latest. Despite the averages, some spurts were found after menarche in 3 girls for Go-Gn, in one for Ar-Go and in another for Ar-Gn. The variability of the timing in relation to menarche was intermediate between variabilities found in relation to PHV and US.

Decelerations before menarche were found for all lengths and percentile groups, except for Go-Gn in the 10th percentile. Maximum median increments were found at or one year before menarche, followed by marked decelerations.

The mean increments for the five girls with the youngest ages at menarche (mean 11.0 years) were compared with the mean increments for the five girls with the oldest ages at menarche (mean 14.8 years). The girls with an early menarche were also early in PHV and US, and they had shorter intervals between US, PHV and menarche than the girls with late menarche.

In addition, the girls with an early menarche had larger spurts in mandibular dimensions and larger increments at the spurts for Go-Gn and Ar-Gn. There were too few spurts in Ar-Go to allow valid comparisons between the two groups.

Other comparisons were made among the three mandibular dimensions in the two girls with the earliest and latest menarche. In the first, US appeared at 8.8 years, PHV at 9.8 and menarche at 10.3 years; in the latest, US appeared at 12.5 years, PHV at 13.8 years, and menarche at 15.3 years. The late-maturing girl was larger in each mandibular dimension until the age at which the pubertal spurts occurred in the early-maturing girl. The differences at that stage were small or reversed, until the spurts in the late-maturing girl once again made her the larger in all three dimensions.

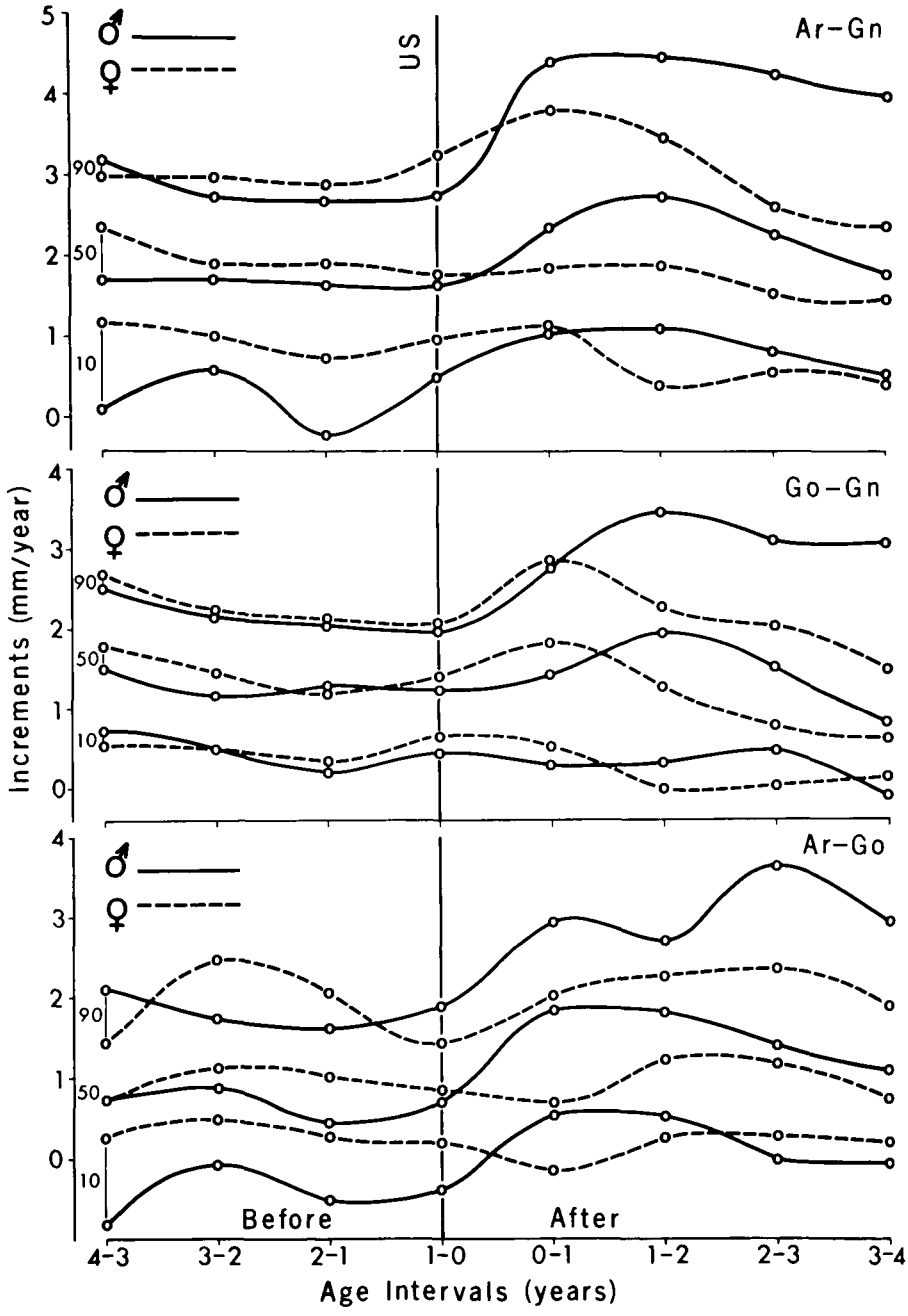

Fig. 2 Tenth, fiftieth and ninetieth percentiles for annual increments in Ar-Gn, Go-Gn and Ar-Go in relation to calcification of the ulnar sesamoid (US).

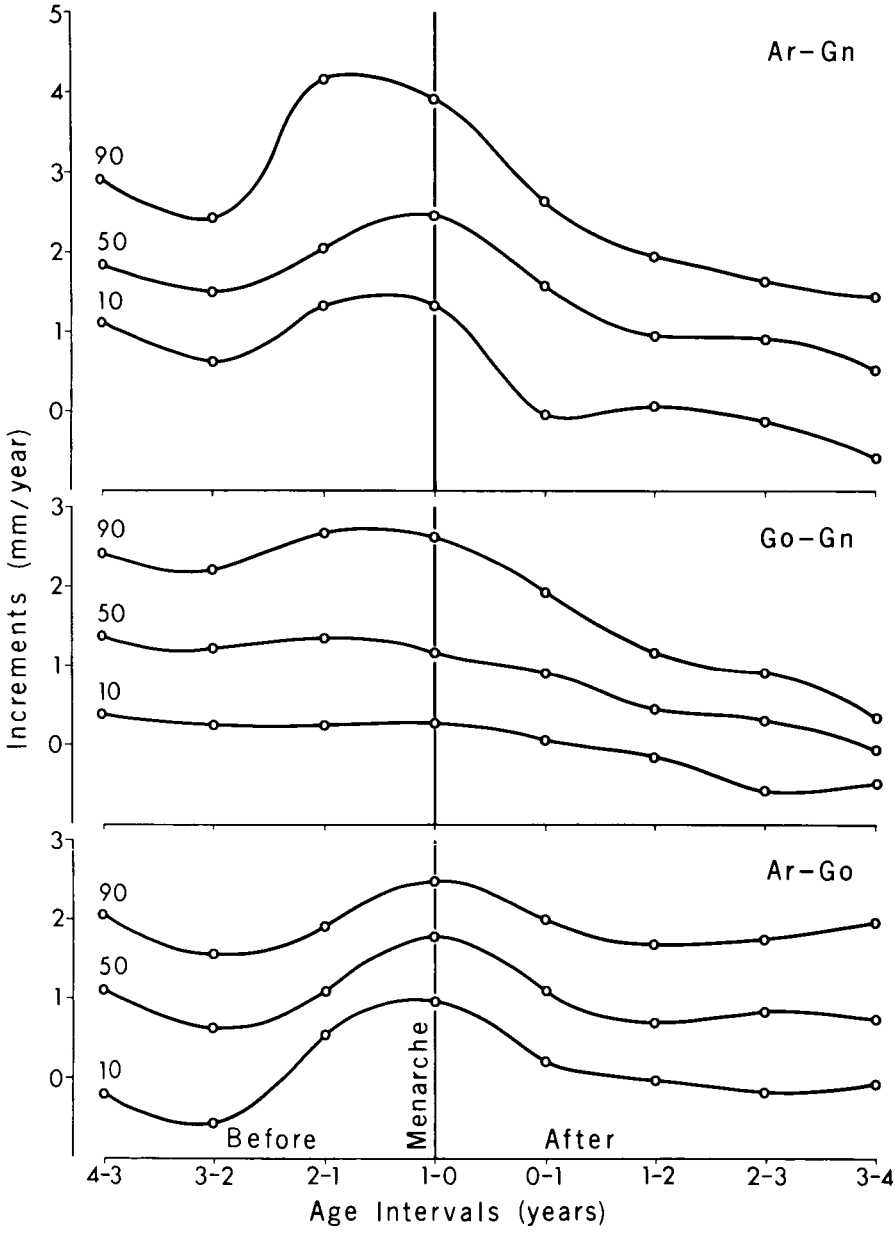

Fig. 3 Tenth, fiftieth and ninetieth percentiles for annual increments in Ar-Gn, Go-Gn and Ar-Go in relation to menarche.

Relationship with Rate of Maturation During Pubescence

The rates of mandibular growth were compared between groups of children who passed quickly through pubescence and those in whom the intervals between pubescent events were relatively extended (Table 5).

The selection of boys for this evaluation was based on the interval from US to PHV, with a mean interval of 0.2 years for the six boys with the most rapid rates of pubescence and 2.8 years for the six with the slowest rates.

Corresponding groups of girls were chosen on the basis of the interval from US to menarche. That mean interval ranged from 1.2 years to 4.3 years. Mean intervals from US to PHV for these two groups of girls were 0.5 years and 2.4 years.

Boys passing slowly through pubescence had larger increments at the spurt for Ar-Go and Ar-Gn, but not for Go-Gn.

In the girls, mean increments at the spurt were smaller for all three dimensions in those who passed more slowly through pubescence. Multiple spurts were slightly less common in boys who developed rapidly than in boys with a slow sequence of pubescent events, but there was an opposite association in the girls.

Relationship with Skeletal Age

The data in Table 6 relate to the timing of first pubertal spurts in the three mandibular dimensions in relation to chronological age and the skeletal ages of the hand-wrist and the knee. The mean Greulich-Pyle (GP) skeletal ages are close to the mean chronological ages (CA) for each measurement in each sex, but the mean Roche-Wainer-Thissen (RWT) ages tend to be about 0.6 year higher.

The variation in the timing of these spurts is even more important. The standard deviation in relation to CA

TABLE 5

Means for Maximum Pubertal Spurts in Children with Rapid and Slow Sequences of Pubertal Events.

	Increment at Spurt (mm/yr)	*Size of Spurt (mm)*
Ar-Go		
Boys — rapid	2.9	2.3
— slow	3.6	3.2
Girls — rapid	2.3	2.0
— slow	2.1	1.4
Ar-Gn		
Boys — rapid	2.7	1.9
— slow	4.7	3.0
Girls — rapid	4.8	3.4
— slow	1.8	1.3
Go-Gn		
Boys — rapid	3.8	2.8
— slow	3.3	2.8
Girls — rapid	2.9	2.0
— slow	2.5	2.1

TABLE 6

Ages (years) of First Pubertal Spurts in Relation to Chronological Age (CA), Greulich-Pyle Skeletal Age of the Hand-wrist (GP) and Roche-Wainer-Thissen Skeletal Age of the Knee (RWT).

	CA		*GP*		*RWT*	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Boys						
Ar-Go	13.5	1.7	13.5	1.1	14.2	1.2
Ar-Gn	13.1	1.4	13.0	1.2	13.6	1.6
Go-Gn	13.2	1.4	13.1	1.4	13.6	1.7
Girls						
Ar-Go	11.8	1.3	11.8	1.2	12.4	1.2
Ar-Gn	11.6	1.6	11.4	1.3	12.3	1.1
Go-Gn	11.3	1.8	11.2	1.8	12.0	2.0

The sample sizes are the same as in Table 4.

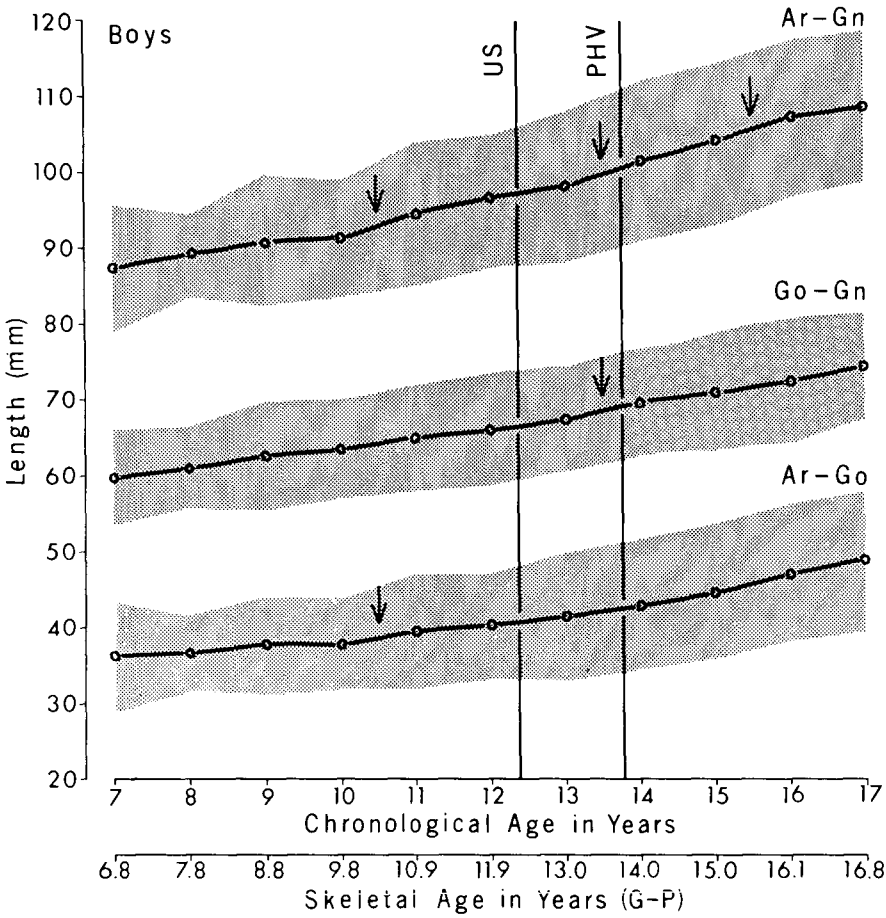

Fig. 4 Means ± 2 S.D. for mandibular dimensions in boys in relation to chronological age and Greulich-Pyle skeletal age. The arrows indicate differences between successive means that would meet the criterion for spurts.

was about 1.5 years, slightly less in relation to GP ages for most comparisons, and larger in relation to RWT ages for some. The findings for the timing of multiple spurts were similar. It should be noted that comparable variations also exist in the relation of the skeletal ages to chronological age.

Figures 4 and 5 show means and ranges of two standard deviations for the three dimensions plotted on CA and GP age scales. Variations in the timing of spurts and other changes in growth rate must be smoothed in such group data. Nevertheless, there were some differences between successive *means* (indicated by arrows) that were large enough to qualify as spurts. The mean dimensions of Go-Gn were larger in boys at all ages, and for Ar-Gn after 13 years and Ar-Go after 15 years. It is hoped that these figures may prove useful in evaluating data from individual patients.

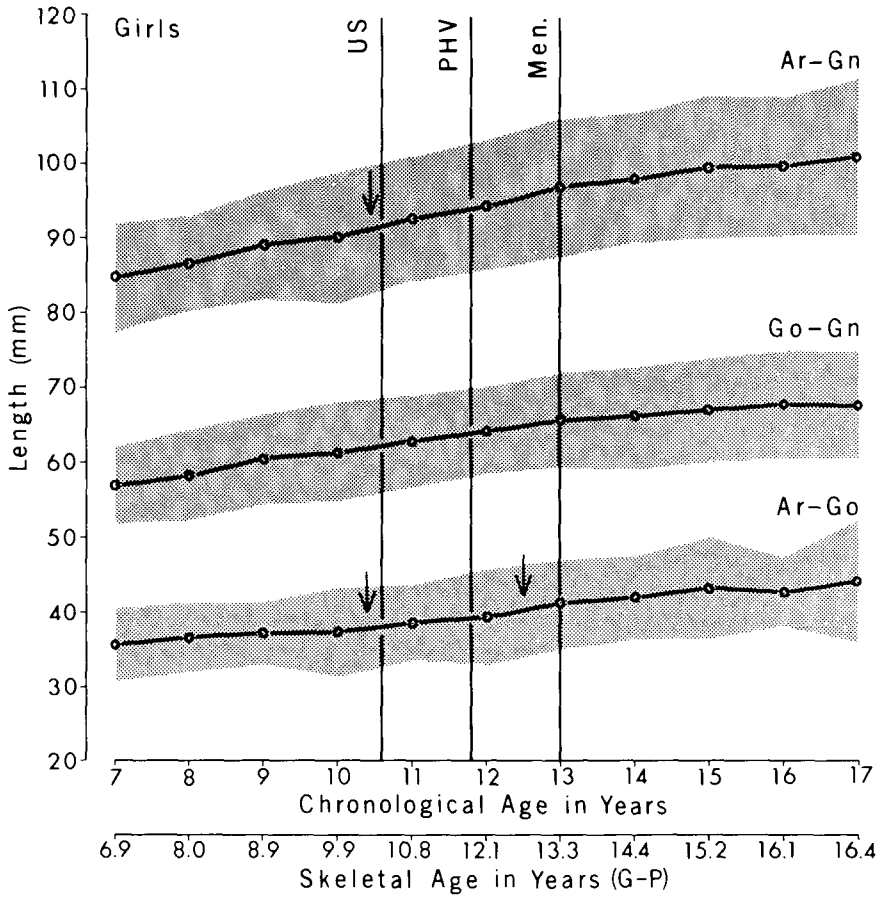

Fig. 5 Means ± 2 S.D. for mandibular dimensions in girls in relation to chronological age and Greulich-Pyle skeletal age. The arrows indicate differences between successive means that would meet the criterion for spurts.

Relationship with Stature

Data at age 18 for the five tallest boys and the five shortest boys were also compared (Table 7). The mean statures of the two groups differ by 16.0 cm. The mean ages at PHV do not differ markedly between these groups (tall, 13.75 years; short, 13.55). Age at US (tall, 12.5 years; short, 12.70) and the mean RWT skeletal age at the chronological age of 13 years indicate that the tall boys tend to be slightly more skeletally advanced. This was not indicated by the GP skeletal age, which was more closely correlated with the chronological age of this sample.

The maximum pubertal spurts in Go-Gn occurred considerably later in the tall boys, but corresponding differences for the other two dimensions were small. All spurts were slightly larger in the tall boys. The mean postpubertal growth in Go-Gn was 0.9mm

TABLE 7

Means for Maximum Pubertal Spurts in Tall and Short Boys.

	Age at Spurt (yr)	*Size of Spurt (mm/yr)*	*Total Increment After PHV (mm)*
Ar-Go			
Tall ...	13.3	2.7	7.5
Short ..	13.7	2.5	8.9
Ar-Gn			
Tall ...	13.3	3.4	11.0
Short ..	13.3	3.1	12.4
Go-Gn			
Tall ...	14.8	2.6	7.6
Short ..	13.5	2.6	6.7

greater in the tall boys, but for Ar-Go it was 1.5mm less and for Ar-Gn 1.4mm less.

Comparisons between boys and girls selected for having the largest or the smallest total increment in stature after PHV showed increments in mandibular dimensions after PHV tending to be greater in those with large increments in stature. This association between late adolescent growth in stature and in the mandible was much closer in boys than girls.

Discussion

The present findings are essentially in agreement with those reported by others.[5,8,9,11-14] Pubertal spurts occurred in each dimension for most of the children examined. Maj and Luzi[10] also reported the absence of spurts in some children. Previous studies have identified pubertal spurts in mandibular dimensions subjectively, without objective operational criteria. This may contribute to some of the variations among reported findings. However, application of the present criterion to the data published by Nanda[17] supports his claim that spurts did occur in each of the 15 children studied by him.

In the present group, spurts were more common in boys than in girls. This is not an artifact of the criterion applied, because it persists even when sex-specific and individual-specific criteria are used. Very few normal children lack pubescent spurts in stature.[27,28] The differences in the prevalence of spurts between stature, the cranial base[7] and the mandible lead to speculation that the growth patterns and sensitivity of different bones to altered levels of circulating hormones may vary among individuals.

Close relationships between the rates of growth in mandibular dimensions have been reported.[12,13] In the present data, the correlations between the sizes of spurts for pairs of dimensions are significant, although the correlation coefficients are moderate (0.30 to 0.59).

First pubertal spurts occur about 1.4 to 1.9 years later in boys than girls. The present analysis does not confirm an earlier report[16] that the timing of craniofacial pubertal spurts is more variable in girls than boys.

The timing for Ar-Gn in the present group is very similar to that reported earlier for condylion-pogonion.[5,12-15] The findings for Ar-Gn and Ar-Go are in general agreement with an earlier account that spurts in sella-gnathion tend to occur before those in sella-gonion in boys, with their timing close to synchronous in girls.[9] However, the present findings for Ar-Go showing spurts considerably later in boys but not girls do not agree with those reported by others.[12,13,16] In addition, both the first and maximum pubertal spurts in these boys showed larger increments at the spurt, and larger spurts, than the girls.

The mean increments for each dimension decreased before the pubescent spurt in both sexes. The sex differences were small except during the year of the first pubertal spurt, when the values were greater for boys. Others have reported similar findings.[5,12-15,29]

Differences between the timing of PHV and the spurts varied widely. Mandibular spurts did not occur in some children until the third year after PHV. These findings are not in agreement with some claims that mandibular spurts are almost synchronous with PHV.[5,6,14,16]

The largest median annual increments occur during the year of PHV or the following year. The decrease in these increments prior to PHV was less marked in boys.

Pileski *et al*[30] reported that the maximum rate of mandibular elongation occurred after US in 75 percent of their subjects. Almost all first pubertal spurts in the present study occurred after US, with Ar-Go showing the largest lag.

The timing of spurts was less closely related to US than to PHV. This might be expected because PHV reflects the timing of growth spurts, while US is a stage in the maturation of a single bone. The total increments in stature and in mandibular dimensions after PHV were closely associated, particularly in boys. When median annual increments were calculated relative to menarche, the largest values were in the year of menarche or the year before. The spurts occur considerably earlier than the peak growth, with a particularly long interval for Go-Gn.

The intervals between pubertal events within individuals indicate the rates of pubescent changes. The increments at the spurts tend to be large in rapidly maturing girls and slowly maturing boys.

The literature generally indicates that the timing of spurts in mandibular dimensions is closely associated with skeletal age, particularly in boys.[6,11,14,16] Luke,[31] however, found little relationship between skeletal maturity and mandibular growth. This relationship was examined in the present study by comparing the standard deviations at pubertal spurts of chronological ages (CA), Greulich-Pyle (GP) skeletal ages and Roche-Wainer-Thissen (RWT) skeletal ages. The standard deviations were slightly lower for GP than for CA, while those for RWT ranged near those for CA. In all cases the differences were small, showing that the relationship of the timing of these spurts to those indices of skeletal age was not much closer than with chronological age to which they were originally related.

The present findings are inconclusive in regard to possible associations between stature and mandibular dimensions. However, the total increments in stature and in mandibular dimensions after PHV were associated closely in boys and slightly in girls.

First pubertal spurts tended to occur at about 13.0 to 13.5 years in boys and 11.5 years in girls, but their timing varied considerably among individuals. The standard deviations for age at occurrence were about 1.3 to 1.8 years, indicating that an age range of ± 1.5 years around the above means would include about two thirds of the children (Figures 4 and 5).

If spurts have clinical relevance, it is important to be able to determine whether or not they have occurred in a particular individual. If only chronological age is used, one could expect that spurts will have occurred in only one of six boys before age 11.7, and in

only three of 100 boys before age 10.2 years. The corresponding ages for girls would be 9.9 and 8.3 years. However, there is much more uncertainty when ages near the mean age of occurrence are considered. The present study has shown that the use of GP or RWT skeletal age would add little to one's ability to identify children in whom pubertal spurts have occurred in the mandible (Table 6).

Many have claimed that the timing of spurts is related more closely to rate of maturation than to chronological age,[5,6,11,14] particularly in boys.[16] Similarly, Johnston *et al*[32] reported that in girls with normal occlusion the variance in percentage of adult size achieved is less related to skeletal age than to chronological age for Go-Gn and Ar-Go. The present analysis confirms this view for the relationships with peak height velocity and menarche, but shows little relationship with the indices of skeletal age.

The timing of first pubertal spurts in relation to the onset of ossification of the ulnar sesamoid was as variable as the relationship with chronological age for boys, and only slightly less variable for girls. Bergersen[14] indicated that there is a close association between the timing of mandibular spurts and US, and that the spurts tend to occur about 0.6 years before US. In the present data, the spurts occurred after US for each dimension in each sex. Radiographic techniques were not compared.

Menarche occurs too late to be a useful quide in orthodontic practice. Age at PHV can be obtained only if serial data for the statures of individuals extend from a few years before to a few years after the expected age of PHV. Consequently, PHV can be determined only in retrospect, not in real time when it could be useful clinically.

Chronological age can be used only as a rough guide, because about 95 percent of children have their first mandibular pubertal spurts within the following age ranges:

Boys: Go-Gn from 10.4 to 16 years
A-Go from 10.1 to 17.0 years
Ar-Gn from 10.4 to 15.8 years

Girls: Go-Gn from 7.7 to 14.9 years
Ar-Go from 9.2 to 14.4 years
Ar-Gn from 8.4 to 14.7 years

In addition, the data in Figures 4 and 5 should assist judgments of the normality of dimensions in relation to chronological and skeletal age.

Summary

Annual cephalometric radiographs of 67 children were used to analyze mandibular growth during pubescence. Annual increments were calculated for articulare-gonion (Ar-Go), articulare-gnathion (Ar-Gn) and goniongnathion (Go-Gn). Pubertal spurts were recorded for annual increments within two years of peak height velocity (PHV) that exceeded the immediately preceding increment by at least 1 mm (corrected for enlargement).

Such spurts in mandibular dimensions are common but not universal. They were more common in the boys, but occurred about 1.5 years earlier in the girls. They tended to be larger in boys, although the mean increments in the two sexes were similar before and after the spurts.

First pubertal spurts usually occur before PHV, but there was considerable variation in this relationship. Almost all first pubertal spurts occur after ulnar sesamoid ossification and before menarche. The variability of

their timing was less in relation to PHV than in relation to skeletal age, menarche or ulnar sesamoid ossification.

It can be desirable to determine whether a spurt has occurred in an individual patient. For this purpose, Greulich-Pyle skeletal age may be only slightly more meaningful than chronological age, and neither is sufficiently precise for many clinical applications.

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