Elongation of the Cranial Base in Girls during Pubescence

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One of the most dramatic features of growth in children is the pubertal spurt in stature that, anatomically considered, is due mainly to accelerated elongation of bones in the lower limb and trunk. It is well known that individuals differ in the amounts and timing of this spurt.[1] It is less well known that, within individuals, bones differ in the amounts and timing of their spurts leading to changes in the relationships between bone lengths.[2,3] Despite the small number of relevant studies, many consider that pubertal growth spurts occur in the craniofacial skeleton that are related both to orthodontic prognosis and to the selection of ages for orthodontic therapy.[4,5,6] Clearly, pubertal spurts cannot occur in bones that reach adult size before puberty, e.g., auditory ossicles.[7,8] Small pubertal spurts occur in the width, length and circumference of the head.[9,10] Pubertal spurts occur also in ectocranial skeletal dimensions studied radiographically[11,12,13] but not in anteroposterior cranial vault length measured between endocranial termini.[13] There is evidence that spurts occur in some mandibular dimensions in most individuals.[14-18] Similarly, spurts have been reported in maxillary dimensions[15,19,20] and in sella-gonion.[21]

Some cranial base lengths (e.g., S-N, Ba-N) in girls are about 95% of their adult size (Lewis and Roche, unpublished) at the mean ages when girls reach peak height velocity.[22,23] For comparison, peak height velocity (PHV) occurs when about 83% of adult stature has been achieved.[22,23,24] These findings indicate that only small pubertal spurts are possible in cranial base lengths unless they occur before PHV. The mean ages of PHV for American white children are similar to those for spheno-occipital fusion[25,26] after which only small increments occur in Ba-S. Consequently, if spurts occur in Ba-S, they would be expected to precede PHV.

Studies concerning pubertal spurts in the cranial base are few and inconclusive. Nanda[5] reported pubertal spurts in sella-nasion. His data were recorded at approximately annual intervals from about three to nineteen years in ten boys and five girls. He interpolated to six-monthly intervals and calculated percentage increments after three-point smoothing twice. From inspection of these smoothed graphs Nanda concluded that each of these children had a pubertal spurt in S-N; these tended to occur slightly later than PHV. His raw data have been recalculated to provide annual increments (mm/year) not necessarily beginning at birthdays. On inspection these increments do not show pubertal spurts when graphed without smoothing. Hunter,[15] using data from twenty-five boys and thirty-four girls, reported that pubertal spurts occurred in S-N at about the same age as PHV. The manner in which Hunter presented these data does not allow a reassessment of his conclusion. The reliability of the recorded data is very important in any analysis of possible pubertal spurts. This information is not available for the study by Hunter,[15] but Nanda[5] reported small within-observer errors after pooling data for seven parameters. The study by Pedersen[27] is relevant to the present subject but his sample was too small to allow firm conclusions.

Material and Methods

The present analysis was based on annual cephalometric radiographs of forty-one girls taken within one month of the nearest birthday. These girls, who are enrolled in the Fels Longitudinal Sample, form part of a Southwest Ohio white community. They were of middle socio-economic status and normal in health. The serial cephalometric radiographs that were measured extended from at least two years before to at least two years after the age of peak height velocity (PHV) for each child. Consequently, the chronological age ranges of the serial radiographs differ among the girls. One radiograph was missing from the series in eleven girls; two nonconsecutive radiographs were missing in seven girls. When a radiograph was missing, the two-year increment was apportioned equally to each annual interval.

All the radiographs were traced by one individual and all points checked by another. S-N, Ba-N, and Ba-S were measured to the nearest 0.1 mm using Helios calipers. The recorded distances were corrected for the known radiographic enlargement. The measurements were made by several observers whose within- and between-observer errors ($n = 155$ and 278, respectively) had means of about 0.1 mm and standard deviations of about 0.1 mm. These compare favorably with reported values.[28-32]

Possible spurts in the cranial base were identified from unsmoothed graphs of annual increments (mm/year) for each length. As an operational procedure, it was considered that a spurt had occurred if an annual increment exceeded the immediately preceding increment by at least 0.5 mm. An increment was considered pubertal if any part of the increment occurred in the age range from two years before to two years after PHV. Other spurts were identified outside this age range using the same operational procedure. By this procedure the first increment for a girl could not be a spurt, irrespective of its size, because it could not be compared with a preceding increment. A few increments had small negative values; the increments immediately following these were not considered spurts unless they were at least 0.5 mm/year after the preceding negative increment had been subtracted. The age at which each spurt occurred was recorded as the midpoint of the interval for which it was observed. The midpoints of the spurts were midway between successive birthdays, because radiographs were scheduled at birthdays. There were multiple spurts in some girls; consequently, analyses have been made of "first pubertal spurts" and "maximum spurts" for each length. The latter were the largest increments for each girl, irrespective of age.

Other information relating to these children included serial measurements of stature that were used to obtain six-monthly increments; the midpoint of the interval with the largest increment was recorded as the age of peak height velocity (PHV). When two successive increments were equally the largest, the midpoint of this combined interval was recorded as PHV. In none of these girls were two nonconsecutive increments equally the largest. The age of menarche was recorded from six-monthly inquiry at appropriate ages. Left hand-wrist radiographs were taken at six-monthly intervals. The Greulich-Pyle atlas[33] was used to obtain bone-specific skeletal ages for the hand-wrist interpolating between standards to the nearest three months when this appeared appropriate. The recorded skeletal ages were the arithmetic means of these bone skeletal ages. In each girl the age at onset of ossification of the ulnar sesa-

TABLE I
Means and Standard Deviations of Growth and Maturation Parameters in the Forty-One Girls

Parameter	*Mean*	*s.d.*
Stature at 16 yrs. (cm.)	163.0	5.8
Age at PHV (yrs.)	11.7	1.2
Age at menarche (yrs.)	12.8	1.2
Age at ossification of ulnar sesamoid (yrs.)	10.5	1.0
Skeletal age at chronological age 13.0 years	13.2	0.6

moid of the first metacarpophalangeal joint was recorded as the midpoint of the interval from the last radiograph in which this was not ossified to the first radiograph in which it was. The means and standard deviations for these girls (Table I) are similar to those reported for other healthy American children for stature at sixteen years, and ages at PHV, at menarche, and at ossification of the ulnar sesamoid, and skeletal age at the chronological age of thirteen years.[34,35]

Findings

The graphs were inspected applying the operational criteria described earlier. Spurts occurred during the pubertal period (i.e., PHV ±2 years) for each length in most of the girls (Table II) and there were two spurts during this period in some of the girls. In some girls spurts did not occur in some lengths at *any* age (S-N, 5; Ba-N, 1; and Ba-S, 10). For each length, there were a few girls in whom the only spurts noted were either before or after the limits of PHV ± 2 years. Examples of the distance and incremental graphs for one girl are shown in Figures 1 and 2. Distance graphs are appropriate for viewing differences in size between girls, e.g., tall, short. They are less suitable for recognizing or quantifying growth increments. Incremental graphs were used for the latter purpose (Fig. 2). In these graphs each rectangular "block" represents an annual increment in a cranial base length; these increments were obtained from annual measurements. Pubertal spurts were not observed in any of these lengths in two girls and such spurts were observed only in Ba-N in two other girls. The two girls in whom pubertal spurts did not occur in any cranial base length were moderately accelerated, but not extreme, in the recorded parameters of growth and development. One of these two girls had a spurt in Ba-N more than two years after PHV; in the other girl a spurt occurred in Ba-N more than two years before PHV. In neither of these girls was there a spurt in S-N or Ba-S at any age. Most of the girls who lacked a pubertal spurt in S-N or Ba-S did not have a spurt outside the range PHV ± 2 years. On the other hand, there were multiple spurts in these lengths in many of the girls. S-N had more than one spurt in twenty-one girls, Ba-N in twenty-three girls and Ba-S in thirteen girls.

Pubertal spurts were relatively more common in Ba-N and less common in Ba-S, when defined according to the above criteria. This was, to some extent, related to the magnitudes and

TABLE II
The Incidence and Size (mm) of First Pubertal Spurts in the Forty-One Girls

Length	n	Increment before spurt		Increment at spurt		Increment after spurt	
		Mean	s.d.	Mean	s.d.	Mean	s.d.
S-N	35	0.2	0.30	1.2	0.45	0.4	0.53
Ba-N	39	0.6	0.50	2.0	0.83	0.8	0.84
Ba-S	28	0.3	0.31	1.4	0.59	0.4	0.49

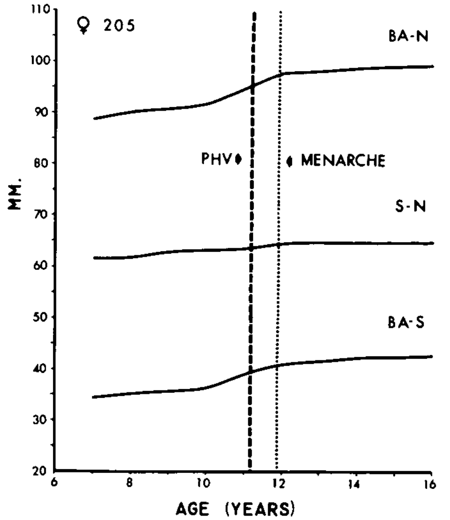

Fig. 1 A distance graph of three cranial base lengths. The vertical lines indicate the age of peak height velocity and menarche for this girl.

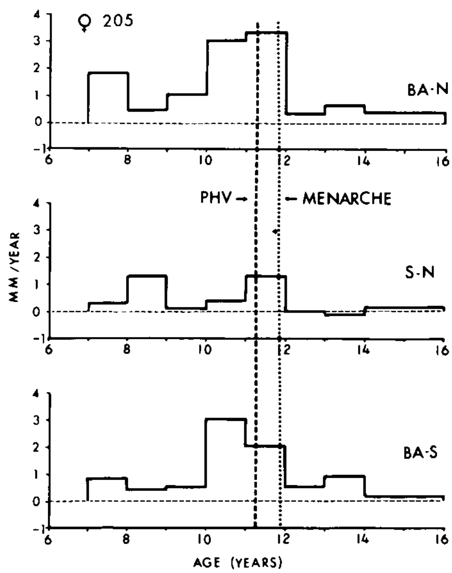

Fig. 2 An increment graph for the same girl as in Figure 1. Note that the first pubertal and maximum spurts for S-N are equal in amount.

rates of growth of these cranial base lengths. Consequently, an alternative definition was applied. In girls studied serially the median rate of growth in stature during the pubertal spurt is about twice that from four to six years before menarche.[36] Median annual increments were obtained for each cranial base length in the forty-one girls in relation to age at menarche. For each of these lengths a spurt was *redefined* as a rate twice that of the median rate from four to six years before menarche, when these rates were relatively stable across age. According to this definition spurts occurred in S-N (30 girls), Ba-N (21 girls) and Ba-S (20 girls). The introduction of the concept of relative change in rate of growth reduced the number of spurts differentially between lengths but they were still common.

The mean annual increments of first pubertal spurts were greater for Ba-N than for S-N or Ba-S (Table II). The mean increments immediately after these spurts slightly exceeded the immediately preceding increments for each cranial base length. There were corresponding patterns in the mean increments of these lengths during the maximum spurts both in regard to size of the mean increments at the spurts and the relative size of the mean increments immediately before or after them. This is not surprising, because, for each length, the first pubertal spurts were also the maximum spurts in a majority of the girls.

The first pubertal spurts in cranial base lengths were more common before than after PHV. For each length the annual interval with the highest incidence was that between one and two years before PHV. The maximum spurts were common within one year of PHV for S-N, from PHV to two years after for Ba-N, and between PHV and one year before for Ba-S. The first pubertal spurts occurred at mean chronological and skeletal ages of about 11.5

TABLE III

Ages of Occurrence of First Pubertal Spurts (Years)

Length	n	C.A. Mean	C.A. s.d.	S.A. Mean	S.A. s.d.	Interval Before PHV Mean	Interval Before PHV s.d.	Interval Before Menarche Mean	Interval Before Menarche s.d.	Interval After U.S. Ossification Mean	Interval After U.S. Ossification s.d.
S-N	35	11.5	1.48	11.5	1.48	0.3	1.37	1.4	1.20	1.0	1.31
Ba-N	39	11.4	1.67	11.4	1.57	0.3	1.79	1.5	1.18	0.9	1.30
Ba-S	28	11.3	1.33	11.4	1.36	0.5	1.01	1.6	1.12	0.8	0.96

C.A. = Chronological Age
S.A. = Skeletal Age
U.S. = Ulnar Sesamoid of the first metacarpophalangeal joint.

years (Table III) with only small differences in mean age between the lengths and only small differences between the variances for chronological and skeletal ages. The mean ages were close to PHV but about 1.5 years before menarche and about one year after ossification of the ulnar sesamoid. The variances tended to be smaller for ages in relation to menarche or ossification of the ulnar sesamoid than for the other ages. The sizes of these variances indicate that some children differed markedly from the means in the timing of pubertal spurts. By the operative criteria the first pubertal spurts necessarily occurred within a restricted age range. Consequently, the timing of maximum spurts was also considered. These tended to occur earlier for Ba-N and Ba-S than for S-N. The variances of the ages of occurrence of maximum spurts, whether considered in relation to chronological age, skeletal age, peak height velocity, menarche or ossification of the ulnar sesamoid, were in general larger for Ba-N than for S-N or Ba-S. Considering the three lengths as a group, the variances of the ages of occurrence of the maximum spurts were largest in relation to chronological age and smallest in relation to menarche but the differences between these and other variances were small.

The mean increments during the first pubertal spurts were compared between the five girls who were the tallest at sixteen years and the five girls who were the shortest at that age (Table IV). For each length all of the mean increments and all of their variances were slightly larger in the tall girls. Corresponding comparisons between increments immediately preceding or succeeding these spurts showed similar trends. The mean increments during

TABLE IV

Size (mm) of Increments During Spurts in the Five Tallest and the Five Shortest Girls

	Group	First pubertal spurts Mean	First pubertal spurts s.d	Maximum spurts Mean	Maximum spurts s.d.
S-N	tall	1.5	0.57	1.8	0.77
S-N	short	1.1	0.35	1.1	0.35
Ba-N	tall	2.3	1.08	2.6	0.66
Ba-N	short	2.1	0.66	2.1	0.66
Ba-S	tall	1.6	0.82	1.6	0.71
Ba-S	short	1.5	0.42	1.9	0.43

the maximum spurts for each girl were compared between the same groups of girls. These were larger in the tall girls than in the short girls except for Ba-S. The variances of these means were considerably greater in the tall girls than in the short girls for S-N and Ba-S.

Three girls were selected in whom PHV, menarche and ossification of the ulnar sesamoid occurred at markedly younger chronological ages than usual. Data from these early maturing girls were compared with data from four girls in whom the same events were delayed. The differences between the two groups of girls in the mean ages of these events were 4.1 years for peak height velocity, 4.4 years for menarche, and 3.3 years for ossification of the ulnar sesamoid. As expected, the first pubertal spurts in the cranial base occurred much later in the late maturing girls; the differences between the mean ages of the spurts for the two groups of girls were less for Ba-S than for S-N or Ba-N. These findings are illustrated by distance graphs for an early and a late maturing girl (Fig. 3). The differences in levels of S-N and Ba-N between these girls were small until elongation accelerated before menarche in the early maturing girl. These differences were reduced subsequently when elongation accelerated in the late maturing girl at about thirteen years. The differences between these two girls in Ba-S were very small at all ages. These data should be interpreted with caution because they refer to the first pubertal spurts. By definition, these spurts were within two years of PHV and thereby were constrained to occur earlier in early maturing girls than in late maturing girls. The increments during the first pubertal spurts differed in mean size only slightly between these two groups of girls in S-N and Ba-S but the mean increment in Ba-N was markedly greater in the early maturing girls. Similar findings were obtained from corresponding

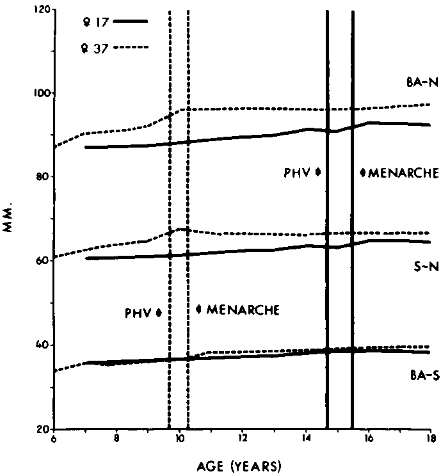

Fig. 3 Distance graphs for an early (- - - - -) maturing and late (——) maturing girl.

comparisons between early and late maturing girls in respect of maximum spurts. The maximum spurts in each cranial base length tended to occur at younger ages in early rather than in late maturing girls; these were not necessarily within two years of PHV. The mean maximum increments tended to be considerably larger in the early maturing girls than in the late maturing girls for Ba-N and Ba-S but not for S-N.

The forty-one girls varied not only in rate of maturation, but also in the lengths of the intervals between PHV and menarche. There was general support for the hypothesis that the length of the interval between these events was associated positively with the size of the first pubertal spurts (mm/year) in the cranial base as illustrated by the data from two girls (Fig. 4). When this interval is short it is reasonable to conclude that the girl has passed quickly through the various phases of pubescence.

Pearson product moment correlation coefficients were calculated between the increments of the first pubertal spurts in the three cranial base lengths using data from the twenty-six girls who had

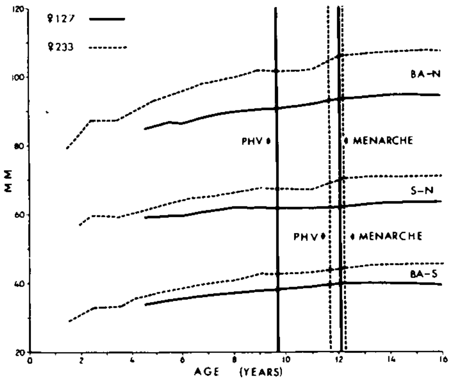

Fig. 4 Distance graphs for a girl (- - - - -) in whom PHV and menarche were separated by only 0.6 years and for a girl (——) in whom they were separated by 2.4 years.

pubertal spurts in all three lengths (Table V). Coefficients were calculated also between the increments of the maximum spurts. Each coefficient was positive but those for S-N vs. Ba-S were close to zero for both pubertal and maximum spurts.

The incremental data were reviewed in relation to intervals before and after menarche. Rectilinear interpolations were made because the ages at menarche were distributed somewhat randomly between birthdays. The findings have been presented as centiles (Fig. 5) for successive annual intervals before or after menarche. The tenth and ninetieth centiles have been included only for those intervals for which increments were determined in more than eighteen girls. In each length the fiftieth

TABLE V

Correlation Coefficients (r) Between the Sizes of Increments During Spurts in the Twenty-Six Girls who had Pubertal Spurts in All Three Lengths

	First pubertal spurts	Maximum spurts
S-N v. Ba-N	.52	.46
S-N v. Ba-S	.03	.13
Ba-N v. Ba-S	.13	.71

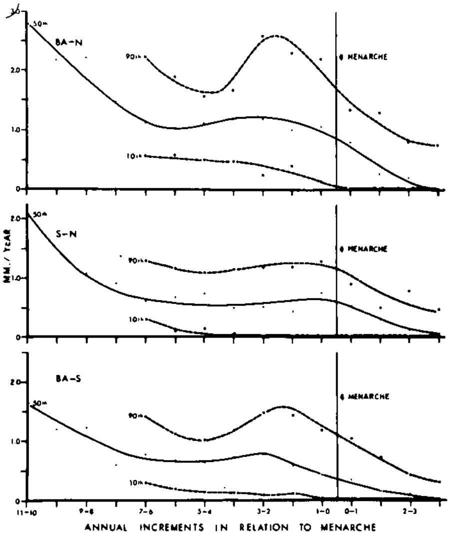

Fig. 5 Tenth, fiftieth (median) and ninetieth centiles for annual increments in cranial base lengths.

centiles (medians) indicate rapid deceleration until about seven years before menarche after which there are accelerations until about two to three years before menarche for Ba-N and Ba-S. Each period of acceleration was followed by a further period of deceleration. The acceleration in S-N tended to occur slightly later. The ninetieth and tenth centile lines show similar patterns, but the accelerations were most marked in the ninetieth centiles and least in the tenth centiles for each length. This figure demonstrates also that, during the five years before menarche, the median annual increments approximate 0.6 mm for S-N and 1.1 mm for Ba-N. The corresponding increments for Ba-S are about 0.7 mm from six years before to one year before menarche when they decrease to about 0.4 mm.

Discussion

This investigation has demonstrated pubertal spurts in cranial base lengths, when spurts are defined as accelerations of (at least) 0.5 mm/year. It is recognized, however, that the recorded increments were small and that technical errors might have influenced the analysis. The graphs of increments in the girls studied, like most data of this type, reflect both actual changes and errors due to imperfect techniques. Nevertheless, there is convincing evidence that these spurts are real. Both first pubertal spurts and maximum spurts occurred at younger ages in early rather than in late maturing girls and at ages close to those of PHV. The mean increments (mm/year) during the spurts were larger in tall than in short girls and their sizes were correlated positively between cranial base lengths. Furthermore, the spurts tended to be larger in girls who passed quickly through puberty as indicated by a small interval from PHV to menarche. It is clear from Figure 5 that spurts occur. The rates of elongation increased before menarche; these increases succeeded periods of rapid deceleration making it evident that a change in rate occurred.

It has been suggested that pubertal spurts in S-N reflect apposition at N.[37-40] However, the data of Roche[41] do not show definite pubertal spurts for cranial thickness at nasion. The total increment, from eight to sixteen years, in the distance from the endocranial aspect of the frontal bone to sella is no more than 2 mm[42] making it clear that substantial pubertal spurts do not occur in this dimension.

In general, the present findings confirm those of Nanda[5] and Hunter[15] for S-N but the present spurts occurred slightly earlier in relation to PHV than those reported by Nanda. It is of interest that spurts do occur in an endocranial base dimension (Ba-S) although, apparently, spurts do not occur in endocranial vault dimensions.[13]

The occurrence of recognizable pubertal spurts in cranial base lengths does not prove these are of practical importance. The latter must be judged from the central tendencies and distributions of the differences between increments before, during, and after these spurts. It must be decided whether the variations, with puberty, in the rates of cranial base elongation are sufficiently large to influence clinicians in decisions about the timing of orthodontic treatment. If so, it would be important to determine whether these spurts have occurred in individual patients. Serial cephalometric data provide the most certain guide. In their absence other data should be employed. In the girls studied spurts were uncommon after chronological and skeletal ages of thirteen years or after menarche. This is in general agreement with reported associations between the percentage of mature length attained by S-N, the age of the pubertal spurt in S-N and skeletal age.[15,43] In addition, age at closure of the spheno-occipital synchondrosis and, thus, the ability of the cranial base to elongate at this site is related to skeletal maturity status.[44]

Summary

Annual cephalometric radiographs of forty-one girls have been used to analyze pubertal spurts in cranial base lengths. A spurt was identified as an increment at least 0.5 mm/year greater than the immediately preceding increment. Spurts occurred for S-N, Ba-N, and Ba-S in most of the girls. As expected, these spurts tended to be larger for Ba-N than for the other lengths. First pubertal spurts occurred close to the age of peak height velocity and at chronological and skeletal ages of about 11.5 years. This was approximately 1.5 years before menarche and about one year after ossification of the ulnar sesamoid. Both first pubertal and maximum spurts tended to occur at younger ages in early rather than in late maturing girls and tended to be larger in girls who passed rapidly through the phases of puberty.

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ACKNOWLEDGMENTS

We are grateful for the assistance of Mrs. Betty Wagner, Miss Eileen Seitz, and Mr. Joseph Allison. This work was supported by Grants DE-HD-03472 and DE-HD-01294 from the National Institutes of Health, Bethesda, Maryland.

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