Cranial Base Elongation in Boys During Pubescence

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Recently in this journal,[1] pubertal spurts were reported in some cranial base dimensions in a majority of girls studied. A spurt was defined as an increment at least 0.5 mm in excess of the previous annual increment. These spurts tended to be larger for Ba-N than for either S-N or Ba-S. The first spurts during puberty for these dimensions in each girl were near the age at which the rate of growth in height was maximal (PHV). This was at chronological and skeletal ages of about 11.5 years, about 1.5 years before menarche and about one year after the onset of ossification of the ulnar sesamoid of the first metacarpophalangeal joint. Both first pubertal spurts and maximum spurts during pubescence tended to occur at younger ages in early than in late maturing girls and to be larger in those who passed rapidly through pubescence. Considering these findings for girls, it would be expected that boys would have corresponding spurts in rates of cranial base elongation that were associated similarly with other parameters.

Pubertal spurts in stature occur, of course, in both boys and girls. Furthermore, in each sex there are pubertal spurts in the elongation of limb bones[2,3] and in many craniofacial dimensions.[4-21] Milo Hellman[22-25] was among the earliest to investigate the latter spurts. At first, he used osteological material but later reported measurements made on the living. During these investigations he realized that analyses should be based on a maturational age rather than chronological age and that serial data were required. In his 1937[25] paper, Hellman presented limited serial caliper measurements that allowed the tentative conclusion that spurts occurred in facial dimensions.

At the average age when boys reach PHV, the mean lengths of S-N, Ba-N and Ba-S are from 94.5 to 97.1% of the corresponding adult lengths (Lewis and Roche, unpublished). For comparison, boys achieve their maximum rate of growth in stature (PHV) when about 89.8% of adult stature has been reached.[26,27]

Nanda[5] reported data from ten boys studied by the Child Research Council (Denver). These boys had been radiographed at approximately annual intervals from about three years until puberty and then about each second year until an age ranging from seventeen to twenty-three years. Using interpolated data, Nanda obtained increments for each six-month interval and calculated percentage increments after three-point smoothing twice. By inspection of these smoothed graphs he concluded that each boy had a pubertal spurt in S-N that tended to occur slightly later than the spurt in stature. These findings are in agreement with Hunter's data[13] for twenty-five boys also among those studied by the Child Research Council. Pedersen[28] reported accelerations in the rates of elongation of Ba-S at about twelve to fifteen years and a rapid acceleration in S-N from eight to fifteen years in boys. He considered these accelerations should not be interpreted as pubertal growth spurts because similar accelerations were present in his data throughout the age range from four to eighteen years.

Pubertal spurts in S-N have been reported in some Australian aboriginal boys.[29] The mean increment during the spurt was 2.5 mm/year (s.d., 1.1). Bergersen[30] reported spurts in S-N in some Denver boys at a mean age of 13.3 years (s.d., 1.2); in others only questionable spurts occurred. Both Brown et al.[29] and Bergersen[30] considered that the timing of cranial base spurts was related more closely to skeletal age than to chronological age.

Material and Methods

The present data were derived from fifty-eight boys enrolled in The Fels Longitudinal Study. All these boys had annual cephalometric radiographs within one month of each birthday except for ten boys who missed one examination and one boy who missed two examinations. When this occurred, the two-year increment was divided equally to annual increments. The methods of tracing and measurement, the way in which the data were checked and the reliability of the recorded data have been described.[1] After correction for radiographic enlargement the data were used to obtain annual increments (mm/year) for each cranial base length.

The difference between successive annual increments necessary for classification as a spurt was 0.75 mm in the boys. This is greater than that used for girls because the mean rates of elongation of cranial base dimensions were much greater in the boys than the girls. A spurt was considered pubertal if at least part of it occurred within two years of PHV. Despite extensive checking, retracing and remeasuring, a few negative increments remained in the serial data for individuals; these apparent decreases did not exceed 0.2 mm. Because these negative increments were considered to reflect technical rather than biological effects, the immediately succeeding increments were not considered spurts unless they were at least 0.75 mm/year after subtracting the preceding negative increment. The age of each spurt was recorded as the midpoint of the interval for which it was observed. In some boys multiple spurts occurred in the same dimension; consequently, first pubertal spurts and maximum spurts have been considered separately for each length.

TABLE I

Means and Standard Deviations of Growth and Maturation Parameters in the Fifty-Eight Boys

Parameter	Mean	s.d.
Stature at 18 yrs. (cm)	177.7	5.0
Age at PHV (yrs.)	13.6	0.9
Age at ossification of ulnar sesamoid (yrs.)	12.6	1.1
Skeletal age at chronological age 15 years	15.1	0.7

Other data included in the serial growth records of these boys have been used in the present analyses. These data are serial statures, the age of the maximum increment in stature (PHV), serial hand-wrist skeletal ages (Greulich-Pyle) and age at the onset of ossification of the ulnar sesamoid of the first metacarpophalangeal joint. The methods by which these data were obtained have been described in the companion paper.[1] Means and standard deviations for stature at eighteen years and for several developmental ages in these boys are similar to those for other healthy American boys[26,27] (Table 1).

Findings

A computer printout for each boy provided the length of each cranial base dimension at every examination after these lengths had been corrected for radiographic enlargement. In addition, these printouts provided annual increments and identified spurts according to the criteria described earlier. Most of the boys had spurts in each cranial base length after the age of eight years and these were multiple in

TABLE II

The Incidence and Size (mm) of First Pubertal Spurts in the Fifty-Eight Boys

Length	Increment before spurt		Increment at spurt		Increment after spurt	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
S-N	0.20	0.26	1.53	0.54	0.93	0.80
Ba-N	0.47	0.43	2.47	0.92	1.53	1.24
Ba-S	0.30	0.30	1.76	0.71	0.61	0.79

many (S-N, 32 boys; Ba-N, 40 boys; Ba-S, 31 boys). Spurts during the pubertal period (PHV ± 2 years) were lacking in only six boys for S-N, three boys for Ba-N, and eleven boys for Ba-S (Table II). The analyses that have been made relate to both first pubertal spurts and maximum spurts.

There were no boys in whom pubertal spurts were absent in all three cranial base dimensions, but in two boys spurts occurred in Ba-N only. One of these boys had a spurt in Ba-S after puberty. He had an acceleration of elongation in S-N at about the time of PHV but the rate of change was insufficient for this to be defined as a spurt. The second boy, with a spurt in Ba-N only, had accelerations in Ba-S and S-N within the pubertal period but their magnitudes were not quite sufficient for classification as spurts.

Pubertal spurts were less common in S-N than in Ba-N and were still less common in Ba-S. This order of incidence matched the order of the mean sizes of these lengths at corresponding ages and their mean elongation rates during corresponding age intervals. Consequently, an alternative criterion for identification of spurts was applied. Median annual increments were obtained for these three cranial base lengths in relation to age at onset of ossification of the ulnar sesamoid (Fig. 1). For each length, a spurt was redefined as an increase between successive increments at least equal to

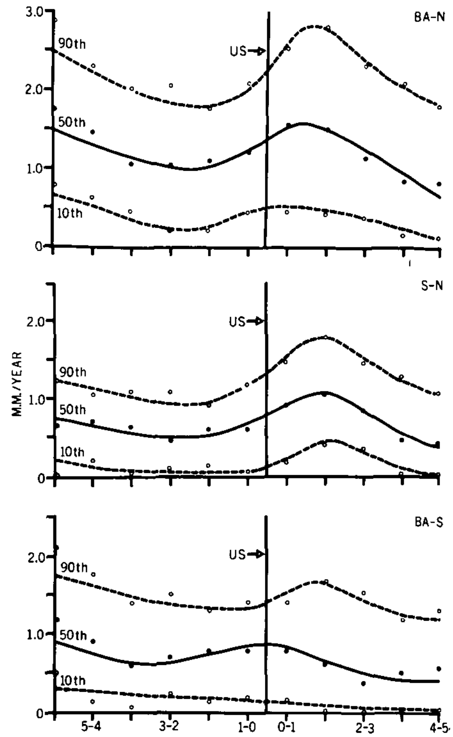

Fig. 1 Tenth, fiftieth (median) and ninetieth centiles for increments in cranial base lengths. These increments have been calculated for annual intervals before and after ossification of the ulnar sesamoid (US).

the median increment for the same length in this group of boys from two to four years before ulnar sesamoid ossification. These median rates are 0.45 mm/year for S-N, 1.05 mm/year for Ba-N and 0.7 mm/year for Ba-S. This was considered appropriate because the rate of growth in stature for boys approximately doubles during puberty.[31] When this definition was used, spurts were noted commonly in S-N (55 boys), Ba-N (52 boys) and Ba-S (50 boys). The application of this alternative criterion to the classification of spurts caused only small changes in the number of boys in whom spurts were observed.

Mean annual increments for each

TABLE III

Ages of Occurrence of First Pubertal Spurts (Years)

Length	C. A.		S. A.		Interval Before PHV		Interval After U.S. Ossification	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
S-N	13.3	1.48	13.2	1.44	0.3	1.18	0.7	1.44
Ba-N	12.8	1.40	12.6	1.41	0.8	1.03	0.3	1.34
S-Ba	13.0	1.39	12.8	1.44	0.5	1.17	0.4	1.46

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

length were considered in relation to the annual intervals immediately before, during, and immediately after the first pubertal spurts. In each interval the mean increments were larger for Ba-N than for either of the other lengths. The mean increment in S-N was the smallest for the interval before the spurt but was considerably larger for that for Ba-S in the interval immediately after the spurt. For each length, the mean increment after the spurt was greater than the mean increment before the spurt and the corresponding standard deviations were larger also. This indicates that acceleration prior to the first pubertal spurts is more abrupt than the deceleration after these spurts. The mean increments indicate that the acceleration (difference between rates before and during the spurt) is greater for Ba-N than for the other two lengths. The mean rate of deceleration (difference between rates during and after the spurt) is greater for Ba-S than for the other two lengths and smallest for S-N.

The mean increments in the three lengths during maximum spurts were calculated. These maximum spurts were not restricted to the age range PHV ± 2 years but to ages after eight years. These showed patterns of differences between the three lengths similar to those found for first pubertal spurts. In addition, each length showed patterns of differences between increments before, during and after maximum spurts generally similar to those for first pubertal spurts (Table II). This similarity was expected because the first pubertal spurts were also the maximum spurts in many boys. Despite this, some differences occurred. In the maximum spurts there were only small differences between the mean accelerations and decelerations and, during both phases, the rates of change were greater in Ba-N than in the other two lengths.

An analysis was made of the timing of first pubertal spurts in relation to chronological and skeletal age, PHV and age at ulnar sesamoid ossification (Table III). These first pubertal spurts tended to occur slightly earlier in Ba-N than in either S-N or Ba-S but the variability of ages was similar for all three lengths. The spurts in Ba-N tended to occur from 12.6 to 12.8 years of chronological or skeletal age; those in the other dimensions tended to occur up to 0.6 years later. For each cranial base length, the mean chronological and skeletal ages at which the first pubertal spurts occurred were similar. This was expected because the mean differences between chronological and skeletal age were small (Table I).

The first pubertal spurts tended to occur *before* PHV and *after* ossification of the ulnar sesamoid. There were only small differences between the three lengths in the variances of the timing of first pubertal spurts except for a slight tendency for the Ba-N variances to be smaller. When compared with the variances for chronological age, those for skeletal age and for age in relation to ulnar sesamoid ossification were similar, but those for the interval after PHV were smaller for each length. However, all the variances exceeded one year and show a marked tendency for the timing of spurts to vary whether considered in relation to chronological age, skeletal age, PHV or age of ulnar sesamoid ossification. This marked variability occurred within the range PHV ± 2 years.

The timing of maximum spurts was considered also. These tended to occur slightly earlier in Ba-S than in the other lengths and slightly later than the first pubertal spurts. Those in S-N tended to occur after PHV but the maximum spurts in the other lengths tended to occur before PHV. These spurts usually occurred after ulnar sesamoid ossification and their timing was variable, especially for Ba-S.

It was hypothesized that the spurts in cranial base elongation would be larger in tall boys than in short boys. This was tested by collating data for the five tallest and the five shortest boys at the age of eighteen years. One of the short boys had no pubertal spurt in Ba-S (Table IV). The data do not clearly support or reject this hypothesis. The mean increments for S-N tended to be larger in the tall than the short boys, both for first pubertal spurts and for maximum spurts but there were only small differences between the tall and short boys in their mean Ba-N increments during spurts. The short boys tended to have larger spurts in Ba-S than the tall boys during both first pubertal and maximum spurts. The variances, both for the size of first pubertal spurts and maximum spurts, tended to be larger in the tall boys than in the short boys for S-N and Ba-N but the reverse tendency occurred for Ba-S.

TABLE IV

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

Group	First pubertal spurts		Maximum spurts	
	Mean	s.d.	Mean	s.d.
S-N tall	1.7	0.57	2.4	0.88
S-N short	1.4	0.37	1.7	0.23
Ba-N tall	3.0	1.27	3.4	1.14
Ba-N short	3.0	1.09	3.2	0.85
Ba-S tall	1.6	0.57	1.6	0.64
Ba-S short	2.6*	1.50	2.6	1.15

* Represents four boys only; one of the five shortest did not have a pubertal spurt in Ba-S.

The data for Ba-S lengths in these boys were reviewed. The mean Ba-S increments for each of the two annual increments immediately prior to the first pubertal spurts were similar in the tall and short boys. However, Ba-S tended to be longer in the tall than the short boys at eleven years. These data show that Ba-S tends to elongate more rapidly in tall than in short boys before eleven years although the mean increments are similar in tall and short boys from then until the first pubertal spurts which tend to be smaller in the tall boys.

Data from early and late maturing boys were compared. Three boys were chosen to represent each group on the basis of the ages at which they reached PHV and at which ossification occurred in the ulnar sesamoid. These two groups of boys differed by 4.6 years in mean ages of peak height velocity and by 3.4 years in the mean ages at which the ulnar sesamoid ossified. One of the early maturing boys lacked a pubertal spurt in Ba-S; another lacked a pubertal spurt in Ba-N. There were definite tendencies for first pubertal spurts and for maximum spurts to occur at

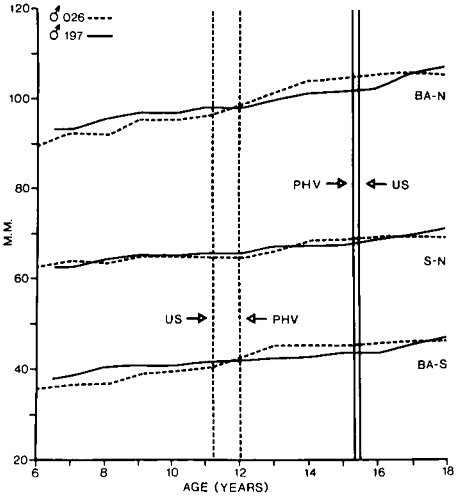

Fig. 2 Distance graphs of cranial base lengths in an early maturing (- - - -) and a late maturing boy (————). US = age at onset of ossification in ulnar sesamoid; PHV = age at peak height velocity.

younger ages in the early maturing than in the late maturing boys to extents that corresponded approximately to the mean differences between these groups in the timing of PHV and ulnar sesamoid ossification. The mean sizes of increments during spurts, when compared between early and late maturing boys, had similar patterns for first pubertal and maximum spurts. There were no differences in Ba-S increments between the two groups but those for Ba-N tended to be smaller and those for S-N to be larger in the early maturing boys.

Figure 2 shows graphs of cranial base lengths against age for two boys who differed markedly in their rates of maturation. In the early maturing boy (026) Ba-N and Ba-S were shorter than in the late maturing boy (197) until about 11.8 years when spurts in these lengths were evident in the early maturing boy. During these spurts, Ba-N and Ba-S became longer in the early than in the late maturing boy. In the latter boy, spurts began in Ba-N and Ba-S at about sixteen years. As a result of these spurts, Ba-N and Ba-S became longer in him than in the early maturing boy at about seventeen years. There were similar but less marked changes in S-N in these boys. The lines representing each cranial base length crossed twice for the two boys. These crossings reflect the effects of differences in the timing of pubertal spurts.

The boys included in the study varied not only in the ages at which the ulnar sesamoid ossified and at which they reached PHV but, in addition, they varied considerably in the intervals between these two ages. It was hypothesized that boys in whom these events were separated widely in time would tend to have gradual spurts of long duration whereas boys in whom these events occurred at or about the same time would have marked cranial base spurts of short duration. The hypothesis was not supported by the present data.

Data from two boys are shown in Figure 3. In boy Number 10, ossification of the ulnar sesamoid and PHV occurred at the same age (13.2 years). If the hypothesis were correct, one would expect a marked rapid spurt at about this age but such did not occur in any of the three lengths. In boy Number 77, ulnar sesamoid ossification occurred about 2.7 years before PHV; there were marked spurts in Ba-N and Ba-S and a moderate spurt in S-N. All of these occurred between the age of ulnar sesamoid ossification and the age of PHV. The initiation of the spurt was close to the age at which the ulnar sesamoid ossified.

Correlation coefficients were calculated between the size of the increments during first pubertal spurts for pairs of cranial base lengths. These were calculated using data from the forty-two boys who had spurts in all three

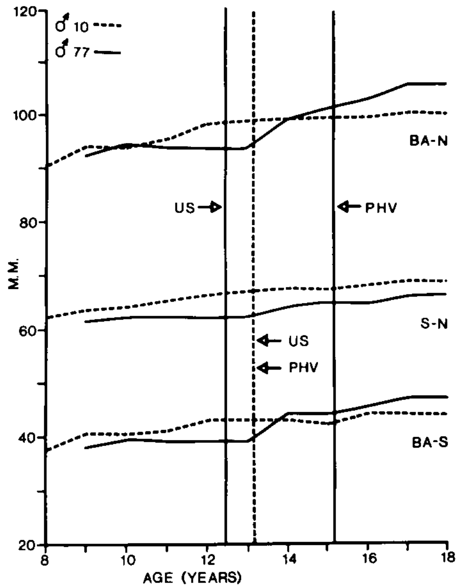

Fig. 3 Distance graphs of cranial base lengths in a boy (-----) in whom onset of ossification in the ulnar sesamoid and PHV occurred at the same age and for another boy (————) in whom these events occurred almost three years apart.

lengths. These coefficients were all positive but those for first pubertal spurts were close to zero except for that between Ba-N and Ba-S which was + 0.5. In the case of maximum spurts, after the age of eight years, the coefficients were positive for the correlations between spurts in S-N and Ba-N and in Ba-N and Ba-S and were larger than the corresponding coefficients for first pubertal spurts. However, there was a small negative correlation coefficient between the maximum increments in S-N and Ba-S (Table V).

The increments in each cranial base length for the fifty-eight boys were used to obtain tenth, fiftieth (median) and ninetieth centiles for annual increments in relation to ossification in the ulnar sesamoid (Fig. 1). Rectilinear interpolations were made to obtain these increments because the ages at ulnar sesamoid ossification were distributed randomly between birthdays. In interpreting this graph, it should be noted that data were available for fifty-eight boys at ages close to the time of ulnar sesamoid ossification but the number was smaller at other ages. However, all of the increments shown in Figure 1 were derived from samples of more than twenty-two boys.

TABLE V

Correlation Coefficients (r) Between the Sizes in Increments During Spurts in Forty-Two Boys Who Had Pubertal Spurts in All Three Lengths

Lengths	First pubertal spurts	Maximum spurts
S-N v. Ba-N	.07	.24
S-N v. Ba-S	.03	—.12
Ba-N v. Ba-S	.50	.63

The three cranial base lengths had similar trends of deceleration for the three-year period between two and six years before ulnar sesamoid ossification. Deceleration continued slightly longer in Ba-N and S-N than in Ba-S. From two years before ulnar sesamoid ossification until one or two years afterwards, the median increments of Ba-N and S-N accelerated, but acceleration of Ba-S lasted only until ulnar sesamoid ossification. In the median increments for each length, acceleration was succeeded by deceleration but the data indicate that by four to five years after ulnar sesamoid ossification, the rate of deceleration was decreasing for S-N and for Ba-S but there was no corresponding decrease in the rate for Ba-N. These changes in median increments were paralleled approximately by those in the tenth and ninetieth centiles.

In addition to size differences there were slight differences in timing between corresponding tenth, fiftieth and ninetieth centiles with the transition from acceleration to deceleration tending to occur later in the ninetieth centiles and earlier in the tenth centiles than in the medians for Ba-N and Ba-S. There was no corresponding tendency for S-N where deceleration began at approximately the same age in each centile level. This graph illustrates that, in regard to median increments, spurts tended to occur earlier in Ba-S than in the other lengths and slightly earlier in Ba-N than in S-N. These demonstrate that the median rate of elongation of Ba-N is about 1 mm/year prior to the pubertal spurt but reaches about 1.5 mm/year during the spurt. The median increment in S-N before the spurt is about 0.5 mm/year and during the spurt is about 1.0 mm/year. The median increment in Ba-S is about 0.6 mm/year before the spurt and rises to about 0.8 mm/year during the spurt. The data in Figure 1 demonstrate also that four to five years after ulnar sesamoid ossification the median increments are about 0.5 mm/year for Ba-S and S-N and about 0.7 mm/year for Ba-N. The corresponding chronological ages are about sixteen to seventeen years.

Increments in cranial base lengths were considered also for annual intervals before and after PHV. The centiles for each length decelerate from about seven to two years before peak height velocity. Later, they accelerate markedly except for the median (fiftieth centile) increments in Ba-S (Fig. 4). The accelerations in Ba-N continue until ages close to PHV, those in S-N continue until ages slightly after it, and those in Ba-S tend to end before PHV except for the slight acceleration in the fiftieth centile that ends near PHV. The centiles for Ba-N have accelerations that are similar in rate to the later decelerations. In S-N, the accelerations are more marked than the corresponding decelerations except those at the tenth centile level in which

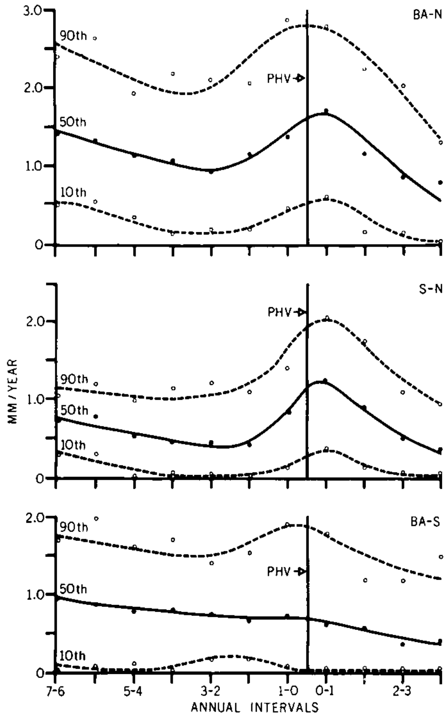

Fig. 4 Tenth, fiftieth (median) and ninetieth centiles for increments in cranial base lengths. These increments have been calculated for annual intervals before and after peak height velocity (PHV).

there is little difference. The accelerations at the ninetieth centile level did not tend to occur earlier than those in other centiles. For these data, grouped in relation to PHV, the median increments at the time when acceleration changes to deceleration is about 1.65 mm/year for Ba-N, 1.15 mm/year for S-N and 0.7 mm/year for Ba-S. Prior to these accelerations the fiftieth centile levels were about 0.8 mm/year for Ba-N, 1.0 mm/year for S-N and 0.7 mm/year for Ba-S.

Discussion

The present analysis has shown pubertal spurts are common in cranial base lengths and that these are larger in Ba-N than in S-N or Ba-S. They occur earlier in early maturing than in late maturing boys but there are no real differences in the size of these spurts between tall and short boys or between boys grouped according to the rate at which they passed through puberty. This report should be interpreted with care because two of the lengths (S-N, Ba-N) have nasion as an end point and their elongation might reflect apposition at nasion rather than growth within the cranial base.[32,33] Ba-S, however, is entirely within the cranial base and it is appropriate to discuss the mechanism of its elongation.

There are three possible sites at which Ba-S can elongate: the spheno-occipital synchondrosis, basion and sella. Elongation at the spheno-occipital synchondrosis cannot occur after there is bony union across the synchondrosis. The age at which this occurs in boys has been reported as 15.0 to 16.5 years.[34-37] Consequently, the spurts observed in the present boys could have been due to changes at this site. There is evidence that apposition occurs in the region of basion before and after spheno-occipital fusion.[34] This is probably small in amount and it is not likely to be responsible for any considerable part of the observed spurts. Because the anteroposterior diameter of the foramen magnum is almost constant after childhood,[41-43] it is probably repositioned posteriorly, to a slight extent, by apposition near basion and resorption near opisthion during puberty.

There is convincing proof that the pituitary fossa, and thereby sella, is relocated more posteriorly by apposition on the anterior wall of the fossa and resorption on its posterior wall.[37-39] In addition, it may be repositioned superiorly[30] but the patterns of deposition and resorption on the floor of the fossa are variable.[40] Posterior repositioning would decrease the distance Ba-S.

Spurts in cranial base lengths have been reported previously at ages similar to those recorded in the present study[28,30] The earlier studies indicate they are generally after PHV[5,13] whereas in the present boys they tended to precede it. The spurts observed in S-N were much smaller than those reported for Australian aboriginal boys, which may reflect ethnic differences or variations in sampling. Brown et al.[29] selected boys with definite pubertal spurts in stature; no such selection was made during the present study. The present analysis has confirmed previous reports[19,29,30,44] that the timing of spurts is related closely to skeletal age.

Summary

Data from fifty-eight boys were used to study pubertal spurts in cranial base elongation. Spurts were recorded when the differences between successive increments were at least 0.75 mm and, alternatively, when these differences equalled or exceeded the median increment during the period from three to four years before ulnar sesamoid ossification. With either criterion, spurts were common in S-N, Ba-N and Ba-S within two years of peak height velocity. Increments for intervals immediately before, during and after first pubertal spurts were larger for Ba-N than for the other lengths. The acceleration with spurts was greater than the deceleration after them; this deceleration was particularly gradual for S-N.

First pubertal spurts occurred slightly earlier in Ba-N than in S-N or Ba-S. Usually, they were before PHV and after ulnar sesamoid ossification. Their timing was equally variable whether related to chronological age, skeletal age or ulnar sesamoid ossification, but less variable in relation to PHV. First pubertal spurts were earlier in early than in late maturing boys. These two groups of boys did not

differ in the size of spurts in Ba-S but the spurts in Ba-N were smaller and those in S-N were larger in the early maturing boys. The rate at which boys passed through puberty, as indicated by the interval from ulnar sesamoid ossification to PHV, as not associated with maximum spurts.

The increments during first pubertal and maximum spurts were similar in short and in tall boys except for Ba-S in which the short boys had larger spurts. Ba-S was longer in tall than in short boys at eleven years and the mean increments in Ba-S were similar in short and tall boys immediately before, during and after first pubertal spurts.

The centiles for annual increments show decelerations until about two years before ulnar sesamoid ossification. Later, there were accelerations until one or two years after this event. These accelerations were succeeded by decelerations that decreased with progressive ages for S-N and Ba-S but not for Ba-N during the period up to five years after ulnar sesamoid ossification. An analysis of increments in relation to PHV showed a similar pattern but a difference in timing. Each centile for the three lengths decelerated until a few years before PHV when accelerations occurred that continued until ages close to PHV.

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