Skeletal age changes in puberty

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SUMMARY Changes in skeletal age and height of 34 Leeds schoolboys were studied in a four year longitudinal survey covering puberty. Tanner and Whitehouse method TW2 was used. In each boy, skeletal age advanced rapidly during puberty, reaching a peak at an age related to that of peak height velocity. The importance of recognising that this acceleration of bone age is normal is stressed, in order to avoid attributing it to other causes.

Skeletal age is a useful diagnostic tool provided correct standards are used and the limitations of accuracy are recognised. For British children the method of Tanner and Whitehouse¹ is the most appropriate as the commonly used alternative of Pyle *et al*² is more approximate and is not a suitable standard for a British population.³

Sometimes skeletal age estimations are undertaken serially at yearly intervals to confirm a diagnostic impression or monitor the course of a disease or treatment. It is often assumed that the skeletal age for a healthy, normal child should advance at approximately the same rate as the chronological age and that any deviation from this pattern may suggest some underlying clinical problem. This conclusion is, however, incorrect for the years of puberty and the present report, based on serial skeletal age estimations in a small group of boys, shows the variable pattern of skeletal age trends that can be found normally at this age.

Subjects and methods

Thirty four healthy boys, most of one year's intake of a Leeds day school, took part in a study of growth and physiological development, other aspects of which will be reported subsequently. The boys' age at the beginning of the study was mean (SD), 10.85 (0.26) years, and observations were continued for four to five years (1976–81), covering the more dramatic growth changes that occurred during puberty. Standard anthropometric measurements and pubertal ratings⁴ were recorded every four months and skeletal age was estimated annually by the TW2 method of Tanner and Whitehouse¹ based on radiographs of the left wrist and hand. These were all undertaken by the same investigator with a reproducibility of mean (SD), 1.7 (1.7)% (0.24

(0.19) year). Serial changes in height and pubertal rating were compared with those of skeletal age.

Height velocities were based on actual increments over a period of one year. Skeletal age changes were also considered in terms of velocities, that is, the skeletal age increases over one year, expressed as years/year. The bone development quotient (BDQ) is a means of relating skeletal age (SA) to chronological age (CA), ($BDQ = SA/CA \times 100$). Although skeletal ages, even when measured by the same experienced worker, cannot be as precise as measurements of height, the velocities provide a useful way of relating skeletal age to changes in height. The age at which skeletal age seems to be increasing most quickly has been termed the age of peak skeletal age velocity. This requires at least three consecutive annual skeletal ages, and the correct peak could be up to 6 months on either side to the observed highest velocity. In only 29 boys were skeletal age data sufficient for analysis, and in these the ages studied spanned the age of peak height velocity. Unfortunately, in only 13 boys was the peak skeletal age velocity unequivocal, having lower values before and after. In the remaining boys, the highest values were used in analysis, and, of these, equal numbers had their highest velocity in the first and in the last time period of the study. There was no difference between the mean ages of highest skeletal age velocity for the selected 13 boys and for the total group of 29 boys, which were mean (SD), (13.74) (0.31) years and 13.76 (0.78) years respectively.

Ethical approval

Agreement to the radiological investigations was given by the Medical Research Council, which agreed to the proposed level of exposure, subject to

certain provisos. These requirements were satisfied by the following undertakings: radiological examinations were kept to a minimum by delaying the first until the boys were over the age of 12 years and performing them only once a year. The approval of the local research ethics subcommittee was obtained and the project was further supported by the professor of paediatrics. The study was approved by the director of education, and the implications were accepted by the parents after full explanation at special meetings.

Results

Anthropometric measurements. Measurements dependent on bony structures, that is, height, sitting height, and biacromial and bi-iliac diameters, showed a closely similar centile distribution to Tanner's standards for British children.⁵ Weight and skinfold measurements were, however, noticeably less at all ages. The age of onset of puberty, that is, testicular growth (genital stage 2 (G2)), was later than the values of Tanner by an average of 1.25 years, and the age of peak height velocity was later by 0.3 (Table 1).

Relation between skeletal age and height changes.

Table 1 shows that peak bone age velocities in most boys exceeded 1 year/year, indicating that skeletal age was advancing more rapidly than chronological age. Fig. 1 shows, for 9 of the boys in whom a definite peak skeletal age velocity was identified, how skeletal age velocity compared with height velocity. There is a close similarity in the pattern, with the skeletal age velocity peak usually a little before the height velocity peak. This was observed in most of the remaining boys for whom the data were sufficient for conclusions to be drawn. Fig. 2 compares the ages of highest recorded skeletal age velocity with those of peak height velocity for all the boys and shows the close correlation between these and the tendency for skeletal age to accelerate in

Fig. 1 Height velocity compared with bone age velocity in 9 boys.

advance of height. The relation between skeletal age (TW2) and chronological age for all 34 boys together is shown in Fig. 3. All the values for boys whose chronological ages came during the course of a full year are pooled to give a value at the midpoint, and the bone age and chronological ages have been correspondingly rounded up or down. This, together

Table 1 Details of ages of events and magnitude of peak height and skeletal age velocities in 29 boys

	Age (years)				Peak velocity	
	When first seen	First sign of puberty* (G2)	Peak height velocity	Peak skeletal age velocity	Height (cm/year)	Skeletal age (years/year)
<i>This study</i>						
Mean (SD)	10.85 (0.26)	12.91* (0.86)	14.27† (1.00)	13.74 (0.78)	9.71 (1.30)	1.73 (0.50)
Range	10.13–11.40	11.15–14.07	12.24–16.87	12.45–16.05	7.74–12.42	0.8–2.8
<i>Tanner's standards</i> ⁵						
Mean (SD)		11.64* (1.07)	13.97+ (1.01)		9.4	

*Tanner genital stage 2—enlargement of testes (G2)—difference highly significant $P < 0.001$.

†Difference not significant.

Fig. 2 Comparison of ages of highest bone age velocity and peak height velocity in 28 boys.

Fig. 3 Relation between pooled bone age and chronological age data based on estimations at approximately yearly intervals in 34 boys. Means and standard deviations for combined values over yearly intervals. (Numbers of bone age estimations contributing are shown in parentheses).

with the failure of a few boys to be x-rayed each year, accounts for the fact that the number of observations does not correspond precisely to the number of subjects. Not unexpectedly, the standard deviation is large, yet although it seems that in the early stages the average skeletal age is retarded compared with the standards, it then accelerates at about the age of peak height velocity. Instead of pooling the data for individuals according to chrono-

Fig. 4 Bone age velocity at intervals before and after the age of peak height velocity. Pooled data on 34 boys studied longitudinally at approximately yearly intervals. Mean (SD).

logical age, pubertal stage can be made the common factor. The age of peak height velocity is the most precisely definable phase of puberty in boys and is compared with skeletal age in Fig. 4. This confirms that in the two years before the age of peak height velocity, skeletal age velocity exceeds 1, that is, skeletal age is advancing faster than chronological age (having been initially retarded—Fig. 3). Table 2 shows that overall skeletal age retardation in the younger ages is accounted for by those boys who have not yet entered puberty. Boys whose testes have not yet started to enlarge (stage G1), who could be considered prepubertal, had low bone development quotients. In contrast, as soon as the boys showed signs of puberty (G2 or more), whatever their chronological age, skeletal ages accelerated. Table 3 shows a highly significant difference in the skeletal ages of boys of the same chronological age, depending on whether or not they were in puberty.

Discussion

Bony development can be analysed in various ways. Grave and Brown⁶ and Hagg and Taranger⁷ related specific ossification events in the wrist and hand to stages of a child's growth activity at puberty. They do not show serial changes in the bones of the hand as a whole, which is the essential feature of the classic methods of 'skeletal age estimation'.

The method of Pyle *et al.*,² based on American children,³ is inappropriate for a British population.

Table 2 Distribution of bone development quotient values in boys in relation to attainment of the first stage of puberty (G2)

Age (years)	Group	Total No	Bone development quotient				
			Mean (SEM)	% distribution			
				<90	90-100	101-110	> 110
12-13	Pre-G2	15	92* (3)	47	47	0	7
	Post-G2	9	105* (2)	0	22	33	45
13-14	Pre-G2	12	90* (3)	58	33	0	8
	Post-G2	15	104* (2)	7	20	53	20
14-15	Pre-G2	1	90	0	100	0	0
	Post-G2	27	101 (1)	7	26	59	7
15-16	Pre-G2	—	—	—	—	—	—
	Post-G2	30	100 (1)	7	33	53	7
All ages combined	Pre-G2	28	91*	50	43	0	7
	Post-G2	81	102*	6	27	53	14

*Values that are significantly different from each other in the same age group ($P<0.01$).

Table 3 Skeletal age of boys in relation to attainment of first stage of puberty (G2). Mean (SEM), with number of subjects in italics

Group	Age (years)	12-13	13-14	14-15	15-16
Pre-G2	Chronological age	12.23 (0.05) (15)	13.28 (0.05) (12)	14.0 (1)	—
	Skeletal age	11.23 (0.33) (15)	11.95 (0.35) (12)	12.6 (1)	—
Post-G2	Chronological age	12.47 (0.10) (9)	13.43 (0.06) (15)	14.40 (0.05) (27)	15.40 (0.07) (30)
	Skeletal age	13.14 (0.33) (9)	13.95 (0.26) (15)	14.60 (0.22) (27)	15.41 (0.17) (30)

Groups compared		Levels of significance			
Chronological age v Skeletal age	Pre-G2	$P<0.01$	$P<0.01$	—	—
	Post-G2	NS	NS	NS	NS
Pre-G2 v post-G2	Chronological age	NS	NS	—	—
	Skeletal age	$P<0.001$	$P<0.001$	—	—

NS — not significant.

It is also very approximate, matching as closely as possible with a limited series of radiographs (to which have been attributed particular skeletal ages). Using this method with American children, Anderson *et al*⁶ did not find a significant acceleration in skeletal age relative to chronological age in pubertal boys, though there was a suggestion of this in girls, corresponding to the age of peak height velocity. The TW2 method¹ is much the most appropriate and accurate for British children, but few reports have shown how skeletal ages change over the years of puberty in individual children. The original standards were based on the pooled data of many children who had been x-rayed once, and from which means and standard deviations for skeletal 'score' have been derived through the years of

childhood. It is well known that the heights of normal healthy individual children plotted on centile charts adhere to a centile position before puberty but then commonly deviate from the composite 'norms', depending on the age at which the pubertal growth spurt occurs in that individual. The present study shows that the same is true of skeletal development as evaluated by skeletal age at puberty. It is of interest that Helm⁹ assessed the skeletal ages of 3817 Danish schoolchildren aged 7 to 18 years by the TW2 method in a cross sectional study and showed a good correlation before puberty. In both sexes at the adolescent age range, however, there was a rapid advance relative to these British standards that coincided with the ages of peak height velocity. In a semilongitudinal survey of

a large group of Dutch children, Van Venrooij-Ysselmuiden and Van Ipenburg¹⁰ found that the annual increment in skeletal age (using the TW2 method) showed a peak coinciding with peak height velocity. Before this rapid speed up in bone age, the children's bone ages were a little retarded compared with the TW2 standards. These findings are very similar to those of the present report.

It might be expected that skeletal age would increase in parallel with chronological age, but this is not the case at puberty for up to two years before the age of fastest growth in stature and for a short time afterwards skeletal age advances more quickly than chronological age and, at its peak, may be 1.5 years/year, or more. If this fact is not recognised, errors in interpretation may be made. Early developers will have their skeletal age acceleration early. Late developers will initially show a relative retardation but their skeletal age will catch up when puberty ultimately occurs.

These bone age changes at puberty must be recognised as normal and not be attributed to pathology. In monitoring treatment, particularly of endocrinological disorders, these changes in skeletal age may be attributed to incorrect treatment when in fact they can be explained readily by the stage of puberty.

In conclusion, it is important to emphasise the need for: (1) the use of the correct skeletal age standards for a population (TW2 for British children); (2) accuracy of skeletal age estimation; (3) consistency by the same observer; (4) recognition of the normal speed-up in skeletal age associated with the rapid phase of growth in puberty.

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