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Maturation indicators and the pubertal growth spurt

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The pubertal growth spurt and dental, skeletal, and pubertal development have been investigated in a prospective longitudinal study of 212 randomly selected Swedish children by means of maturation level indicators suitable for use in clinical orthodontics. The sample was examined from birth to adulthood and included a representative proportion of early-, average-, and late-maturing subjects. The number of dropouts and missing examinations was low and was allowed for in the statistical analysis. The results may therefore be considered representative for Swedish children. There was a 2-year sex difference in age at the beginning, peak, and end of the pubertal growth spurt in standing height. The individual variation was about 6 years at each event in both sexes. Dental development in relation to the pubertal growth spurt was more advanced in boys than in girls, but the individual variation was great in both sexes. Skeletal development at the beginning and peak was more advanced in girls than in boys, whereas at the end of the pubertal growth spurt the skeletal development was more advanced in boys. Dental development, determined by means of dental emergence stages (DES), was not useful as an indicator of the pubertal growth spurt. The peak and end—but not the beginning—of the pubertal growth spurt could be assessed by means of indicators taken from the skeletal development of the hand and wrist and the pubertal development (menarche and voice change).

Key words: Orthodontics, maturity indicator, pubertal growth spurt, dental development, skeletal development, pubertal development

Every skeletal and muscular dimension seems to be involved in the pubertal growth spurt.[1] The pubertal growth spurt is considered to be an advantageous period for certain types of orthodontic treatment and should be taken into account in connection with orthodontic treatment planning.[2–5]

Because of the wide individual variation in the timing of the pubertal growth spurt, chronologic age cannot be used in the evaluation of pubertal growth. Many studies have shown a strong correlation between the peak of facial growth and peak height velocity.[3, 6–9] Longitudinal records of height can therefore be used for evaluation of the facial growth rate during puberty. In the clinical context, longitudinal growth records of height are seldom available. Even with adequate records, it may be difficult to locate the pubertal growth spurt before it is passed, since the increase in growth rate is often too small, especially in many girls, to be clinically discernible. Most of the time the clinician must base his judgment on a single examination and, therefore, determine the status of the individual by cross-sectional evaluation alone.

Stature is not an indicator of maturity. Thus, additional information is necessary to estimate the maturation level of the individual. Such information can be obtained from the dental, skeletal, and pubertal development. By comparing with standards for age and sex, it is possible to assess whether the development of the individual is average, accelerated, or retarded. In orthodontics it is more relevant to evaluate the individual's maturation in relation to his or her own pubertal growth spurt. This presupposes knowledge of relationships in time between maturation indicators and pubertal growth events. Suitable maturation indicators for clinical orthodontics have been devised,[10–12] and the associations between these indicators and the peak of growth have been reported.[3, 10, 12–19]

In samples that have not been followed during a sufficiently long period, especially early and/or late maturers are likely to be underrepresented. Furthermore, in any longitudinal study a substantial number of dropouts is inevitable. Since the dropout rate increases with time, the proportion of early, average, and late maturers in whom the growth events and maturation indicators are determined is very likely to be biased. As

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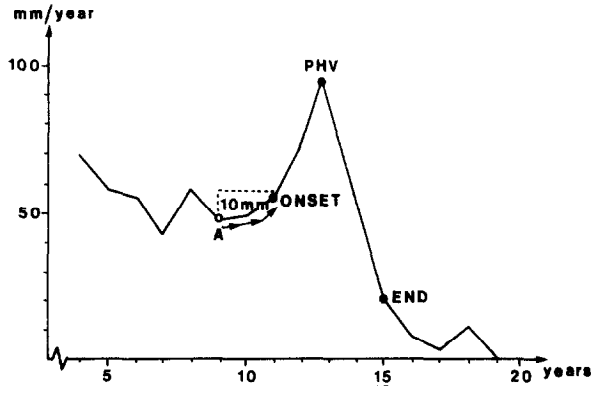

Fig. 1. The pubertal growth spurt. Onset of the spurt (ONSET) is the smallest annual increment from which there is a marked continuous increase in growth rate to PHV. ONSET is found by locating the smallest annual increment *(A)* from which there is a continuous increase in growth rate to PHV. The curve is then followed toward PHV until the growth rate has accelerated 10 mm. ONSET will be indicated by the annual increment which is next below or coincides with this growth rate. Peak height velocity (PHV) is the greatest annual increment during puberty. The end of the spurt (END) is the first annual increment after PHV below 20 mm.

Table I. Definitions of maturity indicators of dental and pubertal development

Dental emergence stages	
Teeth anterior to the molars:	
DES 1	1 to 7 incisors*
DES 2	All incisors
DES 3	1 to 11 canines and/or premolars
DES 4	All canines and premolars
Molar teeth:	
DES M1	1 to 3 first molars*
DES M2	All first molars*
DES M3	1 to 3 second molars
DES M4	All second molars
DES M5	1 to 3 third molars
DES M6	All third molars*
Pubertal development	
M	Menarche; first menstrual bleeding
PPV	Prepubertal voice; the pitch of the voice had not changed noticeably
PV	Pubertal voice; the pitch of the voice had changed noticeably but the voice had not yet acquired adult characteristics
MV	Male voice; the pitch of the voice had acquired adult characteristics

*These stages were not analyzed in this study.

a rule, the impact of this bias is not taken into account in the statistical analysis. Consequently, the representativeness of the results of previous studies is, as a rule, uncertain.

The pubertal growth spurt and maturation of a random sample of Swedish children were analyzed by studying the following factors: the definition of the pubertal growth spurt; age at the beginning, peak, and end of the pubertal growth spurt; age at the attainment of specified maturation level indicators taken from dental, skeletal, and pubertal development; the association between the specified maturation level and pubertal growth spurt.

MATERIALS AND METHODS

A longitudinal prospective and interdisciplinary study of growth and development of 212 children from birth to adulthood in a Swedish urban community began in 1955.[20, 21]

The 212 subjects (90 girls and 122 boys) were born between April, 1955, and March, 1958, at the only maternity unit in the community. The subjects were randomly selected antenatally. At the last programmed annual examination, at 18 years, 160 (75.5 percent) of the 212 original subjects participated. At a follow-up examination at 20 to 22 years, 148 subjects (69.8 percent) were investigated.

The subjects were examined once a year according to a planned schedule. Examinations comprised, among other things, data on standing height, tooth emergence, and pubertal development and a radiograph of the right hand and wrist.

Information on dental, occlusal, and space anomalies, dental decay, and dental care was obtained from other sources. The findings were in general accord with other Scandinavian studies.[22]

Methods of registration

Two examiners of the Swedish growth team[21] performed more than 90 percent of the measurements of height, the recordings of tooth emergence, and the assessments of pubertal development.

Standing height was measured with the stretching-up technique[23] and recorded in millimeters. About 80 percent of the measurements were done in the morning between 8 and 10 A.M.

Tooth emergence was recorded annually by direct inspection. A tooth was considered to have emerged if any part of the crown was visible.

Radiographs of the right hand and wrist were obtained annually by a standardized procedure.[24]

Menarche (Table I). From the age of 10 years onward the girls were asked every 3 months whether or not menarche had occurred.

Voice change. From 10 years onward assessment of the voice in boys was done annually. Voice assessment was done clinically[25] without knowledge of the previous ratings. Three stages of voice change were used (Table I).

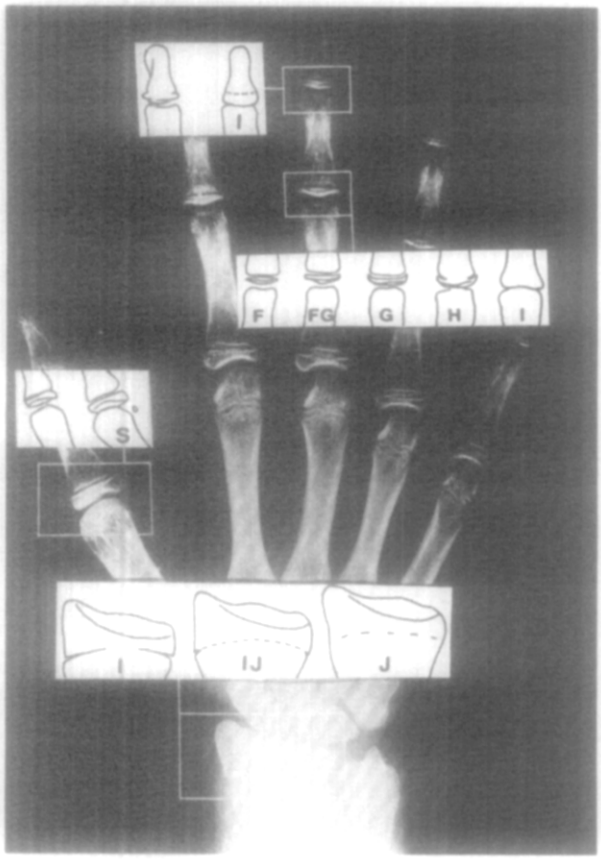

Fig. 2. The ulnar sesamoid (S) of the metacarpophalangeal joint of the first finger before and after ossifying. The distal phalanx of the third finger (DP3) before and after Stage I: fusion of the epiphysis and metaphysis is completed. The middle phalanx of the third finger (MP3): Stage *F*—the epiphysis is as wide as the metaphysis. Stage *FG*—the epiphysis is as wide as the metaphysis and there is distinct medial and/or lateral border of the epiphysis forming a line of demarcation at right angles to the distal border. Stage *G*—the sides of the epiphysis have thickened and also cap its metaphysis, forming a sharp edge distally at one or both sides. Stage *H*—fusion of the epiphysis and metaphysis has begun. Stage *I*—fusion of the epiphysis and metaphysis is completed. The distal epiphysis of the radius: Stage *I*—fusion of the epiphysis and metaphysis has begun. Stage *IJ*—fusion is almost completed but there is still a small gap at one or both margins. Stage *J*—fusion of the epiphysis and metaphysis is completed.

Methods of analysis

Adolescent growth was studied by graphic analysis of the unsmoothed incremental curves of standing height. These curves were based on the annual increments from 3 to 20 years. First, the peak height velocity (PHV) was located on incremental curves for each subject. The growth curves were observed for reliable estimates of the beginning and end of the pubertal growth spurt. A marked, continuous increase in growth

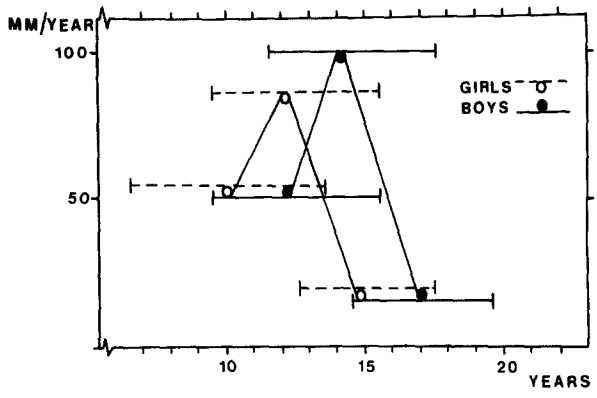

Fig. 3. Mean and range at the beginning (ONSET), peak (PHV), and end (END) of the pubertal growth spurt in girls and boys.

rate up to PHV in all subjects was found from one growth event, ONSET[26] (Fig. 1). In all subjects the increase in growth rate during puberty was more than 10 mm.; that is, ONSET and PHV did not coincide in any subject. A marked, continuous deceleration in growth rate after PHV occurred down to the first annual increment below 20 mm. (END) in practically all subjects. In view of these findings, ONSET was chosen to represent the beginning and END the end of the pubertal growth spurt in this study.

Dental development was assessed by *dental emergence stages* (DES), a grouping of teeth[27] which is, in general, in accordance with that of the dental stages (DS) devised by Björk and associates[11] but with two new stages, denoted DES M3 and DES M5 (Table I). Marked deviations from the symmetrical pattern of tooth emergence were checked and adjusted systematically before the statistical analysis.[22]

Skeletal development in the hand and wrist was analyzed from annual radiographs, taken between the ages of 6 and 18 years, by assessment of the ossification of the ulnar sesamoid of the metacarpophalangeal joint of the first finger (S) and certain specified stages of three epiphyseal bones (closure of epiphyseal plates): the middle and distal phalanges of the third finger (MP3 and DP3) and the distal epiphysis of the radius (R) (Fig. 2). Because several epiphyseal stages were used in this study, we preferred to use definitions and terms in accordance with the TW method.[28] The four bones to be used as indicators of the skeletal development were chosen according to Björk.[3] Eight of the ten indicators[29] (Fig. 2) have been defined by others. In order to obtain maturation indicators of shorter duration, two new epiphyseal stages were defined in this study: one stage in the middle phalanx of the third finger, denoted MP3-FG, and one stage in the distal end of the radius, denoted R-IJ.

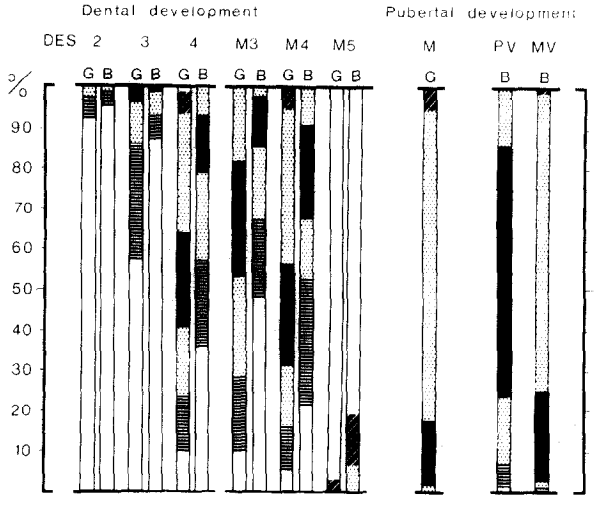

Fig. 4. Attainment of indicators of dental and pubertal development in relation to the occurrence of the pubertal growth events in girls and boyd (cumulative percent). Coincidence is marked. ▤ = ONSET; ■ = PHV; ▨ = END; ⊡ = pubertal growth.

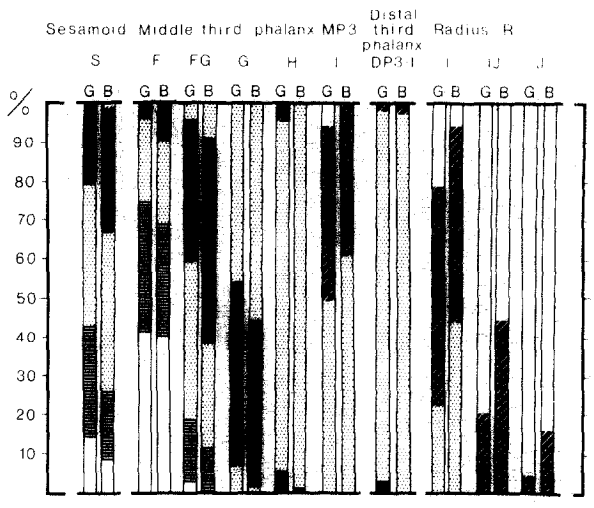

Fig. 5. Attainment of indicators of skeletal development in relation to the occurrence of the pubertal growth events in girls and boys (cumulative percent). Coincidence is marked. ▤ = ONSET; ■ = PHV; ▨ END; ⊡ = pubertal growth.

Table II. The sequence of pubertal growth events* and specified maturity indicators* according to the mean ages (given in years within brackets)

	Girls			*Boys*		
Age	*Dental development**	*Skeletal development**	*Pubertal development**	*Dental development*	*Skeletal development*	*Pubertal development*
8	DES 2 (8.0)			DES 2 (8.3)		
9	DES 3 (9.2)					
		MP3-F (9.5)				
10		Onset (10.0)		DES 3 (10.1)		
		S (10.7)				
11	DES M3 (11.3)	MP3-FG (11.3)				
					MP3-F (11.7)	
	DES 4 (11.9)			DES M3 (11.8)		
12		PHV (12.0)				
	DES M4 (12.2)				Onset (12.1)	
		MP-3G (12.4)				
				DES 4 (12.5)		
				DES M4 (12.7)		
13			M (13.1)		S (13.1)	
		DP3-I (13.3)				
		MP3-H (13.5)				
					MP3-FG (13.7)	
						PV (13.9)
14		MP3-I (14.3)			PHV (14.1)	
					MP3-G (14.6)	
		R-I (14.8)				
15		End (14.8)				MV (15.0)
					MP3-H (15.6)	
					DP3-I (15.6)	
16		R-IJ (15.8)			MP3-I (16.3)	
					R-I (16.5)	
		R-J (16.7)				
17					END (17.1)	
					R-IJ (17.6)	
18					R-J (18.0)	
19	DES M5 (18.9)			DES M5 (19.1)		

*For definitions, see Table I and Figs. 1 and 2.

Table III. Probit analysis of age (in years) at occurrence of pubertal growth spurt and maturity indicators in Swedish girls and boys

	Sex	Mean	SD	Adjustment to probit line[a]		Range	Sex difference in years
				CHI^2	df		
Pubertal growth spurt							
Onset	F	10.04	1.26	3.03	7	6.5- 13.5	20.4 ***
	M	12.08	1.20	3.83	6	9.5- 15.5	
PHV	F	11.98	1.02	9.41	6	9.5- 15.5	2.09 ***
	M	14.07	1.08	2.53	6	11.5- 17.5	
End	F	14.82	0.88	1.19	5	12.5- 17.5	2.23 ***
	M	17.05	0.98	1.32	5	14.5- 19.5	
Dental development							
DES 2	F	7.97	0.68	0.37	3	6.5- 9.8	0.33 ***
	M	8.30	0.79	9.86	5	6.8- 11.5	
DES 3	F	9.21	0.97	5.61	5	7.2- 12.3	0.86 ***
	M	10.07	0.97	5.70	6	7.5- 13.3	
DES 4	F	11.87	1.56	6.32	8	8.9- 16.5	0.59 **
	M	12.46	1.14	5.00	5	10.5- 15.8	
DES M3	F	11.34	1.11	7.69	5	9.2- 14.5	0.42 **
	M	11.76	1.03	1.00	6	8.3- 14.5	
DES M4	F	12.20	1.21	4.08	6	9.8- 15.8	0.48 **
	M	12.68	1.08	3.90	5	10.5- 15.8	
DES M5	F	18.88	1.44	1.30	2	15.2-	0.26
	M	19.14	1.69	1.51	3	14.3-	
Skeletal development							
S	F	10.73	1.03	3.48	4	8.5- 12.5	2.39 ***
	M	13.12	1.12	3.86	6	10.5- 16.5	
MP3-F	F	9.51	1.06	0.47	6	6.5- 12.5	2.15 ***
	M	11.66	1.26	3.71	6	8.5- 14.5	
MP3-FG	F	11.34	0.95	1.57	4	9.5- 13.5	2.35 ***
	M	13.69	1.00	2.95	5	11.3- 16.5	
MP3-G	F	12.42	1.02	3.08	4	10.5- 14.5	2.20 ***
	M	14.62	0.99	4.06	6	11.7- 17.5	
MP3-H	F	13.45	0.96	3.34	5	11.5- 16.3	2.10 ***
	M	15.55	1.07	2.43	4	13.5-(18.5)	
MP3-I	F	14.32	0.99	2.27	4	12.5- 16.7	1.97 ***
	M	16.29	1.02	2.93	4	14.5-(19.5)	
DP3-I	F	13.33	0.91	7.14	5	11.5- 16.5	2.28 ***
	M	15.61	1.06	2.33	4	13.5-(18.5)	
R-I	F	14.79	1.09	1.64	5	12.5- 17.5	1.75 ***
	M	16.54	0.95	6.21	4	14.5-(19.5)	
R-IJ	F	15.79	1.06	3.59	5	13.5-(18.5)	1.79 ***
	M	17.58	0.80	3.22	4	15.7-(20.5)	
R-J	F	16.73	1.19	7.50	5	14.5-(20.5)	1.28 ***
	M	18.01	0.92	3.02	4	16.5-(22.5)	
Pubertal development							
Menarche	F	13.08	1.11	2.98	6	10.7- 16.1	
Pubertal voice	M	13.90	0.95	2.49	5	11.5- 16.5	
Male voice	M	15.02	0.91	0.52	4	12.5- 17.5	

[a]No value of chi^2 is statistically significant ($p < 0.05$).
**$p < 0.01$; ***$p < 0.001$.

Pubertal development was assessed from 10 to 18 years by determining the occurrence of menarche in girls and the voice change in boys[25] (Table I).

Statistical analysis. Calculations have been performed on an IBM 3031 computer using the statistical analysis system of SAS (SAS Users Guide, 1979 edition).

Probit analysis[30] has been used to calculate mean values and standard deviations of age at attainment of the pubertal growth events and maturation indicators.

The age of a subject at the attainment of any pubertal growth event and specified maturation indicator was defined as the midpoint of the age interval during which

Table IV. Correlation coefficients between ages at occurrence of pubertal growth events and various dental emergence stages in girls (N = 78-80) and boys (N = 100-105)

Pubertal growth spurt	*Sex*	*Dental emergence stages*								
		DES 1	*DES 2*	*DES 3*	*DES 4*	*DES M1*	*DES M2*	*DES M3*	*DES M4*	*DES M5[a]*
ONSET	F	0.18	0.23*	0.33**	0.27*	0.25*	0.25*	0.30**	0.22*	0.13
	M	−0.07	−0.04	−0.05	0.12	0.08	0.16	0.04	0.10	0.15
PHV	F	0.23*	0.34**	0.29**	0.27*	0.27*	0.21	0.26*	0.23*	0.01
	M	−0.03	0.03	0.16	0.14	0.07	0.14	0.08	0.13	0.16
END	F	0.23*	0.28*	0.31**	0.35**	0.28*	0.26*	0.34**	0.31**	−0.23
	M	0.01	0.04	0.16	0.11	0.01	0.07	0.01	0.07	0.25

[a]Nineteen girls and twenty-six boys were included in the analysis of DES M5.
*p <0.05; **p <0.01.

Table V. Correlation coefficient between ages at occurrence of pubertal growth events and various skeletal stages in girls and boys

Pubertal spurt	*Sex*	*Skeletal stage*									
		S	*MP3-F*	*MP3-FG*	*MP3-G*	*MP3-H*	*MP3-I*	*DP3-I*	*R-I*	*R-IJ*	*R-J*
ONSET	G	0.56 (75)	0.30 (74)	0.61 (74)	0.61 (68)	0.60 (69)	0.64 (70)	0.70 (67)	0.60 (66)	0.56 (60)	0.55 (54)
	B	0.53 (88)	0.28 (85)	0.67 (85)	0.66 (87)	0.70 (77)	0.73 (83)	0.70 (78)	0.54 (69)	0.39 (56)	0.25 (45)
PHV	G	0.63 (75)	0.50 (73)	0.75 (74)	0.79 (68)	0.80 (69)	0.79 (70)	0.86 (67)	0.76 (66)	0.77 (60)	0.75 (54)
	B	0.73 (87)	0.41 (83)	0.81 (84)	0.83 (86)	0.85 (77)	0.87 (83)	0.85 (78)	0.74 (69)	0.55 (56)	0.38 (45)
END	G	0.69 (74)	0.50 (73)	0.76 (74)	0.79 (68)	0.81 (69)	0.74 (70)	0.83 (67)	0.81 (66)	0.82 (60)	0.73 (54)
	B	0.71 (86)	0.46 (83)	0.77 (83)	0.82 (86)	0.85 (77)	0.83 (83)	0.85 (76)	0.64 (69)	0.50 (56)	0.48 (45)

The number of subjects is included in the analysis is shown in parentheses.

Table VI. Correlation coefficients between ages at occurrence of pubertal growth events and various indicators of puberty in girls (N =79-80) and boys (N = 91-98)

Event	*Sex*	*Pubertal spurt*		
		ONSET	*PHV*	*END*
Menarche	F	0.60***	0.77***	0.76***
Pubertal voice	M	0.64***	0.82***	0.78***
Male voice	M	0.55***	0.73***	0.75***

***p < 0.001.

the change occurred. The individual ages were used in the correlation analyses ad modum Pearson.

The age distribution of the attainment of the maturation indicators in relation to the occurrence of the pubertal growth events was described as a cumulative percentage (Figs. 4 and 5). In the calculations of cumulative percentage the same principles that were used in the probit analysis were applied.

RESULTS

The pubertal growth spurt

There were large differences in the ages at the pubertal growth events between and within the sexes (Fig. 3). On average, the pubertal growth spurt began (ONSET) at 10.0 and 12.1 years and ended (END) at 14.8 and 17.1 years in girls and boys, respectively (Tables II and III). In both sexes peak height velocity (PHV) occurred 2 years after ONSET, that is, at 12.0 years in girls and 14.1 years in boys.

In both sexes the early maturers reached END before the late maturers had reached ONSET (Fig. 3). The earliest-maturing girl began the pubertal growth spurt and reached PHV about 6 years before the last-maturing girl and about 8 years before the last-maturing boy.

Dental development and the pubertal growth spurt

The association between the attainment of the dental emergence stages and the pubertal growth events was found to be statistically significant only in girls and was then only weak (Table IV).

The sex differences for ages at the pubertal growth events were larger than for the dental emergence stages (Tables II and III). The dental development was more advanced in boys than in girls at all three pubertal growth events (Fig. 4). Irrespective of sex, a subject could be in any of the dental emergence stages, DES 1-4 and DES M2-M4, at the beginning of the pubertal

growth spurt (ONSET). At peak height velocity (PHV) more than 90 percent of the boys but only about 60 percent of the girls were in DES 4 and DES M4. At the end of the pubertal growth spurt (END) all subjects but one girl were in DES 4. At END some boys (19 percent) and a few girls (3 percent) were in DES M5.

The dental emergence stages were not useful as indicators of the pubertal growth spurt, but the following findings may be of clinical interest (Fig. 4):

DES 2 was attained/passed by practically all subjects at ONSET.

DES 3 was attained/passed by all subjects at PHV.

DES 4 was attained before END by all boys, and at END by practically all girls.

DES M3 was attained/passed by practically all boys at PHV.

DES M4 was attained/passed by all boys before and by all girls at END.

DES M5 was not attained before END by any girl.

Skeletal development and the pubertal growth spurt

The association between the attainment of the skeletal stages and peak height velocity (PHV) and the end of the spurt (END) was closer than that between skeletal development and the beginning of the spurt (ONSET) in both sexes (Table V). The sex difference for the attainment of early-occurring skeletal stages was greater and for late-occurring skeletal stages less than that for the pubertal growth events (Tables II and III).

Skeletal development at ONSET and PHV was more advanced in girls than in boys, whereas at END the skeletal development was more advanced in boys (Fig. 5). At ONSET about 40 percent of the girls and 25 percent of the boys had an ossified ulnar sesamoid (S). At PHV about 90 percent of the subjects were in either stage MP3-FG or stage MP3-G. At END about 95 percent of the boys and 80 percent of the girls were in one of the three radius stages (R-I, R-IJ, and R-J).

The skeletal stages were useful as indicators of the pubertal growth spurt, and the following findings are of clinical interest (Fig. 5):

Sesamoid

S was usually (girls 86 percent, boys 92 percent) attained during the acceleration period of the pubertal growth spurt (ONSET-PHV). All subjects except one boy had an ossified sesamoid (S) at PHV. In 20 percent of the girls and in more than 30 percent of the boys S was attained in the same annual interval as PHV.

Middle third phalanx

MP3-F was attained before ONSET by about 40 percent of the subjects and at PHV by the last subjects.

MP3-FG was attained 1 year before or at PHV by about 90 percent of the subjects.

MP3-G was attained at or 1 year after PHV by about 90 percent of the subjects.

MP3-H was attained after PHV but before END by practically all boys and about 90 percent of the girls.

MP3-I was attained before or at END in all subjects except a few girls.

Distal third phalanx

DP3-I was attained during the deceleration period of the pubertal growth spurt (PHV-END) by all subjects. Two of the girls (3 percent) but none of the boys attained DP3-I at PHV.

Radius

R-I was attained 1 year before or at END by about 80 percent of the girls and about 90 percent of the boys

R-IJ and R-J were not attained before END by any subject.

Pubertal development and the pubertal growth spurt

The association between the indicators of pubertal development (menarche in girls and voice changes in boys) and the pubertal growth events was close in both sexes (Table VI). According to the mean ages (Tables II and III), menarche (M) occurred 1.1 years after peak height velocity (PHV). The pubertal voice (PV) was attained 0.2 years before PHV, and the male voice (MV) 0.9 years after PHV (Tables II and III).

One girl (1 percent) had a bleeding before PHV, but it was probably not a menstrual bleeding.[29] Accordingly, probably no girl had reached menarche before PHV. All girls had experienced menarche at the end of the pubertal growth spurt (END) (Fig. 4). Menarche occurred during the same age interval as PHV in 16 percent of the girls and in the same age interval as END in 5 percent of the girls (Fig. 4).

In practically all boys (99 percent) the complete change from prepubertal to male voice occurred during the pubertal growth spurt (ONSET-END). Only one boy developed a pubertal voice 1 year before the beginning of the spurt (ONSET), and he was one of three in whom a pubertal voice was registered at three consecutive examinations.[29] In more than 60 percent the pubertal voice was attained in the same age interval as PHV. Male voice was attained during the deceleration period of the spurt (PHV-END) in all boys but two (2 percent), who had a male voice before PHV.

At ONSET only a few boys had experienced a voice change (Fig. 4). About 85 percent of the boys had pubertal or male voice at PHV. All boys had a male voice at END.

DISCUSSION

A study of pubertal growth and maturation requires a representative sample of prepubertal subjects who are

followed to adulthood. This is mandatory in order to include both early and late maturers. Even if the observation period is sufficient, there is a great risk that the inevitable dropout, usually large and increasing with time, will bias the proportions of early, average, and late maturers included in the statistics. Moreover, the sample should be representative of the population in which the calculated reference values are to be used.

Previous reports on associations between various maturation indicators and pubertal growth are based on small numbers of subjects with adequate records. The subjects have been selected from a considerably larger sample, such as persons included in a growth study or a group of orthodontic patients. Even if the primary sample is selected at random, there is a risk that the dropout is not random. Owing to the sampling procedures, the representativeness of previous reports is uncertain.

The present sample is representative of a Swedish urban community.[20, 21] The dropouts are few, and their growth pattern did not differ from that of the total sample.[21] Owing to the few dropouts and the small number of missing examinations, the pubertal growth events and maturation indicators were determined in a very large proportion of the original sample.[22]

As shown by the ranges given for the pubertal growth events and the maturation indicators (Table III), both early and late maturers of both sexes were included. The bias in the statistics was reduced by means of information obtained from the dropouts, subjects with missing examinations, and subjects who had not attained a late-occurring maturation indicator at the last programmed examination.

The individual unsmoothed incremental curves of height were based on annual increments calculated between specified target ages.[21] It should be pointed out that height was recorded in millimeters, usually in the morning, by a trained examiner using the stretching-up technique.[23] Because of these measures, the obtained increments were reliable and valid; that is, the influence of measuring errors and fluctuations in height during the day was reduced, and the influence of seasonal variations in growth rate was eliminated.[31]

The individual unsmoothed incremental curves of height were analyzed by visual inspection, a method suitable for orthodontics.[3] The clinical use of individual curves of pubertal growth in height assumes that the individuals are examined before the beginning of the pubertal growth spurt and during a sufficiently long period of time. To obtain reliable estimate of pubertal growth often can only be made at PHV or after, because the acceleration period is too short and/or the increase in growth rate is too small to be clinically discernible in some individuals.[32]

This study showed a sex difference of 2 years in age at the beginning (ONSET), peak (PHV), and end (END) of the pubertal growth spurt (Fig. 4). Within each sex the range for each pubertal growth event was about 6 years. A similar range for age at PHV in both sexes has been reported in another Swedish study.[33] The early maturers of each sex have completed the pubertal growth spurt before the late maturers have begun the spurt. Accordingly, the timing of orthodontic treatment dependent upon on influenced by the change in growth rate during puberty cannot be planned solely on the basis of the patient's chronologic age.

In this study *dental development* was assessed by means of dental emergence stages (DES) (Table I), a simple grouping of emerged teeth which is suitable for treatment planning in orthodontics.

The association between the indicators of dental development and pubertal growth was weak in both sexes, which is in agreement with previous reports.[3, 10, 34] Consequently, indicators of dental development are not useful for evaluating pubertal growth in clinical orthodontics.

It is evident from the ranges for the dental emergence stages in relation to age at the pubertal growth events[27] (Fig. 4) that orthodontic treatment based solely on dental maturity will be carried out in periods of greatly varying growth rate in both sexes.

Skeletal development of the hand and wrist was assessed in four bones chosen according to Björk[3] (Fig. 5). A greater number of epiphyseal stages were used in this study in order to obtain indicators of shorter duration, which are more informative than those of long duration.[35] The reproducibility of the indicators was in general accord with the findings in other studies.[29]

Reliable indicators taken from skeletal development were found for the peak (PHV) and end (END) but not for the beginning (ONSET) of the pubertal growth spurt. This may be due to the fact that the estimation of ONSET is less reliable than that of PHV and END (Fig. 1). Furthermore, during the end of the prepubertal period the radiographic changes in form of the bones of the hand and wrist are small.[28] There is, therefore, a lack of indicators of skeletal development during this period, and the available indicators are of long duration.

The ossification of the ulnar sesamoid (S) was not a reliable indicator of the beginning of the pubertal growth in either sex. In this study some subjects of both sexes attained S before the beginning of the pubertal growth spurt (ONSET), while 20 percent of the girls and more than 30 percent of the boys did not attain S

until peak height velocity (PHV) (Fig. 6). It has been stated that S does not occur later than PHV.[3, 10, 12, 19] However, occasional individuals attain S just after PHV[14, 18, 29] (Table VI). In clinical context this means that if S is not attained, neither is PHV. If S is *just* attained, most individuals are in the acceleration period of the pubertal growth spurt.

According to Björk,[3] the pubertal growth spurt ends with the complete fusion of the third distal phalanx (DP3-I). Schouboe[19] reported that DP3-I in some girls coincided with PHV, which was also found in this study. In girls DP3-I is therefore not an absolute indicator that PHV has been passed.

In this study the beginning (ONSET) and the end (END) of the pubertal growth spurt were defined on the incremental curve in each subject.[26] Like PHV, these two growth events (ONSET and END) will represent approximately the same level of maturity of growth in all individuals. Since assessment of the skeletal development of the hand and wrist only permits reliable estimates of PHV and later growth events,[29] radiographs of the hand and wrist are of limited value before the earliest age at which PHV can occur, that is, at about 9.5 years in girls and 11.5 years in boys.

Pubertal development was assessed by means of indicators suitable in the orthodontic context—menarche in girls and voice change in boys. For obvious reasons, maturation indicators which require physical examination of secondary sex characters are not applicable in clinical orthodontics. In this study menarche and voice change were determined by a prospective method, which is the most reliable method. The reliability of voice assessment has been questioned.[36] However, it has been reported that boys are quite certain about the status of their voices when they were asked.[37] The findings in this study[25] support the view that the voice changes can be reliably assessed clinically.

Several investigators[10, 17, 19] have found that menarche never occurred before peak height velocity (PHV). In this study one girl had a bleeding before PHV,[25] and similar findings have been reported from another Swedish study.[16, 33] Furthermore, some girls, particularly those who are maturing much earlier or later than their peers, may deliberately give false answers when they are asked whether or not menarche has occurred. In clinical orthodontics it is not possible to verify data on menarche against other signs of puberty, since that would require a physical examination. Menarche is therefore a highly reliable but not an absolute indicator that PHV has been reached or passed. If menarche has not occurred, growth rate may be decreasing but has certainly not yet reached the level of the end of the pubertal growth spurt (END).

Boys experienced the complete change from prepubertal to male voice when they were in the pubertal growth spurt (Fig. 4). Consequently, the pubertal voice, which can last as little as a few months or as long as several years,[38] is a reliable indicator of the pubertal growth spurt. Pubertal voice was attained close to PHV, and male voice was attained at PHV or after. Consequently, a male voice indicates that the boy has attained or passed PHV.

In clinical work girls can thus be asked from the age of 10 years whether or not menarche has occurred, and in boys assessment of the voice can be done from the age of 11 years. The use of these indicators will reduce the need for radiographs of the hand and wrist.

The analysis in this study was based on age at attainment of the various maturation indicators, which requires serial data. In clinical work, however, evaluation of maturity must often be done from a single examination. Despite this, useful information on pubertal growth can be obtained by determining whether or not a certain maturation indicator has been attained (for example, S, ossification of the ulnar sesamoid). More information can be obtained if the maturation indicator is one of a series of discrete stages (for instance, MP3-F . . . MP3-I), especially if the indicators are of brief duration. In clinical work the individual will be assessed as being *within* a certain stage, which has been attained earlier. The maturation indicators of skeletal and pubertal development are of limited value for prediction of the pubertal growth, since those indicators that were closely related to the pubertal growth events occurred close in time or after the pubertal growth events.

The findings in this study[25–29] are in general agreement with other studies. The differences in some of the results toward the longitudinal studies were presumably due to differences in sampling procedures, methods of registration, and/or methods of statistical analysis rather than to population differences. In this study the analysis of pubertal growth and maturation was based on reliable and valid data obtained from a relatively large sample. The results given in this article are considered representative for Swedish children.

Orthodontic treatment based solely on dental maturity and/or chronologic age will be carried out in periods of highly varying growth rate in both sexes, owing to the wide variation in timing of the pubertal growth spurt. The use of longitudinal records of height requires that certain practical conditions be met. Despite this, it is often not possible to determine the period of maxi-

mum growth before it is reached or passed. Longitudinal or cross-sectional evaluation of maturity by means of pubertal development and of skeletal development of the hand and wrist will give reliable information as to whether or not a certain period of pubertal growth has been attained.

CONCLUSIONS

There was a 2-year sex difference in age at the beginning, peak, and end of the pubertal growth spurt. The individual variation was about 6 years at each growth event in both sexes.

Dental development, assessed by means of dental emergence stages, was not useful as an indicator of the pubertal growth spurt.

Dental development in relation to the pubertal growth spurt was more advanced in boys than in girls, but the individual variation was great in both sexes.

The peak and end, but not the beginning, of the pubertal growth spurt could be determined by means of indicators taken from the skeletal development of the hand and wrist and the pubertal development (menarche and voice change), which are suitable for use in clinical orthodontics.

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