Growth and Normal Puberty

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ABSTRACT. We reviewed the growth characteristics of American boys and girls from published studies, including age at takeoff, age at peak height velocity, peak height velocity, duration of puberty, and the magnitude of the pubertal contribution to adult height. Age at takeoff is highly variable and sex-dependent. The mean takeoff age in children growing at an average rate is ~11 years in boys and 9 years in girls, and peak height velocity occurs at a mean age of 13.5 years and 11.5 years, respectively, in these children. Whole-year peak height velocity is 9.5 cm/y in boys and 8.3 cm/y in girls, with slight variations in the different studies. The contribution of pubertal growth to final height is ~30 to 31 cm in boys, accounting for 17% to 18% of the final height, and 27.5 to 29 cm in girls, accounting for 17% of the final height. The magnitude of pubertal growth has a negative correlation with age at takeoff, but no correlation with final height. Age at takeoff, however, correlates highly with pubertal stage, but correlates negatively with duration of puberty. *Pediatrics* 1998;102:507–511; *puberty, growth, growth velocity, peak height velocity.*

ABBREVIATIONS. HES, Health Examination Survey; SD, standard deviation.

Puberty is a significant physiologic event in human growth and biologic maturation. It begins with the activation of the hypothalamic–pituitary–gonadal axis and ends with the attainment of reproductive capability and the acquisition of adult body composition and habitus.[1] The pubertal growth spurt and the appearance of secondary sex characteristics are the most visible manifestations of puberty. It is the lack of one or both of these that brings most teenagers to a pediatric endocrine clinic. Typically, pubertal growth consists of a phase of acceleration, followed by a phase of deceleration, and the eventual cessation of growth with the closure of epiphyses.

The pubertal growth characteristics that can be quantified and analyzed mathematically include age at takeoff (ie, the onset of growth acceleration), age at peak height velocity, peak height velocity, duration of puberty, and the contribution of the pubertal growth spurt to final adult height.

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METHODS

We reviewed three types of growth studies: longitudinal from birth to maturity, longitudinal during puberty, and cross-sectional.

The longitudinal growth studies that we reviewed included the Fels Research Institute studies, the Denver Child Research Council studies, the Harvard School of Public Health study, and the Guidance Study of the University of California at Berkeley.[2] Another longitudinal study, the Harvard Six-cities Study, was designed primarily to study the effects of indoor and outdoor pollution on the health of children.[3] During this study, height and weight measurements were obtained annually in children 6 to 17 years of age. A substantial number of children were enrolled in this study from six cities in the states of Kansas, Massachusetts, Minnesota, Missouri, Ohio, and Tennessee; these children were considered to be representative of the population of youth in the United States. The other longitudinal studies during puberty were those of Lee[4] and Biro et al.[5]

The US cross-sectional studies that we reviewed and used as the primary sources of the longitudinal and velocity growth charts in this article were the Health Examination Survey (HES) cycle II, which measured thousands of children 6 to 11 years of age, during the period 1963 to 1965; HES cycle III, which measured children 12 to 17 years of age, from 1966 to 1970; and Health and Nutrition Examination Survey I, which measured children 1 to 17 years of age, from 1971 to 1974.[6] The standard growth charts in this article were constructed from data from the last-named study, supplemented by data from HES cycles II and III. The velocity growth charts were constructed by Tanner and Davies[7] from data from cross-sectional studies of the National Center for Health Statistics reported by Hamill and associates.[6]

RESULTS

National Center for Health Statistics data from cross-sectional growth studies reported by Hamill and associates[6] that pertain to pubertal age for boys and girls are shown in Table 1. These data were used by Tanner and Davies to construct growth-velocity charts for US children.[7] Some of the pubertal growth data from the four US longitudinal studies, reported by Thissen and colleagues,[2] are summarized in Table 2. Pubertal growth data from the Harvard Six-cities Study, reported by Berkey and coworkers,[3] are presented in Table 3 along with data from the Harpenden longitudinal growth study.[8] The median values for height and whole-year height velocities in boys and girls 7 to 18 years of age are shown in Table 4, from the Harvard Six-cities Study,[3] and in Table 5, from Tanner and Davies.[7] Growth-velocity curves for US children are shown in Fig 1.

DISCUSSION

The pubertal growth characteristics evaluated in various studies include age at takeoff, height at takeoff, age at peak height velocity, peak height velocity, duration of puberty, and the contribution of the pubertal height gain to final height.

Age at takeoff is sex-dependent and also quite variable even in the same sex. In general, the age at takeoff is 2 years younger in girls. The age at takeoff could not be determined for the girls in HES cycle III, which examined youths 12 to 17 years of age, because of the cross-sectional nature of the study and

the fact that many of the girls already were in puberty.[9] However, the mean ages at various stages of puberty in the boys in this study[10] were similar to the mean ages reported by Tanner and Whitehouse in British children.[11] In HES cycle III, there was no difference in various stages of pubertal development between black boys and white boys.[10] Black girls, however, were consistently more advanced in pubertal stage than were white girls.[9] The ages at takeoff in the white boys (10.45 ± 1.47 years) and the white girls (9.25 ± 1.15 years) in the Harvard Six-cities Study were ~1.5 years (boys) and 1 year (girls) less than those in the British children in the Harpenden study, all of whom were white (Table 3). It should be noted that the data in Table 3 do not include data on black children. In the Harvard Six-cities Study, as in HES cycle III, there was a significant difference between black girls and white girls at every stage of pubertal development.[3]

The age at peak height velocity was ~13 years in boys and 11 years in girls in the four US longitudinal studies.[2] The boys and girls in the Harvard Six-cities Study were 0.5 year older at takeoff than the boys and girls in the four US longitudinal studies, but 0.5 year younger than those in the Harpenden study (Table 4). The standard deviation (SD) for age at peak height velocity is slightly less than 1 year. In boys maturing 2 SD units early

TABLE 1. Heights of US Boys and Girls

Age (y)	Height (cm)			
	Boys		Girls	
	Mean	Median	Mean	Median
9	131.6	133.8	133.2	133.2
10	138.8	139.3	138.5	139.2
11	143.4	143.8	144.0	143.7
12	149.9	149.4	151.9	152.0
13	154.2	154.5	157.1	157.6
14	164.2	165.2	159.1	159.5
15	167.8	168.7	161.5	160.0
16	173.2	173.3	163.8	164.9
17	176.8	177.3	161.4	160.5
18	177.0	176.2	—	—

Data from Hamill et al.[6]

TABLE 4. Fiftieth Percentile Values for Heights and Whole-year Height Velocities in White Boys and Girls With Peak Height Velocities at Typical Age (13 and 11 Years, Respectively)

Age (y)	Boys		Girls	
	Height (cm)	Height Velocity (cm/y)	Height (cm)	Height Velocity (cm/y)
7	122		121	
		5.89		5.80
8	128		126	
		5.62		5.67
9	133		132	
		5.32		5.69
10	139		138	
		5.09		6.04
11	144		144	
		5.32		8.09
12	149		152	
		6.74		5.51
13	156		158	
		9.56		2.85
14	166		161	
		6.21		1.07
15	172		162	
		2.97		0.91
16	175		163	
		1.11		0
17	176		163	
		0.95		0
18	177		163	

Data from Berkey et al.[3]

TABLE 2. Pubertal Growth Characteristics in Four US Longitudinal Studies

	University of California at Berkeley	Denver Child Research Council	Fels Research Institute	Harvard School of Public Health
Girls				
Age at peak height velocity (y)	11.01 (0.83)	11.01 (0.91)	10.96 (0.80)	11.13 (0.87)
Height at takeoff (cm)	141.79 (7.60)	137.25 (6.64)	138.57 (7.44)	140.33 (7.19)
Adult height (cm)	168.12 (6.23)	168.23 (6.69)	168.02 (5.15)	165.75 (5.07)
Pubertal gain (cm)	26.33 (5.69)	30.98 (4.04)	29.45 (6.80)	25.43 (5.64)
Boys				
Age at peak height velocity (y)	13.06 (1.08)	13.31 (1.08)	12.99 (0.93)	12.90 (0.94)
Height at takeoff (cm)	150.60 (6.98)	149.42 (7.14)	149.95 (7.03)	147.39 (5.72)
Adult height (cm)	180.74 (6.58)	180.40 (5.41)	180.85 (5.79)	175.56 (6.11)
Pubertal gain (cm)	30.14 (5.43)	30.98 (4.66)	30.90 (4.34)	28.17 (5.51)

Values are mean (SD).
Data from Thissen et al.[2]

TABLE 3. Pubertal Growth Characteristics for European, White American, and British Children

	Boys		Girls	
	American	European and British	American	European and British
Age at takeoff (y)	10.45 (1.47)	12.05 (0.85)	9.25 (1.15)	10.30 (0.95)
Height at takeoff (cm)	144.00 (—)	146.09 (6.33)	138.00 (—)	137.91 (7.02)
Age at peak height velocity (y)	13.57 (1.11)	13.91 (0.84)	11.49 (1.17)	11.89 (0.90)
Peak height velocity (cm/y)	9.49 (1.44)	8.80 (1.05)	8.14 (1.25)	8.13 (0.78)
Final adult height (cm)	177.00 (—)	173.64 (6.11)	163.00 (—)	163.16 (5.94)
Puberal height gain (cm)	33.00 (—)	27.56 (3.54)	25.00 (—)	25.25 (4.14)

Data are mean (SD). Data from Berkey et al[3] (American) and Tanner and Whitehouse[8] (European and British).

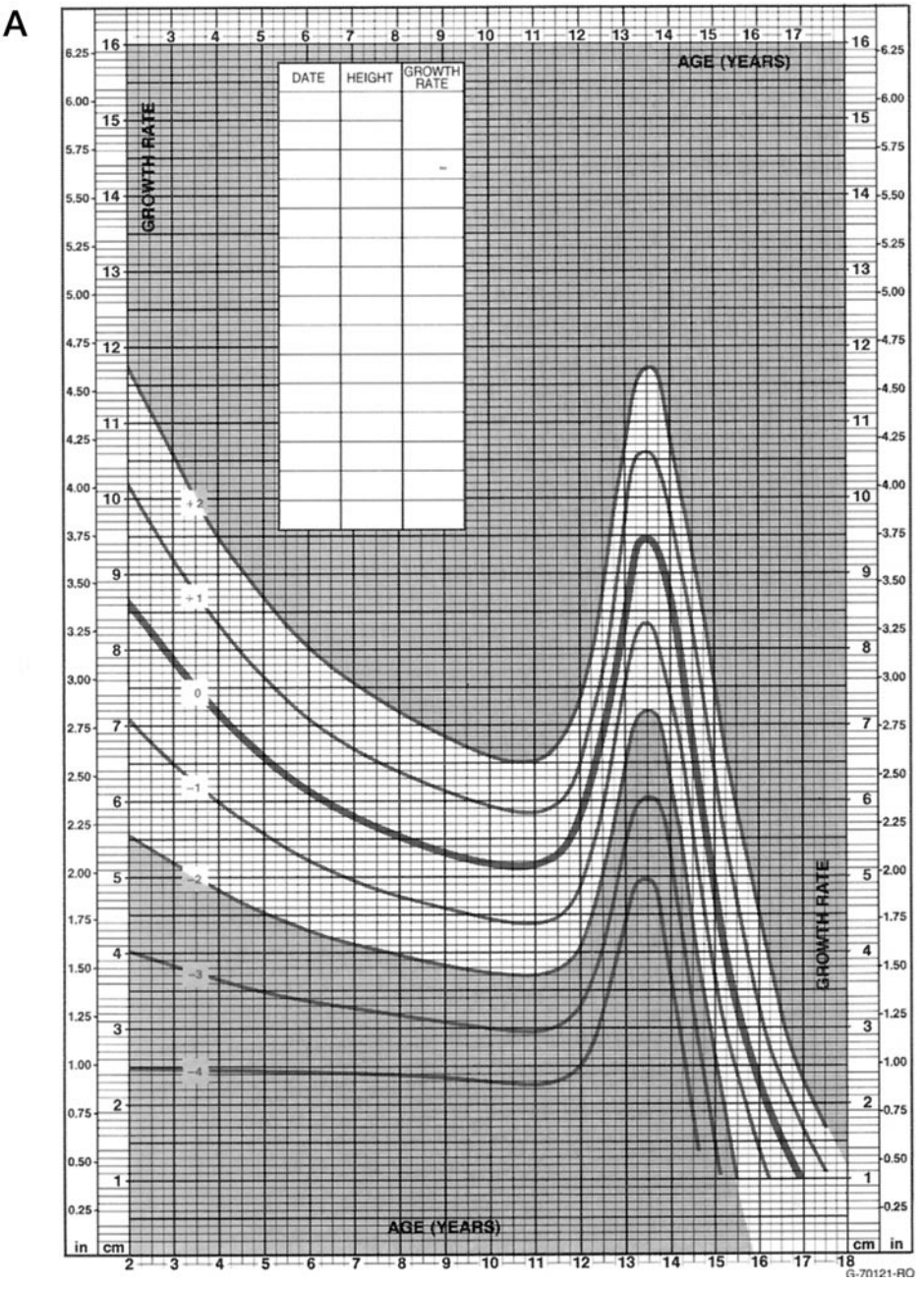

Fig 1. Mean and SD height velocities in boys 2 to 18 years of age (A) and girls 2 to 15 years of age (B). Data from Tanner and Davies.[7]

and 2 SD units late, the age at takeoff ranges from 11.7 to 15.3 years. The corresponding range in girls is 9.7 to 13.3 years.[1]

Peak height velocity is both age- and sex-dependent. It occurs earlier in girls, between Tanner breast stages 2 and 3, and later in boys, between Tanner testis stages 3 and 4. The peak height velocity in average-growing boys with an average age of maturity is 9.5 cm/y and in girls is 8.3 cm/y. The peak height velocity in American boys is 0.7 cm/y greater than that in their British counterparts; there is no difference between American and British girls in peak height velocity. The peak height velocity is highest in early-maturing children and lowest in late-maturing children.[7]

The duration of puberty is quite variable, owing to considerable variation in the onset of puberty. According to Marshall and Tanner, however, this variation does not reach statistical significance.[12,13] In other words, early maturers do not pass through the pubertal stages more rapidly than late maturers. In addition, final height is not affected.[14] In US cross-sectional studies, boys with a mean takeoff age of 11 years reached their final heights by 17 years of age, and girls with a mean takeoff age of 9 years reached their final heights by 14 years of age.[6] The difference in the age at the onset of puberty, which provides boys with two additional years of prepubertal growth, accounts for the greater final height of boys (by 10 to 12 cm).

The magnitude of the pubertal contribution to final adult height is remarkably similar in the four US longitudinal studies (Table 2). The boys in the Harvard School of Public Health study were the shortest

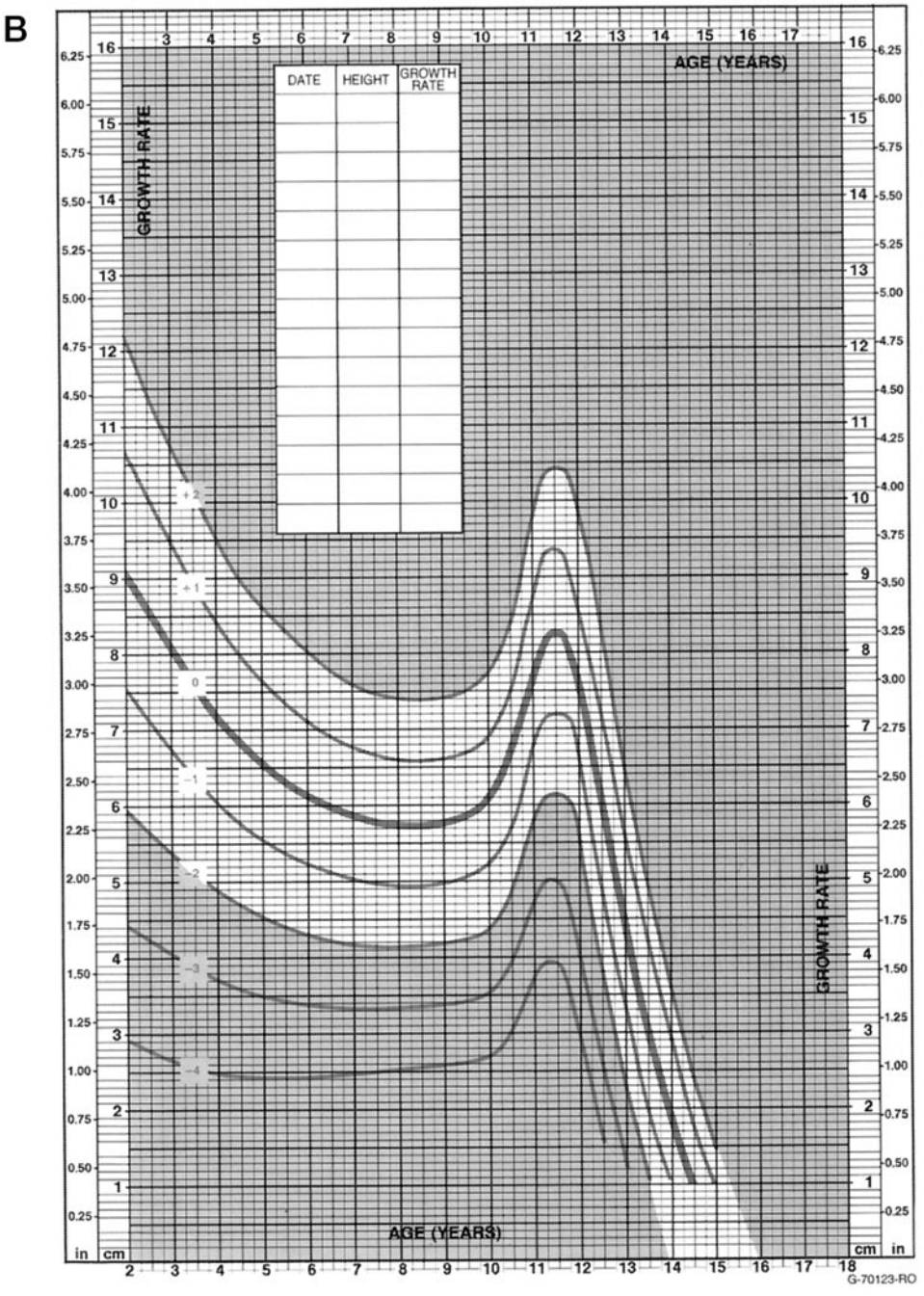

Fig 1. Continued.

as adults; however, their pubertal height gain was slightly greater. The girls in this study were shorter at takeoff by 1 cm and had a pubertal height gain of ~1 cm less than that of the girls in the Guidance Study of the University of California at Berkeley and 4.5 cm less than that of the girls in the Fels Research Institute and Denver Child Research studies. The greatest pubertal height gain in boys in all the studies reviewed here was in the Harvard Six-cities Study (33 cm); in the girls in this study, however, the gain was the lowest (25 cm). The final heights of both the boys and the girls in the Harvard Six-cities Study were less than those in the four US longitudinal studies.

In the Harpenden study, there was a significant correlation between the age at takeoff and the age at Tanner testis stage 2 or breast stage 2 and pubic hair stage 2.[8] The age at peak height velocity also correlated significantly with the age at these stages. There was no correlation between takeoff height or adult height and the pubertal height gain. There was a significant negative correlation between age at takeoff and pubertal height gain.

Pubertal growth, because of its distinct features, must be analyzed differently from prepubertal growth. Cross-sectional studies of the National Center for Health Statistics, the source of the standard growth charts, do not provide relevant information for growth during puberty. As constructed, the percentile curves in these growth charts are useful for evaluating cumulative height or attained height at a given age in the child who is being

TABLE 5. Fiftieth Percentile Values for Heights and Whole-year Height Velocities in Boys and Girls with Peak Height Velocities at Average Age (13.5 and 11.5 Years, Respectively)

Age (y)	Boys		Girls	
	Height (cm)	Height Velocity (cm/y)	Height (cm)	Height Velocity (cm/y)
7	121.9		121.5	
		5.8		5.9
8	127.7		127.4	
		5.4		5.7
9	133.1		133.1	
		5.2		5.8
10	138.3		138.9	
		5.1		6.7
11	143.4		145.6	
		5.3		8.3
12	148.7		153.9	
		6.8		5.9
13	155.5		159.8	
		9.5		3.0
14	165.0		162.8	
		6.5		0.9
15	171.5		163.7	
		3.3		0.1
16	174.8		163.8	
		1.5		
17	176.3			
		0.5		
18	176.8			

Data from Tanner and Davies.[7]

examined. The dynamics of pubertal growth are best represented by height-velocity charts rather than by standard charts. Longitudinal, rather than cross-sectional, growth data are necessary for constructing height-velocity charts. Lacking such longitudinal growth data, Tanner and Davies[7] used cross-sectional data reported by Hamill and associates[6] as well as data from various European studies to construct growth-velocity charts for American boys and girls (Fig 1). These data also are presented in Table 5 and may be compared with corresponding data from the Harvard Six-cities Study presented in Table 4. The data from both sources, in particular the whole-year height velocities, are almost identical, for boys and girls alike. Therefore, these growth charts are suitable for current use.

Clinical use of these growth-velocity charts requires calculating the child's growth velocity and knowing his or her pubertal status. In calculating growth velocity, the increment between two measurements should be not <0.85 year and not >1.15 years. Velocities calculated over shorter periods can reflect only seasonal effects.

SUMMARY

Normal pubertal growth is characterized by acceleration, deceleration, and cessation. The age at takeoff (acceleration) is highly variable and sex-dependent, occurring at a mean age of 11 years in boys and 9 years in girls. A racial difference exists between black girls and white girls. Peak height velocity occurs at a mean age of 13.5 years in boys and 11.5 years in girls.

Peak height velocity is ~9.5 cm/y in boys and 8.3 cm/y in girls. Pubertal height gain averages 31 cm in boys and 29 cm in girls. Age at takeoff has a negative correlation with pubertal height gain, but no correlation with final adult height. There is no correlation between peak height velocity and final height or the magnitude of the pubertal height gain and final height.

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