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.

P uberty 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. 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.
the fact that many of the girls already were in puberty. However, the mean ages at various stages of puberty in the boys in this study were similar to the mean ages reported by Tanner and Whitehouse in British children. In HES cycle III, there was no difference in various stages of pubertal development between black boys and white boys. Black girls, however, were consistently more advanced in pubertal stage than were white girls. 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.

The age at peak height velocity was ~13 years in boys and 11 years in girls in the four US longitudinal studies. 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...
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.8 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.
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. 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
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 used cross-sectional data reported by Hamill and associates 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 take-off (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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# Growth and Normal Puberty

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*Pediatrics* 1998;102:507

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