

## Pubertal Development in Girls

### Variability and Interrelationships<sup>1</sup>

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**Key Words.** Somatic development · Puberty · Girls · Secondary sex characteristics · Menstrual cycles · Adolescent growth spurt · Bone age

**Abstract.** Concerns about somatic disturbances of pubertal development are most frequently due to the large variability in normal growth and development patterns which occur during this age period. This article provides data on the normal variation of the following aspects of pubertal development: secondary sex characteristics, height growth, and menstrual cycles. In addition, clinically relevant interrelationships between the appearance of pubertal signs, height growth and bone age are discussed. The data presented are based on the First Zurich Longitudinal Study.

### Introduction

Concerns raised by adolescents and their parents about deviant somatic development during puberty are rarely due to pathologic conditions. They usually arise as a result of the wide variation in pubertal development. The onset of pubic hair development in an 8-year-old girl might be due to an endocrinological disorder such as *pubertas praecox*, and the absence of menarche in a 16-year-old girl might be caused by a Turner's syndrome. However, it is much more likely that both children represent extremes of the normal spectrum of variation of pubertal development. Knowledge about the variability of pubertal development is therefore a prerequisite for the provision of comprehensive care to the adolescent.

During the last 30 years the various aspects of somatic development during puberty have been investigated extensively. First, the onset of secondary sex characteris-

tics was described [6, 25, 28]. Pubic hair and breast development were investigated in detail, while less attention was paid to other pubertal signs such as the appearance of axillary hair, acne and striae [3, 22]. More recently, height growth during puberty has been studied, and the temporal relationships between the appearance of secondary sex characters, adolescent growth spurt and bone age have been analyzed [3, 14, 15, 18, 26].

A number of studies of the development and variability of menstrual patterns have been carried out during the past 4 decades. However, there are only a few prospective longitudinal surveys describing the individual variability of menstrual cycles [2, 7, 8, 11-13].

In this article the following aspects of pubertal development will be addressed: pubertal characteristics; menstrual cycles; height growth, and bone maturation. Based on the First Zurich Longitudinal Study and the literature, the course and variations of pubertal development will be described and a number of clinically relevant interrelationships between the development of pubertal characteristics, height growth and bone age will be discussed.

<sup>1</sup> This article was partially supported by the Swiss National Science Foundation No. 3988-0.84.

**Method**

Data on growth and development were collected from 283 Swiss children as part of the First Zurich Longitudinal Study (1954–1980). The study was coordinated with four other European longitudinal studies (Brussels, London, Paris and Stockholm) and two African studies (Dakar and Kampala) by the International Children’s Center in Paris [6].

This article comprises data on pubertal development in 142 girls between the ages of 8 and 18 years. During this period approximately 90% of the maximum number of possible examinations were carried out. The children were seen annually at the time of their birthdays ± 14 days up to the age of 9 years. Thereafter, they were examined every 6 months within the same time limits until their annual increment in height was less than 0.5 cm/year. Then they were again seen annually and were discharged when their height increment had become less than 0.5 cm in 2 years. Thus, all girls were seen every 6 months up to the age of 14 and 36% up to the age of 18. None of the girls was discharged before 18 years of age.

Height was measured according to the direction of the CIE [6], using gentle upward pressure under the mastoid process. After the age of 8 years all measurements were taken by the same trained anthropometrist (Miss M. Willisegger).

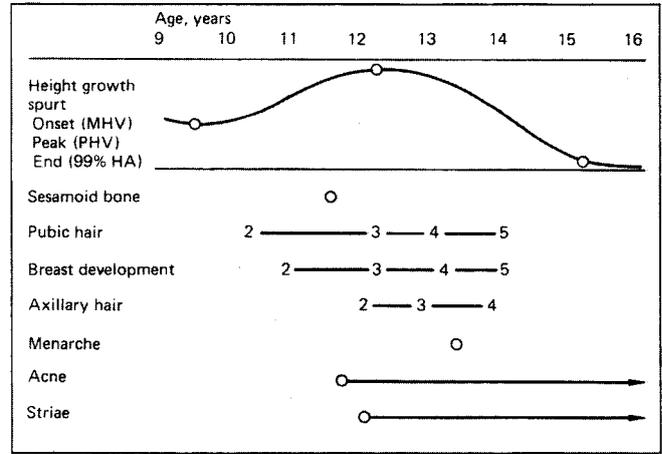
Breast and pubic hair development in all children was rated using the visual inspection method of Tanner [25], by the anthropometrist. The stages of breast development were as follows: stage 1, pre-adolescent, elevation of papilla only; stage 2, breast bud stage, elevation of breast and papilla as a small mound, enlargement of areola diameter; stage 3, further enlargement of breast and areola, with no separation of their contours; stage 4, projection of areola and papilla to form a secondary mound above the level of the breast, and stage 5, mature stage, projection of papilla only, due to recession of the areola to the general contour of the breast.

The pubic hair stages were as follows: stage 1, pre-adolescent, the vellus over the pubes is not developed further than that over the anterior abdominal wall, i.e. no pubic hair; stage 2, sparse growth of long, slightly pigmented, downy hair, straight or only slightly curled, appearing chiefly along the labia; stage 3, considerably darker, coarser and more curled, the hair spreads sparsely over the junction of the pubes; stage 4, hair is now adult in type, but the area covered by it is still considerably smaller than in most adults, there is no spread to the medial surface of the thighs; stage 5, the hair is adult in quantity and type, distributed as an inverse triangle of the classically feminine pattern, spread is to the medial surface of the thighs, and stage 6, spreading of pubic hair up the linea alba or elsewhere above the base of the inverse triangle.

The age at menarche and the subsequent durations of menstrual cycles were recorded by the girls on specially designed calendars given to them during their half-yearly visits. A detailed explanation of how to fill out the calendar was given to the girls, and the importance of keeping accurate records was emphasized. Reliable information as to the exact date of menarche was obtained for 128 of the 142 girls. Bone age was assessed according to Greulich and Pyle [10].

*Definitions and Terminology*

The abbreviations B, PH and AH are used to represent breast, pubic hair and axillary hair stages, respectively. M stands for menarche, and PHV for peak height velocity, the peak height of the adolescent growth spurt. Abbreviations such as B2 or PH3 represent



**Fig. 1.** Mean course of somatic development during puberty in girls. MHV = Mean height velocity; PHV = peak height velocity; HA = height adult.

the age at which the change from one pubertal stage to the next one took place, i.e. the age at which the child passed from B1 to B2, or from PH2 to PH3. Abbreviations such as PH2-M are used to represent the interval between the occurrence of PH2 and that of M.

*Statistical Methods*

Means and standard deviations of the ages at which the various pubertal stages were reached were calculated by the statistical method of Swan [24]. For estimations of the lengths of intervals, interrelationships and correlations between pubertal stages, only data from a 6-month period were used. The age of PHV was estimated from the individual height velocity curves smoothed by spline functions [14].

**Results and Discussion**

*Developmental Course*

The mean course of somatic development during puberty is illustrated in figure 1, and the ages at which each pubertal stage was reached are given in table I. In our longitudinal study, the pubertal growth spurt started at a mean age of 9.6 years, and reached its peak 2.6 years later, namely at 12.2 years. 99% of the adult height was attained at a mean age of 15.25 years. The sesamoid bone appeared in the hand X-ray at the age of 11.5 years, preceding the peak of the pubertal growth spurt in the large majority of the girls. Thus, the absence of the sesamoid bone indicates that maximum height growth is not yet reached.

Pubic hair development began at a mean age of 10.4 years (PH2) succeeded by the onset of breast development (B2: 10.9 years) and of axillary hair development (AH2: 12.0 years). While the onset of development of

these three secondary sex characteristics differed by 1.5 years, they were completed at about the same mean age, of 13.9–14.0 years [15]. A male pubic hair pattern (PH6), i.e. spreading of pubic hair above the base of the inverse triangle of the typical female pubic hair pattern, was seen in 16% of the girls at the age of 18. At this age axillary hair development was complete in all girls (AH4).

Initiation and completion of pubic hair development and completion of breast development occurred in our study at earlier ages than those reported by most previous authors – see review articles by Malina [17] and Marshall [20]. However, breast development started at a relatively late age in our study. These differences are probably due to the different rating procedures employed, e.g. Marshall and Tanner [18] assessed the pubertal stages from photographs while in our study this was done by visual inspection. Another reason for the discrepancies might be that in our study the time period between two consecutive examinations was 6 months, whereas in other studies, such as the Harpenden study [18] and the Swedish longitudinal study [26], the children were seen every 3 months.

The mean age of menarche was 13.4 years which is in good agreement with that found in other European studies: England 13.5 years [2]; Netherlands 13.4 years [28], and France and Sweden 13.0 years [23, 26]. In the United States Macmahon [16] reported lower menarcheal ages of 12.5 years (European origin) and 12.8 years (African origin). In our study menarche occurred in all girls shortly after they reached their adolescent growth spurt peak. This finding is of some clinical relevance as it indicates that once menarche occurred the period of maximum height growth had passed.

Acne was first seen at the age of 11.5 years; its frequency increased steadily up to 15 years and decreased thereafter. 81% of the girls had acne of various degrees and durations between the ages of 11 and 18 years. Striae of the hips were first observed in 12-year-old girls. By 18 years, striae had been noted in 41% of the girls.

#### *Variation of Pubertal Development*

Tables I and II indicate the large variations that were observed in all the studied aspects of pubertal development. The standard deviations varied between 0.9 and 1.3 years, the ranges by 5 and 6.7 years. Pubic hair and breast development occurred in some girls as early as at the age of 8–9 years, while in others they did not occur before the age of 14 years. They were completed in some girls by 11–12 years, while in others not until the age of

18. Menarche occurred at the earliest at 10.1 years and at the latest at 16.8 years.

Not only the timing of pubic hair and breast development but also their duration varied considerably (table II), ranging from less than 1 year up to 6. In our study the duration of pubic hair development and that of breast development were statistically independent of each other [15]. The mean intervals between the initiation of pubic hair development and that of breast development, and menarche were 2.7 and 2.2 years, respectively. In some girls, however, menarche occurred within a year after the onset of pubic hair and/or breast development, while in others up to 6.5 years passed before menarche occurred.

Figure 2 demonstrates that not only does the age at which the pubertal growth spurt occurs vary, but also there is considerable variation in the duration and height of the peak, i.e. the increase in height velocity during the growth spurt. Peak height may be as small as 0.7 cm/year or as large as 5.6 cm/year. In about one third of the girls peak height was less than 2 cm/year. Such a small expression of the growth spurt cannot be detected clinically [14].

According to figure 1, pubic hair development is the first pubertal sign noted, followed by breast and then axillary hair development. However, this sequence also showed considerable variability in our study. In 53% of the girls, the first pubertal sign was the appearance of pubic hair; in 29%, pubic hair and breast development occurred simultaneously, and in 18%, breast development was noted first (table III). These findings are in contradiction with those of Taranger et al. [26], who reported B2 in 45% of the girls and B2 plus PH2 in a further 47%, as the first pubertal signs. These differences again might be due to different rating procedures and examination intervals. The observation that the onset of breast development is detected considerably earlier by palpation than by visual inspection can be of some help clinically [13]. In none of our girls was axillary hair development or menarche noted as the first pubertal sign.

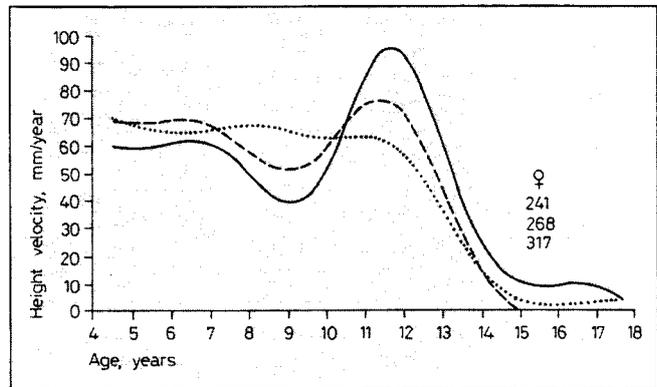
With the exception of B4, omission of stages was observed in only a small percentage of the children. Breast stage 4 was absent in 33% of the girls, indicating that B4 is a more transitory stage than the other breast stages. This is further supported by the fact that reversion from B5 to B4 was occasionally seen.

As a result of the substantial variation in the timing and duration of pubertal development, the majority of the girls are in an intermediate phase in their pubertal

development between the ages of 12 and 14 years. Some of them have already completed their development, while a few have not even started it. It is quite conceivable that such large developmental differences can lead to considerable psychological and social pressure within families, at school, and particularly within peer groups.

*Interrelationships*

In spite of these marked variations, there are still some relationships between height growth, pubertal characteristics and bone maturation, which are of clinical significance. Tables IV and V illustrate that, for a given stage of a pubertal sign, at least 70% of the girls are within two successive stages of any other pubertal sign.



**Fig. 2.** Variability of the pubertal growth spurt demonstrated by 3 individual height velocity curves.

**Table I.** Mean ages at which each stage of puberty was reached (years)

	Mean	SD	Range
<b>Pubertal growth spurt</b>			
Onset	9.6	1.2	6.6–12.9
Age at peak height velocity	12.2	1.0	9.3–15.0
End (99%) HA	15.25	1.1	12.4–18.0
<b>Pubic hair stage</b>			
PH2	10.4	1.2	8.5–14.0
PH3	12.2	1.2	9.5–15.0
PH4	13.0	1.1	10.0–16.0
PH5	14.0	1.3	11.5–17.5
<b>Breast stage</b>			
B2	10.9	1.2	8.0–14.5
B3	12.2	1.2	9.0–15.5
B4	13.2	0.9	10.0–15.5
B5	14.0	1.2	12.0–18.0
<b>Menarche</b>	13.4	1.1	10.1–16.8

HA = Height adult.

**Table II.** Length of intervals between breast and pubic hair stages and menarche (years)

	Mean	SD	Range
<b>Pubic hair development</b>			
PH2–5	3.6	1.1	1.0–6.5
PH2–M	2.7	1.1	0.5–4.9
<b>Breast development</b>			
B2–5	3.2	1.4	0.5–6.5
B2–M	2.2	1.1	0.5–6.5

**Table III.** First apparent secondary sex characteristics

	%
Pubic hair	53
Pubic hair and breast development	29
Breast development	18
Menarche, breast development, pubic hair and/or axillary hair	0

**Table IV.** Percentage of girls in each stage of breast development on reaching each stage of pubic hair development

Pubic hair stage	Breast stage				
	B1	B2	B3	B4	B5
PH2	49	46	5		
PH3		36	51	12	1
PH4		4	47	33	16
PH5		1	6	34	59

**Table V.** Percentage of girls in each stage of pubic hair development on reaching each stage of axillary hair development

Axillary hair stage	Pubic hair stage				
	PH1	PH2	PH3	PH4	PH5
AH1	100	81	28	3	
AH2		17	43	25	1
AH3		2	26	42	7
AH4			3	30	92

**Table VI.** Percentage of girls with acne in each stage of breast development

Acne	Breast stage				
	B1	B2	B3	B4	B5
1	100	99	86	66	52
2		1	8	19	28
3			6	15	20

**Table VII.** Distribution of stages of pubic hair and breast development at the age of peak height velocity (%)

	Stage				
	1	2	3	4	5
Pubic hair	4	37	49	10	
Breast development	5	43	47	2	3

Thus, 95% of the girls were in B1 or B2 when they reached PH2; 81% were in PH3 or PH4 at the onset of axillary hair development. The completion of pubic hair and axillary hair development occurred simultaneously in more than 90% of the girls. There was no occurrence of acne prior to stages 4 and 5 of breast development in the majority of the girls (table VI). Most girls reached their pubertal growth spurt peak while they were in stages 2 and 3 of pubic hair and breast development (table VII). When the girls reached menarche, 20–30% of them were in stage 3 of pubic hair and breast development, 40% in stage 4 and another 20–30% in stage 5 (table VIII).

For very short and very tall girls, it might be of prognostic value to know approximately, the percentage of adult height obtained when pubic hair and breast development are first observed. In our study, at the ages when pubic hair and breast development were initiated, the girls had attained 85.1 and 87.2% of their final adult height, respectively (table IX). Thus leaving mean values of remaining height growth of 24.5 and 21.1 cm, respectively. It has to be emphasized that the standard deviations of these values are again of considerable magnitude.

It is a common clinical assumption that bone age allows a more precise prediction of menarche than does chronological age, and indeed the standard deviations in tables I and X do indicate a closer relationship between

**Table VIII.** Distribution of stages of pubic hair and breast development at menarche (%)

	Stages				
	1	2	3	4	5
Pubic hair	0	3	20	46	31
Breast development	0	5	31	40	24

**Table IX.** Remaining height growth at the onset of pubic hair and breast development

	PH2		B2	
	Mean	SD	Mean	SD
Adult height reached, %	85.1	3.0	87.2	2.9
Remaining growth, cm	24.5	5.1	21.1	5.0

menarche and bone age (SD 0.7 years) than between menarche and chronological age (1.1 years). Menarche occurred in 90% of the girls at a bone age of between 12.5 and 14.5 years. However, the observation that menarche might occur at a bone age as early as 11 and as late as 16 years, clearly indicates that this relationship is also only of limited clinical relevance. According to Marshall and Limongi [19] bone age is only of value for children with severe developmental disorders, but not for healthy children. In order to predict the onset of menarche more precisely, these authors developed a method based on both chronological and bone age.

Frisch and Revelle [9] postulated a close relationship between the occurrence of menarche and body weight, which aroused considerable attention among clinicians. According to them, menarche occurs when a body weight of 48 kg is obtained. In our study the corresponding mean value was 45.5 kg (table X). It ought to be emphasized that, in our study as well as in the study of Frisch and Revelle [9] weight at menarche varied considerably, amongst our girls between 33.3 and 72.5 kg.

How much height growth remains to be completed at menarche? In our study the average height at menarche was 156.9 cm, corresponding to 95.3% of final adult height, the mean remaining height growth being 7.8 cm. The interindividual variability of this relationship was again considerable. Some of our girls had reached less than 90% of their final adult height at menarche, un-

**Table X.** Bone age, weight, height and remaining growth at the age of peak height velocity

	Mean	SD	Range
Bone age, years	13.2	0.7	11.0–16.0
Weight, kg	45.5	6.8	33.3–72.5
Height, cm	156.9	6.3	142.0–170.0
Adult height reached, %	95.3	1.7	89.3–99.2
Remaining height growth, cm	7.8	2.8	1.4–18.0

**Table XI.** Length of menstrual cycles (%) and frequency of ovulatory cycles (%) as a function of gynecological age [8]

	Gynecological age, years					
	0	1	2	3	4	5
Length of menstrual cycle						
< 21 days	7	4	4	3	3	3
21–35 days	70	76	77	81	81	88
> 35 days	23	19	19	15	16	9
Frequency of ovulatory cycles <sup>1</sup>	14	38	50	48	64	87

<sup>1</sup> Serum progesterone > 2 ng/ml (20–23 days) [1].

dergoing an additional height growth of up to 18 cm, whereas a few had already attained up to 99.2% of their adult height at this stage, their remaining height growth being as little as 1.4 cm. The accuracy of the prediction can be improved by taking bone age into account.

Irregularities of the menstrual cycles during the first post-menarcheal years are frequent causes of concern among adolescent girls and their parents. In the first year after menarche, 70% of all menstrual cycles were noted as being of 21–35 days duration (table XI). 23% of the cycles were longer than 35 days, and 7% shorter than 21 days. In agreement with Chiazzie et al. [4], Dewhurst et al. [5], Kantero and Widholm [11, 12], Matsumoto et al. [21] and Treolar et al. [27], we observed a continuous decrease in the number of very long and very short cycles with rising gynecological age [7]. In the fifth gynecological year 88% of the menstrual cycles were of 21–35 days duration, while the frequency of very short and very long cycles declined to 3 and 9%, respectively. According to Apter and Vikko [1], this regulation of the menses cycle is accompanied by an increase in the occurrence of ovulatory cycles. Only in 14% of the children were ovulatory cycles noted by these authors during the first gynecolog-

ical year. The frequency of ovulatory cycles increased to 50% by the end of the second, and to 87% by the fifth gynecological year.

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Received: May 26, 1987

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