Timing of Pubertal Onset in Girls: Evidence for Non-Gaussian Distribution

Anastasios Papadimitriou, Soula Pantsiotou, Konstandinos Douros, Dimitrios T. Papadimitriou, Polyxeni Nicolaidou, and Andreas Fretzayas

Third Department of Pediatrics, University of Athens School of Medicine, Attikon University Hospital, 124 64 Athens, Greece

Context: The timing of the onset of puberty is considered to approximate a normal distribution. However, because many more girls present with early than late puberty, we hypothesized that the distribution of the timing of the onset of puberty in girls might have changed.

Objective/Subjects: The objective of the study was to examine the distribution of the timing of the onset of puberty in normal Greek girls.

Design: Onset of puberty, *i.e.* breast development (B2), was studied longitudinally in 311 prepubertal schoolgirls aged 6.4–8.2 yr until the onset of puberty. We also studied cross-sectionally 126 girls, 6–14 yr old.

Setting: Clinical examinations took place in the school setting.

Results: In the longitudinal study, median of the distribution of age at B2 was 10.0 yr (with the 25th and 75th centiles being 9.2 and 10.6 yr, respectively). Skewness was −0.45 ($P = 0.001$), suggesting a negatively skewed distribution. In the cross-sectional study, 126 subjects were found at B2. The median of the age distribution at B2 was 10.1 yr (with the 25th and 75th centiles being 9.7 and 11.2 years, respectively). Skewness was −0.44 ($P = 0.03$), suggesting a negatively skewed distribution.

Conclusions: A non-Gaussian distribution of the age at the onset of puberty in girls was documented. The currently used cutoff ages for precocious and delayed puberty may not be applicable to modern children; therefore, up-to-date studies on pubertal maturation are much needed. **(*J Clin Endocrinol Metab* 93: 4422–4425, 2008)**

The timing of pubertal onset, in both sexes, is considered to approximate normal distribution (1); therefore, a similar percentage of boys and girls would be expected to present with early or late puberty. However, the incidence of pubertal disorders varies greatly between sexes. Precocious puberty is 10 times more common in girls, whereas delayed puberty is much more common in boys (2). These differences might be attributed to a variety of reasons, *e.g.* the onset of puberty is detected more easily in girls, pubertal growth spurt starts soon after the onset of puberty in girls but is a rather late event in boys and also boys experience more pressure on height than girls as delayed puberty is often accompanied by short stature (3). Moreover, the secular trend for earlier puberty can mostly be substantiated for girls (4, 5).

It is a general impression among clinicians that, at least during the last decade, many girls, but much fewer boys, present with secondary sex characteristics at a younger age than normal. Furthermore, many more girls present with early than late puberty. This led us to hypothesize that the distribution of the timing of pubertal onset in girls might have changed, *i.e.* it might be skewed to the left.

The aim of this study was to examine the distribution of the timing of pubertal onset in normal Greek girls.

Subjects and Methods

Design and participants

We studied longitudinally 311 prepubertal schoolgirls aged 6.4–8.2 yr until the onset of puberty. The girls were examined at 6-month inter-

Abbreviations: B2, Breast stage 2; HSDS, height SD score; BMISDS, body mass index SD score.

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vals in the school setting as part of a longitudinal study on growth and development of girls, details of which have been published previously (6).

We also studied cross-sectionally 126 girls aged 6–14 yr, found at breast stage 2 (B2), as part of another study on growth and development of schoolchildren, performed in 1995 and involving a total of 1032 girls distributed in nine consecutive yearly age groups.

Both studies took place in Athens, Greece. Girls in the longitudinal study belonged mainly to the middle to upper social class and girls in the cross-sectional study belonged mainly to the middle social class.

At each visit, body height was measured with a portable Harpenden stadiometer to the nearest millimeter, and weight was measured with a Secca weighing machine to the nearest 100 g. Girls having a chronic illness (*e.g.* thalassemia, diabetes mellitus, cystic fibrosis) that could influence the timing of pubertal onset were excluded from the study.

To examine differences in auxological characteristics related to the age at pubertal onset we compared height SD score (HSDS) and body mass index SD score (BMISDS) between girls. For this purpose, girls were divided, according to the age of onset of puberty, in three subgroups, namely those entering puberty until 8 yr old (group 1), those at 9 or 10 yr (group 2), and those at 11 yr or later (group 3).

Pubertal onset was defined as the first sign of breast development in the longitudinal study and the presence of B2 according to Tanner classification in the cross-sectional study. In both studies, B2 was assessed by observation of the areola and nipple along with palpation of the mammary gland during physical examination by an experienced physician, trained in pediatric endocrinology.

The studies were approved by the research committee of our institution and also by the Ministry of National Education. Written informed consent was obtained from the parents of the girls participating in the studies.

Statistical analysis

To ensure that the numbers of girls in each of the nine consecutive yearly age groups in the cross-sectional study were roughly the same we used a χ^2 for goodness-of-fit test, which showed that the numbers of subjects did not differ significantly among these nine groups ($P = 0.75$). Normality was checked with Shapiro-Wilk W (7) and skewness-kurtosis (8) tests. Graphical depiction of the distribution of age at onset of puberty was done using histograms and kernel density estimates. The latter provide smoother plots and a more effective way of examining the features of a given distribution. Comparisons between groups were done with one-way ANOVA and Bonferroni correction.

Results

In the longitudinal study, median of the distribution of age at onset of puberty was 10.0 yr (third, 25th, 75th, and 97th percentiles were 7.5, 9.2, 10.6, and 11.7 yr, respectively), whereas mean (SD) value was 9.9 (1.01) yr. The earliest age a girl presented breast development was 7.0 and the latest 12.1 yr. Skewness and kurtosis were −0.45 ($P = 0.001$) and 3.52 ($P = 0.07$), respectively, *i.e.* the distribution is negatively (to the left) skewed (Fig. 1). Shapiro-Wilk W and skewness-kurtosis tests rejected the null hypothesis that the sample came from a normally distributed population ($P = 0.001$ and $P = 0.002$, respectively).

In the cross-sectional study, 126 subjects were found to be at stage B2. Median of the distribution of the age at pubertal onset was 10.1 yr (third, 25th, 75th, and 97th percentiles were 6.5, 9.7, 11.2, and 12.7 yr, respectively), whereas mean (SD) value was 10.3 (1.13) yr. Skewness and kurtosis were −0.44 ($P = 0.03$) and 4.20 ($P = 0.01$), respectively, suggesting that the distribution was negatively (to the left) skewed and sharply peaked.

FIG. 1. Distribution of the age at onset of puberty in the longitudinal study. Histogram and a superimposed kernel density estimate of the distribution. The *thick continuous line* represents a kernel density estimate.

Shapiro-Wilk W and skewness-kurtosis tests rejected the null hypothesis that the sample came from a normally distributed population ($P < 0.001$ and $P = 0.01$, respectively) (Fig. 2).

In the longitudinal study, mean HSDS for groups 1, 2, and 3 were 1.48 (0.95), 0.93 (0.84), and 0.03 (0.72), respectively ($P < 0.001$); differences existed between groups 1 and 2 ($P < 0.001$), 2 and 3 ($P < 0.001$), and 1 and 3 ($P < 0.001$). Mean BMISDS for the three subgroups were 1.68 (1.03), 0.52 (0.92), and 0.18 (0.83), respectively ($P < 0.001$); differences existed between groups 1 and 2 ($P < 0.001$) and 1 and 3 ($P < 0.001$).

Mean (SD) HSDS, in the cross-sectional study, for the three subgroups were 1.82 (1.10), 1.01 (0.81), and 0.33 (0.74), respectively ($P < 0.001$); differences existed between groups 1 and 2 ($P = 0.011$), 2 and 3 ($P < 0.001$), and 1 and 3 ($P < 0.001$). Mean BMISDS for the three subgroups were 2.11 (1.38), 0.97 (1.18), and 0.78 (1.50), respectively ($P < 0.001$); differences existed between groups 1 and 2 ($P < 0.001$) and 1 and 3 ($P < 0.001$).

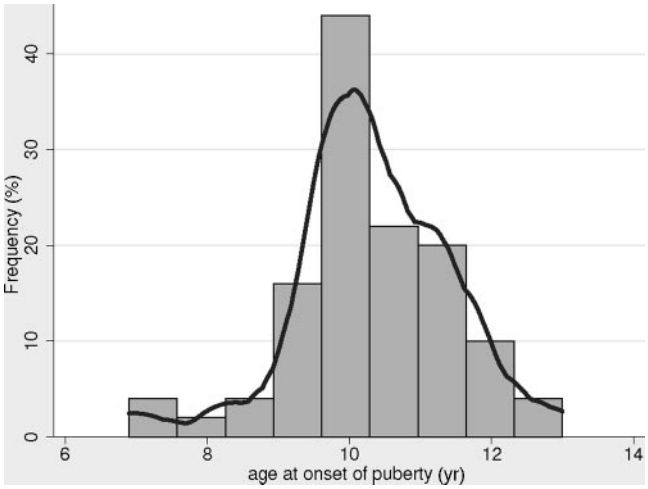

FIG. 2. Distribution of the age at onset of puberty in the cross-sectional study. Histogram and a superimposed kernel density estimate of the distribution. The *thick continuous line* represents a kernel density estimate.

Discussion

Onset of puberty in females is defined as the appearance of breast development and in males as the attainment of testicular volume of more than 3 ml. If these changes occur before the age of 8 yr in girls and 9 yr in boys, they are considered as precocious. These age limits, however, have been conventionally defined, based on the 95% confidence intervals from epidemiological studies performed 40 yr ago on British children (9, 10).

During the 20th century, a secular trend for earlier onset of sexual maturation has been universally reported in children, the trend being more robust in girls, as it was shown by the fall of the age at menarche in all populations of the industrialized world (11, 12). Moreover, the data seem sufficient to suggest that the observed secular trend toward earlier onset of breast development and menarche from 1940 to 1994 may be related to environmental factors, *e.g.* endocrine-disrupting chemicals (particularly estrogen mimics and antiandrogens) as well as increase in body fat (13). Furthermore, there are data to suggest a change in the maturational tempo of girls during the last 25 yr. As it was recently denoted (14) from data gathered from women born between 1977 and 1979, only moderate correlation (0.37–0.38) between menarche and onset of puberty was found, whereas earlier studies conducted on women born between 1920 and the 1960s reported much higher correlations (0.64–0.86). Indeed, studies carried out during the last 10 yr in Spain, the United States, and Greece (6, 15, 16) showed that early maturing girls present a compensatory delay in pubertal progression that could explain the moderate correlation between the age at menarche and at pubertal onset.

In this report we show that pubertal onset in girls does not follow a normal distribution, *i.e.* the distribution is skewed to the left, which means that more girls start puberty early than late. Our findings of a non-Gaussian distribution of the age at B2 in girls in both the longitudinal and the cross-sectional studies, which also differed in social class, suggest that this is a common biological phenomenon in Greek girls, at least for the middle and upper social classes, which comprise the majority of modern Greek society.

Our data may explain why more girls present with early sexual development in the last 2 decades, a phenomenon that often induces anxiety to parents and clinicians. The non-Gaussian distribution of the age at pubertal onset implies that most girls presenting secondary sexual characteristics between the age of 7 and 8 yr are probably normal girls entering puberty at an early age, although this could be firmly proven only if longitudinal follow-up along with hormonal and radiological data were available. Moreover, the data of this study, coupled with the differences of the maturational tempo related to the onset of puberty (6, 15), *i.e.* that early maturing girls often present a longer time span from pubertal onset to menarche than average and late maturing girls, may explain why many girls entering puberty between the age of 7 and 8 yr have a slowly progressing pubertal pattern (17).

The common clinical experience, that many girls present with secondary sex characteristics at a younger age than normal, prompted a study of secondary sex characteristics in a large number of U.S. girls in 1997 (18). The results were that a significant proportion of U.S. girls enter puberty much earlier than the age of 8 yr that was considered normal. Based on these observations, the Drug and Therapeutics and Executive committees of the Lawson Wilkins Pediatric Endocrine Society reexamined the age limits for the definition of precocious puberty in girls in the United States (19). The new guidelines suggested that sexual maturation should be considered as precocious when occurring before the age of 7 yr in white and 6 yr in black girls. Although these guidelines were criticized (20), there is still uncertainty for the actual cutoff age for precocious puberty, so most clinicians, at least in Europe, still use the age limits set by Tanner in his dated studies.

Our data, from both longitudinal and cross-sectional studies, suggest that the appropriate cutoff ages for precocious or delayed puberty, at least for Greek girls, but possibly for other populations as well, may be 7.5 and 12.5 yr, respectively.

As far as the auxological characteristics are concerned, our data show that girls with early onset of puberty tend to be taller and have more body fat than those who enter puberty at a later age.

In conclusion, our data provide evidence for a non-Gaussian distribution of the age at pubertal onset in girls, suggesting that the currently used cutoff ages for precocious and delayed puberty may not be applicable to modern children. Therefore, up-to-date studies on pubertal maturation are much needed.

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Address all correspondence and requests for reprints to: Anastasios Papadimitriou, M.D., Third Department of Pediatrics, University of Athens School of Medicine, Attikon University Hospital, Rimini 1 Street, Athens 124 64, Greece. E-mail: anpapad@med.uoa.gr.

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