Original Research Article

An Updated Analysis of Pubertal Linear Growth Characteristics and Age at Menarche in Ethnic Chinese

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Objectives: Concerns regarding change in the onset and tempo of pubertal growth in ethnic Chinese have posed a need for current information on growth characteristics. This study is to update the normative data of pubertal linear growth characteristics and distribution of age at menarche in healthy Chinese adolescents.

Methods: A multistage stratified cluster sampling investigation based on age and sex was designed for anthropometric data collection in 2008, including 15,204 healthy boys and 13,047 healthy girls. The PB1 mathematical growth model was utilized to derive biological parameters of the adolescent growth curves. Ages at menarche were estimated in 6,476 girls through probit analysis at the ages at which 10%, 25%, 50%, 75%, and 90% of the girls attained menarche.

Results: The peak growth age (PGA) was 12.6 years for boys and 10.6 years for girls. The PHV was 6.91 cm/yr in boys and 6.69 cm/yr in girls. The overall increments of adult height since 1985 were 3.3 cm for males and 2.3 cm for females, yielded rates of 1.4 and 1.0 cm/decade, respectively. Less than 10% of Chinese girls experience onset of menses before 11.38 years, and approximately 90% of all Chinese girls are menstruating by 13.88 years, with a median age of 12.63 years.

Conclusions: The current study showed an advancing trend in PGA in both Chinese boys and girls. Decreasing menarche age was also observed for Chinese girls. These updated data would serve as useful reference for interpretation of endocrine and growth status and growth disorders in Chinese during peripubertal period. Am. J. Hum. Biol. 23:132–137, 2011.

Information on the normal pubertal growth and development is essential for planning health promotion programs and serves as baseline for pediatricians to assess diseases with potential growth disturbance. It is well recognized that the timing of onset of puberty depends on complex interactions of both genetic and environmental factors (Bundak et al., 2007). Secular trend toward an earlier onset of puberty and advanced growth tempo was observed from different studies, part of which could be related to the rapid changes in dietary habits and major socioeconomic changes (Ji and Chen, 2008; Rees, 1993). Thus, the use of regularly updated growth charts and developmental information for different ethnic groups would be important to avoid misinterpretation of growth characteristics. Tanner had suggested that standard reference growth curves should be revised every 10 to 15 years in developing countries (Tanner et al., 1966). Currently used growth charts for Chinese children, however, were mostly constructed with auxological data obtained from the last decade or longer (Xu et al., 1997; Ye et al., 1999). In addition, the age at menarche, which is indicative of the remaining growth potential and reliably associated with decelerated growth velocity (Sanders, 2007), is considered an important parameter that need to be captured.

For assessing linear growth, height velocity curves (HVC) are preferentially selected for mathematical quantification and analysis of pubertal growth characteristics, including age at takeoff, peak growth age (PGA), peak height velocity (PHV), duration of puberty, and the contribution of pubertal growth spurt to the final adult height (Abbassi, 1998; Dimeglio, 2001). These aforementioned parameters could help in the assessment of residual growth potential during puberty upon which many clinical decisions would depend on. Such data, however, are not readily available in the Chinese. Tanner pointed out additionally that longitudinal study rather than cross-sectional study should be used to construct growth velocity curves (Tanner and Davies, 1985). However, the inherent difficulties in long-term longitudinal study are well known. Thus, results derived from larger and properly sampled cross-sectional studies are considered acceptable and practical (Abbassi, 1998).

The objective of the present study is to update the normative data for the onset and tempo of puberty linear growth and distribution of age at menarche in a large sample of healthy Chinese children and adolescents, to construct growth velocity curves and to analyze the growth characteristics in puberty.

SUBJECTS AND METHODS

Study design and sampling

This cross-sectional survey followed a randomized multistage stratified cluster sampling design based on age and sex. It surveyed school age students from 11 primary

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TABLE 1. Anthropometric data of stature in each age-sex group for boys and girls

	Boys (15,204)			Girls (13,047)		
Age (yr)	Height (cm)	Height gain per year (cm/yr)	*n*	Height (cm)	Height gain per year (cm/yr)	*n*
8	132.1 ± 5.9		1,265	131.2 ± 5.7		1,089
9	136.6 ± 6.4	4.5	1,627	136.2 ± 6.7	5.0	1,265
10	141.5 ± 6.9	4.9	1,696	142.3 ± 7.4	6.1	1,368
11	148.1 ± 8.1	6.6	1,667	149.1 ± 7.6	6.8	1,491
12	155.4 ± 8.7	7.3	1,646	154.3 ± 6.7	5.2	1,348
13	161.4 ± 8.4	6.0	1,617	157.2 ± 6.2	2.9	1,349
14	166.6 ± 7.4	5.2	1,703	159.1 ± 5.6	1.9	1,530
15	170.6 ± 6.4	4.0	1,843	160.3 ± 5.2	1.2	1,713
16	172.5 ± 5.8	1.9	1,515	160.9 ± 5.2	0.6	1,414
17	173.6 ± 5.6	1.1	625	161.1 ± 5.4	0.2	480

and middle schools in the urban and rural area of Changzhou, which is a well-developed region in southeast China. The socioeconomic status of the local residents is representative of modern Chinese citizens, and human body size is well homogenous because they are mainly Han Chinese. The proportion of rural individuals was 45% in our study. For each gender cohort, all subjects recruited were grouped according to their chronological age. Subjects aged 8.00 to 8.99 years were taken as the 8-year-old group, those aged 9.00 to 9.99 years as 9-year-old group and the same analogy was used for all the other age groups. The sample size included at least 1,000 children in each age-sex group with the sole exception of the 17-year-old group (Table 1), which provides sufficient precision for the construction of growth charts. Disabled students and students from institutes of physical education and children/adolescents diagnosed to have scoliosis or diseases affecting growth were excluded from this study. Finally within the 28,716 volunteers, a total of 15,204 healthy boys and 13,047 healthy girls aged 8 to 17 years who did not meet any exclusion criteria were recruited. The research protocols were approved by the University and Hospital Ethic Committee. The entire cross-sectional survey was carried out in October, 2008.

Anthropometric measurement

Growth parameters including chronological age, standing height, sitting height, and arm span were obtained following standard protocols. Portable measuring devices (Manufactured under the supervision of China Institute of Sport Science) with scale sensitivity of 1 mm were used for anthropometric measurements. Each subject was measured in the afternoon with shoes and socks off. The team of measurers was composed of one physician (H.B.L.) and five other doctors from the preventive health care department, all of which were systematically trained to ensure standardization of the investigation procedure. Each measurement was taken twice by two measurers, and the mean value was used for computation. In case of discrepancy exceeding 0.5 cm between two measurements, a third measurement would be performed and the mean of the two closest values would be used. Age of onset of menarche was collected from the female subjects or their guardians. In all, 6,476 of the 13,047 female subjects already have menarche at the time of recruitment.

TABLE 2. Value of PHV and parameters in PB1 mathematical model of growth

	Boys	Girls
A	175.08	161.38
B	155.85	140.27
C	0.67	0.68
D	0.04	−0.04
E	12.61	10.61
PHV (cm/yr)	6.91	6.69

A is adult height, *B* is the height at peak height velocity, *C* and *D* are age scale factors, *E* is an age constant representing peak growth age (PGA).

Data analysis

Descriptive statistics was performed using SPSS software (version 13.0, Chicago, IL) and the mean height of each age-sex group was calculated and presented as means ± standard deviation (SD). The PB1 mathematical model of growth, which fits the pubertal growth spurt well, was applied for construction of growth velocity curves (Ledford and Cole, 1998). The model equation is as follows:

$$Y(t) = A - \frac{2(A-B)}{\exp[C(t-E)] + \exp[D(t-E)]} + \varepsilon$$

where t is chronological age, $Y(t)$ is height at age t, A is adult height, B is another height constant representing the height at peak height velocity, C and D are age scale factors, E is an age constant representing PGA, and ϵ is the error. Values of A, B, C, D, E, and ϵ were calculated through iterative analysis using SPSS 13.0 software. MATLAB7.3 software was applied for calculation of growth velocity and construction of growth velocity curves. The percentile (50th centile) growth curves, for boys and girls of average height, were plotted using SPSS 13.0 software. Probit analysis was used to calculate the median menarche age and estimate ages at menarche at which 10%, 25%, 50%, 75%, and 90% of the girls attained menarche. The fiducial limits of these estimates were computed to indicate the level of precision for these estimated ages from the probit analysis. The narrower range represents higher precision of the estimated age.

RESULTS

Characteristics of growth charts

The results of the anthropometric measurements of each age group for both gender cohorts were summarized in Table 1, including average height, height increment per year and the number of subjects in each age-sex group. The interobserver variation was assessed to be 0.3 cm. The value of the parameters A, B, C, D, E in the PB1 mathematical model equation and PHV were listed in Table 2 for boys and girls, respectively. It was found that PHV occurred at a mean age of 12.6 years for boys and 10.6 years for girls, while the mean height at PHV was 155.8 cm for boys and 140.2 cm for girls.

Growth curves for boys and girls were separately illustrated in Figures 1 and 2. Growth in height tended to plateau off at age 16 in boys and age 14 in girls. The average height at the age of 17 was 173.6 cm for boys and 161.1 cm for girls. Figures 3 and 4 summarized the derived height velocity curves for boys and girls which both showed a parabolic shape with a growth accelerating

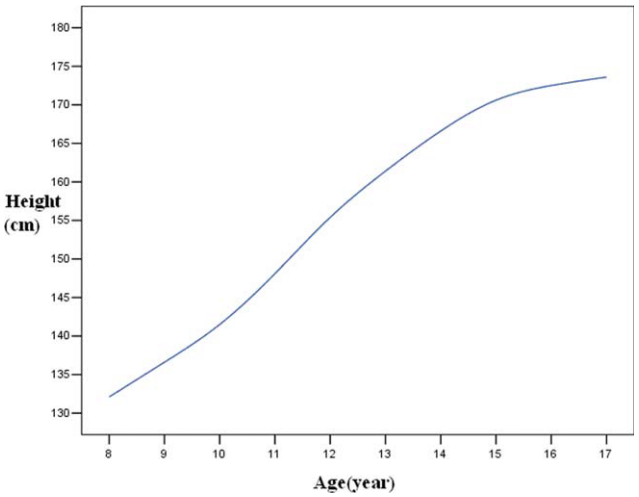

Fig. 1. Line chart of height with age in male Chinese children and adolescents. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

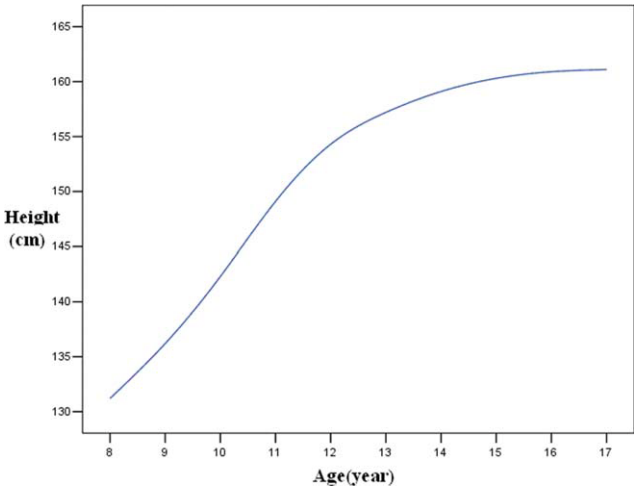

Fig. 2. Line chart of height with age in female Chinese children and adolescents. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

phase and a decelerating phase. PHV was found to have an average of 6.91 cm/yr in boys and 6.69 cm/yr in girls. The mean height velocity was approximately 1 cm/yr in boys and girls of about 17 years and 15 years, respectively, with mean height values of 173.6 cm and 160.3 cm, respectively. The pubertal growth characteristics were summarized in Table 3. Age at takeoff was estimated to be 9.3 years of age in boys and 8.0 years of age in girls. The mean contribution of pubertal growth to final height was 35.7 cm in boys, and 29.1 cm in girls, accounting for 20.4% and 18.0% of their respective final heights.

Age at menarche

Distribution of age at menarche for healthy girls was analyzed, with approximately 40.6% of girls experienced onset of menses at age of 12 to 13 years, which accounted for the maximum share in total. The average menarche age was 12.62 ± 0.99 years (range 7.9–16.4 years), with

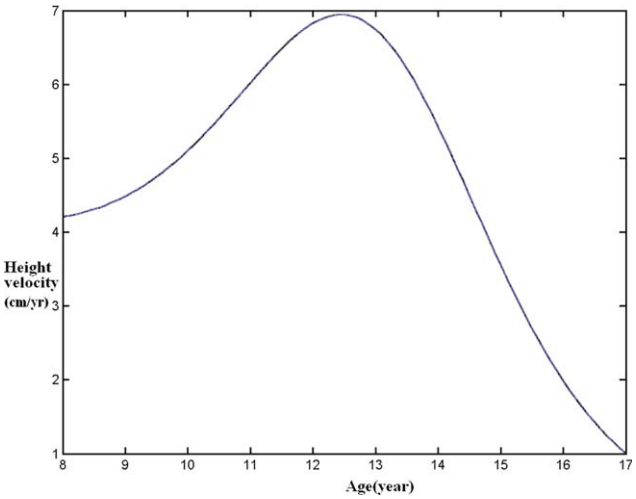

Fig. 3. Height velocity curve for Chinese boys. The curve is parabolic shaped, constructed of a growth accelerating phase and a growth decelerating phase. PHV occurs at a mean age of 12.6 years for boys and PHV in 6.91 cm/yr in boys. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

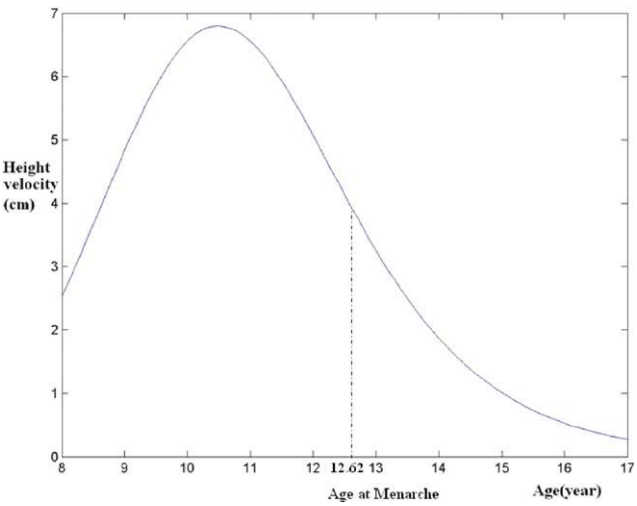

Fig. 4. Height velocity curve for Chinese girls. PHV occurred at a mean age of 10.6 years for girls and PHV is 6.69 cm/yr in girls. Average age at menarche is 12.62 years. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 3. Pubertal growth characteristics in our cross-sectional study

	Boys	Girls
Age at takeoff (yr)	9.3	8.0
Age at peak height velocity (yr)	12.6	10.6
Peak height velocity (cm/yr)	6.91	6.69
Final adult height (cm)	175.08	161.38
Puberal height gain (cm)	35.7	29.1
Contribution of the pubertal growth to final adult height (%)	20.4	18.0

the median age at 12.63 years. Age at menarche was also presented when 5%, 10%, 25%, 75%, 90%, and 95% of all girls had attained menarche (Table 4). Probit plot for age

TABLE 4. Ages at Menarche in years by probit analysis for selected percentiles of Chinese girls who were menstruating

	5%	FL	10%	FL	25%	FL	50%	FL	75%	FL	90%	FL	95%	FL
Over all	11.027	11.017–11.038	11.381	11.373–11.390	11.973	11.967–11.980	12.631	12.626–12.636	13.288	13.282–13.294	13.879	13.872–13.887	14.234	14.225–14.243

FL is the fiducial limits. The fiducial limits for overall were based on 95% confidence limits.

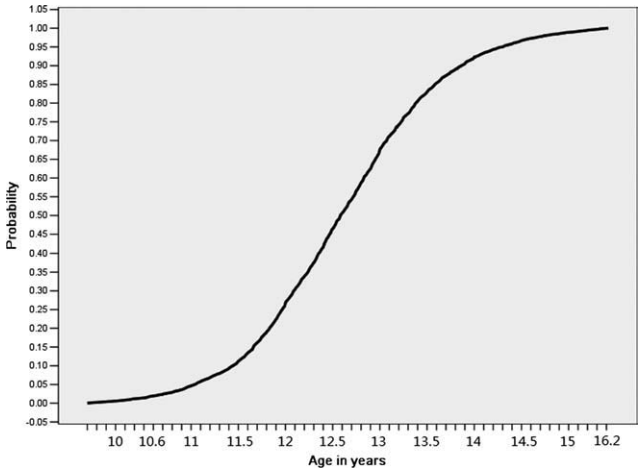

Fig. 5. Probit plots for age at menarche for Chinese girls.

at menarche was shown in Figure 5. Only 10% were menstruating at 11.38 years of age, while by 13.88 years of age, 90% were found to have attained menarche. For clinical utility, 5% and 95% values were added, and they were 11.017 years and 14.225 years, respectively.

DISCUSSION

Pubertal growth is a unique feature of the human growth pattern manifested initially as growth acceleration, followed by deceleration and final cessation which matched with the closure of epiphyses (Abbassi, 1998). It is widely recognized that the dynamics of pubertal growth are best represented through construction of height-velocity charts rather than conventional growth charts (Abbassi, 1998). Good reference chart of pubertal growth characteristics could help in monitoring of child growth, discovering early growth disorder, and is useful for diagnosis of certain diseases and assessment of therapeutic effects. For instance, the selection of treatment strategy for adolescent idiopathic scoliosis requires accurate assessment of patients' residual growth potential, which is tightly associated with therapeutic effectiveness and prognosis (Sanders et al., 2007). However, the onset of puberty is known to be affected by an interaction of genetic and environmental factors. In a number of studies, it was found that the onset is occurring at increasingly younger ages in many industrialized countries (Ong et al., 2006). Regular and timely updating of the normative pubertal growth parameters, especially in developing countries are deem necessary. In China, positive secular trends in physical growth of children and adolescents are clearly observed in the past decade (Ji and Chen, 2008), which would result in an overall upward displacement of growth curves for all in children and adolescent cohorts.

Pubertal growth characteristics

The present analyses revealed that boys with a mean takeoff age of 9.3 years reached their final heights by age 17, and girls with a mean takeoff age of 8.0 years reached their final heights by 15. PHV occurred at a mean age of 12.6 years for boys and 10.6 years for girls. And PHV was 6.91 cm/yr in boys and 6.69 cm/yr in girls, respectively. The interval between age at takeoff and age at PHV were

comparable between boys and girls. Pubertal height gain was 35.7 cm in boys and 29.1 cm in girls, which was accountable for 20.4% and 18.0%of their respective final adult height. Compared with other pubertal growth studies for European, White American, and British children with pubertal height gain ranged from 27.56 to 33.00 cm in boys and 25.00 to 30.98 cm in girls (Berkey et al., 1993; Tanner et al., 1976; Thissen et al., 1976), slightly higher mean pubertal height gain was found in the Chinese. The final adult height revealed by the PB1 mathematical model of growth in our study was 175.08 cm in boys and 161.38 cm in girls. Difference of pubertal height gain within different sex (6.6 cm) accounted for approximately 48.2% of the discrepancy of final adult height within different genders (13.7 cm). Average postpubertal height gain was 1.48 cm in boys and 1.08 cm in girls. Thus difference of prepubertal growth should account for the last unexplained part of discrepancy in final adult height. Prepubertal height gain showed a discrepancy of approximately 5.9 cm between boys and girls in our study, owing to the difference in the age at takeoff. Thus, height attained at onset of puberty was found to play an important influence on the final adult height.

Many reports including longitudinal or cross-sectional studies, have attempted to analyze the pubertal growth characteristics mathematically. A cross-sectional study conducted in American white children by Hamill et al. reported mean PGA to be 13.5 years in boys and 11.5 years in girls. The mean PHV was 9.5 cm/yr in boys and 7.5 cm/yr in girls (Hamill et al., 1977). Another longitudinal study by Berkey et al. in American white children found PHV of 9.49 cm/yr and 8.14 cm/yr for boys and girls, respectively. Mean age at PHV was 13.57 years in boys and 11.49 years in girls (Berkey et al., 1993). Results of the aforementioned cross-sectional study are in compliance with longitudinal study. The age at takeoff is highly variable and sex-dependent, occurring at a mean age of 11 years in American boys and 9 years in American girls (Abbassi, 1998). Compared with our results, the caucasian children were found to have higher PHV and later PGA, which could account for the higher final adult height.

Considering especially the ethnic difference, studies concerning growth in xanthoderm were reviewed. A longitudinal study of growth patterns conducted by Lee et al. in Taipei found the age at PHV to be 12.5 years for boys and 10.5 for girls, and the PHV was 8.0 cm/yr in boys and 7.0 cm/yr in girls. The mean final height was 170.8 cm and 158.7 cm in boys and girls of about 17 years and 15 years, respectively (Lee et al., 2004). Apart from estimated PHV in boys, which was approximately 1 cm/yr lower, our results were comparable to Lee's conclusion. PHV of our study was remarkably similar to the finding of another cross-sectional study in Japanese population (Table 5) (Ali et al., 2000). As for the Han Chinese population in Mainland China, national surveys on the growth of school-age children and adolescents have been performed systematically every 5 years since 1985. Evidence shows an overall positive secular trend in physical growth found between 1950 and 2005, with mean stature of the 18-year-old increased from 166.6 to 173.4 cm for boys and from 155.8 to 161.2 cm for girls, yielding rates of increase of 1.3 and 1.1 cm/decade, respectively (Ji and Chen, 2008). PHV derived from the 2005 National survey was similar to the findings of our study, being 6.7 cm/yr in boys and 6.8 cm/yr in girls. PGA was 13 years and 11 years for boys and girls, respectively (Ji and Chen, 2008). Cross-sectional survey using the JPA2 mathematical model in the 1980s concluded that PGA was as 13.6 years for boys and 11.5 years for girls, while age at take off was 10.2 years for boys and 8.7 years for girls. Obviously an advancing trend in age at take off and PHV was noted. PHV occurred, on average, 1 year earlier when compared with adolescents in the 1980s. The overall increments of adult height since 1985 in China were 3.3 cm for males and 2.3 cm for females, yielded rates of 1.4 and 1.0 cm/decade, respectively. We believe that improvement of socioeconomic conditions and livelihood could contribute to the gradual movement toward the genetically determined upper limit of the individual's growth potential.

TABLE 5. Pubertal growth characteristics in different ethnic population

	Our study (2008)	America[a] (1977)	Taipei[a] (1997)	Japan[a] (1981)
Boys				
Age at PHV	12.6	13.5	12.5	12.93
PHV	6.91	9.5	8.0	6.86
Height at PHV	155.8	160.25	154.6	150.18
Girls				
Age at PHV	10.6	11.5	10.5	10.60
PHV	6.69	8.3	7.0	6.07
Height at PHV	140.2	149.75	143.0	137.18

[a]Data from Hamill et al. (1977) (America), Lee et al. (2004) (Taipei), and Ali et al. (2000) (Japan).

Age at menarche

Menarche is an important milestone for determining sexual maturation in adolescent girls. Onset of menarche reliably correlates with decreasing growth velocity (Sanders, 2007). No consensus definition of a normal range for age at menarche is available since it can vary with race and ethnicity, nutritional status, and environmental conditions. The present study revealed that less than 10% of Chinese girls experienced onset of menses before 11.38 years and approximately 90% were menstruating by age 13.88, with a median age of 12.63 years. The range of the fiducial limits was 0.01 to 0.025 years for the estimated age at menarche. This distribution of age at menarche indicates that approximately 40.6% of healthy Chinese girls experience menarche at age of 12 to 13 years and about 87.3% start to menstruate between 11 and 14 years. It is also noteworthy that earlier menarche age (12.62 ± 0.99 years) is apparent compared with 13.86 years in the early 1980s (Wu et al., 2000). Results of national cross-sectional survey conducted between 2003 and 2005 concluded that menses occurred at 12.27 years, which is slightly earlier than our findings (Ma et al., 2009). A reasonable interpretation is that research subjects in their survey were urban healthy Chinese girls, while adolescents from rural areas, who account for 70% of the population of the whole nation, were not documented in their study. Ethnic difference was small compared with US girls (12.43 years) (Chumlea et al., 2003). In addition, menarche is occurring approximately 2 years after PGA in our study. It is described in the literature that the age at PHV is highly correlated with menarche age (Hoshi and Kouchi, 1981). The correlation coefficient is reported to be 0.71 by Nicholson and Hanly (1953), 0.93 by Deming (1957) and 0.77 by Hoshi and Kouchi (1981).

Thus a reasonable assumption is proposed by Hoshi and Kouchi that the secular trend of menarche should be associated with a similar trend for PHV age (Hoshi and Kouchi, 1981), which is consistent with findings of our study (PGA advanced: 1 years M, 0.9 years F vs. Menarche age advanced: 1.24 years). The interval between PHV and menarche is reported to be 0.6–1.2 years by Pantsiotou et al. (2008), 1.5 years by Rao et al. (1998), and 0.5 to 2 years by Ylikoski (2005). Additionally this interval is reported to be comparable between girls actively trained in sport and those not active in sport (Geithner et al., 1998). Variation of this interval may be attributable to variations in genetic and environmental factors within different ethnic population.

In conclusion, the present study updated the pubertal growth characteristics and age at menarche in ethnic Chinese. It should be noted that the current study is a cross-sectional study. Generally, longitudinal study should be preferentially selected to construct growth velocity curves. However, a long-standing longitudinal study with large sample size is barely impossible to implement in current China because of high rate of loss of follow-up. In addition, in previous studies, results of PHV and PGA derived from cross-sectional data (Hamill et al., 1977) are in compliance with longitudinal study (Berkey et al., 1993). Thus the present study on pubertal growth characteristics from cross-sectional study with large and properly sampling may be considered as an optional alternative to the prospective longitudinal studies. Nevertheless, the significance of a longitudinal growth study should not be ignored. It would be meaningful in the future to expand the study to include other regions both cross-sectionally and longitudinally.

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