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Total number of authors:
6

Age at spermarche: 15-year trend and its association with Body Mass Index in Chinese school-aged boys

Yi Song, PhD[1,2], Jun Ma, PhD[1 *], Hai-Jun Wang, PhD [1*], Zhiqiang Wang, PhD [1,3], Patrick W.C. Lau, PhD [4], Anette Agardh, PhD [2]

[1] Institute of Child and Adolescent Health, School of Public Health, Peking University, Beijing, China

[2] Social Medicine and Global Health, Department of Clinical Sciences, Lund University, Malmö, Sweden

[3] Centre for Chronic Disease, School of Medicine, University of Queensland, Health Sciences Building, Royal Brisbane & Women's Hospital, Herston, Australia

[4] Department of Physical Education, Hong Kong Baptist University, Kowloon Tong, Hong Kong, China

Running title: Trend of age at spermarche and relation to BMI

Address correspondence to: [1]Jun Ma, Institute of Child and Adolescent Health School of Public Health, Peking University, Beijing, China, [majunt@bjmu.edu.cn], 86-10-82801624 or [2]Hai-Jun Wang, Institute of Child and Adolescent Health, School of Public Health, Peking University, Beijing, China, [whjun1@bjmu.edu.cn], 86-10-82805583

Abstract

Background: Little literatures report the secular trends of age at spermarche and the association between body mass index (BMI) and male puberty are controversial.

Objective: To estimate the trend of age at spermarche in China, and explore the association of spermarche with BMI.

Methods: We used four cross-sectional Chinese National Surveys on Students' Constitution and Health (CNSSCH, 1995, 2000, 2005, and 2010). The median age at spermarche was determined by using probit analysis. Logistic regression was used to assess the association of spermarche with BMI.

Results: The age at spermarche in Chinese boys dropped from 14.57 years to 14.03 years from 1995 to 2010 with a decrease by 4.3 months per decade. The boys with BMI-for-age Z-score lower than -2 had the latest age at spermarche. A higher BMI/BMI-for-age Z-score was associated with an increased likelihood of having reached spermarche, and this association keeps steady at each survey point.

Conclusion: The study provides an evidence of secular trend of an earlier age at spermarche over the past 15 years in China and this decrease is accompanied by a simultaneous increase in BMI. The strategies and interventions focused on thinness may promote both their nutritional status and puberty development.

Key words: spermarche; Body Mass Index; puberty; China

Introduction

Similar to the onset of menarche in female sexual maturation, spermarche (onset of the release of spermatozoa) is regarded as a milestone in male puberty, because the establishment of spermatogenesis only occurs if a boy's reproductive system gained sufficient maturation (1). Numerous studies have shown that a trend toward an earlier menarche is occurring among girls (2-3), but the data for evaluating secular trends in male pubertal development are still limited (4). Because gonadal maturation in boys is not characterized by a critical visible event as in menarche in girls, few studies of secular trends in age at spermarche have been reported worldwide (5), either in China or elsewhere. Also, many studies are outdated, and findings in Chinese populations have only focused on local regions (6). Consequently, the secular trend of age at spermarche in Chinese boys keeps unclear.

Many studies in girls suggest that the increasing body mass index (BMI) among adolescents appears to coincide with the increasing trend in pubertal timing (7-8). Increased adiposity may trigger estrogen production, leading to the early onset of menarche in girls. However, the studies analyzing association between BMI and spermarche in boys are scare. Although previous studies have used different variables, such as voice break, age at onset of pubertal growth spurt and at peak height velocity, pubic hair development, testicular volume, and penis length to assess male puberty (9-13), the findings of association between BMI and those variables are controversial (9). Some studies in Europe report that estimated mean age at onset of puberty, such as age at onset of pubertal growth spurt and at peak height velocity, age of initial appearance of pubic hair, and age at attainment of testicular volume above 3 ml has declined with the coincident increase in BMI (10-13), whereas among US boys a negative association has been found between boys' testicular volume and BMI (14) and higher BMI in earlier childhood may be associated with later onset of puberty which is measured by Tanner genitalia staging in a longitudinal study (15). Still some studies have not been able to document an association between onset of puberty and BMI (5, 16). The question as to whether a relationship between spermarche and BMI exists, and whether such a relationship has changed over the past 15 years in Chinese boys remains unanswered.

The use of ejacularche as a marker of pubertal development is challenged by the inherent risk of recall bias or subjective bias, but a previous study has shown that age at spermarche in boys can be determined by personal interview, which may be more accurate and convenient than measurement of spermaturia in population-based studies (5, 17). Using this method, spermarcheal data are collected in the Chinese National Surveys on Students Constitution and Health (CNSSCH) (18-19), which has been conducted every five years using identical methods. As the largest nationally representative sample of school-aged children and adolescents in China, it provides an opportunity to study the trends of age at spermarche and explore the relationship between spermarche and BMI in China. The present analysis aimed to 1) estimate the trend of age at spermarche from 1995 to 2010; and 2) determine any possible association between age at spermarche and BMI.

Methods

Subjects

Data were obtained from the 1995, 2000, 2005, and 2010 CNSSCH surveys. The sampling procedure, as previously described in detail (18-19), was the same at all CNSSCH time points. The participants were primary and high school boys aged 7- 18 years from the same areas in each province. All subjects were selected by stratified cluster sampling, in that sampling took place in classes randomly selected from each grade in the selected school. Consequently, sample size in age-specific subgroups varied slightly in each survey. Each province had an equal size of sample from three socioeconomic classes ("upper", "moderate", and "low") at the regional level. Five aspects were taken into consideration in defining the socioeconomic status of the region level: regional gross domestic product, total yearly income per capita, average food consumption per capita, natural growth rate of population, and the regional social welfare index (18-19). The present study included only those of Han ethnicity aged 11-18 years boys with the spermarcheal data. Population of Han ethnicity represents 92% of the total Chinese population. They came from 26 mainland provinces and 4 municipalities, excluding Tibet (where Han ethnicity is the minority). All eligible participants had lived in the area for at least one year. They received medical examinations before the national survey, to ensure that they had no overt physical or mental disorders. The sample sizes of present study for different years were from 7,094 to 9,268 in each age-specific subgroup (Table S1). The project was approved by the Medical Research Ethics Committee of Peking University Health

Science Center (IRB00001052-13082). Informed consent was obtained verbally because written consent was difficult to obtain in the large sample. The information of participants were anonymized and de-identified prior to analysis and that their privacy would thus be respected.

Measures

Individual spermarcheal data were collected by the status quo method. Boys aged ≥ 11 years in each CNSSCH were interviewed face to face by male physicians or professionals and were asked whether or not they had experienced a first ejaculation. Almost all school boys of that age group have some knowledge on male pubertal events from their school health education; moreover, the interviewers were well trained to create a harmonious atmosphere and not to let the boys answer under stress. The interviewers were also prepared to provide sufficient explanation of sperm emission, if necessary, during the interview. Boys were also encouraged to ask questions freely. A dichotomous response (yes/no) was obtained for spermarcheal status. The boys who did not understand sperm emission after explanation, could not remember their ejaculation history, or who refused to answer questions were regarded as invalid cases and excluded from the study. Boys' ages were recorded and calculated as decimal ages (e.g., 11.00–11.99 years, 12.00–12.99 years).

Height (cm) and weight (kg) were all measured using similar instruments at all survey sites (18-19). Participants were required to wear only light clothing and stand erect, barefoot, and at ease while being measured. Weight was recorded to the nearest 0.1 kg with a standardized scale and height recorded to the nearest 0.1 cm with a portable stadiometer. Both the scales and stadiometers were calibrated before use. BMI was calculated as body weight (kg) divided by height (m) squared (kg/m^2). BMI-for-age Z-score is a quantitative measure of the deviation of a specific BMI value from the mean of that population, and was calculated according to World Health Organization (WHO) references (20). Nutritional status was defined according to the growth references of BMI-for-age Z-score for 5-19 years developed by the WHO, i.e. thinness: <-2SD; overweight: >+1SD; obesity: >+2SD (21). Measurements at the survey site were conducted by a team of field professionals who had passed a training course in anthropometric measurements.

Statistical analyses

Mean BMI and BMI-for-age Z-score were calculated by each age group. The distributions of BMI-for-age Z-scores for four surveys were represented using kernel densities, which are nonparametric smoothed graphs independent of bin width when compared to histograms. The percentages of boys having reached spermarche in each age group were determined. The median age at spermarche and 95% confidence interval (CI) in subgroups for different years were calculated using probit analysis (22). We fit probit models to the proportion of boys of each age group who had reached spermarche. A cumulative normal curve was fitted to the proportion of boys within each age group who were spermarcheal, and the median age at spermarche was the corresponding age at which 50% of boys in the population were predicted to have reached spermarche. Analysis of variance tests compared BMI and BMI-for-age Z-score for pre-spermarcheal and post-spermarcheal boys in different years. Logistic regression was used to assess the association between the log odds of being spermarcheal and BMI/BMI-for-age Z-score, age, urban–rural residence, province, socio-economic status, and school. A two-sided *P*-value < 0.05 was considered significant. The design effect of cluster sampling by school was taken into account in the logistic regression models using Stata 12.1(Stata Corp., College Station, TX, USA). All other analyses were conducted with SPSS 20.0 (SPSS, Chicago, IL).

Results

Percentage of boys having reached spermarche and trend of median age at spermarche

Table 1 shows the percentage of boys who had reached spermarche at each age in different years. By 18 years, more than 96% of the participants had attained spermarche at each survey point. The percentages of spermarcheal boys were shown to be S-shaped curves with declining age at spermenarche over time (Fig. S1). Median age at spermarche in Chinese boys dropped from 14.57 to 14.03 years from 1995 to 2010 with a decrease by 4.3 months per decade. The difference between 1995 and 2010 was significant according to the non-overlapping 95% CI of age at spermarche estimate (Table 1).

BMI-for-age Z-score distribution and BMI comparisons between pre-spermarcheal *and post-spermarcheal boys*

Between 1995 and 2010, the mean BMI of Chinese boys continuously increased over time in most subgroups (data not shown). Fig. S2 shows a similar trend whereby the curves of BMI-for-age z-score distribution shifted to the right over time at almost every percentile. The M-d Plot of BMI by each age group also showed an analogous trend (data not shown). In most age subgroups, boys of the same age who had reached spermarche had a higher mean BMI than boys who had not (Table S2). For example, post--spermarcheal boys aged 14 had a mean BMI 0.7, 0.5, 0.7 and 0.4 units higher in 1995, 2000, 2005 and 2010, respectively, in the CNSSCH, compared with pre-spermarcheal boys of the same age ($P < 0.001$ at each survey). The mean BMI-for-age z-score showed an analogous result (Table S2).

Association of spermarche with BMI/ BMI-for-age Z-score

Table 2 shows that median age at spermarche decreased with increasing BMI-for-age Z-score. Boys with BMI-for-age Z-score lower than -2 had the oldest age at spermarche compared with the others, whereas boys with BMI-for-age Z-score between 1 and 2, or BMI-for-age Z-score higher than 2 had younger age at spermarche than the other two groups. Table 3 shows that in each survey point, higher BMI/BMI-for-age Z-score was associated with an increased likelihood of having reached spermarche, after adjusting for age, urban–rural residence, province, socio-economic status, and school. The odds ratios (OR) for BMI in the logistic regression models are almost identical for the surveys from 2000 to 2010, while the OR was slightly higher in 1995.

Discussion

To our knowledge, the present study is the first to describe the trend of decreasing age at spermarche in a nationally representative sample. Over the past 15 years, age at spermarche has dropped from 14.57 to 14.03 years, an average decrease of 4.3 months per decade, which is consistent with the pace of the decreasing trend of age at menarche in Chinese school-aged girls (an average decrease of 4.5 months per decade) (18). Also, this declining trend is similar with the male puberty development in other countries, but the pace is faster. One study in Poland reported an over 3-month decrease between 2000 and 2010 in the age of initial appearance of pubic hair in boys (12). Another study in Thailand showed that the age at testicular enlargement Tanner II had declined by 0.15 years/decade (1.8 months/decade) from 1975 to 2012 (23). The median age at spermarche in 2010 (14.03 years) is close to that reported in a local study of nine metropolitan cities in China in 2003-2005 (14.05 years) (24) and is later than that of German boys (13.8 years in 2005) (25). Current environmental factors, including changes in diet, less physical activity, and other modern lifestyle changes and exposures, especially exposure to chemicals, i.e. the frequent use of chemicals with endocrine-active properties in household products and contamination of soil, water, and food sources by persistent chemical pollutants result in ubiquitous exposures, which may be related to the trend of earlier pubertal onset (26-27).

Our findings are in agreement with many previous studies that nutritional status is an important regulator of puberty, i.e. underweight could delay onset of puberty and reduce pubertal growth spurt whereas overweight or obese children are more likely to enter puberty early (9, 28). In the present study, boys with BMI-for-age Z-scores lower than -2 have the latest age at spermarche. Our finding are consistent with a study in Bulgaria showing that the onset and progression of pubic hair stages in boys were significantly and positively associated with weight and BMI, and that underweight boys developed puberty later at every stage (28). Moreover, our findings suggest that nutritional strategies and interventions such as the program for improving student nutrition among rural compulsory school students, which was issued by the State Council in 2011 (29) targeting boys who are thin, may have effects on both their nutritional status and puberty development.

In accordance with findings from a previous study showing rapid early weight gain associated with advanced puberty in both sexes (9) and a clear association between increasing BMI and earlier pubertal development in girls (18), our study has shown that a downward shift of median age at spermarche is accompanied by a simultaneous increase in BMI in boys. We also observed that higher BMI or BMI-for-age Z-score is associated with the earlier spermarche at every survey and our cross-sectional analyses of pre- and post-spermarcheal boys at each survey are supportive for this as well, i.e. post-spermarcheal boys had a higher mean BMI or BMI-for-age Z-score compared with their pre-spermarcheal counterparts in most age groups. Our results are consistent with previous findings that a higher BMI is related to earlier pubertal onset in boys (10-13, 28). For example, the Copenhagen Puberty Study found that

BMI was associated with declining age at pubertal onset during a 15-year period. This decline may represent earlier central activation of the hypothalamic-pituitary gonadal axis, as the age-adjusted luteinizing hormone levels were significantly higher in the most recent cohort compared with that from 15 years prior (13). One of the possible mechanisms linking obesity with puberty is that the combination of various hormonal stimuli is related to increased body fat. Increased conversion of androgens to estrogen and increased bioavailability of circulating sex steroids could also contribute to earlier activation of the hypothalamic-pituitary-gonadal axis and thereby to the earlier initiation of puberty in the obese (10, 30).

In girls, epidemiological evidence has shown that earlier menarche and higher BMI may act together in later years to the detriment of a woman's health (18). The authors of a study of pubertal development in boys in the United State ssuggested that although mean ages of beginning genital and pubic hair growth and early testicular volumes were 6 months to 2 years earlier than in past studies, this apparent rapid decrease may not reflect healthy conditions (27). Early age at spermache and higher BMI in boys may act together to influence male health, with psychological, emotional, and behavioral affects, given the current phenomena of social and emotional delay in achieving adulthood (27). Therefore, longitudinal tracking is needed to clarify the impact of the interaction between overweight/ obesity and puberty development on boys' future health.

Our study has several potential weaknesses. It was not a prospective cohort study, as each CNSSCH was a cross-sectional survey conducted on different participants. The median age at spermarche may not reflect the exact situation of one generation, and this may only be clarified by a longitudinal cohort study in the future. In addition, we did not conduct the Tanner stage assessment to measure sexual maturity or comparison of spermarche to testicular volume in the present study. However, as this is a largescale epidemiological study based on multiple surveys of school-aged boys with identical methods throughout China, these findings may reflect the trend of age at spermarche of Chinese boys in general.

Conclusion

From 1995 to 2010, median age at spermarche of Chinese boys decreased from 14.57 to 14.03 years, and during this same interval, the BMI of boys increased continually. Increasing BMI/BMI-for-age z-score was associated with an increased likelihood of being spermarcheal when adjusted for age, urban－rural residence, province, socioeconomic status and school at each survey year, and the associations were relatively stable over time. This suggests that nutritional interventions focusing on thinness of boys may also have an effect on their pubertal development.

Conflicts of interest statement: The authors declared no conflicts of interest.

Acknowledgment

YS conceived and designed the study, carried out the initial analyses and prepared the first draft of the manuscript. JM, HJW and ZW critically reviewed and revised the manuscript. YS and JM conducted the research and collected the data. ZW, P WC and AA interpreted data, developed materials analysis tools and revised the manuscript. All authors read and approved the final manuscript. We thank WK Liao, WH Xing, and X Zhang for their permission on accessing the 1995, 2000, 2005 and 2010 Chinese National Survey on Student’s Constitution and Health data. We also appreciate the students who participated in the surveys for their cooperation. The data analysis of the present study was supported by a grant from the National Natural Science Foundation of China (81302442), and the preparation for publication was supported by the Research special fund of the Ministry of Health public service sectors funded projects (201202010).

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Table 1 Median age at spermarche and percentage of boys who had reached spermarche from 1995 to 2010

Age (yrs)	1995		2000		2005		2010	
	N[a]	Percent spermarcheal	N[a]	Percent spermarcheal	N[a]	Percent spermarcheal	N[a]	Percent spermarcheal
11~	145	1.7	274	3.1	331	3.9	230	3.2
12~	434	5.0	621	6.9	825	10.2	800	11.2
13~	2028	23.2	2338	26.3	2536	32.0	2463	33.3
14~	4417	50.5	5004	55.8	5313	64.4	5105	66.3
15~	6505	74.4	7353	81.7	7641	84.9	6862	85.3
16~	7778	89.6	8372	93.2	8605	93.9	8159	95.5
17~	8364	95.8	8481	95.4	8798	95.8	8480	97.8
18~	8365	96.7	8734	97.8	9050	97.7	8517	97.9
Age at spermarche	14.57(14.35-14.78) [b]		14.33(14.07-14.58) [b]		14.10(13.79-14.39) [b]		14.03(13.72-14.32) [b*]	

a N is the number of boys at that age who had reached spermarche.

b Estimates are the age at which 50% boys are at onset of sperm emission and 95% confidence interval from probit analysis.

* age at spermarche in 2010 was significantly different from 1995.

Table 2 Median age at spermarche and 95% CI stratified by nutritional status from 1995 to 2010

Nutritional status	1995	2000	2005	2010
BMI-for-age Z-score < -2	15.03(14.81-15.27)*	14.71(14.48-14.95)*	14.50(14.09-14.89)*	14.43(14.19-14.66)*
-2 ≤ BMI-for-age Z-score ≤ 1	14.54(14.30-14.77)	14.31(14.05-14.57)	14.09(13.78-14.38)	14.02(13.66-14.34)
1 < BMI-for-age Z-score ≤ 2	14.33(14.08-14.60)	14.09(13.82-14.37)	13.92(13.63-14.22)	13.96(13.67-14.26)
BMI-for-age Z-score ＞ 2	14.27(14.08-14.48)	14.23(13.85-14.67)	13.90(13.59-14.24)	13.91(13.75-14.09)

* median age at spermarche in boys with BMI-for-age Z-score < -2 was significantly different from other boys

Table 3 Logistic regression models predicting spermarcheal status from BMI or BMI-for-age Z-score for different CNSSCH years (OR(95% CI))

Period	BMI [a]	BMI-for-age Z-score [a]
1995	1.10(1.08-1.12)	1.28(1.23-1.34)
2000	1.05(1.04-1.07)	1.16(1.12-1.21)
2005	1.05(1.04-1.07)	1.17(1.12-1.22)
2010	1.03(1.01-1.04)	1.10(1.06-1.14)

a: adjusted for age, urban- rural areas, province, socioeconomic status and school.

Supplemental Table 1 Sample sizes of boys aged 11~18 years in CNSSCH of different years

Age (yrs)	1995	2000	2005	2010
11~	8739	8870	8430	7094
12~	8720	8971	8063	7162
13~	8737	8882	7928	7396
14~	8741	8972	8256	7701
15~	8741	9001	8997	8043
16~	8679	8987	9167	8541
17~	8728	8888	9187	8672
18~	8651	8927	9268	8700
Total	69736	71498	69296	63309

Supplemental Table 2 Mean BMI and BMI-for-age Z-score in pre-spermarcheal and post-spermarcheal boys from 1995 to 2010 (Mean (*S.D*))

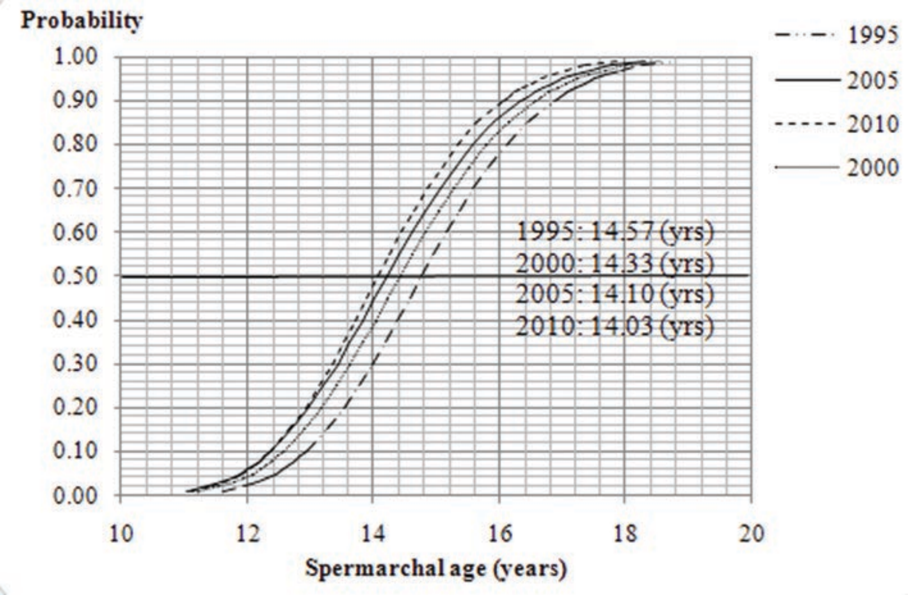
Age (yrs)	1995		2000		2005		2010	
	Pre-spermarcheal	Post-spermarcheal	Pre-spermarcheal	Post-spermarcheal	Pre-spermarcheal	Post-spermarcheal	Pre-spermarcheal	Post-spermarcheal
BMI								
11~	16.5(2.30)	17.6(2.87)**	17.1(2.82)	17.8(2.92)**	17.7(3.07)	18.2(3.41)**	18.4(3.42)	18.8(3.51)
12~	16.9(2.31)	18.1(2.71)**	17.5(2.95)	18.1(2.82)**	18.0(3.18)	18.8(3.47)**	18. 7(3.45)	19.5(3.82)**
13~	17.6(2.40)	18.3(2.48)**	17.9(2.86)	18.7(3.04)**	18.3(3.16)	19.0(3.16)**	19.0(3.36)	19.5(3.35)**
14~	18.0(2.35)	18.7(2.48)**	18.4(2.84)	18.9(2.90)**	18.6(3.12)	19.3(3.18)**	19.3(3.31)	19.7(3.31)**
15~	18.7(2.45)	19.0(2.30)**	19.0(2.90)	19.4(2.84)**	19.1(2.98)	19.6(3.12)**	19.8(3.50)	20.1(3.26)**
16~	19.4(2.47)	19.5(2.29)	19.7(2.85)	19.9(2.74)	20.1(3.41)	20.1(3.05)	19.9(3.12)	20.3(3.06)**
17~	19.9(2.37)	19.9(2.20)	19.8(2.62)	20.3(2.83)**	20.0(2.98)	20.4(2.90)*	21.3(4.09)	20.7(3.09)*
18~	20.1(2.27)	20.1(2.12)	21.1(3.28)	20.6(2.71)*	20.1(3.44)	20.6(2.91)*	20.8(2.94)	20.9(3.02)
Total	17.4(2.49)	19.5(2.35)**	17.8(2.96)	19.8(2.89)**	18.2(3.18)	20.0(3.09)**	18.8(3.44)	20.3(3.19)**
BMI-for-age Z-score								
11~	-0.61(1.15)	-0.07(1.25)**	-0.36(1.29)	0.02(1.23)**	-0.09(1.33)	0.12(1.36)**	0.21(1.37)	0.38(1.31)
12~	-0.70(1.13)	-0.15(1.20)**	-0.45(1.29)	-0.14(1.21)**	-0.22(1.32)	0.09(1.29)**	0.04(1.33)	0.34(1.34)**
13~	-0.68(1.09)	-0.30(1.04)**	-0.58(1.22)	-0.23(1.20)**	-0.43(1.29)	-0.11(1.21)**	-0.12(1.28)	0.13(1.19)**
14~	-0.82(1.07)	-0.45(1.01)**	-0.69(1.19)	-0.42(1.15)**	-0.60(1.26)	-0.27(1.20)**	-0.30(1.24)	-0.11(1.20)**
15~	-0.79(1.05)	-0.60(0.96)**	-0.68(1.15)	-0.50(1.10)**	-0.66(1.17)	-0.43(1.18)**	-0.42(1.31)	-0.26(1.18)**
16~	-0.71(1.00)	-0.64(0.92)*	-0.64(1.08)	-0.55(1.04)*	-0.52(1.24)	-0.49(1.13)	-0.59(1.19)	-0.38(1.11)**
17~	-0.72(0.97)	-0.71(0.88)	-0.77(1.01)	-0.59(1.04)**	-0.72(1.10)	-0.57(1.07)**	-0.32(1.31)	-0.45(1.11)
18~	-0.82(0.90)	-0.80(0.84)	-0.49(1.16)	-0.65(1.10)*	-0.91(1.24)	-0.66(1.06)**	-0.59(1.06)	-0.55(1.09)
Total	-0.70(1.11)	-0.64(0.93)**	-0.51(1.25)	-0.53(1.08)*	-0.31(1.31)	-0.47(1.14)**	-0.03(1.33)	-0.33(1.16)**

* ANOVA tests compared BMI and BMI-for-age Z-score for pre-spermarcheal and post-spermarcheal boys, P <0.05; ** P <0.01.

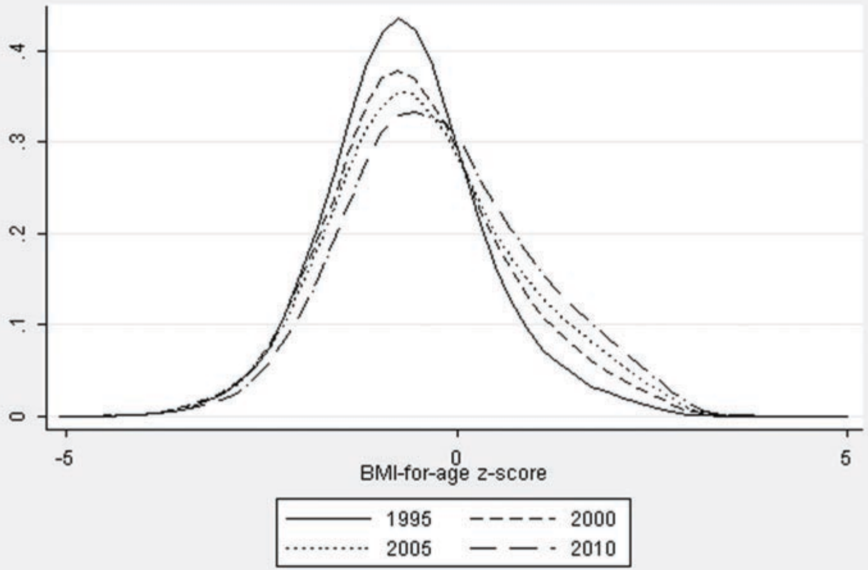
Legends

Supplemental Figure 1 Probit plots for age at spermarche in Chinese boys: from 1995 to 2010.

Supplemental Figure 2 BMI-for-age Z-score distribution shifts among Chinese school-aged boys from 1995 to 2010.



Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
10
12
14
16
18
20
Spermarchal age (years)
1995
2005
2010
2000
1995: 14.57 (yrs)
2000: 14.33 (yrs)
2005: 14.10 (yrs)
2010: 14.03 (yrs)


.4
.3
.2
.1
0
-5
0
5
BMI-for-age z-score
1995
2000
2005
2010