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Percent Body Fat at Age 5 Predicts Earlier Pubertal Development Among Girls at Age 9

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Abstract

Objective—This study examines the causal direction of the relationship between weight status and pubertal timing in girls using a longitudinal sample of 183 white girls followed from ages 5 to 9.

Methods—Girls' weight status (body mass index percentile, percent body fat, waist circumference) was assessed when they were 5, 7, and 9 years old, and their pubertal development was assessed when they were 9 years old (breast development, Estradiol, Pubertal Development Scale). Information from all measures of pubertal development at 9 years was combined to identify girls exhibiting earlier ($N = 44$) and later ($N = 136$) pubertal development relative to the sample. Girls' weight status at each age (5, 7, and 9 years old) and change in weight status across the ages of 5 to 9 years were used to predict their pubertal timing at 9 years of age.

Results—Girls with higher percent body fat at 5 years, and girls with higher percent body fat, higher BMI percentile, or larger waist circumference at 7 years, were more likely to be classified with earlier pubertal development at 9 years. In addition, girls showing larger increases in percent body fat from 5 to 9 years of age, and larger increases in waist circumference from 7 to 9 years of age, were more likely to exhibit earlier pubertal development at 9 years. Results were still present after controlling for accelerated growth.

Conclusions—Girls with higher weight status in early childhood were more likely to exhibit earlier pubertal development relative to peers at 9 years, indicating that weight status preceded pubertal timing in girls.

Keywords

puberty; pubertal timing; girls; weight status; body fat; body mass index; waist circumference; longitudinal study

Girls are entering puberty at younger ages today in comparison to the past.^{1–4} Historically, reductions across time in the age of onset of puberty were attributed to greater access to food and improved nutritional status resulting in better health.⁵ A recent large-scale study among American girls suggests that this downward trend in the timing of the onset of puberty is continuing. Girls on average are experiencing the onset of breast development between 8 and 9 years old, a year earlier than 20 years ago.^{6,7} In contrast to previous years, these more recent secular trends in pubertal timing among girls coincide with increases in overnutrition and the

prevalence of childhood obesity.^{4,8} For example, a study comparing 2 cohorts of girls from the Bogalusa study found that girls from the more recent cohort (1992–1994) were more overweight and were twice as likely to reach menarche before 12 years than similar-aged girls from the earlier cohort (1978–1979).⁴ The overlapping trends in obesity and pubertal timing raise the possibility that increased fatness may be driving the current patterns of earlier initiation of puberty among girls. Although research has generally refuted⁹ the hypothesis that a critical threshold of fatness is necessary to trigger the onset of puberty among girls,^{10,11} research has revealed positive associations between degree of overweight and timing of puberty, such that girls who are more overweight experience earlier puberty than girls who are not overweight.^{12–15}

The purpose of this study was to investigate whether girls' weight status is causally implicated in early pubertal timing. To do this, it was necessary to establish that individual differences in weight status are clearly present before pubertal onset and that such differences predict subsequent individual differences in pubertal timing. Studies to date that have investigated the relationship between weight status and timing of puberty have generally relied on cross-sectional data^{12–15} and, as a result, cannot rule out the alternative hypothesis that early pubertal timing leads to the accumulation of fat and the development of overweight status. In addition, existing longitudinal studies have not examined weight status early enough in development to separate the directionality of pubertal onset and weight status^{16–18} or have relied solely on body mass index (BMI) as a measure of adiposity, which confounds fat mass and lean body mass.^{19,20}

Using longitudinal data for a sample of girls who were followed from the ages of 5 to 9, this study assesses whether weight status at 5, 7, and 9 years and changes in weight status from the ages of 5 to 9 predict pubertal timing at 9 years. That is, this study assesses whether weight status precedes pubertal timing. Key strengths of this study include its longitudinal design beginning at 5 years and the use of multiple measures of weight status and pubertal development. Based on suggestive data from previous research, we predicted that higher weight status as early as 5 years of age and greater increases in weight status from 5 to 9 years would be associated with earlier onset of puberty at 9 years independent of overall accelerated growth.

METHODS

Participants

Participants were part of a longitudinal study investigating girls' nutrition, early experience, and development from 5 to 9 years. At entry to the study, participants included 197 5-year-old girls and their mothers. One hundred ninety-two families were reassessed when girls were 7 years, and 183 were assessed a third time when girls were 9 years. Families were assessed within the same 6-week interval every 2 years and the mean age of girls at each time of assessment was 5.3 ($\pm .3$), 7.3 ($\pm .3$), and 9.3 ($\pm .3$) years. Eleven families dropped out of the study before the girls were 9 years old, resulting in a final sample size of 181 girls and their parents. Families who did and did not complete the study did not differ in family income or girls' weight status (percentage body fat, BMI percentile). Based on mothers' reports on the Pubertal Development Scale (PDS)²¹ when girls were 5 years old, no girls exhibited precocious puberty.

Procedures

Girls and their parents were recruited for the study through flyers and newspaper advertisements in addition to letters sent to all families with age-eligible girls within a 5-county radius. Girls were recruited based on their age and the absence of severe food allergies and chronic medical problems; girls were not recruited based on weight status or stage of pubertal

developmental. The study was approved by the Institutional Review Board of the associated university.

Measures of girls' weight status included percent body fat, BMI percentile, and height (assessed at 5, 7, and 9 years), in addition to waist circumference (assessed at 7 and 9 years). Measures of girls' pubertal development included the PDS (assessed at 5, 7, and 9 years), breast development (assessed at 7 and 9 years), and estradiol (assessed at 9 years). Trained research assistants collected all anthropometric data. Registered nurses assessed girls' breast development and collected blood samples. Mothers completed the PDS, a self-report questionnaire of girls' pubertal status.

Measures of Weight Status

BMI—Girls' height and weight were measured in triplicate and were used to calculate BMI (weight (kilograms)/height (meters)²). BMI percentiles were calculated using the 2000 growth charts from the Centers for Disease Control and Prevention.²²

Percent Body Fat—Girls' fat mass was estimated using measures of their weight, skinfold thickness, and bioelectrical impedance. Girls' subscapular and tricep skinfold thicknesses were measured in duplicate on the right side of the body. Similarly, 2 assessments of bioelectrical impedance were taken. Average subscapular and tricep skinfold thickness, bioelectrical resistance, and height and weight were entered into the following validated equation by Goran et al.²³ to calculate fat mass (kilograms): $(0.16 \times \text{subscapular skinfold thickness}) + (0.33 \times \text{weight (kilograms)}) + (0.11 \times \text{tricep skinfold thickness}) - (0.16 \times \text{height}^2/\text{resistance}) - (0.43 \times \text{gender [0 = girls]}) - 2.4$.

Waist Circumference—Waist circumference (centimeters) was measured in duplicate at the top of the upper hipbone (right ileum). Waist circumference was chosen over waist-to-hip ratio because research shows that it provides a better estimate of abdominal or trunk fat,^{24, 25} it is a more effective prognostic tool for estimating disease risk among adults,²⁶ and it has been linked to disease risk among children.²⁷

Measures of Pubertal Development

Estradiol—Blood samples collected on filter paper were used to measure levels of estradiol (picograms per milliliter). Girls arrived at the laboratory at 7:45 AM after an overnight fast. All blood samples were collected between 8 AM and 9 AM. The samples were air-dried and then frozen until assayed as outlined in Shirtcliff et al.²⁸ The estradiol assay has been validated against serum samples in both adults and children and its sensitivity is sufficient for the detection of prepubertal levels of estradiol in girls. Specifically, the minimum concentration at which estradiol could be distinguished from 0 was 2 pg/mL. The intraassay coefficient of variation was 16% and the interassay coefficient was 8.9%.

Breast Development—Breast development was assessed by visual inspection of the breasts using a Tanner rating scale from 1 (no development) to 5 (mature breast).²⁹ The nurses and research assistants performing the breast examinations were trained by Herman-Giddens and colleagues.⁶ Each breast was rated according to Tanner criteria and the mean of the breast ratings was calculated. In instances where the average breast score was between 2 breast stages (eg, 1.5), the breast stage was rounded down because the higher breast stage had not been fully achieved. Palpation of the breast, which is the superior method to assess breast development, was not possible in this study because it was conducted in a university setting. However, research has indicated that overweight and nonoverweight girls are as likely to be misclassified in the absence of palpation.⁷

PDS—Mothers provided information on their daughter's pubertal development by completing the PDS.²¹ The PDS is a nonintrusive measure of pubertal development and consists of 6 items assessing growth or change in height, the presence of body hair (including underarm and pubic hair), skin changes (especially the presence of pimples), breast development, and menstruation. Previous research supports the reliability and validity of this scale.^{21,30} Mothers also reported their own age at menarche as an index of genetic contribution to girls' timing of puberty.

Classification of Timing of Puberty

Each measure of pubertal development outlined above has advantages and disadvantages. Estradiol provides an objective measure of pubertal development. However, there is substantial variation in level of estrogen at any stage of pubertal development, making it difficult to determine a specific cutoff to define early maturation. The assessment of breast development can also be problematic. Although we were able to obtain a visual assessment of breast development, rather than relying on self-reports from girls, fat tissue can be mistaken for breast tissue in cases where the breast is not palpated. However, a key advantage of this method is that it is widely used by researchers and clinicians thereby increasing its applicability. Finally, reports on the PDS reflect mothers' assessments of girls' secondary sexual characteristics and physical signs of puberty. The advantage of the PDS is that it is simple and inexpensive to administer, yet it is based on the assumption that mothers are knowledgeable about daughters' pubertal status.

Because all measures of pubertal development have strengths and weaknesses, information from these 3 measures were combined into an overall index of pubertal status, which categorized girls as having either earlier or later timing of puberty at 9 years relative to the sample. Earlier developers were girls who fulfilled at least 2 of the following 3 criteria: 1) highest tertile for estradiol; 2) Tanner stage 3 for breast development; and 3) highest tertile for the PDS. Using these criteria, 44 girls were classified as earlier developers and 136 were classified as later developers. The aforementioned criteria were chosen to identify a select group of girls who were clearly more physically mature than girls of the same age. Consequently, these groups indicate timing of puberty relative to same-age peers in the sample and are not intended as clinical indices of either precocious or delayed puberty.

Statistical Analyses

Differences for earlier and later developing girls in background characteristics and measures of pubertal development at 9 years were assessed using one-way analysis of variance (continuous variables) and χ^2 analysis (categorical variables). In cases where differences in background differences were identified for the 2 groups, these variables were entered as covariates in the analyses that followed. A series of univariate logistic regression analyses assessed the likelihood of being an earlier developer at 9 years based on girls' 1) estimated percent body fat at 5, 7, and 9 years; 2) BMI percentile at 5, 7, and 9 years; 3) waist circumference at 7 and 9 years; and 4) height at 5, 7, and 9 years. These analyses were rerun at each age controlling for height to determine if the effects of percent body fat, BMI percentile, and waist circumference on pubertal timing were independent of accelerated growth in general. To examine associations between weight status and each individual measure of pubertal status, correlations between percent body fat, BMI percentile, waist circumference, and height at each age and each measure of pubertal status at 9 years were calculated using Spearman rank correlation analysis. Finally, multivariate logistic regression using polynomial trend scores was used to assess whether change in percent body fat and waist circumference from 5 to 9 years predicted the likelihood of experiencing earlier pubertal timing at 9 years. Polynomial trend scores for each variable are orthogonal (ie, independent) and thus are not susceptible to the problem of collinearity. For percent body fat, the following trend scores were created: 1) average across 5, 7, and 9 years; 2) linear change from the ages of 5 to 9; and 3) quadratic

change. For waist circumference, 1) average waist circumference across the ages of 7 to 9; and 2) linear change from the ages of 7 to 9 were calculated. The longitudinal analyses were rerun controlling for average height from the ages of 5 to 9 and linear change in height to control for accelerated growth. All analyses were conducted using SAS version 8.01 (SAS Institute, Cary, NC).

RESULTS

Background Characteristics

Families were white, well-educated (mothers' mean years of education = 14.5 ± 2.2 ; fathers' mean years of education = 14.9 ± 2.8), and had a median income between \$35 000 and \$50 000, reflecting the demographic characteristics of the area from which the families were sampled. As shown in Table 1, the prevalence of overweight and obesity increased slightly among girls between 5 to 9 years, with the greatest increases noted between 7 to 9 years. Increases across time were also noted in girls' percent body fat, BMI percentile, height, and waist circumference, although increases for BMI percentile were only noted between 7 and 9 years. As was expected, values for all measures of pubertal development increased with age. By 9 years, 56% of girls showed some breast development (ie, more than or equal to stage 2).

Weight Status at Each Age as a Predictor of Pubertal Timing

As shown in Table 2, at 9 years, girls classified as experiencing earlier puberty had significantly higher estradiol levels, more advanced breast development, and higher scores on the PDS than girls classified with later pubertal development, thereby supporting the construct validity of the 2 pubertal timing groups. In addition, 59% and 30% of girls classified as earlier pubertal development were overweight and obese, respectively, at 9 years. The comparable figures for the later developing girls were 21% and 8%.

Girls with higher percent body fat and girls who were taller at 5 years were significantly more likely to be classified as showing earlier pubertal timing at 9 years relative to their same-age peers (Table 3). Similarly, girls with higher weight status (percent body fat, BMI percentile, and waist circumference) and girls who were taller at 7 years were more likely to be an earlier developer at 9 years. Finally, at 9 years, earlier developers had significantly higher weight status (percent body fat, BMI percentile, and waist circumference) and were significantly taller than later developers. All associations between weight status at 5, 7, and 9 years and timing of puberty at 9 years were independent of girls' height, thereby ruling out the possibility that results simply reflect accelerated growth. The only exception was girls' percent body fat at 5 years. This relationship was reduced from being significant ($P < .05$) to being marginally significant ($P < .10$).

Similar results were found when each measure of pubertal development at 9 years was considered separately in a series of correlation analyses (Table 4). Specifically, higher percent body fat and greater height at 5 years were associated with more advanced pubertal development at 9 years for at least 2 of the 3 measures of puberty. Higher BMI percentile at 5 years was associated with more advanced pubertal development at 9 years for 1 of the 3 measures of puberty (ie, breast development). Girls' height and all measures of weight status (percent body fat, BMI percentile, and waist circumference) at 7 years were positively associated with all measures of pubertal development at 9 years; the 1 exception in this instance was the association between BMI percentile at 7 years and estradiol at 9 years. At 9 years, height and all measures of weight status were positively and concurrently associated with more advanced pubertal development for all measures of puberty.

Change in Weight Status as a Predictor of Pubertal Timing

Girls with higher average percent body fat across 5, 7, and 9 years (odds ratio [OR] = 1.18; 95% confidence interval [CI] = 1.07–1.30) and girls who showed greater linear increases in percent body fat from 5 to 9 years (OR = 1.17; 95% CI = 1.05–1.30) were significantly more likely to be classified as earlier developers at 9 years. Similar results were found for waist circumference. That is, girls with higher average waist circumference across 7 and 9 years (OR = 1.11; 95% CI = 1.05–1.18) and girls who showed greater linear increases in waist circumference from 7 to 9 years (OR = 1.12; 95% CI = 1.01–1.24) were more likely to be classified as earlier developers at 9 years. Findings for percent body fat and waist circumference were independent of girls' average height and increases in height.

Additional Analyses

Analyses were rerun using only Tanner breast stage, the most commonly used measure of pubertal development, to classify earlier and later developers. Girls with stage 1 breast development at 9 years were considered later developers and girls at stage 2 or greater at 9 years were classified as earlier developers. Results indicated that earlier developing girls had significantly higher percent body fat, BMI percentile, and greater waist circumference beginning at 5 years, independent of their height, and showed more rapid increases in these measures across time (data not shown). As would be expected, due to potential misclassification of overweight girls as showing more advanced pubertal development, all ORs were larger than those reported in the preceding analyses.

DISCUSSION

Using a longitudinal sample of girls followed from the ages of 5 to 9, results from this study illustrate that girls with higher weight status preceding puberty were at greater risk of earlier onset of puberty at 9 years. Specifically, girls with higher percent body fat at 5 years, and girls with higher percent body fat, higher BMI percentile, or larger waist circumference at 7 years were more likely to show more advanced pubertal development at 9 years. In addition, girls who showed greater increases in percent body fat from 5 to 9 years, or greater increases in waist circumference from 7 to 9 years, were more likely to experience earlier pubertal development at 9 years. Although earlier developers also exhibited accelerated growth from the ages of 5 to 9, results for weight status were still present after controlling for accelerated growth. The key contributions of this study are that it convincingly shows that weight status temporally precedes pubertal timing in a sample of white girls and that the association between weight status and pubertal timing is evident across multiple measures of weight status and pubertal timing.

Approximately 56% of girls in this study had begun breast development by 9 years. This figure differs somewhat from that reported by Herman-Giddens et al⁶ in which 32% of 9-year-old white girls had begun breast development. The discrepancy in these figures cannot be attributed to a lack of breast palpation in the current study because neither study used palpation to determine breast development. It is possible that the earlier onset of breast development in this sample is due to the high rate of overweight among the girls. Specifically, 30% of girls in this study were overweight at 9 years. However, this possibility is only speculative, as Herman-Giddens et al⁶ did not report the prevalence of overweight in their sample. Although the validity of visually assessing breast development is questionable, similar results were identified across all 3 measures of puberty. That is, no meaningful differences in the results were found when the 3 measures were combined to define earlier and later puberty, when only breast development was used to make a similar classification, and when each measure was assessed individually as a continuous variable. Consequently, results from this study are generalizable

across methods and are applicable to both clinical and academic settings, which generally have access to different resources to measure pubertal development.

There are at least 4 mechanisms that may explain the relationship between weight status during early and middle childhood and earlier onset of puberty among girls. First, a third parameter such as genetic influences may explain both early obesity and early onset of puberty. Obesity is known to have a genetic component.³¹ Obese mothers may have also had earlier onset of puberty, a trait that is passed on to their daughters. In this study, however, no differences were found in mothers' age at menarche for girls with earlier and later puberty. Second, it is possible that both greater stores of body fat and earlier timing of puberty reflect a process of accelerated growth beginning early in development (ie, before 5 years). In this study, girls who experienced earlier puberty were taller at 5 years and showed acceleration in growth leading up to pubertal onset. However, results for each measure of weight status were still significant or marginally significant once height was taken into consideration. A third possibility is that excess estrogen produced by greater body fat may be a trigger for earlier onset of puberty. Research suggests that the central accumulation of body fat has an especially strong influence on levels of estradiol among pubertal-aged girls³² and may hasten the onset of puberty beyond that due to total body fat.²³ This is consistent with our finding that waist circumference and change in waist circumference were positively associated with pubertal timing. Finally, obesity is associated with higher concentrations of leptin, which may have a permissive^{33,34} (ie, facilitative) or a direct^{18,35} effect on the onset of puberty in girls. Leptin is released from the adipocytes and may act as a metabolic signal to the hypothalamic pituitary gonadal axis for increased production of sex steroids.³⁶

Although the genetic predisposition for earlier puberty can be ruled out as an explanation for findings in this study, additional longitudinal research is needed to disentangle the contributions of accelerated growth, estrogen, and leptin in explaining the association between body fat (including total body fat and body fat distribution) and change in body fat across middle childhood and earlier onset of puberty among white girls at 9 years. Ideally, such a study would begin at birth, would continue through to mid or late adolescence, and would incorporate repeated assessment of height, weight, body fat, body fat distribution, estrogen, leptin, and pubertal development. Additional research is also needed to determine if higher levels of body fat precede pubertal onset in girls from different racial and ethnic groups and whether differences in fat levels during early childhood can help to explain earlier onset of puberty in African American girls in comparison to white girls.^{6,12,13}

Implications

Overweight and early timing of puberty among girls have both been linked to negative health and psychological outcomes. Overweight and obesity increase the risk of cardiovascular disease, diabetes, and cancer and psychosocial outcomes such as depression and low self-esteem.³⁷ The finding that overweight is causally implicated in the onset of earlier pubertal development suggests that being overweight during middle childhood may also place girls at increased risk for negative outcomes associated with early puberty such as higher rates of delinquent behaviors,^{38,39} greater risk of reproductive cancers,⁴⁰ and a greater likelihood of elevated weight status during adulthood.⁴¹ In the case of weight status during adulthood, the present research calls into question whether or not early puberty per se, or weight status preceding puberty, is a risk factor for overweight during adulthood and indicates a need for additional longitudinal studies to separate the influence of each factor in explaining obesity among adults. The practical implications of these findings emphasize the need for the implementation of early prevention and treatment programs for childhood overweight, beginning as early as the preschool period.

CONCLUSIONS

This study indicates that body fat levels during middle childhood are causally implicated in earlier timing of puberty among white girls. Higher percent body fat and greater abdominal adiposity at 5 and 7 years and greater increases in these variables across middle childhood were associated with earlier timing of puberty at 9 years. Future research can build on the results of this study by using a more detailed assessment of pubertal timing, by following girls from birth until adolescence, by focusing on the mechanisms that may explain the association between body fat and timing of puberty, and by assessing whether the results of this study are applicable to girls from other ethnic groups.

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ABBREVIATIONS

BMI	body mass index
PDS	Pubertal Development Scale
CI	confidence interval
OR	odds ratio

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TABLE 1**Measures of Growth and Body Fat at Each Age**

	5 Years Old	7 Years Old	9 Years Old
Mean percent body fat	17.47 (3.8)	19.1 (4.1)	22.2 (5.0)
Mean BMI percentile	59.7 (26.7)	59.0 (27.5)	64.3 (27.0)
Mean waist circumference (cm)	NA	59.4 (6.1)	66.9 (8.3)
Mean height (cm) ¹	111.2 (4.6)	123.7 (5.3)	135.8 (6.0)
Overweight	19%	20%	30%
Obese	5%	9%	13%
Mean estradiol (pg/mL)	—	—	2.8 (3.2)
Mean pubertal development scale	1.3 (0.2)	1.4 (0.2)	1.6 (0.3)
Breast development			
Tanner stage 1	—	86%	44%
Tanner stage 2	—	14%	35%
Tanner stage 3	—	0%	21%

Waist circumference was only assessed at 7 and 9 years. Estradiol was measured at 9 years only. Tanner breast stage was assessed at 7 and 9 years. All other measures of growth were obtained at ages 5, 7, and 9 years.

TABLE 2

Differences in Background Characteristics and Measures of Pubertal Development at 9 Years for Girls Classified With Earlier and Later Pubertal Development*

	Earlier Puberty <i>N</i> = 44	Later Puberty <i>N</i> = 136
Mean age in y	9.4 (.3) ^a	9.3 (.3) ^a
Family income (median)	\$35 000–\$50 000 ^a	\$50 000 ^{†a}
Fathers' mean years of education	14.7 (2.6) ^a	14.9 (2.8) ^a
Mothers' mean years of education	14.5 (2.2) ^a	14.9 (2.8) ^a
Mothers' mean age at menarche	12.5 (1.3) ^a	12.8 (1.3) ^a
Mean estradiol (pg/mL)	5.2 (4.9) ^a	2.0 (1.6) ^b
Breast development (%)		
Tanner stage 1	14% ^a	54% ^b
Tanner stage 2	22% ^a	39% ^b
Tanner stage 3	64% ^a	7% ^b
Mean PDS	1.9 (.22) ^a	1.4 (.27) ^b

* Different superscript letters indicate significant differences for the earlier and later puberty groups ($P < .05$).

[†] Classification of timing of puberty: earlier timing of puberty = girls who fulfilled at least 2 of the following 3 criteria:

^a highest tertile for estradiol;

^b Tanner stage 3 breast development; and

^c highest tertile for the PDS. Later puberty = girls who fulfill 1 or fewer of the criteria. These groups indicate timing of puberty relative to the sample and are not intended as clinical measures of either precocious or delayed puberty.

TABLE 3
Results From Logistic Regression Analysis Using Weight Status at Each Age to Predict the Likelihood of Experiencing Earlier Pubertal Timing at 9 Years

	Earlier Puberty (Mean)	Later Puberty (Mean)	OR	OR Controlling for Height
5 y				
Percent body fat	18.9 (4.4)	17.0 (3.6)	1.14 (1.04–1.24)**	1.10 (1.0–1.21) [†]
BMI percentile	66.1 (26.1)	57.8 (26.6)	1.01 (1.0–1.03)	1.01 (.99–1.02)
Height (cm)	114.26 (4.96)	110.17 (4.03)	1.25 (1.14–1.37)***	—
7 y				
Percent body fat	21.4 (4.3)	18.3 (3.8)	1.18 (1.09–1.29)***	1.15 (1.05–1.30)**
BMI percentile	70.8 (26.9)	55.3 (26.7)	1.02 (1.01–1.04)***	1.02 (1.01–1.04)**
Waist circumference (cm)	63.2 (6.8)	58.1 (5.3)	1.14 (1.08–1.2)***	1.10 (1.03–1.17)**
Height (cm)	127.20 (5.67)	122.61 (4.64)	1.21 (1.12–1.32)***	—
9 y				
Percent body fat	25.5 (5.0)	21.1 (4.5)	1.20 (1.11–1.30)***	1.17 (1.08–1.27)***
BMI percentile	79.6 (22.5)	59.4 (26.6)	1.04 (1.02–1.05)***	1.03 (1.02–1.05)***
Waist circumference (cm)	73.4 (8.8)	64.8 (6.9)	1.14 (1.09–1.19)***	1.10 (1.05–1.16)***
Height (cm)	140.37 (6.30)	134.34 (5.15)	1.22 (1.13–1.31)***	—

Means are presented for illustrative purposes. Differences in the means were not tested using analysis of variance as this assumes that pubertal timing is the independent variable and weight status is the dependent variable. Logistic regression was used to determine whether weight status at a particular age could be used to predict the likelihood of experiencing earlier pubertal development.

Classification of timing of puberty: Earlier puberty = girls who fulfilled at least 2 of the following 3 criteria: (a) highest tertile for estradiol; (b) Tanner stage 3 breast development; and (c) highest tertile for the PDS. Later puberty = girls who fulfilled 1 or fewer of the aforementioned criteria. These groups indicate timing of puberty relative to the sample and are not intended as clinical measures of either precocious or delayed puberty.

* $P < .05$.

** $P < .01$.

*** $P < .001$.

[†] $P < .10$.

TABLE 4
Spearman Rank Correlations Among Anthropometric Measures at Each Age and Pubertal Development at 9 Years

	Measures of Pubertal Development at 9 Years		
	Estradiol	Breast Development	PDS
5 y			
Percent body fat	.15*	.32***	.11
BMI percentile	.10	.25***	.07
Height	.16*	.19**	.24***
7 y			
Percent body fat	.20**	.53***	.29***
BMI percentile	.13	.42***	.16*
Waist circumference	.19**	.46***	.25***
Height	.20**	.16*	.29***
9 y			
Percent body fat	.21**	.62***	.33***
BMI percentile	.20**	.59***	.28***
Waist circumference	.23**	.62***	.33***
Height	.23**	.22**	.35***

* $P < .05$.

** $P < .01$.

*** $P < .001$.