Relation of body composition, parental overweight, pubertal stage, and race-ethnicity to energy expenditure among premenarcheal girls[1–3]

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ABSTRACT

Background: Previous studies assessed the influence of parental weight status, sexual maturation, race-ethnicity, and energy expenditure among children, but few examined these issues comprehensively.

Objective: The objective was to determine whether differences in energy expenditure among premenarcheal girls are related to the pubertal stage and the race-ethnicity of the girls or to the weight status of their parents.

Design: We measured the body composition and the energy expenditure of 196 nonobese girls enrolled in a longitudinal study. Total body water was measured by the isotopic dilution of ^{18}O water. We measured resting metabolic rate with the use of indirect calorimetry and daily energy expenditure by the doubly labeled water method. We used established criteria to determine sexual maturation. Parental weight status was based on body mass index.

Results: Resting metabolic rate was higher among girls with ≥ 1 overweight parent than among girls with 2 normal-weight parents. Total energy expenditure was also higher among girls with ≥ 1 overweight parent, but these results were of borderline significance. We found no effect of pubertal stage on resting metabolic rate. Nonresting energy expenditure was significantly lower among pubertal girls than among prepubertal girls. After adjustments for age and body composition, we noted that resting metabolic rate, nonresting energy expenditure, and total energy expenditure were all significantly lower among black girls than among white girls.

Conclusions: Differences in resting metabolic rate and total energy expenditure among premenarcheal girls were associated with parental weight status and the girls' race-ethnicity, whereas differences in nonresting energy expenditure were associated with pubertal stage and race-ethnicity. Whether the observed differences in energy expenditure persist after puberty and predict weight gain during puberty awaits the results of longitudinal analyses. *Am J Clin Nutr* 2002;76:1040–7.

INTRODUCTION

The prevalence of obesity among children and adolescents in the United States and worldwide has been escalating (1, 2). In the United States, the prevalence of overweight in children doubled between 1980 and 1994: recent survey data indicate that 13% of children aged 6–11 y and 14% of children aged 12–19 y are overweight (3).

Genetic and lifestyle factors may influence the rate of and differences in growth and development from preadolescence through adolescence. Several studies have examined the effects of parental obesity on energy expenditure among children, but the findings have been equivocal (4–6). The data from which to assess the effect of pubertal stage on energy expenditure are limited (7–9), and most of the reported studies that examined differences in energy expenditure and race-ethnicity have examined only resting metabolic rate (RMR) (5, 7, 9–13). No prior studies comprehensively examined the effects of maturation, race-ethnicity, and parental weight status on all the major components of energy expenditure.

In the 1980s, many cross-sectional studies were conducted to determine whether obesity was associated with a reduction in total energy expenditure (TEE) or in two of its components, RMR and the thermic effect of food. In several studies of nonobese and obese children and adolescents (8, 14–16), obese children were not found to have lower RMR or TEE. Similar findings have been reported for adults (17, 18). Although no reductions in energy expenditure were reported in the obese state, a reduction in energy expenditure in the preobese state could be a risk factor for the subsequent development of obesity (19).

Other factors contribute to the variability in energy expenditure. Fat-free mass (FFM) is the major determinant of RMR (14, 16, 17, 20–22), and fat mass appears to exert an independent effect (8, 23). Age and sex also contribute to variability in RMR (21, 24, 25). In one study, familial components of energy expenditure accounted for 11% of the variability in RMR in Native Americans from the southwestern United States (21).

To determine whether low energy expenditure among premenarcheal girls is a risk factor for greater body weight and fat gain during puberty, we initiated in 1990 a longitudinal study of the relation of energy expenditure to body composition, parental weight status, stage of sexual maturation, race-ethnicity, and

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premenarcheal age. After accounting for differences in age and body composition in this cross-sectional analysis, we determined whether maturational stage, race-ethnicity, or parental weight status had further effects on TEE, RMR, or nonresting energy expenditure (NREE).

SUBJECTS AND METHODS

Subjects

Between September 1990 and June 1993, we enrolled 196 girls in the Massachusetts Institute of Technology (MIT) Growth and Development Study. The criteria for enrollment were premenarcheal status and a triceps skinfold thickness < 85th percentile for age and sex (26). Premenarcheal girls aged 8–12 y were recruited from the Cambridge and Somerville public schools in Massachusetts and the MIT summer day camp and among friends and siblings of enrolled subjects. All participants were healthy, free of disease, and not taking any medication that affected body composition or energy expenditure. The study protocol was approved by both the Committee on the Use of Humans as Experimental Subjects at MIT and the Human Investigation Review Committee of the New England Medical Center.

Study design

The girls were admitted to the Clinical Research Center (CRC) at MIT for an overnight visit. At the time of their initial visit, a physician obtained a medical history and examined each girl to ensure that she was in good health. On the evening of admission, study participants consumed no food or beverages after 1800. At 2000, the staff obtained a baseline urine sample, and each participant was given 0.25 g ^{18}O water and 0.1–0.12 g $^{2}H_2O$/kg estimated total body water (TBW). After administering the isotopes, the study staff collected all urine voided until 0600 the next morning to determine the loss of isotope in the urine. The second void of the morning was collected at approximately 0800 to measure ^{18}O and ^{2}H enrichment above baseline values. This same sample was used to determine TBW and the initial time point of the energy-expenditure period. Participants were asked to collect a timed urine sample at home on days 1, 2, 4, 7, and 10. Participants returned to the CRC 2 wk after admission. At that time, the staff collected the second void of the day to end the energy-expenditure period.

Resting metabolic rate

We used an indirect calorimeter with customized software and fitted with a ventilated hood to measure RMR (14, 27) on 2 occasions: the morning after the participants were admitted to the Clinical Research Center and 2 wk later when they returned to the center at the end of the energy-expenditure period. We measured RMR for 30 min after an overnight fast; this measurement was immediately preceded by a 30-min rest period. During the measurement, the participants were allowed to read to minimize fidgeting. Their book was placed on top of the hood. A research assistant turned the pages for the participant as she cued with her eyes that she needed to have the pages turned. In a previous study (28), we found no differences in energy expenditure among subjects who were sitting, reading, or watching television. The intraclass correlation coefficient for RMR in a group of adolescents studied previously with this system was 0.98 (14). In the current cohort, the correlation coefficient for RMR measured in the same subject on 2 separate days was 0.96, which indicated that the measurements were highly reproducible.

The sample sizes for RMR, NREE, and TEE varied slightly because of missing or invalid data. RMR data from 5 girls were excluded because of excessive movement. If a girl's second RMR determination was ≥ 10% different from the first, she was asked to return for a third measurement, and we used the mean of the 2 closest results in the analysis. Such excessive variation occurred in 23 girls. For 2 participants who returned for a third measurement and for 1 participant who could not return, the measurements from these visits agreed to within 12%. We included these data in the analyses. We excluded the RMR data for one participant whose 2 measurements differed by 18%. We also excluded energy expenditure data for 12 participants who became ill during the 2-wk study period or who were on vacation, which meant that the energy-expenditure period did not represent their usual activity pattern.

Other variables

Either a study physician or a female co-investigator used Tanner's criteria (29) of breast development to determine sexual maturation. We classified the girls as either prepubertal (Tanner stage 1) or pubertal (Tanner stage 2 or 3).

Early in the study, we measured the height and weight of each participant's biological parents (who were dressed but were not wearing shoes). We obtained the height and weight of 180 mothers and 139 fathers. Parental overweight was defined as a body mass index (BMI; in kg/m^2) ≥ 25. Participants were classified as having 2 normal-weight biological parents or ≥ 1 overweight biological parent. A total of 42 participants could not be classified by parental weight status. These included participants who were adopted or for whom there were data from one lean biological parent only. We also included 20 sister pairs and 2 sets of 3 sisters. For the analyses of parental weight status, we randomly selected one sister to be included in the analysis. The participants were asked to indicate their race-ethnicity (white, black, Hispanic, Asian, or other) on the activity questionnaires.

Mass spectroscopy analysis

Isotopic analyses for assessment of body composition and energy expenditure were conducted at the US Department of Agriculture Human Nutrition Research Center at Tufts University (Boston) on 2 isotope ratio mass spectrometers (Hydra Gas; PDZ Europa Ltd, Northwich, United Kingdom, and Sira 10; Micromass, Altrincham, United Kingdom). The laboratory modified a technique of Prosser et al (30, 31) to measure isotopic enrichments of deuterium on the Europa instrument, and we used that instrument for the oxygen analyses in all but 4 participants. Approximately one-third of the hydrogen samples were analyzed on the SIRA 10 instrument, and the other two-thirds were analyzed on the Europa instrument. In a subset of 14 subjects, we compared the mean hydrogen elimination rate (k_h) for the 2-wk period on the 2 machines and found no significant differences (0.0833 on the SIRA and 0.0835 on the Europa, $P = 0.42$). We based the criteria for acceptable values on the SE of replicate measures: 0.35 for oxygen and 1.5 for deuterium.

Body composition

We used TBW to estimate body composition. Oxygen dilution space was calculated according to the method of Halliday and Miller (32) with the assumption that the ^{18}O dilution space was 1% higher than TBW and that the deuterium dilution space was 3% higher than the ^{18}O dilution space (33). FFM was further assumed to be 73% water (34). We calculated percentage body fat by subtracting FFM from body weight and then dividing the difference (fat) by weight (× 100%).

Energy expenditure

We used a modification of the equation of Lifson and McClintock (35) to calculate the mean daily rate of carbon dioxide production (rCO_2; in mol CO_2/d):

$$rCO_2 = (N/2.078)(1.01\ k_o - 1.04\ k_h) - 0.0246\ r_{Gf} \qquad (1)$$

where N is TBW in mol, k_o is the ^{18}O elimination rate, and r_{GF} is the estimated rate of isotopically fractionated water loss and is equal to $1.05N(1.01\ k_o - 1.04\ k_h)$ (35, 36). The elimination rates of the ^2H and ^{18}O isotopes were calculated according to the 2-point method, in which the isotopic enrichment relative to the concentration before the dose and the difference in time between the collection of the initial and final urine samples are measured, as follows:

$$k = (\ln APE_i - \ln APE_f)/\Delta\ \text{time} \qquad (2)$$

where APE is atom percentage excess.

Initially, we designed the study to use the multipoint method of determining the rates of elimination of the 2 isotopes, but the participants' compliance in collecting urine samples at home was inconsistent. Thus, we used the 2-point method to calculate energy expenditure. We used for our calculations only the timed urine samples that were obtained at the CRC.

We used Weir's equation (37) to calculate TEE. We determined rCO_2 by the doubly labeled water method and calculated oxygen consumption from rCO_2 and the food quotient. Using the 7-d food records that were kept by the participants during the second week of the energy-expenditure study, we calculated the proportions of dietary fat, carbohydrate, and protein (38) to determine the food quotient. For girls who did not keep a food diary ($n = 9$), the mean food quotient for the cohort was imputed. We calculated NREE by subtracting RMR from TEE.

The theoretical precision of the doubly labeled water method for measuring rCO_2 is 3% (39). Validation studies conducted in 4 laboratories using respiratory-exchange measurements found the precision of the doubly labeled water method to be 5% (40).

Statistical analysis

We used SAS software, version 8 (SAS Institute, Inc, Cary, NC) to conduct all analyses. We examined descriptive statistics and graphic displays to identify outliers and to ensure that assumptions of normality for linear regression modeling were met. All the variables except NREE were analyzed after the data were log transformed to achieve normality. Pearson's correlation coefficients were used to identify the body-composition variables that should be evaluated in subsequent multivariate linear models. We conducted chi-square tests to test for homogeneity of proportions for categorical variables (parental weight status, pubertal status, and race-ethnicity). Our strategy was first to determine which body-composition variables (or weight) were significantly related to the energy-expenditure variables. After adjustment for body composition or weight, we estimated separate general linear models to assess the influence of pubertal stage, race-ethnicity, and parental weight status on RMR, NREE, and TEE. Age was retained in all models, regardless of its statistical significance, to provide comparability with other studies. We estimated least-squares means from these models separately for the key categorical variables: parental overweight (yes or no), prepubertal or pubertal status, and white, black, or other race-ethnicity. We set the α level for all statistical tests at 0.05. We conducted stratified analyses when 2-way interactions between the key categorical variables were identified.

RESULTS

The mean (±SD) age of the subjects was 10.1 ± 1.0 y. Of the 196 participants, 123 girls were prepubertal and 73 were pubertal; all were premenarcheal. With the use of our classification for parental weight status, we found that 32.5% ($n = 50$) of subjects had 2 lean parents and 67.5% ($n = 104$) had ≥ 1 overweight parent. On the basis of the categories for race-ethnicity, 141 participants classified themselves as white, 28 as black, 13 as Hispanic, and 10 as Asian; 5 participants categorized themselves as "other." As we expected, age, weight, and height were all significantly higher among the pubertal participants than among the prepubertal participants ($P < 0.001$). FFM and fat mass also were significantly greater among the girls in the pubertal group, even after adjustment for height. Mean percentage body fat was 22.8 ± 4.7% for prepubertal girls and 24.1 ± 6.0% for pubertal girls. RMR, NREE, and TEE were all significantly greater among the girls in the pubertal group than among those in the pubertal group (**Table 1**). The mean (±SD) weight change over the 2-wk period of the TEE study was 0.22 ± 0.45 kg, or 0.70 ± 1.34%. More girls gained small amounts of weight than lost small amounts of weight.

The bivariate Pearson's correlation coefficients of RMR, NREE, and TEE with FFM, weight, and fat were all significant, except for the correlation of fat mass with NREE (data not shown). The correlations between FFM and RMR and between FFM and TEE were strong ($r = 0.81$ and 0.82, respectively). The correlation between weight and RMR was 0.80 and that between weight and TEE was 0.75. We observed moderate correlations for weight and FFM with NREE ($r = 0.48$ and 0.58, respectively). Fat mass was moderately correlated with RMR ($r = 0.49$) and TEE ($r = 0.38$). Age was moderately correlated with TEE ($r = 0.40$) and only weakly correlated with NREE ($r = 0.33$) and RMR ($r = 0.30$).

We observed no significant differences between the racial-ethnic distribution of the girls who had ≥ 1 overweight parent and the girls with 2 normal-weight parents or between those of the girls in the prepubertal and the pubertal groups. We did note that girls in the pubertal groups were more likely than were girls in the prepubertal group to have ≥ 1 overweight parent (chi-square test, $P < 0.04$).

Multivariate analysis

The final models that describe the relations of RMR, NREE, TEE, and body composition are shown in **Table 2**. We found that FFM, fat mass, and age were all significantly related to RMR, FFM and fat mass were significantly related to NREE, and only FFM was significantly related to TEE. For both NREE and TEE, the models that included a term for FFM explained more of the variance than did the models that included weight (NREE: $R^2 = 0.37$ compared with 0.24; TEE: $R^2 = 0.68$ compared with 0.57). After identifying the best set of body-composition values for each energy-expenditure variable, we added maturational stage, race-ethnicity, and parental overweight separately to determine whether any had a significant effect on energy expenditure.

TABLE 1
Participant characteristics at study entry in 1990–1993[1]

	Prepubertal group (n = 123)	Pubertal group (n = 73)	Total (n = 196)
Age (y)	9.7 ± 0.8	10.7 ± 0.9[2]	10.1 ± 1.0
Weight (kg)	30.1 ± 4.3	37.9 ± 5.8[2]	33.0 ± 6.2
Height (cm)	136.9 ± 6.9	146.3 ± 7.6[2]	140.4 ± 8.5
FFM (kg)	23.1 ± 3.1	28.6 ± 4.1[2]	25.2 ± 4.4
Fat mass (kg)	6.9 ± 2.0	9.2 ± 3.1[2]	7.9 ± 2.7
Percentage body fat (%)	22.8 ± 4.7	24.1 ± 6.0	23.3 ± 5.2
RMR (kJ/d)	4908 ± 506 [121]	5512 ± 610 [69][2]	5127 ± 617
NREE (kJ/d)	2817 ± 746 [112]	3174 ± 730 [66][2]	2949 ± 758
TEE (kJ/d)	7723 ± 1035 [114]	8777 ± 1076 [70][2]	8124 ± 1167
Race-ethnicity (%)			
White	75.6	64.4	71.4
Black	13.0	16.4	14.3
Hispanic	6.5	6.8	6.6
Asian	4.1	6.8	5.1
Other	0.8	5.5	2.6
Parental overweight (%)[3]			
Both with BMI <25	36.1	19.2	32.5
≥1 with BMI ≥25	64.0	80.9[4]	67.5

[1] $\bar{x}$ ± SD unless otherwise indicated; n in brackets. FFM, fat-free mass; RMR, resting metabolic rate; NREE, nonresting energy expenditure; TEE, total energy expenditure.
[2,4] Significantly different from prepubertal group: [2] $P < 0.01$, [4] $P < 0.04$.
[3] Missing information on parental BMI for 42 participants; one sister chosen randomly was included.

Separate analyses were performed because of the complexity of the analysis and the relatively large sample size.

Parental weight status

The RMR was higher among girls with ≥1 overweight parent than among those with 2 normal-weight parents (**Table 3**). For girls with ≥1 overweight parent, TEE was slightly higher, but the results were of only borderline significance ($P < 0.08$). These results did not change when we compared girls with 2 normal-weight parents and those with 2 overweight parents. Because of the significant difference in the number of prepubertal and pubertal participants with 2 normal-weight parents, we compared the RMR of the girls with 2 normal-weight parents with the RMR of those with ≥1 overweight parent, stratified by pubertal status. In both the prepubertal and pubertal groups, we found that RMR appeared to be higher among the girls with ≥1 overweight parent. The differences were significant in the pubertal girls ($P < 0.05$) and of borderline significance in the prepubertal girls ($P < 0.08$). We observed no significant differences in NREE according to parental weight status in either the prepubertal or the pubertal group. However, in the pubertal group, girls with ≥1 overweight parent had a significantly greater TEE than did girls with 2 normal-weight parents. In the prepubertal group, we found no significant difference between TEE among girls with 2 normal-weight parents or that among those with ≥1 overweight parent (Table 3).

Maturational stage

We found no differences in RMR and TEE among the girls in the prepubertal and the pubertal groups (**Table 4**). However, NREE was significantly lower in the pubertal group than in the prepubertal group ($P < 0.05$).

Race-ethnicity

Because there were few Hispanic and Asian participants, we reclassified those girls as "other" in race-ethnicity. Black girls had a significantly lower RMR, NREE, and TEE than did white girls (**Table 5**). The "other" category was too heterogeneous for meaningful interpretation.

Maturational stage and race-ethnicity

Because both pubertal status and race-ethnicity were related to energy expenditure, we stratified by pubertal status to determine whether the effect of race-ethnicity differed by pubertal status (Table 5). In both the prepubertal and the pubertal groups, we found that RMR and TEE were lower among black girls. After we stratified by pubertal status, the differences in NREE between black and white prepubertal girls and black and white pubertal

TABLE 2
Relation of body composition to energy expenditure by multivariate analysis[1]

	lnRMR (R^2 = 0.69)			NREE (R^2 = 0.37)			lnTEE (R^2 = 0.68)		
Measure	Estimate	SE	P	Estimate	SE	P	Estimate	SE	P
Intercept	8.184	0.446	<0.0001	−1559.982	1011.174	0.1247	7.640	0.558	<0.0001
lnFFM	0.576	0.036	<0.0001	711.496	85.301	<0.0001	0.742	0.0476	<0.0001
lnFat mass	0.049	0.016	0.0025	−101.369	36.056	0.0055	−0.011	0.020	0.5645
lnAge	−0.194	0.06	0.0014	21.727	137.05	0.8742	−0.123	0.076	0.1055

[1] RMR, resting metabolic rate; NREE, nonresting energy expenditure; TEE, total energy expenditure; FFM, fat-free mass.

TABLE 3
Effect of least-squares mean energy expenditure and parental weight status on energy expenditure[1]

Group	Both parents with BMI < 25 (n = 42)	≥1 parent with BMI ≥ 25 (n = 94)
Total		
RMR (kJ/d)	8.512 ± 0.010 (4974) [41]	8.547 ± 0.007[2] (5151) [91]
NREE (kJ/d)	2900 ± 108 [37]	3016 ± 71 [85]
TEE (kJ/d)	8.978 ± 014 (7930) [38]	9.007 ± 0.009 (8162) [88]
Prepubertal		
RMR (kJ/d)	8.476 ± 0.012 (4797) [31]	8.502 ± 0.009 (4925) [54]
NREE (kJ/d)	2831 ± 114 [28]	2868 ± 86 [48]
TEE (kJ/d)	8.943 ± 0.014 (7651) [29]	8.950 ± 0.011 (7708) [48]
Pubertal		
RMR (kJ/d)	8.570 ± 0.019 (5268) [10]	8.627 ± 0.010[3] (5581) [37]
NREE (kJ/d)	2846 ± 230 [9]	3273 ± 113 [37]
TEE (kJ/d)	9.003 ± 0.028 (8126) [9]	9.097 ± 0.013[2] (8924) [40]

[1] $\bar{x}$ ± SE of the log-transformed resting metabolic rate (RMR) and total energy expenditure (TEE) and the actual value of nonresting energy expenditure (NREE); geometric means (in parentheses) are the anti-logs of the logged mean values; n in brackets. NREE and lnRMR were adjusted for log-transformed age, fat, and fat-free mass. Log-transformed TEE was adjusted for log-transformed age and fat-free mass.
[2] Significant differences in parental weight status, $P < 0.01$.
[3] Significant difference in parental weight status, $P < 0.05$.

girls were no longer significant, although the magnitude of the differences persisted.

DISCUSSION

Obesity arises from an energy imbalance: an increase in energy intake, a decrease in energy expenditure, or both. Factors that may contribute to either an increase in energy intake or a decrease in expenditure have been the focus of considerable research. In this first comprehensive report, we examined the components of energy expenditure among normal-weight premenarcheal girls to determine whether we could identify characteristics associated with a reduction in energy expenditure. Studies of energy expenditure in children and adolescents (summarized in **Table 6**) have not comprehensively considered age, body composition, parental weight status, maturational stage, and race-ethnicity. We found potentially important differences in energy expenditure associated with these variables. Lower energy expenditure in the nonobese state could potentially be a risk factor for subsequent obesity.

TABLE 4
Least-squares mean energy expenditure and maturation stage[1]

	Prepubertal group	Pubertal group
RMR (kJ/d)	8.535 ± 0.007 (5089) [121]	8.536 ± 0.010 (5096) [69]
NREE (kJ/d)	3057 ± 64 [112]	2766 ± 89[2] [66]
TEE (kJ/d)	9.003 ± 0.009 (8123) [114]	8.976 ± 0.012 (7912) [70]

[1] $\bar{x}$ ± SE reflects the log-transformed resting metabolic rate (RMR) and total energy expenditure (TEE) and the actual value of nonresting energy expenditure (NREE); geometric means (in parentheses) are the anti-logs of the logged mean values; n in brackets. NREE and lnRMR were adjusted for log-transformed age, fat, and fat-free mass. Log-transformed TEE was adjusted for log-transformed age and fat-free mass.
[2] Significantly different from prepubertal group, $P < 0.05$.

The cross-sectional studies that have examined the relation between parental obesity and energy expenditure have been contradictory. In an early study, Griffiths and Payne (43) used heart rate monitoring to measure energy expenditure in a group of 4–5-y-old children of obese and nonobese parents. The results of the study suggest that the children of obese parents had lower energy expenditures than did the children of nonobese parents. However, because heart rate–monitoring devices may interfere with typical activity and because the relation between heart rate and oxygen consumption at low levels of activity is not linear, the results of this study are not clear. Goran et al (4) reported no significant differences in TEE (measured by the doubly labeled water method) between children of normal-weight and overweight parents, but they studied both normal-weight and overweight boys. They also reported that some of their participants had an RMR > TEE, a finding that is not physiologically possible. Treuth et al (5) found no differences in energy expenditure between the nonobese prepubertal daughters of normal-weight parents and of obese parents. Wurmser et al (6) reported that normal-weight daughters of overweight parents had a higher RMR (5330 kJ/d) than did normal-weight daughters of normal-weight parents (5017 kJ/d). Our findings of a higher RMR among the girls with ≥ 1 overweight parent are in keeping with those of Wurmser et al. Our data provide no support for the hypothesis that children with overweight parents may have a lower metabolic rate and thus are at elevated risk for developing obesity.

When we stratified our sample by pubertal status, we found higher RMR and TEE among pubertal girls with ≥ 1 overweight parent than among those with 2 normal-weight parents. The significance of these findings remains unclear. Because NREE was not higher among girls with overweight parents, the increase in TEE appears to reflect the increase in RMR. Although parental obesity was not associated with NREE in the pubertal period, an environmental influence of parental overweight on NREE may become evident later in adolescence.

The lack of differences in RMR between prepubertal and pubertal girls that we observed is consistent with the other cross-sectional analyses of pubertal status and energy expenditure (8, 9). In contrast with our findings, Sun et al (7) reported that RMR decreased among children from Tanner stage 1 to Tanner stage 3. The design of their study, although it is longitudinal, includes several limitations. Distinguishing prepubertal girls from pubertal girls is not difficult, but categorizing girls between Tanner stages 2 and 5 presents greater problems. In our analysis, we categorized girls as prepubertal (Tanner 1) or pubertal but premenarcheal (Tanner 2 or 3) to minimize misclassification. Several other limitations apply to the study by Sun et al: menarche was not accounted for, boys and girls were analyzed together, and the ages of the prepubertal children in the study ranged from 5 to 11 y.

Morrison et al (9) reported a lower RMR among postmenarcheal girls than among premenarcheal girls. This finding suggests that the decline in RMR with age may be related to the timing of menarche. The lower NREE that we observed among pubertal girls suggests that the energy spent on activity may decline as the girls enter puberty.

We found significantly lower RMR, NREE, and TEE among black girls than among white girls; NREE was significantly lower among black girls in the total sample, but not when stratified by pubertal status. This finding may reflect inadequate power. Our findings are consistent with other studies that found lower RMRs among black children than among white prepubertal children

TABLE 5
Least-squares mean energy expenditure and race-ethnicity[1]

Group	White girls (*n* = 140)	Black girls (*n* = 28)	Other ethnicity (*n* = 28)
Total			
RMR (kJ/d)	8.538 ± 0.005[a] (5106) [137]	8.485 ± 0.013[b] (4839) [26]	8.570 ± 0.012[c] (5273) [27]
NREE (kJ/d)	3010 ± 53[a] [128]	2730 ± 12[b] [25]	2859 ± 123[a,b] [25]
TEE (kJ/d)	9.002 ± 0.007[a] (8118) [131]	8.943 ± 0.016[b] (7650) [27]	8.997 ± 0.016[b] (8075) [26]
Prepubertal			
RMR (kJ/d)	8.493 ± 0.007[a] (4879) [92]	8.456 ± 0.017[b] (4702) [15]	8.539 ± 0.017[c] (5108) [14]
NREE (kJ/d)	2876 ± 61[a] [85]	2628 ± 147[a] [15]	2635 ± 147[a] [12]
TEE (kJ/d)	8.952 ± 0.008[a] (7719) [86]	8.905 ± 0.019[b] (7372) [16]	8.935 ± 0.022[a,b] (7952) [12]
Pubertal			
RMR (kJ/d)	8.618 ± 0.009[a] (5530) [45]	8.538 ± 0.019[b] (5104) [11]	8.637 ± 0.018[b] (5638) [13]
NREE (kJ/d)	3215 ± 101[a] [43]	2910 ± 223[a] [10]	3240 ± 191[a] [13]
TEE (kJ/d)	9.083 ± 0.013[a] (8802) [45]	9.005 ± 0.027[b] (8140) [11]	9.093 ± 0.024[b] (8896) [14]

[1] $\bar{x}$ ± SE reflects the log-transformed resting metabolic rate (RMR) and total energy expenditure (TEE) and the actual value of nonresting energy expenditure (NREE); geometric means are the anti-logs of the logged mean values; *n* in brackets. NREE and lnRMR were adjusted for log-transformed age, fat, and fat-free mass. Log-transformed TEE was adjusted for log-transformed age and fat-free mass. Means in the same row with different superscript letters are significantly different, $P < 0.05$.

(5, 9, 10, 13), adolescents (12), and adults (44, 45). Two studies examined the effect of race-ethnicity on NREE and TEE; one study (5) found a lower TEE among black girls than among white girls, but the investigators saw no differences in the energy expended on activity. The other study reported no differences in any component of energy expenditure among black girls or white girls (11).

Morrison et al (9) found differences in RMR between prepubertal white girls and black girls but no such differences between pubertal white girls and black girls. In our sample, both RMR and TEE differed significantly between black girls and white girls of both maturational stages. Differences between the findings of Morrison et al and ours may be due in part to their study cohort, many members of which were overweight, whereas none of our subjects were overweight.

Although our study represents one of the largest single studies with comprehensive energy-expenditure measurements, several limitations of our study are noteworthy. We did not have sufficient numbers of Hispanic and Asian participants for the analyses to be stratified by race-ethnicity. Furthermore, we did not have adequate power to stratify our analysis of parental obesity by both pubertal status and race-ethnicity. However, when we limited our analysis to white girls, our findings regarding the effect of parental obesity on energy expenditure by pubertal status were essentially unchanged. Finally, our determination of FFM was based on the assumption of a hydration factor of 0.73 for FFM. Recent studies using a multicompartmental model in which the components of FFM, protein, water, and minerals were measured independently suggest that the hydration factor may vary among persons by age, sex, maturation, and race-ethnicity (46, 47). However, it is not clear whether the between-group variability exceeds the within-group variation.

Longitudinal studies are needed to determine whether reductions in energy expenditure during the premenarcheal period are associated with increased weight gain throughout adolescence. Such studies will also help to clarify whether reductions in energy

TABLE 6
Previous studies of the effect of parental weight status, pubertal status, and race-ethnicity on energy expenditure in children[1]

Reference	Considered in analysis: Parental obesity	Pubertal status	Race-ethnicity	Outcome measured	Results
Fontvieille et al, 1992 (41)	No	No	Yes	RMR	No differences between Pima Indian children and white children
Goran et al, 1995 (42)	No	No	Yes	RMR, AREE, TEE	TEE and AREE lower in white children than in Mohawk children
Goran et al, 1995 (4)	Yes	No	No	RMR, NREE, TEE	No effect of parental obesity
Morrison et al, 1996 (9)	No	Yes	Yes	RMR	Lower RMR in black girls than in white girls; no differences between prepubertal and pubertal girls but lower RMR in postmenarcheal girls than in premenarcheal girls
Kaplan et al, 1996 (10)	No	No	Yes	RMR	Lower RMR in black girls than in white girls
Yanovski et al, 1997 (13)	No	No	Yes	RMR	Lower RMR in black girls than in white girls
Molnar et al, 1997 (8)	No	Yes	No	RMR	No effect of pubertal status
Wurmser et al, 1998 (6)	Yes	No	No	RMR	Higher RMR in normal-weight girls with 2 overweight parents than in normal-weight girls with 2 normal-weight parents
Sun et al, 1998 (11)	No	No	Yes	RMR, NREE, TEE	No differences between black children and white children
Wong et al, 1999 (12)	No	No	Yes	RMR, NREE, TEE	RMR, NREE, and TEE lower in black girls than in white girls
Treuth et al, 2000 (5)	Yes	No	Yes	RMR, NREE, TEE	No effect of parental weight status; RMR and TEE lower in black girls than in white girls
Sun et al, 2001 (7)[2]	No	Yes	Yes	RMR	Lower RMR in black children than in white children; lower RMR in children in Tanner stages 3 and 4,5 than in those in stage 1

[1] RMR, resting metabolic rate; AREE, activity-related energy expenditure; TEE, total energy expenditure; NREE, nonresting energy expenditure.
[2] Respresents a longitudinal analysis.

expenditure in preobese black children contribute to the higher prevalence of obesity seen among black girls than among white girls (2, 48) and whether decreases in NREE and TEE with maturation represent risk factors for the development of obesity during adolescence. Our findings suggest that these relations are complex and that they vary among the energy-expenditure components. Thus, parental obesity, maturational stage, and race-ethnicity should be carefully considered in an analysis designed to examine energy expenditure and its changes over time.

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