Prepubertal Asians have less limb skeletal muscle

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Skeletal muscle has a central role in intermediary metabolism, aerobic power, and strength. Its mass increases as a portion of body weight during growth, accounting for 21% at birth, 36% at adolescence, and 45% in adulthood (13). Observed gender differences in fracture risk in adults have led to investigation of childhood race and gender differences in bone mineral mass and its growth (3, 4, 15). Similarly, differences in risk for metabolic disorders, even in adolescence, suggest the importance of evaluation of race and gender differences in skeletal muscle mass in children, especially before the dramatic changes of puberty (1, 5, 11, 12, 19, 26).

Greater limb lean tissue mass has been reported in African-American compared with Caucasian children throughout Tanner stages 1–5 (31). Ellis et al. (3, 4) reported race differences in fat-free mass (FFM) between 5- to 7-yr-old African-American and Caucasian children. A failure to control for pubertal staging has left many other reports less easy to interpret. Race differences in total body bone mineral content (TBBMC), adjusted for total body bone area, age, height, and weight, have been reported in prepubertal African-American, Asian, and Caucasian girls and boys. African-American children had greater TBBMC than Asian and Caucasian children (15), whereas no differences were found between Asian and Caucasian children.

Gender differences in lean body mass (LBM) (2–4, 7, 33) have been reported from birth throughout childhood, girls having smaller amounts than boys. A recent report from a longitudinal analysis of children followed from Tanner 1–5 found that Tanner 1 girls had smaller limb lean mass than boys (31). TBBMC was reported to be smaller in Tanner 1 girls compared with boys among African-Americans, Asians, and Caucasians (15).

The availability of dual-energy X-ray absorptiometry (DXA) has provided a technique that allows for the indirect assessment of total body and regional lean tissue mass in both pediatric and adult populations. Skeletal muscle mass is the largest component of lean tissue mass. Appendicular skeletal muscle (ASM) accounts for >74% of total body skeletal muscle in adults (30). Previous studies in adults (14, 17) support the validity of DXA estimates of ASM, which represents the combined lower and upper limb fat-free soft tissues. Earlier studies in adults from our laboratory reported significantly larger amounts of ASM in boys compared with girls and in African-Americans compared with Caucasians, after adjusting for stature, weight, and age (10).

Of interest to us was whether gender and race differences evident in adulthood already exist in prepuberty. Little is known about body composition (including skeletal muscle mass) in Asians and whether Asians are similar to or different from African-Americans and Caucasians. The essential role of skeletal muscle in many physiological processes throughout the lifespan makes understanding of factors affecting it.

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significant. The recently reported greater incidence of Type 2 diabetes mellitus in adolescents in the USA (particularly in girls from minority populations) (1, 5, 11, 12, 26) and in Japan, for example (20), makes evaluation of race and gender differences in pediatric skeletal muscle mass especially important. Identification and characterization of differences could form the basis for further investigation of the associated metabolic implications.

The primary aim of this study was to test the hypothesis that prepubertal Asians have less ASM mass compared with African-Americans and Caucasians. We carried out this aim by examining in a cross-sectional cohort the independent effect of race on DXA-measured ASM mass, after controlling for age, stature, and body weight.

The second aim of this study was to test the hypothesis that ASM is smaller in prepubertal Asian girls compared with Asian boys, after controlling for age, stature, and body weight.

METHODS

Protocol

All medical and body composition evaluations were carried out on the same day with the subject clothed in a hospital gown and without shoes. Subjects reported for testing to the Body Composition Unit, St. Luke’s-Roosevelt Hospital Center. The study was approved by the Institutional Review Board of St. Luke’s-Roosevelt Hospital, and a parent or guardian of the subject gave written consent to participate.

Subjects

Subjects were 170 girls (67 Asian, 46 African-American, and 57 Caucasian) and 166 boys (69 Asian, 32 African-American, and 65 Caucasian) who had participated in a multiracial body composition investigation (15). Recruitment of subjects occurred over a 5-yr period through local schools and flyers posted in the local community. Inclusion criteria required that subjects be prepubertal, ambulatory with no orthopedic problems that could potentially affect any of the variables under investigation, and healthy without any diagnosed medical conditions. Pubertal status was established according to the criteria of Tanner (32) by a pediatrician or pediatric nurse practitioner, and only Tanner 1 subjects were included in the present analyses.

Race was determined by self-report. All parents and grandparents for each child were required to be Asian (for Asians), non-Hispanic African-American (for African-Americans), and non-Hispanic Caucasian (for Caucasians). The Asians were of Chinese and Korean descent.

Body Composition

Body weight was determined from the sum of fat, lean, and bone mineral masses by whole body DXA, which is provided as a routine software feature. Height was measured to the nearest 0.5 cm with a stadiometer (Holtain, Crosswell, Wales). FFM was determined as the difference between DXA-derived body weight and DXA fat mass.

ASM

Total body fat, fat-free body mass, and ASM mass were measured with a whole body DXA (DPX, Lunar Radiation, Madison, WI). Pediatric software version 3.8G was used to analyze all of the DXA scans.

The calculation of ASM mass has been previously described in detail (24). With the use of specific anatomic landmarks, the legs and arms are isolated on the skeletal X-ray planogram (anterior view) (Fig. 1). The arm encompasses all tissue extending from the center of the arm socket to the phalange tips, avoiding contact with the ribs, pelvis, or greater trochanter. The leg consists of all tissue extending from an angled line drawn through the femoral neck to the phalange tips. The system software provides the total mass, ratio of soft tissue attenuations, and bone mineral mass for the isolated regions. The ratio of soft tissue attenuation for each region was used to divide bone mineral-free tissue of the extremities into fat and fat-free components. The fat-free soft tissue of the extremities was assumed to represent ASM.
ASM was taken as the combined sum of leg and arm fat-free soft tissue. Repeated daily measurements over 5 days in four adult subjects showed a coefficient of variation (CV; mean ± SD) of 2.2 ± 0.6% for arm skeletal muscle and 1.5 ± 0.9% for leg skeletal muscle. In prepubertal girls, 6-wk apart measurement showed a CV of 2.30% of total body FFM, 4.09% for total arm mass, and 2.75% for total leg mass (6). An anthropomorphic spine phantom made up of calcium hydroxapatite embedded in a 17.5 × 15 × 17.5 cm block was scanned for quality control each morning before subject evaluation. The phantom was also scanned immediately before and after all DXA system manufacturer maintenance visits. The measured phantom bone mineral density was stable throughout the study period at 1.166–1.196 g/cm². Ethanol and water bottles (8-liter volume), simulating fat and fat-free soft tissues, respectively, were scanned as soft tissue quality control markers monthly. The range in measured R values over the study period was 1.255–1.258 (CV = 0.127%) and 1.367–1.371 (CV = 0.103%), for ethanol and water, respectively.

**ASM Measurement Method**

Unpublished data from our laboratory in nine prepubertal girls and boys show DXA-measured ASM and magnetic resonance imaging (MRI)-derived skeletal muscle mass to be highly correlated (r = 0.92). Skeletal muscle mass was measured by using whole body multislice MRI. The pediatric protocol involved the acquisition of ~35–40 axial images, 10-mm thickness, and at 25-mm intervals across the whole body with the use of a 1.5-T scanner (6X Horizon, General Electric, Milwaukee, WI). The technical errors for repeated measurements of the same scan by the same observer of MRI-derived skeletal muscle tissue volume in our laboratory are 0.7% (9). MRI volume estimates were converted to mass by using assumed stable density of 1.04 g/cm² (30).

DXA- and MRI-measured lower limb skeletal muscle mass have been shown to be highly correlated (r = 0.94, P < 0.001) in adults (29). DXA-measured ASM and computerized axial tomography-derived total body skeletal muscle mass have been shown to be highly correlated (r = 0.95, P < 0.001) in adults (35). Similarly, high correlations have been found between DXA-measured ASM and MRI-derived total body skeletal muscle mass in adults (r = 0.98) (18).

**Statistical Analysis**

Data were analyzed by using the statistical program SPSS version 8.0 (1997, SPSS Institute, Chicago, IL). Between-race differences in baseline subject characteristics were tested by using a one-way ANOVA for each gender, followed by pairwise multiple-comparison tests with Bonferroni correction. Pearson’s correlation coefficients were used to establish the univariate relationships between ASM and other body composition components and subject demographic characteristics. To assess the effects of race and gender on ASM, ASM mass was used as the dependent variable, and race and gender were fitted after adjustment for height, weight, and age in multiple-regression models. To assess the effects of height, weight, and age on ASM within race- and gender-specific groups, ASM mass was used as the dependent variable, and height, weight, and age were used as the independent variables in multiple-regression models. Potential interaction terms were explored for selected variables. Statistical significance was set at P < 0.05, and, for multiple-comparison tests, the P values were adjusted. Group subject data are expressed as means ± SD.

**RESULTS**

**Subject Characteristics**

The subject characteristics are summarized in Table 1. There were no differences in age, weight, height, body mass index, and percent body fat among the three girl race groups. The Asian girls had less FFM (P = 0.01), ASM mass (P < 0.001), and TBBMC (P = 0.002) than the African-American girls. Asian girls had less FFM (P = 0.02), ASM mass (P = 0.02), and TBBMC (P = 0.03) than the Caucasian girls.

There were no differences in age, weight, height, body mass index, and FFM among the three male race groups. African-American boys had a trend toward larger ASM mass than the Caucasian boys (P = 0.07).

**ASM Univariate Correlations**

ASM mass was significantly and positively correlated with age, height, body weight, body mass index, and fat-free body mass (all P < 0.01) in Asian, Caucasian, and African-American girls and boys (Table 2). ASM was highly correlated with FFM (r = 0.98–0.99) in all groups.

**ASM Mass**

ASM mass multiple-regression models for the six subgroups (Asian girls and boys, Caucasian girls and boys, African-American girls and boys) explored the

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Table 1. Subject characteristics

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<td>Asian</td>
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<td>African-American</td>
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<tr>
<td>Age, yr</td>
<td>7.8 ± 1.4</td>
<td>8.3 ± 1.6</td>
<td>7.8 ± 1.4</td>
<td>8.2 ± 1.6</td>
<td>7.8 ± 1.5</td>
<td>7.8 ± 1.6</td>
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<td>Body weight, kg</td>
<td>27.2 ± 6.73</td>
<td>30.2 ± 10.2</td>
<td>29.9 ± 8.4</td>
<td>31.8 ± 9.13</td>
<td>30.0 ± 9.5</td>
<td>32.9 ± 12.8</td>
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<tr>
<td>Height, m</td>
<td>1.28 ± 0.09</td>
<td>1.31 ± 0.11</td>
<td>1.30 ± 0.09</td>
<td>1.32 ± 0.11</td>
<td>1.31 ± 0.10</td>
<td>1.32 ± 0.11</td>
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<tr>
<td>BMI kg/m²</td>
<td>16.9 ± 2.6</td>
<td>17.6 ± 3.7</td>
<td>17.8 ± 3.8</td>
<td>18.2 ± 3.0</td>
<td>17.3 ± 3.2</td>
<td>18.7 ± 4.9</td>
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<td>Body fat, kg</td>
<td>6.5 ± 4.1</td>
<td>7.4 ± 6.2</td>
<td>7.0 ± 5.9</td>
<td>7.2 ± 4.6</td>
<td>5.6 ± 4.9</td>
<td>7.0 ± 7.9</td>
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<td>Fat-free body mass, kg</td>
<td>20.8 ± 3.4</td>
<td>22.7 ± 4.9</td>
<td>23.0 ± 3.5</td>
<td>24.6 ± 5.4</td>
<td>24.3 ± 5.4</td>
<td>25.9 ± 5.6</td>
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<tr>
<td>ASM, kg</td>
<td>8.5 ± 1.7‡</td>
<td>9.5 ± 2.5</td>
<td>10.2 ± 1.9</td>
<td>10.3 ± 2.8</td>
<td>10.1 ± 2.8§</td>
<td>11.5 ± 3.1</td>
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<td>TBBMC, kg</td>
<td>0.97 ± 0.19‡</td>
<td>1.08 ± 0.26</td>
<td>1.12 ± 0.23</td>
<td>1.15 ± 0.28</td>
<td>1.09 ± 0.29</td>
<td>1.20 ± 0.32</td>
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Values are means ± SD. ASM, appendicular skeletal muscle; TBBMC, total body bone mineral content; BMI, body mass index. *P < 0.05 and †P < 0.001, Asian vs. African-American. ‡P < 0.05, Asian vs. Caucasian. §P = 0.07, for Caucasian vs. African-American.
Table 2. ASM mass univariate correlations

<table>
<thead>
<tr>
<th></th>
<th>Girls</th>
<th>Boys</th>
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<tr>
<td></td>
<td>Asian</td>
<td>Caucasian</td>
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<tr>
<td>ASM vs.</td>
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<tr>
<td>Age</td>
<td>0.72 (0.07)</td>
<td>0.76 (0.05)</td>
</tr>
<tr>
<td>Body weight</td>
<td>0.92 (0.09)</td>
<td>0.91 (0.08)</td>
</tr>
<tr>
<td>Height</td>
<td>0.88 (0.08)</td>
<td>0.92 (0.08)</td>
</tr>
<tr>
<td>BMI</td>
<td>0.66 (0.07)</td>
<td>0.70 (0.05)</td>
</tr>
<tr>
<td>FFM</td>
<td>0.98 (0.09)</td>
<td>0.99 (0.09)</td>
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FFM, Fat-free mass. All correlations are $P < 0.01$.

Table 3. ASM mass multiple regression analysis models

<table>
<thead>
<tr>
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<th>Regression Coefficients</th>
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<tr>
<td></td>
<td>Height, cm</td>
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<tr>
<td>Girls</td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>0.07 ± 0.02*(0.44†)</td>
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<tr>
<td>Caucasian</td>
<td>0.09 ± 0.03*(0.66†)</td>
</tr>
<tr>
<td>African-American</td>
<td>0.12 ± 0.02*(0.74†)</td>
</tr>
<tr>
<td>Boys</td>
<td></td>
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<tr>
<td>Asian</td>
<td>0.10 ± 0.02*(0.52†)</td>
</tr>
<tr>
<td>Caucasian</td>
<td>0.14 ± 0.03*(0.54†)</td>
</tr>
<tr>
<td>African-American</td>
<td>0.16 ± 0.04*(0.62†)</td>
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Values are estimates of regression coefficient ± standard error of estimate (SEE). Nos. in parentheses represent partial correlation coefficient between ASM and the corresponding variable, controlling for the other variables in the same model. $R^2$, explained variance. *$P < 0.01$, †$P < 0.001$, where $P$ refers to the significance of the regression coefficient and partial correlation in the regression model.

The independent effects of height, weight, and age on ASM (Table 3).

**Height, weight, and age.** With the use of multiple-regression analyses to predict ASM, height and body weight explained between 90 and 95% of the ASM variance in all six subgroups. Only in Caucasian girls did age contribute significantly to the multiple-regression model ($P = 0.002$).

**Gender.** After adjusting for height, body weight, and age, Asian girls had smaller ASM compared with Asian boys ($P < 0.001$). However, gender differences in ASM were also found in Caucasians and African-Americans ($P < 0.001$) (Fig. 2, gender). The magnitude of the gender difference in ASM was not different across race groups. The gender effects on ASM were dependent on weight and height across all race groups ($P < 0.005$). The gender effect on ASM increased as height and weight increased.

**Race.** After adjusting for height, weight, and age, Asian girls and boys had less ASM than Caucasian girls ($P = 0.004$) and boys ($P = 0.07$). Asian and Caucasian girls and boys had less ASM compared with African-American girls ($P < 0.001$) and boys ($P < 0.001$) (Fig. 3, race). Within Asian and Caucasian girls, the race effect on ASM was dependent on height. As height increased, the differences in ASM between Asian and Caucasian girls increased ($P = 0.019$) (Fig. 4). Specifically, Asian girls tended to have more ASM than Caucasian girls at shorter heights and less ASM at taller heights. The slope of the regression line for African-American girls was not significantly different from that for Asian and Caucasian girls (Fig. 4). No race interaction effects were observed in boys.

**DISCUSSION**

This study, to our knowledge the first including Asian children, shows that, after adjusting for height, weight, and age, prepubertal Asian girls and boys have less ASM mass compared with Caucasians and African-Americans. The present findings demonstrate prepubertal sexual dimorphism of ASM in Asians, as they do for the other races, and extend previous reports of gender differences in FFM in prepubertal children to Asians (2–4, 7, 33). Our results indicate that race (i.e., Asian, Caucasian, and African-American) and gender are independent determinants of a prepubertal child's ASM mass.

**Skeletal Muscle Mass Determinants**

**Height, weight, and age.** Our results indicate that height and weight are the main correlates of ASM, explaining in excess of 80% of between-individual variations in this sample. Healthy children grow in height and weight with increasing age. Thus the univariate correlation of age with ASM is expected, as age alone is...
a proxy for normal growth. However, age was an independent contributor to ASM in the regression model for Caucasian girls only, for whom it increased the explained variance by 1.05%.

In these same prepubertal children, age was an independent determinant for adjusted TBBMC in all gender-race groups (15). Together, these two studies suggest that prepubertal individuals of the same gender, race, height, and weight, but of differing ages, will have the same ASM, but that the older child will have greater TBBMC. LBM has been reported to grow steadily during childhood, with the proportion of body weight as LBM remaining fairly constant (7, 8, 23). However, the difference between the effect of age on ASM and TBBMC observed in this population suggests that the proportion of the subcompartments of FFM (e.g., ASM and TBBMC) change during normal childhood growth.

Gender. In all race groups, ASM was smaller in girls than in boys after adjusting for stature, weight, and age. Our findings are in contrast to some previous reports (27) of no gender differences in body composition by DXA during Tanner stages 1 and 2 but are consistent with the findings of others (2–4, 7, 31, 33). The different models for determinants of ASM for girls and boys in our study imply that factors regulating gender-specific skeletal muscle mass are clearly present in children before the appearance of the physical signs of puberty. The lack of an independent effect of age suggests that the gender difference is stable through prepuberty.

The mechanism for this gender difference is unclear. Gonadal steroids are major mediators of adult sexual dimorphism of body composition, including fat-free soft tissues (28). Previous reports demonstrated that prepubertal girls have higher concentrations of circulating estradiol than prepubertal boys (21) and that gonadotropin and gonadal steroids increase gradually in both boys and girls from the age of 5 yr (25, 34). Thus prepuberty is a period with gender differences in circulating concentrations of sex steroids and of changes in these concentrations with advancing age. The earlier skeletal maturation of girls, for example, has been attributed to the greater estradiol level in girls compared with boys (21). In contrast, the gender differences observed in this cross-sectional study were stable across ages, suggesting a nonhormonal (possibly genetic) mechanism.

Race. Our study results indicate that Asians have less ASM mass than do Caucasians and African-Americans and Caucasians have less ASM mass than do African-Americans. The significantly less ASM of prepubertal Asian children compared with Caucasians and African-Americans is in the same direction as that reported in adults (36). A recent report by Mackelvie et al. (22) found that Asian Tanner 1 girls have 1.7 kg less LBM than do Caucasian girls. However, no adjustment was made for the 2.5-kg weight difference between the two race groups. We are unaware of any previous studies of skeletal muscle mass in Asian children, although Ishida et al. (16) reported higher ultrasound-derived absolute muscle thicknesses in Caucasian compared with Japanese young adult women (20–30 yr) at eight sites on arms, trunk, and legs. The correlation of

Fig. 3. ASM mass in Asian, Caucasian (Cauc), and African-American (AA) girls and boys. Values are means adjusted for height, weight, and age. Significant differences: *Asian vs. African-American, \( P < 0.001; \) †Asian vs. Caucasian, \( P = 0.004 \) (girls) and \( P = 0.07 \) (boys); ‡Caucasian vs. African-American, \( P < 0.001 \).

Fig. 4. ASM mass vs. height in African-American (○), Caucasian (●), and Asian (▲) girls (A) and boys (B). Dashed, solid, and dotted lines represent the linear regression lines for African-American, Caucasian, and Asian, respectively. A: African-American: ASM = 18.3 \([\text{height (m)}] - 13.74, r^2 = 0.78\), SE of estimate (SEE) = 0.90, \( P < 0.001, n = 46 \). Caucasian: ASM = 20.7 \([\text{height (m)}] - 17.53, r^2 = 0.85, \text{SEE} = 0.98, P < 0.001, n = 57 \). Asian: ASM = 17.2 \([\text{height (m)}] - 13.46, r^2 = 0.77, \text{SEE} = 0.81, P < 0.001, n = 67 \). B: African-American: ASM = 25.6 \([\text{height (m)}] - 22.26, r^2 = 0.80, \text{SEE} = 1.42, P < 0.001, n = 32 \). Caucasian: ASM = 25.1 \([\text{height (m)}] - 22.88, r^2 = 0.86, \text{SEE} = 1.05, P < 0.001, n = 65 \). Asian: ASM = 24.2 \([\text{height (m)}] - 21.75, r^2 = 0.85, \text{SEE} = 1.06, P < 0.001, n = 69 \).
ASM and FFM was high within each group (Table 2). Nevertheless, when FFM was added as an independent variable (African-American vs. Caucasian, African-American vs. Asian), race was a significant variable in the regression model. Therefore, whereas larger amounts of ASM may be explained in part by larger amounts of FFM, it does not account for all of the between-race differences.

Several investigators have previously reported greater DXA-derived lean tissue mass and bone mineral content in African-American compared with Caucasian children (3, 4, 15, 31). Our findings suggest race differences in total FFM and its subcomponent ASM in prepubertal children. Of interest, in our study the differences in ASM persist after adjustment for height, weight, and age among all three race groups, whereas Horlick et al. (15) found that the only significant difference in adjusted TBBMC was between African-Americans vs. Asians and Caucasians. This suggests that the proportions of specific FFM subcomponents may differ by race. Although mechanisms leading to skeletal muscle differences among races were not explored in the present study, one previous report suggests an endocrine basis. (37).

Study Limitations

**Sample representativeness.** The participants in our study were volunteers from the New York metropolitan area and not randomly selected. All subjects were in good health but may not be representative of the general pediatric population. The minimum and maximum ages of the study population were 5 and 12 yr, respectively, and, therefore, our regression models may not be indicative of ASM in younger and older prepubertal children.

Conclusions

The prepubertal period as defined by Tanner stage 1 is a dynamic phase exhibiting both gender and race dimorphisms in regional skeletal muscle mass. These data are the first to demonstrate a less amount of ASM in prepubertal Asian children compared with Caucasians and African-American children. In addition, gender differences in ASM are present before the onset of puberty in Asians, Caucasians, and African-Americans. These findings confirm that body composition should be interpreted according to gender and race and, in particular, that different standards for skeletal muscle may be applicable to Asian children.

The central role of skeletal muscle in intermediary metabolism and in the development and maintenance of bone mass throughout the lifespan means that factors that mediate skeletal muscle need to be understood. This study demonstrates some of the race and gender characteristics of prepubertal skeletal muscle mass and provides a basis for investigation of the associated health and metabolic implications.

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REFERENCES


