Percentage of appendicular skeletal muscle mass reference and association with metabolic Syndrome in Korean adolescents

Da Hye Lee¹, Sung-Chan Kang², Seung-sik Hwang², Yun Jeong Lee¹,³, Hwa Young Kim³,⁴, Seong Yong Lee³,⁵, Choong Ho Shin¹,³, Jaehyun Kim³,⁴

¹Department of Pediatrics, Seoul National University Children’s Hospital, Seoul, Korea
²Department of Public Health Science, Graduate School of Public Health, Seoul National University, Seoul, Korea
³Department of Pediatrics, Seoul National University College of Medicine, Seoul, Korea
⁴Department of Pediatrics, Seoul National University Bundang Hospital, Seongnam, Korea
⁵Department of Pediatrics, Seoul Metropolitan Government-Seoul National University Boramae Medical Center, Seoul, Korea

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Address for correspondence: Jaehyun Kim
Department of Pediatrics, Seoul National University Bundang Hospital, 82, Gumi-ro 173 Beon-gil, Bundang-gu, Seongnam 13620, Korea
Email: pedendo@snubh.org
ORCID: 0000-0002-0203-7443
Abstract

**Purpose:** The association between appendicular skeletal muscle mass (ASM) and cardiometabolic risk has been emphasized. We estimated reference values of the percentage of ASM (PASM) and investigated its association with metabolic syndrome (MS) in Korean adolescents.

**Methods:** Data from Korea National Health and Nutrition Examination Survey performed between 2009 and 2011 was used. Tables and graphs of reference PASM were generated using 1,522 subjects (807 boys) aged 10 to 18. The relationship between PASM and each component of MS in adolescents was further analyzed in 1,174 subjects (613 boys). Moreover, the pediatric simple metabolic syndrome score (PsiMS), homeostasis model assessment of insulin resistance (HOMA-IR), and the triglyceride glucose (TyG) index were analyzed. Multivariate linear and logistic regressions adjusting for age, sex, house income, and daily energy intake were performed.

**Results:** In boys, PASM increased with age, but girls showed a different trend that declines with age. PsiMS, HOMA-IR, and TyG index showed inverse associations with PASM (PsiMS, $\beta = -0.105$, p-value <0.001; HOMA-IR, $\beta = -0.104$, p-value <0.001; TyG index, $\beta = -0.013$, p-value <0.001). PASM z-score was negatively associated with obesity (aOR 0.22, 95% CI 0.17-0.30), abdominal obesity (aOR 0.27, 95% CI 0.20-0.36), hypertension (aOR 0.65, 95% CI 0.52-0.80), and elevated triglycerides (aOR 0.67, 95% CI 0.56-0.79).

**Conclusions:** The probability of acquiring MS and insulin resistance decreased with higher PASM values. The reference range may offer clinicians information that aid the effective management of patients. It is urged that clinicians monitor the body composition using standard reference databases.

**Keywords:** Muscle, Skeletal; Reference Values; Metabolic Syndrome; Insulin Resistance; Pediatric Obesity
Introduction

The prevalence of metabolic syndrome (MS) is increasing worldwide.\(^1\,^2\) MS in adolescents can persist into adulthood and predict cardiovascular disease and type 2 diabetes 25-30 years after onset.\(^3\,^4\) Therefore, early detection and management of MS are becoming particularly essential. Insulin resistance (IR) is regarded as a primary etiology of MS while it is not included in the definition of MS.\(^5\,^6\) Skeletal muscle plays an essential role in lipid and protein metabolism, as well as insulin-mediated glucose utilization.\(^7\) Appendicular skeletal muscle mass (ASM) is a highly reliable predictor of total body skeletal muscle mass.\(^8\) ASM refers to the mass of extremities after subtracting fat and bone mass from the total mass of extremities.\(^9\) Dual-energy X-ray absorptiometry (DXA) is a simple and quick method to evaluate body composition, including skeletal muscle mass, that can estimate ASM.\(^10\) ASM adjusted by weight (percentage of ASM [PASM]) is commonly used instead because ASM increases with weight and height.

Recently, the importance of ASM’s impact on metabolic health has emerged. The negative correlation between sarcopenia and metabolic health has been reported in adults.\(^11\)-\(^13\) There is a growing interest in the relationship between low muscle mass and metabolic risk in the pediatric population.\(^14\)-\(^16\) IR similarly increases with low skeletal muscle mass, elevating the risk of metabolic disorders.\(^17\) However, there are no reference values of PASM for Korean adolescents computed using nationally representative population-based data.

In this study, reference values of PASM were generated for Korean adolescents aged between 10 and 18 years utilizing the LMS (Lambda for the skew, Mu for the median, and Sigma for the generalized coefficient of variation) method.\(^18\) We further investigated the link between PASM, IR, and MS in adolescents.

Materials and methods

1. Study population
Data from Korea National Health and Nutrition Examination Survey (KNHANES) performed between 2009 and 2011 was used. KNHANES is a cross-sectional, nationally representative study carried out by the Division of Chronic Disease Surveillance, Korea Centers for Disease Control and Prevention. Subjects were selected via proportionate allocation using multistage stratification for systematic sampling. The specific methods for collecting KNHANES data have been disclosed elsewhere.\textsuperscript{19) The study population is outlined in detail in the Supplementary Figure 1. Subjects of this study ranged in age from 10 to 18 years (n=4,598). Those who did not have any DXA values (n=2,679) or had an underlying disease (n=13) were excluded from the analysis. Additionally, subjects with extreme anthropometric parameters (n= 384) were removed for reference value computation. Extreme anthropometric parameters were defined as height, weight that were below the third percentile or more than the 97th percentile corresponding to the subject’s age and sex according to the 2017 Korean National Growth Chart.\textsuperscript{20) The reference value of ASM was produced using 1,522 subjects.

Using the reference value, further investigation of the association between PASM and MS in adolescents was carried out. The study excluded subjects missing either laboratory results (n=527) or household income and daily energy intake (n=185). Those who had a fasting time prior to blood samples of less than 8 hours (n=20) were further excluded. The overall sample consisted of 1,174 subjects.

2. Appendicular skeletal muscle mass indices

DXA examination was conducted using a QDR Discovery fan beam densitometer (QDR4500A; Hologic, Inc., Bedford, MA). Body composition data measured by DXA included lean mass, fat mass (FM, g), and bone mineral content (BMC, g). ASM was calculated by deducting FM and BMC from the total mass of arms and legs.\textsuperscript{8) PASM was measured using the following formula: PASM = \([ASM (kg)/weight (kg) \cdot 100 \, (\%)].\textsuperscript{8,21)\n
3. Anthropometric and biochemical assessments

Each participant’s medical information was gathered by skilled investigators. All participants
underwent physical examinations measuring height (cm) by stadiometer (Seca 225, Seca, Hamburg, Germany) and weight (kg) by an electronic balance (GL-6000-20, G-tech, Seoul, Korea). Body mass index (BMI) was defined as weight (kg) divided by height squared (kg/m²). The z-score of height, weight, and BMI was created by transforming the subject’s height, weight, and BMI relative to the standard values described in the 2017 Korean National Growth Chart. The waist circumference (WC) was recorded at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest during expiration by flexible tape (Seca 220, Seca, Hamburg, Germany). The z-score of WC was produced by transforming a subject’s WC relative to the reference values acquired from KNHANES 2007-2019. Blood pressure (BP) was evaluated by a mercury sphygmomanometer (Baumanometer, W.A. Baum Co., Copiague, NY, USA) after the participant had taken a rest in a sitting position for at least 5 minutes. All BP was estimated on the right arm three times, and then the mean value of the last 2 measurements was chosen for the analysis. Blood samples were obtained from experienced medical personnel and delivered to the central laboratory (NEODIN Medical Institute, Seoul, Korea) for measurement. Using the Hitachi Autonomic Analyzer 7600 (Hitachi Ltd., Tokyo, Japan), total cholesterol, serum triglyceride, and high-density lipoprotein cholesterol (HDL-C), fasting plasma glucose (FPG) were assessed by enzyme method. Insulin level was determined by 1470 WIZARD gamma-Counter (PerkinElmer, Turku, Finland). The monthly household income of each subject was categorized into quintiles. Dietitians with training conducted a survey of dietary habits, 24-hour recall, and food frequency questionnaires. The Korean Foods and Nutrients Database of the Rural Development Administration was used to calculate daily energy intake.

4. Metabolic syndrome and insulin resistance

In children, the diagnostic criteria for MS vary by gender, age, and race. In this study, the modified National Cholesterol Education Program - Third Adult Treatment Panel (modified NCEP-ATP III) criteria were used. Each component of MS was defined as follows: abdominal obesity as having WC ≥ 90th percentile for corresponding age and sex based on the Korean national growth chart, high BP as having BP ≥ 90th percentile corresponding height, age, and sex referring to the Korean reference,
elevated FPG as having FPG ≥ 110 mg/dL, elevated triglyceride as having triglyceride ≥ 110 mg/dL, low HDL-C as having HDL-C < 40 mg/dL.\textsuperscript{20,24} Subjects were classified as having MS if three or more criteria were satisfied.

Pediatric simple metabolic syndrome score (PsiMS), a continuous variable, was obtained to quantify MS risk.\textsuperscript{25,26} The following formula was used to calculate the PsiMS. \textit{PsiMS} = \[ 2 \cdot \text{WC (cm)/height (cm)} + \text{FPG (mg/dL)/100 + triglycerides (mg/dL)/150 + systolic BP (mmHg)/130 – HDL-C (mg/dL)/40} \textsuperscript{.27} \]

IR was defined as having the homeostasis model assessment of insulin resistance (HOMA-IR) higher than 95% for age, and sex in Korean adolescents.\textsuperscript{6,28} Another reliable marker of IR, the triglyceride glucose (TyG) index was additionally analyzed. The TyG index has been proposed as a more efficient IR indicator compared to the HOMA-IR score.\textsuperscript{29} The formulas are as follows: \textit{HOMA-IR} = \[ \text{FPG (mg/dL) \cdot fasting insulin (μIU/mL)/405} \]; \textit{TyG index} = \[ \ln[\text{TG (mg/dL)} \cdot \text{FPG (mg/dL)/2}] \textsuperscript{.30} \]

5. Statistical analysis

The LMS method estimates 3 parameters: the power parameter of the Box-Cox transformation (\textit{Lambda [L]}), the median (\textit{Mu [M]}), and the generalized coefficient of variation (\textit{Sigma [S]}) by age and sex. The \textit{z}-score, or standard deviations (SD) from the mean, by age, and sex can be calculated from LMS parameters by using the following formula: \textit{z}-score = \[ ((\text{estimated value}/\text{M})^{1-1})/(\text{L x S})] \textsuperscript{.31} \]

Variables with skewed distributions such as ASM, PASM, FPG, insulin, HOMA-IR, triglyceride, and HDL-C were log-transformed for the analysis and reported with geometric means and standard errors. Data were shown as \textit{β}-coefficient, standard error and \textit{p}-value for linear regression analysis and an adjusted odds ratio (aOR), 95% confidence interval (CI), and \textit{p}-value for logistic regression analysis. Multivariate analyses were performed after adjusting for age, sex, house income (quintile), daily energy intake, and BMI \textit{z}-score. A sub-analysis was conducted by stratifying data into BMI \textit{z}-score <2 and BMI \textit{z}-score ≥2 groups. Stata, version 16.1 (StataCorp LP, College Station, TX, USA) was used to perform all statistical analyses. All numbers and percentiles used to analyze the relationship between PASM and MS were weighted values computed using the \textit{svy} command to adjust the KNHANES
sampling design. The *marginsplot* command was utilized for graphical visualization of the predicted probability of MS and IR according to the PASM z-score. A two-sided *p*-value less than 0.05 was considered statistically significant.

6. Ethical statement

The KNAHNES was approved by the Institutional Review Board of the Korea Centers for Disease Control and Prevention (2009-01CON-03-2C, 2010-02CON-21-C, and 2011-02CON-06-C). All participants and/or their legal guardians in the KNHANES 2009-2011 provided informed consent. The present study was approved by the Institutional Review Board of Seoul National University Bundang Hospital (Approval No. X-1911/579-905). All procedures were performed in accordance with the Declaration of Helsinki.

RESULTS

1. ASM reference

There were 1,522 subjects whose ages ranged anywhere from 10 to 18, comprising 807 boys (53.0%) and 715 girls (47.0%). The mean and SD of the z-scores for height, weight, and BMI were 0.24 ± 0.04, 0.08 ± 0.04, and -0.05 ± 0.04, respectively. The z scores for height, weight, and BMI of boys (girls) had means and SDs of 0.28 ± 0.05 (0.18 ± 0.05), -0.11 ± 0.06 (0.05 ± 0.06), and -0.05 ± 0.06 (-0.05 ± 0.06), respectively.

Table 1 shows the L, M (50th percentile), and S values and 3rd, 10th, 50th, 90th, and 97th percentiles for PASM at each age for boys and girls. The reference percentiles for PASM are shown in Figure 1. Boys had generally higher values compared to girls regardless of age. PASM increases with age in boys, as shown by the 50th percentile increasing from 25.1% to 31.1% (Fig. 1A). Girls, on the other hand, have a distinct pattern. Their PASM declines with age after peaking at 10-12 years of age, as shown by the 50th percentile falling gradually from 25.2% to 23.6% between 10 to 18 years of age (Fig. 1B).

2. PASM and metabolic syndrome
Table 2 summarizes the clinical characteristics of the study population that were tested for MS. There were 1,174 participants, comprising 613 boys (52.7%) and 561 girls (47.3%). The mean age of boys was 13.9 ± 0.1 years and that of girls was 13.9 ± 0.1 years. Girls had a significantly lower values of ASM and PASM than boys (Girls, ASM 13.2 ± 0.1 kg, PASM 26.9 ± 0.2%; Boys, ASM 18.3 ± 0.2 kg, PASM 32.8 ± 0.2%). The z-scores for boys’ and girls’ PASM were 0.09 ± 0.06 and -0.14 ± 0.07, respectively.

The results of multivariate linear regression analysis for the relationships between PASM and MS or IR are shown in Table 3. It was shown that PASM had inverse associations with PsiMS, HOMA-IR, and TyG index when age, sex, household income, and daily caloric intake were taken into consideration (PsiMS, β -0.105, p-value <0.001; HOMA-IR β -0.104, p-value <0.001; TyG index, β -0.013, p-value <0.001). Sex-stratified analysis showed significant negative associations between the PASM z-score and MS or IR (Figure 2). The interaction between PASM z-score and MS was correlated stronger in boys than girls (Fig. 2A). Both boys and girls had a similar association between the PASM z-score and IR (Fig. 2B). The predictive probability of MS and IR both dropped as the PASM z-score increased.

The aORs for MS and IR computed using PASM z-score are shown in Supplementary Table 1. Increased PASM lowered the risk of obesity (aOR 0.22, 95% CI 0.17-0.30), abdominal obesity (aOR 0.27, 95% CI 0.20-0.36), high BP (aOR 0.65, 95% CI 0.52-0.80), and elevated triglycerides (aOR 0.67, 95% CI 0.56-0.79). There was no statistically significant association between PASM and FPG. MS and IR had aORs of 0.34 (95% CI 0.26-0.45) and 0.50 (95% CI 0.41-0.62), respectively.

We stratified subjects into two groups based on the BMI z-score and conducted additional analyses (Supplementary Table 2). In the non-obese group (BMI z-score <2), the PsiMS, HOMA-IR, and TyG index were all negatively associated with PASM (PsiMS, β -0.080; HOMA-IR, β -0.079; TyG index, β -0.011, all p-value <0.001). When the BMI z-score was added as a covariate, only the TyG index demonstrated a significant negative correlation with PASM (β -0.005, p-value <0.033). MS and IR exhibited adjusted odds ratios (aORs) of less than 1, and these were statistically significant. In the total population and girls in the obese group (BMI z-score >2), only PsiMS had a significant negative correlation with PASM (β -0.135, p-value 0.004) while HOMA-IR and TyG index were not significantly
correlated with PASM. aORs for MS and IR were not significant in the obese group.

DISCUSSION

The present study introduces the reference value of PASM for Korean adolescents aged between 10 and 18. The reference value was established using the nationally representative data acquired from 2009-2011 KNHANES. Since low PASM was shown to increase the risk of MS and IR, it is crucial for clinicians to have a reference value when evaluating a patient’s metabolic status.

It is recognized that total lean body mass is strongly correlated with skeletal muscle mass. ASM is used as a major indicator of sarcopenia because it is highly associated with skeletal muscle mass. We measured body composition by DXA and calculated z-scores for ASM indices including PASM in adolescents.

Changes in PASM are demonstrated differentially in distinct ethnic groups. Perhaps these distinctions are due to genetic heritability, thus it is important to provide nation-specific references. While US girls’ PASM increased until they grow into adulthood, Korean and Chinese girls, on the other hand, had the maximum PASM at the age of 10-12 and declined during the subsequent adolescence period. There has been a study to obtain the reference of ASM indices in Korea, but the LMS values were not provided. The LMS value can be useful in clinical and research settings to obtain the z-score of patients and know at what percentile the z-score falls compared to the entire population. The strength of this study is that it provides LMS values of PASM by age and sex in Korean adolescents.

In terms of annual changes in PASM, sex was also a significant contributor. PASM was found to increase gradually in boys, but the growth was relatively flat in girls. In girls, lean mass and lean mass index tend to increase with age. However, the slope progressively becomes less steep and flattens when reaching adulthood. Girls aged between 10 and 18 may gain more fat mass than muscle mass, resulting in a decrease in PASM. In contrast, boys’ PASM increased at a faster rate until later in life. Sex discrepancy may have resulted from differences in puberty and sex hormones, but further research is needed to identify the causes.

Early diagnosis of MS and management of future risk factors are important because MS in adolescence often carries over into adulthood. Low muscle mass in the elderly has been linked to an increase and
MS. It was not so long before interest in the association between metabolic dysfunction and skeletal muscle mass in youth began to develop. The relationship between low skeletal muscle mass and MS in the pediatric population has only been addressed in a small number of studies. In the study of pediatric subjects using national data in the US, low muscle mass was reported to have a correlation with metabolic risk factors, but no direct analysis on MS and IR was done. Other studies included adolescents simply compared MS risk with the presence of relatively low muscle mass.

To the best of our knowledge, the present study is the first study that integrates PASM into the evaluation of MS and IR in the pediatric population. The inverse association between the PASM z-score and MS or IR in adolescents was also validated in the study. PsiMS, HOMA-IR, and TyG index, which represent MS and IR as continuous variables, had a significant negative correlation with PASM. Each component of MS, except for FPG, was substantially related to PASM. FPG was not significantly associated with PASM. Elevated FPG was found in only 5 out of 1174 individuals, which is too few numbers compared to other cardiometabolic risk factors. It was challenging to run a statistical analysis and determine its significance. IR was more common, observed in 185 individuals, and the aOR was significantly lower. It is expected that low PASM is associated with impaired insulin action. It is possible that there wasn’t enough time for IR to develop into impaired FPG due to the young age of the subjects. In adult studies, the incidence of impaired FPG and type 2 diabetes has been reported to be increased in individuals with low ASM. Therefore, further follow-up studies with larger sample sizes are needed to better understand the association between ASM and metabolic risks in adolescents.

We conducted additional stratified analyses to evaluate the potential confounding effects of obesity status. Specifically, we examined whether the results differed based on BMI z-scores. In the non-obese group with a BMI z-score of less than 2, MS and IR tended to decrease as PASM increased. However, these tendencies disappeared in the obese group with a BMI z-score of 2 or more except for PsiMS. Consistent with our findings, studies in adults similarly reported a loss of protective effect of muscle mass in the obese group compared to the non-obese group. A complete mechanism for this remains unclear. One hypothesis is that body weight and ASM tend to be proportional in obese patients, with a concomitant increase in intramuscular lipid portion. The increased intramuscular lipid content in
obese patients may reduce the impact of ASM on metabolic risk by interfering with its ability to accurately gauge pure fat-free mass. Another hypothesis is that the harmful effects of adiposity and the protective effects of muscle may interact, resulting in the harmful effects of adiposity outweighing the beneficial effects of muscle in the obese group, thus canceling out the gains from muscle.\textsuperscript{41,43}

The limitations of this study are as follows: first, it is challenging to clarify the causal relationship between PASM with MS because of the weakness of the cross-sectional study design. Second, puberty status was not applied to the analysis due to a lack of data. Since puberty is an important time for muscle mass acquisition, a more detailed analysis could have been conducted with puberty status information. Third, there was no DXA data in children under the age of 10, hence the reference values could not be obtained for those younger than 10 years old. In the future, a study to find the reference of ASM even at a younger age is needed.

In conclusion, the LMS reference value provided in this study may offer clinicians information that will enable the effective management of patients. The chance of acquiring MS and IR increases with declining skeletal muscle mass. Based on the results of the current study, it is recommended that body composition should be monitored contingent on the reference values. Further longitudinal studies are required for the long-term outcome in children and adolescents with varying degrees of muscle mass.

Notes

Conflicts of interest: No potential conflict of interest relevant to this article was reported.

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Data availability: The data that support the findings of this study can be provided by the corresponding author upon reasonable request.
References


Figure guide

Fig.1. Centile curves for percentage of appendicular skeletal muscle mass in Korean adolescents aged 10-18 years. A. Boys and B. Girls. The lines represent the 5th, 25th, 50th, 75th, 90th, and 95th centiles.

Fig.2. Adjusted probability of A. metabolic syndrome, B. insulin resistance according to percentage of appendicular skeletal muscle mass z-score. Plot was generated after sex-stratified logistic regression after adjusted for age, household income (quintile), daily energy intake.
Table 1. Reference values for percentage of appendicular skeletal muscle mass (%) in Korean adolescents

| Age (yr) | Male | | | | | | | | Female | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | L | S | 3p | 10p | M | 90p | 97p | | n | L | S | 3p | 10p | M | 90p | 97p |
| 10 | 99 | 0.188 | 29.128 | 0.114 | 23.421 | 25.131 | 29.128 | 33.628 | | 91 | -2.123 | 27.992 | 0.093 | 24.124 | 25.171 | 27.992 | 32.113 |
| 11 | 100 | 0.543 | 30.441 | 0.112 | 24.364 | 26.233 | 30.441 | 34.934 | | 87 | -1.237 | 27.925 | 0.096 | 23.725 | 24.903 | 27.925 | 31.914 |
| 12 | 110 | 0.737 | 31.626 | 0.106 | 25.492 | 27.408 | 31.626 | 35.998 | | 73 | -0.585 | 27.690 | 0.095 | 23.354 | 24.611 | 27.690 | 31.427 |
| 13 | 85 | 0.929 | 32.575 | 0.100 | 26.481 | 28.413 | 32.575 | 36.775 | | 107 | -0.133 | 27.409 | 0.093 | 23.066 | 24.359 | 27.409 | 30.900 |
| 14 | 111 | 1.153 | 33.311 | 0.095 | 27.292 | 29.230 | 33.311 | 37.318 | | 81 | 0.253 | 27.141 | 0.090 | 22.821 | 24.137 | 27.141 | 30.416 |
| 15 | 88 | 1.378 | 33.895 | 0.089 | 27.989 | 29.918 | 33.895 | 37.702 | | 75 | 0.547 | 26.892 | 0.088 | 22.603 | 23.933 | 26.892 | 30.007 |
| 16 | 67 | 1.532 | 34.299 | 0.084 | 28.603 | 30.479 | 34.299 | 37.905 | | 77 | 0.711 | 26.665 | 0.087 | 22.413 | 23.744 | 26.665 | 29.681 |
| 17 | 81 | 1.545 | 34.506 | 0.080 | 29.078 | 30.864 | 34.506 | 37.949 | | 75 | 0.692 | 26.500 | 0.086 | 22.301 | 23.615 | 26.500 | 29.486 |
| 18 | 66 | 1.470 | 34.568 | 0.077 | 29.364 | 31.066 | 34.568 | 37.910 | | 49 | 0.588 | 26.436 | 0.087 | 22.263 | 23.561 | 26.436 | 29.447 |

L, skew; M, median; S, coefficient of variation.
Table 2. Clinical characteristics of the study population

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total</th>
<th>Boys</th>
<th>Girls</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (%)</td>
<td>1,174</td>
<td>613 (52.7)</td>
<td>561 (47.3)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>13.9 ± 0.1</td>
<td>13.9 ± 0.1</td>
<td>13.9 ± 0.1</td>
<td>0.888</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.1 ± 0.4</td>
<td>164.8 ± 0.6</td>
<td>157.0 ± 0.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>54.3 ± 0.5</td>
<td>57.7 ± 0.7</td>
<td>50.4 ± 0.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>BMI z-score</td>
<td>-0.04 ± 0.04</td>
<td>-0.04 ± 0.06</td>
<td>-0.04 ± 0.06</td>
<td>0.959</td>
</tr>
<tr>
<td>BMI category</td>
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<td></td>
<td></td>
<td>0.226</td>
</tr>
<tr>
<td>Normal, n (%)</td>
<td>935 (79.6)</td>
<td>479 (78.1)</td>
<td>456 (81.3)</td>
<td></td>
</tr>
<tr>
<td>Overweight, n (%)</td>
<td>127 (10.8)</td>
<td>67 (10.9)</td>
<td>60 (10.7)</td>
<td></td>
</tr>
<tr>
<td>Obesity, n (%)</td>
<td>112 (9.5)</td>
<td>67 (10.9)</td>
<td>45 (8.0)</td>
<td></td>
</tr>
<tr>
<td>Household income (quintile), n (%)</td>
<td>160 (13.6)</td>
<td>79 (12.9)</td>
<td>81 (14.4)</td>
<td>0.111</td>
</tr>
<tr>
<td>WC (cm)</td>
<td>67.4 ± 0.3</td>
<td>68.3 ± 0.4</td>
<td>66.3 ± 0.4</td>
<td>&lt;0.001</td>
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<tr>
<td>Systolic BP (mmHg)</td>
<td>107.5 ± 0.4</td>
<td>116.1 ± 0.5</td>
<td>104.6 ± 0.5</td>
<td>&lt;0.001</td>
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<tr>
<td>Diastolic BP (mmHg)</td>
<td>67.1 ± 0.3</td>
<td>68.0 ± 0.4</td>
<td>66.1 ± 0.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Triglyceride (mg/dL) *</td>
<td>76.6 ± 1.7</td>
<td>76.3 ± 2.4</td>
<td>77.0 ± 1.8</td>
<td>0.792</td>
</tr>
<tr>
<td>HDL-C (mg/dL) *</td>
<td>48.1 ± 0.4</td>
<td>46.6 ± 0.4</td>
<td>49.7 ± 0.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LDL-C (mg/dL) *</td>
<td>88.6 ± 0.9</td>
<td>84.6 ± 1.2</td>
<td>93.2 ± 1.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>FPG (mg/dL) *</td>
<td>88.7 ± 0.2</td>
<td>89.3 ± 0.3</td>
<td>88.0 ± 0.3</td>
<td>0.001</td>
</tr>
<tr>
<td>Insulin (mIU/L) *</td>
<td>12.4 ± 0.2</td>
<td>12.2 ± 0.3</td>
<td>12.7 ± 0.3</td>
<td>0.169</td>
</tr>
<tr>
<td>Metabolic syndrome, n (%)</td>
<td>57 (4.9)</td>
<td>36 (5.9)</td>
<td>21 (3.7)</td>
<td>0.090</td>
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<tr>
<td>Insulin resistance, n (%)</td>
<td>185 (15.8)</td>
<td>91 (14.9)</td>
<td>94 (16.8)</td>
<td>0.369</td>
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<tr>
<td>PsMs</td>
<td>4.17 ± 0.02</td>
<td>4.19 ± 0.02</td>
<td>4.16 ± 0.02</td>
<td>0.181</td>
</tr>
<tr>
<td>HOMA-IR *</td>
<td>2.72 ± 0.04</td>
<td>2.68 ± 0.06</td>
<td>2.75 ± 0.06</td>
<td>0.398</td>
</tr>
<tr>
<td>TyG index *</td>
<td>8.11 ± 0.02</td>
<td>8.11 ± 0.03</td>
<td>8.11 ± 0.02</td>
<td>0.971</td>
</tr>
</tbody>
</table>

Data are expressed as weighted mean ± standard error or as numbers (percent), except for log-transformed variables. Overweight is defined as BMI 85-94th percentile for age and sex, obesity is defined as BMI above 95th percentile for age and sex.

The asterisk (*) indicates the variable that was log-transformed for the analysis and expressed as the geometric mean.

ASM, appendicular skeletal muscle mass; BMI, body mass index; BP, blood pressure; FPG, fasting plasma glucose; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, the homeostasis model assessment of insulin resistance; TyG index, the product of triglyceride and fasting glucose levels; PSI MS, predicted sufficient muscle mass; BMI z-score, BMI mean for age and sex; Hydrometry, HOMA-IR, HOMA-IR, homeostasis model assessment of insulin resistance; and PLM, percentiles for age and sex.
resistance; LDL-C, low-density lipoprotein cholesterol; PASM, percentage of appendicular skeletal muscle mass; PsiMS, pediatric simple metabolic syndrome score; Q, quintile; TyG index, triglyceride glucose index; WC, waist circumference.
Table 3. Multivariate linear regression coefficients of z-score for percentage of appendicular skeletal muscle mass with metabolic syndrome and insulin resistance

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th></th>
<th></th>
<th>Boys</th>
<th></th>
<th></th>
<th>Girls</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>β</td>
<td>SE</td>
<td>p-value</td>
<td>β</td>
<td>SE</td>
<td>p-value</td>
<td>β</td>
<td>SE</td>
<td>p-value</td>
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<td>PsiMS</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>-0.102</td>
<td>0.014</td>
<td>&lt;0.001</td>
<td>-0.148</td>
<td>0.019</td>
<td>&lt;0.001</td>
<td>-0.062</td>
<td>0.017</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Model 2</td>
<td>-0.105</td>
<td>0.014</td>
<td>&lt;0.001</td>
<td>-0.148</td>
<td>0.020</td>
<td>&lt;0.001</td>
<td>-0.063</td>
<td>0.017</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>HOMA-IR</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>-0.095</td>
<td>0.016</td>
<td>&lt;0.001</td>
<td>-0.138</td>
<td>0.022</td>
<td>&lt;0.001</td>
<td>-0.050</td>
<td>0.019</td>
<td>0.010</td>
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<tr>
<td>Model 2</td>
<td>-0.104</td>
<td>0.015</td>
<td>&lt;0.001</td>
<td>-0.142</td>
<td>0.022</td>
<td>&lt;0.001</td>
<td>-0.066</td>
<td>0.018</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>TyG index</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>-0.012</td>
<td>0.002</td>
<td>&lt;0.001</td>
<td>-0.017</td>
<td>0.003</td>
<td>&lt;0.001</td>
<td>-0.007</td>
<td>0.003</td>
<td>0.007</td>
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<tr>
<td>Model 2</td>
<td>-0.013</td>
<td>0.002</td>
<td>&lt;0.001</td>
<td>-0.017</td>
<td>0.003</td>
<td>&lt;0.001</td>
<td>-0.008</td>
<td>0.003</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Model 1: Simple linear regression. Model 2: adjusted for age, sex, household income (quintile), and daily energy intake.

HOMA-IR, the homeostasis model assessment of insulin resistance; PsiMS, pediatric simple metabolic syndrome score; SE, standard error; TyG index, triglyceride glucose index.
Figure 1.
Figure 2.