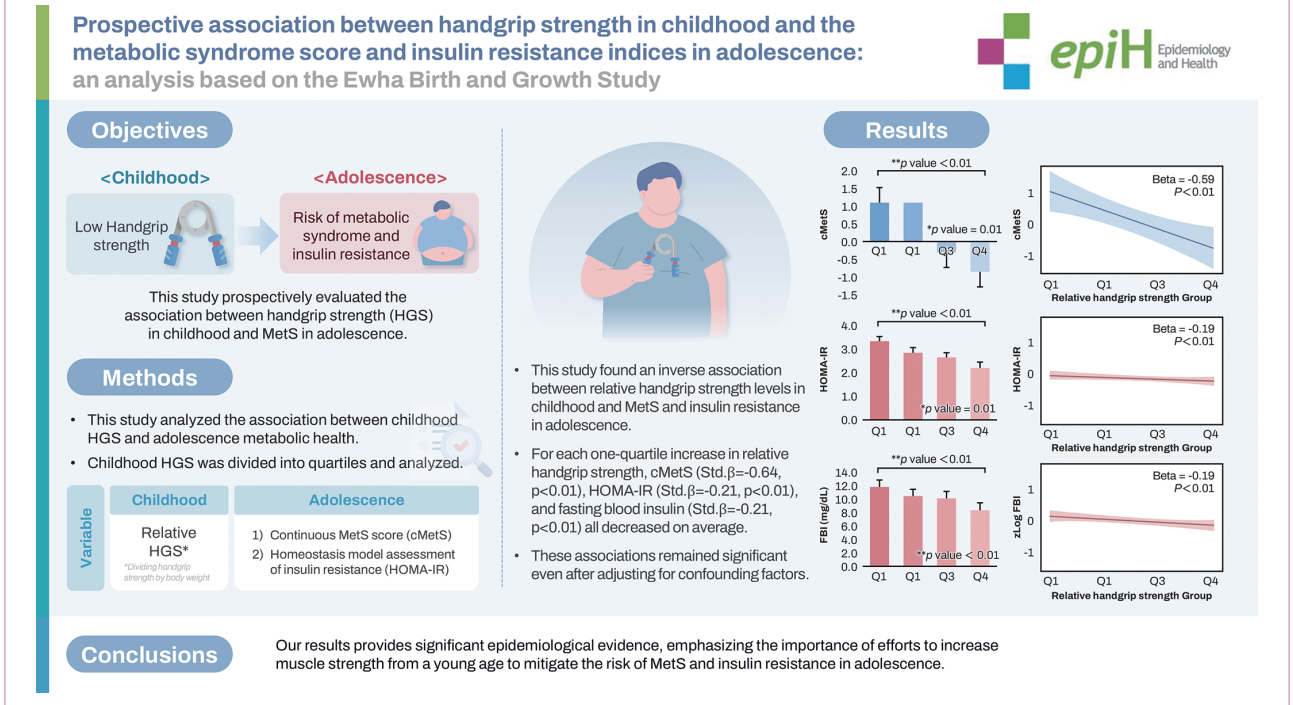
epiH Epidemiology and Health

Prospective association between handgrip strength in childhood and the metabolic syndrome score and insulin resistance indices in adolescence: an analysis based on the Ewha Birth and Growth Study

Seunghee Jun, Hyunjin Park, Hyelim Lee, Hye Ah Lee, Young Sun Hong, Hyesook Park

Epidemiology and Health **Volume: 47, Article ID: e2025001** | https://doi.org/10.4178/epih.e2025001

Graphical Abstract



Key Message:

This study found that higher childhood relative handgrip strength was inversely associated with metabolic syndrome and insulin resistance in adolescence. The findings emphasize the importance of enhancing muscle strength early in life to mitigate metabolic risks.

Open Access

Volume: 47, Article ID: e2025001, 10 pages
https://doi.org/10.4178/epih.e2025001

epiH
Epidemiology and Health

ORIGINAL ARTICLE

Prospective association between handgrip strength in childhood and the metabolic syndrome score and insulin resistance indices in adolescence: an analysis based on the Ewha Birth and Growth Study

Seunghee Jun[1,2], Hyunjin Park[1,2], Hyelim Lee[1,2], Hye Ah Lee[3], Young Sun Hong[4], Hyesook Park[1,2]

[1]Department of Preventive Medicine, Ewha Womans University College of Medicine, Seoul, Korea; [2]Graduate Program in System Health Science and Engineering, Ewha Womans University, Seoul, Korea; [3]Clinical Trial Center, Ewha Womans University Mokdong Hospital, Seoul, Korea; [4]Department of Internal Medicine, Ewha Womans University College of Medicine, Seoul, Korea

OBJECTIVES: Low handgrip strength (HGS) in children and adolescents might be associated with the risk of metabolic syndrome (MetS) and insulin resistance. This study prospectively evaluated the association between HGS in childhood and MetS in adolescence.

METHODS: Based on data from the Ewha Birth and Growth Study, this study analyzed HGS at ages 7 to 9 and metabolic indices at ages 13 to 15. In total, 219 participants were analyzed. The risk of MetS was evaluated using the continuous metabolic syndrome score (cMetS), and insulin resistance was assessed using fasting blood insulin and homeostasis model assessment of insulin resistance (HOMA-IR). Relative HGS in childhood was determined by dividing HGS by body weight and categorized as sex-specific quartiles.

RESULTS: This study found an inverse association between relative HGS levels in childhood and MetS and insulin resistance in adolescence. For each 1-group increase in relative HGS quartiles, cMetS (standarard [Std] $\beta = -0.64$, $p < 0.01$), HOMA-IR (Std $\beta = -0.21$, $p < 0.01$), and fasting blood insulin (Std $\beta = -0.21$, $p < 0.01$) all decreased on average. These associations remained significant even after adjusting for confounding factors.

CONCLUSIONS: Our study showed a prospective association between HGS in childhood and the risk of MetS and insulin resistance in adolescence. It provides significant epidemiological evidence, emphasizing the importance of efforts to increase muscle strength from a young age to mitigate the risk of MetS and insulin resistance in adolescence.

KEY WORDS: Hand strength, Metabolic syndrome, Insulin resistance, Cohort studies

INTRODUCTION

Metabolic syndrome (MetS) is defined by a cluster of conditions including abdominal obesity, high blood pressure, dyslipidemia, and elevated fasting blood sugar levels [1,2]. Insulin resistance is not only a characteristic of MetS but also a risk factor for the syndrome. The syndrome can elevate the risk of cardiovascular diseases due to the interplay of multiple risk factors [3-5]. MetS in adolescents may persist in adulthood. Preventing MetS is crucial, as it significantly increases the likelihood of developing serious health issues such as cardiovascular disease and type 2 diabetes [6,7].

Correspondence: Hyesook Park
Department of Preventive Medicine, Ewha Womans University College of Medicine, 25 Magokdong-ro 2-gil, Gangseo-gu, Seoul 07804, Korea
E-mail: hpark@ewha.ac.kr

Received: Jul 25, 2024 / Accepted: Dec 13, 2024 / Published: Jan 2, 2025

This article is available from: https://e-epih.org/

This is an open-access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

© 2025, Korean Society of Epidemiology

According to a study examining the prevalence and risk factors of MetS in Korean adolescents from 2007 to 2018, the prevalence of MetS, as defined by the National Cholesterol Education Program Expert Panel and Adult Treatment Panel III standards, increased from 4.5% to 6.2%. Additionally, the incidence of hyperglycemia rose from 5.3% to 12.0% [8].

Exercise and physical activity are beneficial for maintaining health and preventing MetS [1,9]. Muscle strength can be assessed through various measures, including maximum weight per repetition, high jump, sit-up, and squat. Handgrip strength, in particular, offers a relatively straightforward method for determining muscle strength and is commonly employed in epidemiological studies [10,11].

Previous studies on adults have reported that low handgrip strength was associated with the risk of cardiovascular disease and diabetes [12,13]. Furthermore, low handgrip strength in adults is related to MetS. A meta-analysis showed an inverse association between handgrip strength and MetS (pooled odds ratio [OR] for handgrip strength [low vs. high], 2.59; 95% confidence interval [CI], 1.08 to 5.63), and also found a significant dose-response relationship (OR, 0.68 per 0.1 relative handgrip strength; 95% CI, 0.52 to 0.75) [14]. In addition, fasting insulin ($\beta = -0.003$, $p = 0.017$) and homeostasis model assessment of insulin resistance (HOMA-IR; $\beta = 0.003$, $p = 0.025$) values showed an inverse linear relationship with relative handgrip strength [15].

Numerous studies have explored the link between handgrip strength and cardiovascular disease in adults. However, research focusing on this association in children and adolescents is limited, with most studies being cross-sectional [12-17] and few being longitudinal. Additionally, there is a lack of research on MetS and insulin resistance, both of which are intermediate risk factors for cardiovascular disease. Therefore, this study aimed to assess the prospective relationship between relative handgrip strength in childhood and the risk of developing MetS and insulin resistance in adolescence.

MATERIALS AND METHODS

Study participants

This study utilized data from the Ewha Birth and Growth Study, a cohort established with pregnant women who visited the Obstetrics and Gynecology Department of Ewha Womans University Mokdong Hospital between September 2001 and June 2006. The cohort specifically included women who sought prenatal care during the 24th weeks to 28th weeks of gestation. It comprised 940 children born to mothers who agreed to participate in the study, with longitudinal observations beginning at the age of 3 in 2005. Regular follow-up examinations were conducted at ages 5 and 7, and then at each subsequent age interval. These follow-up assessments included physical measurements, questionnaires, dietary surveys, and the collection of blood and urine samples. Detailed information about the cohort study can be found in relevant publications [18].

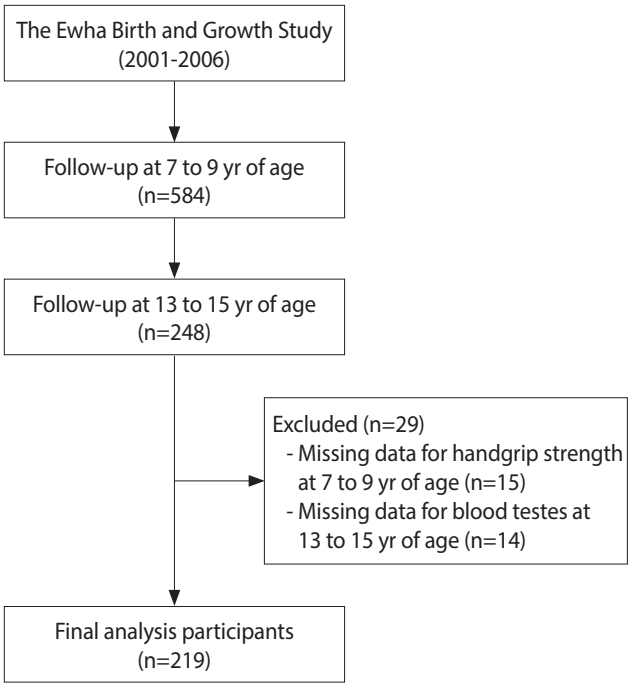


Figure 1. Flow chart of the study participants.

In this study, individuals were defined as study participants if they participated in at least 1 observation during the tracking period at ages 7-9 and attended all observations during the adolescent tracking period at ages 13-15. Of the 584 individuals observed at ages 7-9, 248 were considered study participants at ages 13-15. After excluding individuals with missing data on handgrip strength, MetS scores, and insulin resistance indicators, the final number of study participants was 219 (Figure 1).

Measurement of handgrip strength

Handgrip strength was assessed during a tracking survey when participants were aged 7-9 years. Each participant stood, extended their arm straight and slightly to the side, and then forcefully pulled on a handgrip strength measurement device for 3 seconds using their dominant hand. Measurements were taken 3 times at intervals of 0.1 kg using the Lavisen Digital Hand Grip Dynamometer KS-301 (Lavisen Co., Ltd., Namyangju, Korea). The highest value recorded from the 3 attempts was used for analysis.

Since handgrip strength is correlated with physique, most studies evaluate relative handgrip strength to minimize its influence. This is calculated by dividing handgrip strength (kg) by body weight (kg) [17,19]. Therefore, we calculated relative handgrip strength and assessed it based on quartiles for both boys and girls [13,20]. For boys, the quartiles were defined as follows: first quartile ($Q1 < 0.35$), second quartile ($0.35 \leq Q2 < 0.40$), third quartile ($0.40 \leq Q3 < 0.48$), and fourth quartile ($Q4 \geq 0.48$). For girls, the quartiles were defined as first quartile ($Q1 < 0.33$), second quartile ($0.33 \leq Q2 < 0.38$), third quartile ($0.38 \leq Q3 < 0.43$), and fourth quartile ($Q4 \geq 0.43$).

Measurement of metabolic syndrome score and insulin resistance indices

To assess the risk of MetS in adolescents aged 13-15 years, a continuous metabolic syndrome score (cMetS) was calculated [21,22]. This score included components such as body mass index (BMI), mean arterial pressure, triglycerides (TG), fasting blood glucose, and high-density lipoprotein cholesterol (HDL-C). Each component was standardized using the Z-score method, which accounts for mean, standard deviation (SD), and sex differences. The cMetS was derived by summing these components. Notably, the HDL-C component was multiplied by -1 before addition due to its inverse relationship with MetS risk [22]. A higher cMetS indicates a higher risk of developing MetS.

To assess insulin resistance, fasting blood insulin (FBI) and HOMA-IR values were examined. HOMA-IR is extensively used in clinical and epidemiological research due to its relatively high accuracy in evaluating insulin resistance [23,24]. Higher HOMA-IR values suggest a greater risk of insulin resistance [22].

Covariates

Data on the general characteristics of the study participants were collected through questionnaires during the follow-up examination. Using data collected at ages 13-15, variables such as sex, age, average monthly household income, mother's education level, and frequency of moderate physical activity were considered as confounding factors. These variables were selected based on a literature review [13,15,16]. The frequency of moderate physical activity was categorized into 4 groups: never, 1-2, 3-4, and ≥ 5 times/wk. Additionally, the change in BMI from ages 7-9 to 13-15 was used as a representative indicator of the participant's growth.

Statistical analysis

The normality of the distribution of participant characteristics was assessed. If the values conformed to a normal distribution, the mean and SD were reported; if not, the median and interquartile range were used. Due to the non-normal distribution of TG and FBI levels, a log-transformed analysis was utilized, with results presented after inverse transformation. Additionally, participants' height, weight, and BMI were converted to standard deviation scores (SDS) using the 2017 Korean National Growth Chart for children and adolescents [25]. We employed general linear models to assess the impact of childhood relative handgrip strength levels on MetS score, its components, and insulin resistance in adolescence. Results were presented with adjusted means and 95% CIs, and multiple comparison analysis was conducted using the Tukey method. Linear regression analysis was also used to explore the impact of childhood relative handgrip strength levels on MetS components and insulin resistance in adolescence through trend analysis. These associations were further examined by sex, with all outcome variables standardized and considered. To improve the accuracy of the association between relative handgrip strength and metabolic outcomes, a sensitivity analysis was conducted using body fat mass (BFM) instead of body weight for calculating relative handgrip strength. Body composition, including BFM, was measured using an 8-electrode bioelectrical impedance analysis device, the InBody 230 (Biospace Co. Ltd., Seoul, Korea). All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA), with statistical significance determined at a 0.05 level in 2-sided tests.

Ethics statement

During follow-up, all participants and their guardians received a thorough explanation of the study, and written consent was obtained. The study received approval from the Institutional Review Board of Ewha Womans University Seoul Hospital (IRB No. SEUMC 2020-08-024).

RESULTS

The participants in the study had an average height of 126.10 cm, weight of 26.42 kg, and a BMI of 16.44 kg/m^2. The mean handgrip strength recorded was 10.47 kg, which corresponds to a relative handgrip strength of 0.40 when normalized to body weight. The growth status of both the included and excluded participants was comparable and consistent, as assessed using SDS. Furthermore, no significant differences in handgrip strength were observed (Supplementary Material 1).

A total of 219 participants—107 boys (48.9%) and 112 girls (51.1%)—were included in the study. At 7-9 years of age, boys and girls showed no significant differences in weight, BMI, or blood pressure, but TG and the insulin resistance indices were significantly higher in girls. At 13-15 years of age, boys were significantly heavier and the systolic blood pressure (SBP) was also higher, while girls continued to show higher TG levels ($p = 0.04$). In addition, the weight SDS was significantly higher in boys than in girls ($p < 0.01$), but the BMI SDS was similar between the sexes ($p = 0.56$). However, metabolic indicators, including the cMetS and insulin resistance indices, did not differ significantly between the sexes across both time points (Table 1).

Table 2 shows the relationship between the quartiles of relative handgrip strength at ages 7-9 and the MetS scores, MetS components, and insulin resistance indicators at ages 13-15. Significant differences in cMetS and BMI were observed based on the quartiles of relative handgrip strength ($p = 0.01$ for cMetS and $p < 0.01$ for BMI). The insulin resistance indicators, HOMA-IR and FBI, also showed significant differences according to relative handgrip strength quartiles ($p < 0.01$ for both HOMA-IR and FBI). In the results classified by sex, boys showed differences in BMI and log FBI, while girls showed differences in cMetS, BMI, and log-TG according to the quartiles of relative handgrip strength.

We also assessed associations after adjusting for covariates. We presented the adjusted means for the MetS scores, its components, and insulin resistance indices based on the quartiles of relative handgrip strength (Figures 2 and 3). There was a significant difference in cMetS and BMI. Differences between the lowest and highest quartiles were evident (both $p < 0.01$), based on the Tukey

Table 1. Characteristics of the study participants

Characteristics	Total (n=219)	Boys (n=107, 48.9%)	Girls (n=112, 51.1%)	p-value
At 7-9 yr				
Age (yr)	7.42±0.69	7.39±0.70	7.44±0.69	0.63
Weight (kg)	26.42±6.02	26.79±6.35	26.06±5.69	0.37
Weight SDS	-0.35±1.11	-0.24±1.12	-0.42±1.10	0.22
cMetS	-0.00±3.07	0.03±3.02	-0.03±3.13	0.88
BMI (kg/m^2)	16.44±2.33	16.52±2.47	16.35±2.20	0.59
BMI SDS	-0.36±1.13	-0.34±1.18	-0.39±1.08	0.65
MAP (mmHg)	73.57±7.06	74.37±7.26	72.79±6.82	0.10
SBP (mmHg)	101.77±10.32	103.08±10.35	100.53±10.19	0.07
DBP (mmHg)	59.46±6.65	60.02±7.03	58.93±6.25	0.23
FBG (mg/dL)	79.73±8.58	81.08±9.83	78.47±7.03	0.03
TG (mg/dL)	51.0 (36.0-80.0)	43.0 (32.0-69.0)	56.5 (39.0-93.5)	<0.01
HDL-C (mg/dL)	61.03±11.80	64.25±11.31	58.01±11.50	<0.01
HOMA-IR	1.43±1.04	1.24±0.57	1.61±1.31	<0.01
FBI (μU/mL)	6.7 (5.0-8.5)	6.2 (4.5-7.7)	7.5 (5.5-9.1)	<0.01
At 13-15 yr				
Age (yr)	13.25±0.54	13.21±0.50	13.28±0.59	0.40
Weight (kg)	53.67±10.71	55.78±12.23	51.66±8.61	<0.01
Weight SDS	-0.11±1.03	0.08±1.11	-0.31±0.90	<0.01
cMetS	0.10±3.06	0.08±3.12	0.12±3.02	0.92
BMI (kg/m^2)	20.75±3.41	20.92±3.84	20.59±2.96	0.47
BMI SDS	-0.03±1.13	0.01±1.24	-0.06±1.01	0.56
MAP (mmHg)	81.95±8.59	83.03±8.82	80.92±8.27	0.07
SBP (mmHg)	110.56±11.48	112.36±11.61	108.84±11.13	0.02
DBP (mmHg)	67.65±8.39	68.36±8.84	66.96±7.91	0.22
FBG (mg/dL)	93.51±6.42	93.76±5.73	93.28±7.03	0.58
TG (mg/dL)	77.2 (51.0-88.0)	73.8 (45.0-85.0)	80.5 (54.5-90.5)	0.04
HDL-C (mg/dL)	51.54±9.46	51.39±8.88	51.68±10.02	0.82
HOMA-IR	2.67±1.58	2.56±1.61	2.78±1.54	0.30
FBI (μU/mL)	11.4 (7.5-13.9)	11.0 (6.4-12.9)	11.9 (7.9-14.3)	0.03

Values are presented as mean±standard deviation or median (interquartile range).
SDS, standard deviation score; cMetS, continuous metabolic syndrome score; BMI, body mass index; MAP, mean arterial pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; FBI, fasting blood insulin.

post-hoc test. However, no statistically significant differences were found in other metabolic components. The adjusted mean difference between the lowest and highest quartile was also clear for HOMA-IR and FBI ($p = 0.01$ for HOMA-IR and $p < 0.01$ for FBI).

We assessed the dose-response relationship between relative handgrip strength quartiles and the cMetS, components of MetS, and insulin resistance through linear regression analysis (Figure 4, Supplementary Material 2). As the relative handgrip strength quartile increased, the cMetS value significantly decreased by -0.64 ($p < 0.01$). After adjusting for confounding variables, the negative association between cMetS and relative handgrip strength quartiles remained significant (standarard [Std] $\beta = -0.59$, $p < 0.01$). Additionally, a similar trend was observed for the insulin resistance indices. Both HOMA-IR (Std $\beta = -0.21$, $p < 0.01$) and FBI (Std $\beta = -0.21$, $p < 0.01$) showed significant decreases with increasing relative handgrip strength quartiles. These associations remained significant after adjusting for confounding variables (HOMA-IR: Std $\beta = -0.19$, $p < 0.01$; FBI: Std $\beta = -0.19$, $p < 0.01$). Stratified analyses by sex showed results consistent with the main findings.

The sensitivity analysis results using BFM data showed that, in addition to the significant association shown in the original findings, HDL-C showed a significant association with relative handgrip strength (Supplementary Material 3).

DISCUSSION

The findings of this study indicate an inverse association between relative handgrip strength in childhood and both MetS and insulin resistance in adolescence. Specifically, the associations between cMetS, BMI, HOMA-IR, and FBI persisted even after ad-

Table 2. Univariate analysis of MetS components and insulin resistance indices in adolescence according to relative handgrip strength quartiles in childhood

Variables	Relative handgrip strength quartiles[1]				p-value
	Q1	Q2	Q3	Q4	
Total (n)	55	55	55	54	
MetS score and its components					
cMetS	1.15±3.32	0.29±2.93	-0.27±3.25	-0.80±2.41	<0.01
BMI (kg/m^2)	22.65±3.52	21.45±3.60	19.96±2.85	18.91±2.34	<0.01
MAP (mmHg)	83.01±8.74	81.93±9.10	80.61±9.56	82.26±6.70	0.53
SBP (mmHg)	111.21±11.72	110.65±11.52	109.73±13.69	110.64±8.63	0.93
DBP (mmHg)	68.91±8.74	67.56±9.11	66.05±8.74	68.06±6.69	0.34
FBG (mg/dL)	94.07±8.93	93.31±4.79	93.49±5.78	93.17±5.51	0.89
Log TG[2]	74.0 (54.0-91.0)	72.0 (51.0-94.0)	68.0 (51.0-92.0)	61.5 (48.0-77.0)	0.32
HDL-C (mg/dL)	49.95±10.59	51.16±8.27	52.18±9.48	52.89±9.34	0.39
Insulin resistance index					
HOMA-IR	3.24±2.15	2.69±1.48	2.58±1.27	2.17±1.01	<0.01
Log FBI[2]	12.0 (7.9-16.3)	9.6 (7.5-14.5)	9.9 (7.3-13.5)	8.7 (6.1-11.9)	<0.01
Boys (n)	27	27	27	26	
MetS score and its components					
cMetS	0.87±3.25	0.82±3.30	-0.77±3.02	-0.65±2.65	0.08
BMI (kg/m^2)	22.93±4.30	22.08±4.03	19.70±2.89	18.91±2.48	<0.01
MAP (mmHg)	84.45±9.38	83.70±8.84	80.96±9.53	82.99±7.41	0.51
SBP (mmHg)	113.83±12.67	112.59±10.95	111.11±12.76	111.87±10.30	0.85
DBP (mmHg)	69.76±9.60	69.26±8.87	65.89±9.56	68.56±7.01	0.38
FBG (mg/dL)	95.78±6.49	93.37±4.99	92.56±6.01	93.31±5.08	0.19
LogTG[2]	59.0 (44.0-79.0)	73.0 (46.0-102.0)	60.0 (47.0-87.0)	59.5 (42.0-77.0)	0.60
HDL-C (mg/dL)	51.96±11.38	49.04±7.02	52.52±8.41	52.08±8.17	0.46
Insulin resistance index					
HOMA-IR	3.08±1.87	2.69±1.71	2.44±1.53	2.00±1.10	0.10
Log FBI[2]	12.0 (7.9-16.3)	9.6 (7.5-14.5)	9.9 (7.3-13.5)	8.7 (6.1-11.9)	0.04
Girls (n)	28	28	28	28	
MetS score and its components					
cMetS	1.42±3.41	-0.21±2.47	0.21±3.44	-0.95±2.20	0.03
BMI (kg/m^2)	22.38±2.63	20.85±3.08	20.22±2.84	18.90±2.25	<0.01
MAP (mmHg)	81.62±7.99	80.21±9.18	80.27±9.74	81.57±6.01	0.87
SBP (mmHg)	108.68±10.33	108.79±11.94	108.39±14.64	109.50±6.72	0.99
DBP (mmHg)	68.09±7.90	65.93±9.20	66.21±8.06	67.61±6.47	0.69
FBG (mg/dL)	92.43±10.65	93.25±4.69	94.39±5.51	93.04±5.98	0.77
LogTG[2]	87.0 (61.5-109.0)	68.9 (52.5-90.5)	69.0 (56.0-93.0)	62.5 (53.5-74.0)	0.04
HDL-C (mg/dL)	48.00±9.57	53.21±8.97	51.86±10.55	53.64±10.41	0.14
Insulin resistance indices					
HOMA-IR	3.39±2.41	2.68±1.26	2.71±0.98	2.33±0.92	0.07
Log FBI[2]	14.0 (8.3-17.4)	10.7 (7.7-15.5)	10.8 (8.7-13.4)	9.6 (7.5-12.4)	0.12

Values are presented as mean±standard deviation or median (interquartile range).
MetS, metabolic syndrome; cMetS, continuous metabolic syndrome score; BMI, body mass index; MAP, mean arterial pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; FBG, fasting blood glucose; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; FBI, fasting blood insulin.
[1]Relative handgrip strength quartiles were defined taking sex into account; The range of each quartile is as follows; first quartile (Q1<0.35), second quartile (0.35≤Q2<0.40), third quartile (0.40≤Q3<0.48), and fourth quartile (Q4≥0.48) in boys and first quartile (Q1<0.33), second quartile (0.33≤Q2<0.38), third quartile (0.38≤Q3<0.43), and fourth quartile (Q4≥0.43) in girls.
[2]Statistical analysis was performed using the Kruskal-Wallis test.

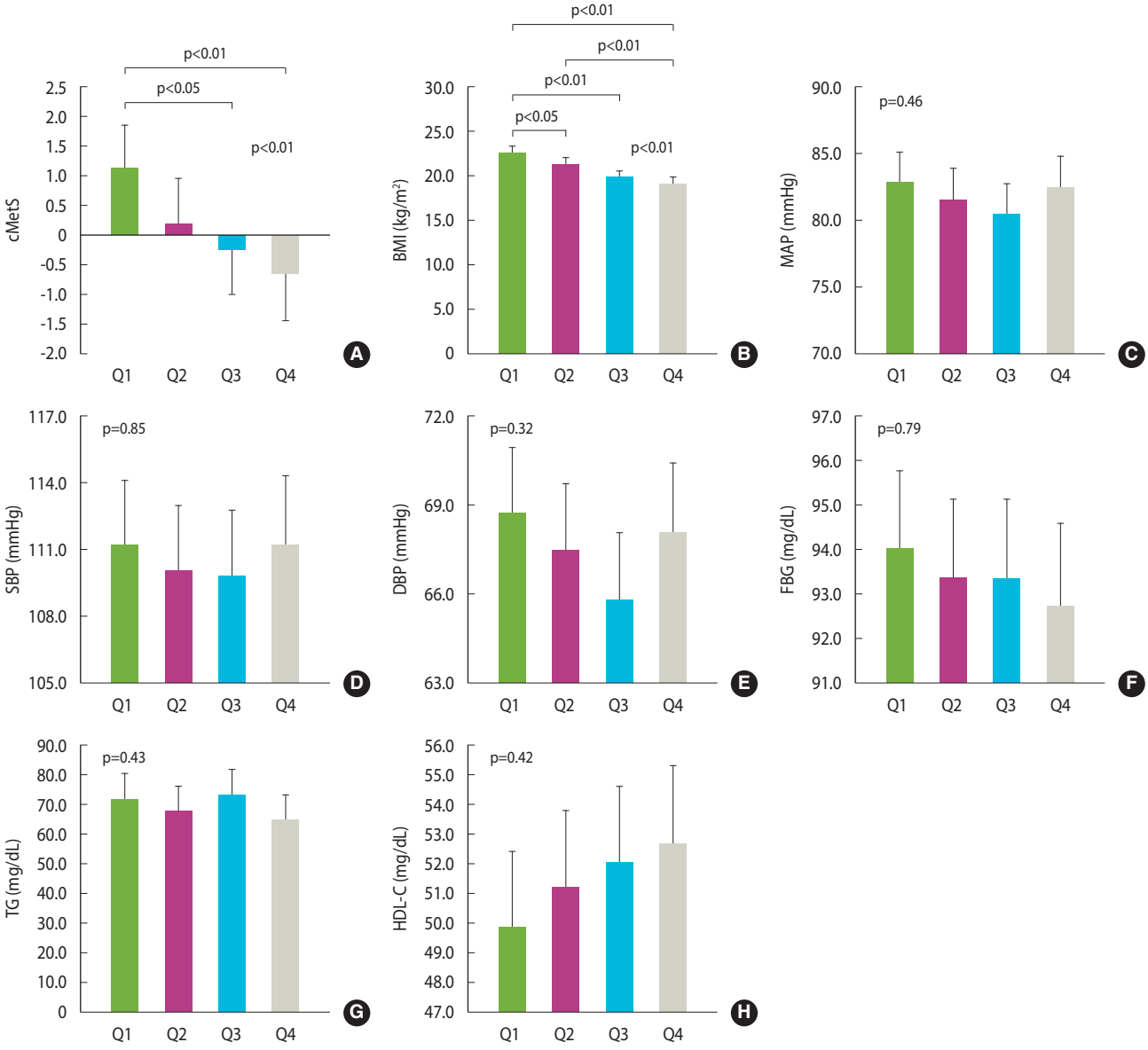


Figure 2. Effects of relative handgrip strength quartiles at 7-9 years of age on metabolic syndrome components at 13-15 years of age. (A) continuous metabolic syndrome score (cMets), (B) body mass index (BMI), (C) mean arterial pressure (MAP), (D) systolic blood pressure (SBP), (E) diastolic blood pressure (DBP), (F) fasting blood glucose (FBG), (G) triglyceride (TG), (H) high-density lipoprotein cholesterol (HDL-C). Results are presented as adjusted means with 95% confidence intervals (CIs). Adjusted mean with 95% CI was estimated under controlling for sex, age, monthly household income, mother's education, moderate physical activity at 13-15 years of age, and change in BMI from the age of 7-9 to 13-15. Multiple comparisons were performed using the Tukey test.

justing for various confounding factors.

Previous studies have lacked prospective assessments of the association between childhood relative handgrip strength and MetS in adolescence. However, the UP&DOWN study conducted in Spain, which included children aged 6-10 years and adolescents aged 12-16 years, demonstrated a consistent inverse relationship between handgrip strength levels and cardiovascular risk factors such as skinfold thickness, SBP, and insulin resistance at both initial and follow-up assessments [26]. Furthermore, research has investigated the connection between childhood physical fitness, including handgrip strength, and cardiovascular risk factors. A longitudinal European study targeting children aged 6-11 years, with a follow-up period of 2 years, indicated that lower fitness levels were linked to increased metabolic risk. In this study, handgrip strength was associated with metabolic risk, though significance was only observed in cross-sectional data [27]. Another study assessing the relationship between childhood muscle strength and the risk of MetS in adulthood found that children with higher

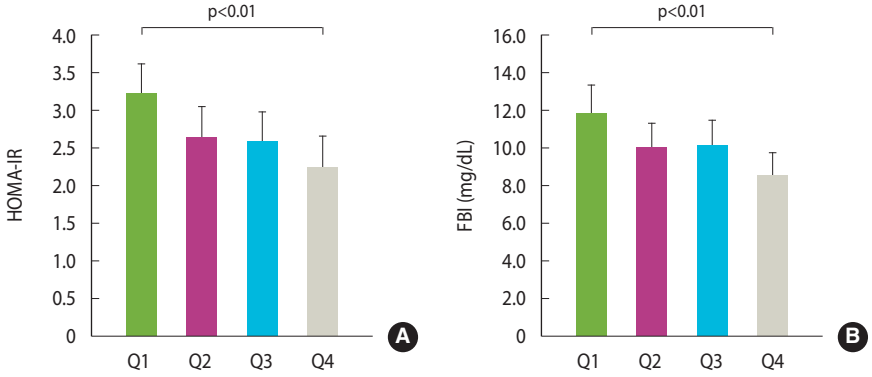


Figure 3. Effects of relative handgrip strength quartiles at 7-9 years of age on insulin resistance indices at 13-15 years of age. (A) homeostasis model assessment of insulin resistance (HOMA-IR) and (B) fasting blood insulin (FBI). Adjusted mean with 95% confidence interval (CI) was estimated under controlling for sex, age, monthly household income, mother's education, moderate physical activity at 13-15 years of age, and change in body mass index from the age of 7-9 to 13-15. Multiple comparisons were performed using the Tukey test. Results are presented as adjusted means with 95% CIs.

muscle strength had a lower risk of developing MetS later in life, with reduced incidence rates observed during adulthood (risk ratio, 0.21; 95% CI, 0.09 to 0.49) [28]. These findings collectively suggest a potential link between childhood muscle strength, particularly relative handgrip strength, and the risk of MetS in both adolescence and adulthood. The results of this study corroborate those of previous research.

Insulin resistance is characterized by a reduced response of the body to the metabolic actions of insulin, which is essential for carbohydrate and lipid metabolism [29]. Therefore, insulin resistance is frequently considered a significant risk factor and a component of MetS [30,31]. Several studies have explored the relationship between handgrip strength and insulin resistance through prospective investigations. One study examining the link between childhood handgrip strength and adult insulin resistance revealed that a 3.57 kg increase in right handgrip strength among 9-year-old boys correlated with a 0.52 mU/L reduction in FBI and a 0.08 decrease in updated HOMA-IR (i.e., HOMA2-IR) in their adult years [32]. Furthermore, a cohort study that followed Danish adolescents for 12 years did not measure handgrip strength but discovered that adolescent muscle strength was inversely related to FBI and markers of insulin resistance in adulthood [33]. Our findings align with these previous studies.

Recent years have seen an increasing trend in the prevalence of MetS among both adults and adolescents in Korea, with rates reaching 22.9% and 4.8%, respectively [34,35]. Data from the Korea National Health and Nutrition Examination Study indicate that the prevalence of insulin resistance among Korean adolescents, assessed using HOMA-IR, was 9.8% [24]. Additionally, the National Health Insurance Service reported that the prevalence of type 2 diabetes among adolescents aged 10-14 and 15-19 in 2016 was 2.8 and 9.9 cases per 10,000 individuals, respectively, marking a significant increase from 2002 [36]. Moreover, the prevalence of hyperglycemia was reported at 11.7 cases per 100 individuals [37]. These trends highlight a growing risk of metabolic disorders, which could potentially lead to adult-onset diseases, underscoring the importance of prevention and intervention efforts. However, the 2022 Korean Youth Risk Behavior Survey revealed that the rate of physical activity among Korean adolescents was low, with rates of 23.4% for boys and 8.8% for girls [38], significantly lower than international standards [39]. Therefore, proactive efforts to promote physical activity are crucial for increasing handgrip strength among Korean children and adolescents.

This study highlights the significance of childhood handgrip strength as a preventive factor against MetS in adolescence from a public health standpoint. Handgrip strength is a key indicator of overall muscle strength, underscoring the need for regular physical activity and strength training beginning at an early age [40]. The World Health Organization and the Korea Ministry of Health and Welfare recommend that children aged 6 and older participate in physical activities, including strength training, at least 3 times a week. Activities like stair climbing, push-ups, and squats are beneficial for muscle strengthening [41,42].

This study has several limitations. First, the participants were selected from a specific hospital, which may limit the generalizability of the results. Second, the study utilized a cohort design, which introduces the potential for bias due to attrition in follow-up observations. However, no significant differences were observed in mean handgrip strength and anthropometry at ages 7-9 years between participants who continued in the follow-up at ages 13-15 years and those who did not. Third, the absence of handgrip strength measurements at ages 13-15 years constrains our ability to elucidate the impact of adolescent handgrip strength levels on the relationship between handgrip strength and metabolic outcomes. Lastly, the frequency of moderate physical activity, considered a confounding variable, was assessed using a questionnaire without an objective evaluation of actual physical fitness or cardiorespiratory fitness. Even with adjustments for changes in BMI to account for physical growth, residual confounding factors may still be present. Despite these limitations, the study's strength lies

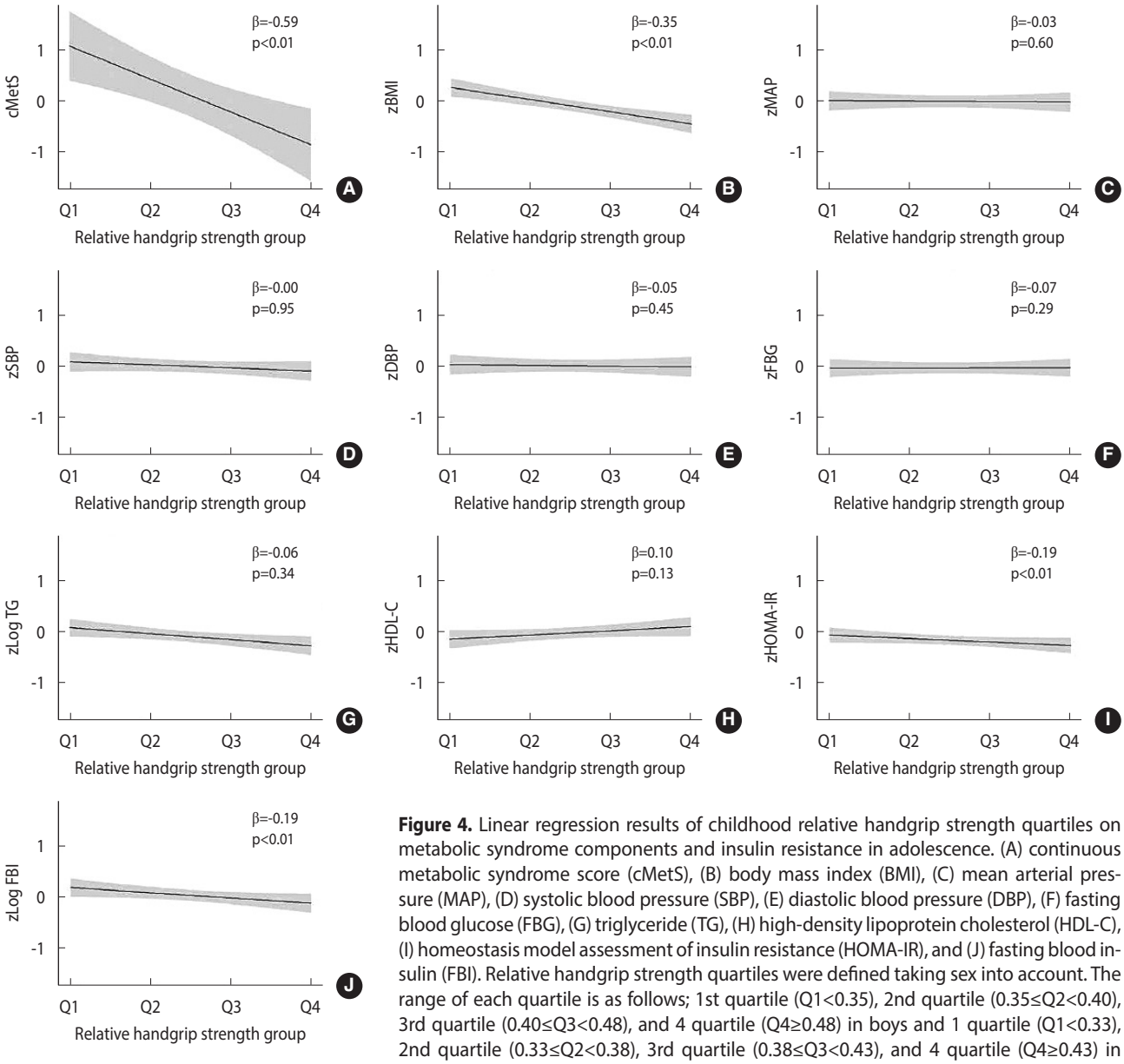


Figure 4. Linear regression results of childhood relative handgrip strength quartiles on metabolic syndrome components and insulin resistance in adolescence. (A) continuous metabolic syndrome score (cMetS), (B) body mass index (BMI), (C) mean arterial pressure (MAP), (D) systolic blood pressure (SBP), (E) diastolic blood pressure (DBP), (F) fasting blood glucose (FBG), (G) triglyceride (TG), (H) high-density lipoprotein cholesterol (HDL-C), (I) homeostasis model assessment of insulin resistance (HOMA-IR), and (J) fasting blood insulin (FBI). Relative handgrip strength quartiles were defined taking sex into account. The range of each quartile is as follows; 1st quartile (Q1<0.35), 2nd quartile (0.35≤Q2<0.40), 3rd quartile (0.40≤Q3<0.48), and 4 quartile (Q4≥0.48) in boys and 1 quartile (Q1<0.33), 2nd quartile (0.33≤Q2<0.38), 3rd quartile (0.38≤Q3<0.43), and 4 quartile (Q4≥0.43) in girls. Beta coefficients were obtained from linear regression model by assigning the median value to each quartile and treating it as a continuous variable. The model was adjusted for sex, age, monthly household income, the mother's education level, moderate physical activity at the age of 13-15 years, and change in BMI from the age of 7-9 to 13-15.

in its evaluation of the association between childhood handgrip strength levels and MetS and insulin resistance in adolescence through a prospective cohort design.

Our findings revealed a significant inverse relationship between childhood handgrip strength and both MetS scores and insulin resistance during adolescence. These results offer valuable epidemiological evidence from a prospective study. Since MetS in adolescence can persist into adulthood, early prevention is essential. Additionally, handgrip strength, which acts as a surrogate marker for muscle strength, seems to be a practical indicator for assessing the risk of MetS and insulin resistance. This highlights the critical need for preventive strategies aimed at improving muscle strength in children.

NOTES

Supplementary materials

Supplementary materials are available at https://doi.org/10.4178/epih.e2025001.

Conflict of interest

The authors have no conflicts of interest to declare for this study.

Hyesook Park has been the associate editor of the *Epidemiology and Health* since 2020. She was not involved in the review process.

Funding

This study was supported by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. RS-2023-00253552).

Acknowledgements

The study was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) for the Ministry of Education and by the BK21 FOUR (Fostering Outstanding Universities for Research).

Author contributions

Conceptualization: Jun S, Park HS. Data curation: Jun S, Park HJ. Formal analysis: Jun S, Park HJ. Funding acquisition: Park HS. Methodology: Lee HA. Visualization: Park HJ, Lee H. Writing – original draft: Jun S. Writing – review & editing: Jun S, Park HJ, Lee H, Lee HA, Hong YS, Park HS.

ORCID

Seunghee Jun: *https://orcid.org/0000-0002-0530-8720*; Hyunjin Park: *https://orcid.org/0000-0001-6536-8787*; Hyelim Lee: *https://orcid.org/0009-0002-4230-0952*; Hye Ah Lee: *https://orcid.org/0000-0002-4051-0350*; Young Sun Hong: *https://orcid.org/0000-0001-8552-9066*; Hyesook Park: *https://orcid.org/0000-0002-9359-6522*

REFERENCES

1. Saklayen MG. The global epidemic of the metabolic syndrome. Curr Hypertens Rep 2018;20:12. https://doi.org/10.1007/s11906-018-0812-z
2. Eckel RH, Grundy SM, Zimmet PZ. The metabolic syndrome. Lancet 2005;365:1415-1428. https://doi.org/10.1016/S0140-6736(05)66378-7
3. Isomaa B, Almgren P, Tuomi T, Forsén B, Lahti K, Nissén M, et al. Cardiovascular morbidity and mortality associated with the metabolic syndrome. Diabetes Care 2001;24:683-689. https://doi.org/10.2337/diacare.24.4.683
4. Ford ES. Risks for all-cause mortality, cardiovascular disease, and diabetes associated with the metabolic syndrome: a summary of the evidence. Diabetes Care 2005;28:1769-1778. https://doi.org/10.2337/diacare.28.7.1769
5. Wu SH, Liu Z, Ho SC. Metabolic syndrome and all-cause mortality: a meta-analysis of prospective cohort studies. Eur J Epidemiol 2010;25:375-384. https://doi.org/10.1007/s10654-010-9459-z
6. Morrison JA, Friedman LA, Gray-McGuire C. Metabolic syndrome in childhood predicts adult cardiovascular disease 25 years later: the Princeton Lipid Research Clinics Follow-up Study. Pediatrics 2007;120:340-345. https://doi.org/10.1542/peds.2006-1699
7. Morrison JA, Friedman LA, Wang P, Glueck CJ. Metabolic syndrome in childhood predicts adult metabolic syndrome and type 2 diabetes mellitus 25 to 30 years later. J Pediatr 2008;152:201-206. https://doi.org/10.1016/j.jpeds.2007.09.010
8. Kim JH, Lim JS. Prevalence trends of metabolic syndrome among Korean children and adolescents from a population-based cross-sectional survey. Life (Basel) 2022;12:1404. https://doi.org/10.3390/life12091404
9. Tan S, Chen C, Sui M, Xue L, Wang J. Exercise training improved body composition, cardiovascular function, and physical fitness of 5-year-old children with obesity or normal body mass. Pediatr Exerc Sci 2017;29:245-253. https://doi.org/10.1123/pes.2016-0107
10. Wind AE, Takken T, Helders PJ, Engelbert RH. Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? Eur J Pediatr 2010;169:281-287. https://doi.org/10.1007/s00431-009-1010-4
11. Milliken LA, Faigenbaum AD, Loud RL, Westcott WL. Correlates of upper and lower body muscular strength in children. J Strength Cond Res 2008;22:1339-1346. https://doi.org/10.1519/JSC.0b013e31817393b1
12. Gubelmann C, Vollenweider P, Marques-Vidal P. Association of grip strength with cardiovascular risk markers. Eur J Prev Cardiol 2017;24:514-521. https://doi.org/10.1177/2047487316680695
13. Yi DW, Khang AR, Lee HW, Son SM, Kang YH. Relative handgrip strength as a marker of metabolic syndrome: the Korea National Health and Nutrition Examination Survey (KNHANES) VI (2014-2015). Diabetes Metab Syndr Obes 2018;11:227-240. https://doi.org/10.2147/DMSO.S166875
14. Wen Y, Liu T, Ma C, Fang J, Zhao Z, Luo M, et al. Association between handgrip strength and metabolic syndrome: a meta-analysis and systematic review. Front Nutr 2022;9:996645. https://doi.org/10.3389/fnut.2022.996645
15. Li S, Zhang R, Pan G, Zheng L, Li C. Handgrip strength is associated with insulin resistance and glucose metabolism in adolescents: evidence from National Health and Nutrition Examination Survey 2011 to 2014. Pediatr Diabetes 2018;19:375-380. https://doi.org/10.1111/pedi.12596
16. Kang Y, Park S, Kim S, Koh H. Handgrip strength among Korean adolescents with metabolic syndrome in 2014-2015. J Clin Densitom 2020;23:271-277. https://doi.org/10.1016/j.jocd.2018.09.002
17. Chun SW, Kim W, Choi KH. Comparison between grip strength and grip strength divided by body weight in their relationship with metabolic syndrome and quality of life in the elderly. PLoS One 2019;14:e0222040. https://doi.org/10.1371/journal.pone.0222040
18. Lee HA, Park B, Min J, Choi EJ, Kim UJ, Park HJ, et al. Cohort profile: the Ewha Birth and Growth Study. Epidemiol Health 2021;43:e2021016. https://doi.org/10.4178/epih.e2021016
19. Choquette S, Bouchard DR, Doyon CY, Sénéchal M, Brochu M, Dionne IJ. Relative strength as a determinant of mobility in elders 67-84 years of age. a nuage study: nutrition as a determinant of

successful aging. J Nutr Health Aging 2010;14:190-195. https://doi.org/10.1007/s12603-010-0047-4
20. Pyo E. Association between relative handgrip strength and obesity in Korean adolescents: based on Korean National Health and Nutrition Examination Survey (2018). J Korean Soc Sch Health 2020;33:203-212 (Korean). https://doi.org/10.15434/kssh.2020.33.3.203
21. Eisenmann JC. On the use of a continuous metabolic syndrome score in pediatric research. Cardiovasc Diabetol 2008;7:17. https://doi.org/10.1186/1475-2840-7-17
22. Heshmat R, Heidari M, Ejtahed HS, Motlagh ME, Mahdavi-Gorab A, Ziaodini H, et al. Validity of a continuous metabolic syndrome score as an index for modeling metabolic syndrome in children and adolescents: the CASPIAN-V study. Diabetol Metab Syndr 2017;9:89. https://doi.org/10.1186/s13098-017-0291-4
23. Tagi VM, Giannini C, Chiarelli F. Insulin resistance in children. Front Endocrinol (Lausanne) 2019;10:342. https://doi.org/10.3389/fendo.2019.00342
24. Yi KH, Hwang JS, Kim EY, Lee SH, Kim DH, Lim JS. Prevalence of insulin resistance and cardiometabolic risk in Korean children and adolescents: a population-based study. Diabetes Res Clin Pract 2014;103:106-113. https://doi.org/10.1016/j.diabres.2013.10.021
25. Kim JH, Yun S, Hwang SS, Shim JO, Chae HW, Lee YJ, et al. The 2017 Korean National Growth Charts for children and adolescents: development, improvement, and prospects. Korean J Pediatr 2018;61:135-149. https://doi.org/10.3345/kjp.2018.61.5.135
26. Castro-Piñero J, Perez-Bey A, Cuenca-Garcia M, Cabanas-Sanchez V, Gómez-Martínez S, Veiga OL, et al. Muscle fitness cut points for early assessment of cardiovascular risk in children and adolescents. J Pediatr 2019;206:134-141.e3. https://doi.org/10.1016/j.jpeds.2018.10.026
27. Zaqout M, Michels N, Bammann K, Ahrens W, Sprengeler O, Molnar D, et al. Influence of physical fitness on cardio-metabolic risk factors in European children. The IDEFICS study. Int J Obes (Lond) 2016;40:1119-1125. https://doi.org/10.1038/ijo.2016.22
28. Fraser BJ, Huynh QL, Schmidt MD, Dwyer T, Venn AJ, Magnussen CG. Childhood muscular fitness phenotypes and adult metabolic syndrome. Med Sci Sports Exerc 2016;48:1715-1722. https://doi.org/10.1249/MSS.0000000000000955
29. Lebovitz HE. Insulin resistance: definition and consequences. Exp Clin Endocrinol Diabetes 2001;109 Suppl 2:S135-S148. https://doi.org/10.1055/s-2001-18576
30. Roberts CK, Hevener AL, Barnard RJ. Metabolic syndrome and insulin resistance: underlying causes and modification by exercise training. Compr Physiol 2013;3:1-58. https://doi.org/10.1002/cphy.c110062
31. Vukovic R, Milenkovic T, Stojan G, Vukovic A, Mitrovic K, Todorovic S, et al. Pediatric siMS score: a new, simple and accurate continuous metabolic syndrome score for everyday use in pediatrics. PLoS One 2017;12:e0189232. https://doi.org/10.1371/journal.pone.0189232
32. Fraser BJ, Blizzard L, Schmidt MD, Juonala M, Dwyer T, Venn AJ, et al. Childhood cardiorespiratory fitness, muscular fitness and adult measures of glucose homeostasis. J Sci Med Sport 2018;21:935-940. https://doi.org/10.1016/j.jsams.2018.02.002
33. Grøntved A, Ried-Larsen M, Ekelund U, Froberg K, Brage S, Andersen LB. Independent and combined association of muscle strength and cardiorespiratory fitness in youth with insulin resistance and β-cell function in young adulthood: the European Youth Heart Study. Diabetes Care 2013;36:2575-2581. https://doi.org/10.2337/dc12-2252
34. Lee J, Kang SC, Kwon O, Hwang SS, Moon JS, Chae HW, et al. Temporal trends of the prevalence of abdominal obesity and metabolic syndrome in Korean children and adolescents between 2007 and 2020. J Obes Metab Syndr 2023;32:170-178. https://doi.org/10.7570/jomes22059
35. Huh JH, Kang DR, Kim JY, Koh KK. Metabolic syndrome fact sheet 2021: executive report. CardioMetab Syndr J 2021;1:125-134. https://doi.org/10.51789/cmsj.2021.1.e15
36. Hong YH, Chung IH, Han K, Chung S; Taskforce Team of the Obesity Fact Sheet of the Korean Society for the Study of Obesity. Prevalence of type 2 diabetes mellitus among Korean children, adolescents, and adults younger than 30 years: changes from 2002 to 2016. Diabetes Metab J 2022;46:297-306. https://doi.org/10.4093/dmj.2021.0038
37. Yoo SE, Lee JH, Lee JW, Park HS, Lee HA, Kim HS. Increasing prevalence of fasting hyperglycemia in adolescents aged 10-18 years and its relationship with metabolic indicators: the Korea National Health and Nutrition Examination Study (KNHANES), 2007-2018. Ann Pediatr Endocrinol Metab 2022;27:60-68. https://doi.org/10.6065/apem.2142068.034
38. Korea Disease Control and Prevention Agency. Trends in the proportion of adolescents engaged in physical activities, 2012-2022. Public Health Wkly Rep 2023;16:1561-1562 (Korean). https://doi.org/10.56786/PHWR.2023.16.45.3
39. World Health Organization. Global status report on physical activity 2022: let's get moving!; 2022 [cited 2024 Oct 15]. Available from: https://www.who.int/teams/health-promotion/physical-activity/global-status-report-on-physical-activity-2022
40. Ito T, Sugiura H, Ito Y, Noritake K, Ochi N. Relationship between the skeletal muscle mass index and physical activity of Japanese children: a cross-sectional, observational study. PLoS One 2021;16:e0251025. https://doi.org/10.1371/journal.pone.0251025
41. World Health Organization. WHO guidelines on physical activity and sedentary behavior; 2023 [cited 2024 Oct 15]. Available from: https://www.who.int/publications/i/item/9789240015128
42. Ministry of Health and Welfare. Physical activity guidelines for Koreans (2023) revised edition [cited 2024 Oct 15]. Available from: https://www.mohw.go.kr/board.es?mid=a10411010100&bid=0019&act=view&list_no=1479208&tag=&nPage=1 (Korean).