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Handgrip Strength Is Associated with Metabolic Syndrome and Insulin Resistance in Children and Adolescents: Analysis of Korea National Health and Nutrition Examination Survey 2014–2018

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Background: Reduced handgrip strength (HGS) is associated with adverse cardiometabolic health outcomes. We examined HGS, metabolic syndrome (MetS), and insulin resistance (IR) in children and adolescents.

Methods: The following population-based data from 2,797 participants (aged 10–18 years) of the Korea National Health and Nutrition Examination Survey 2014–2018 were analyzed: complete anthropometric measures, HGS, MetS, and IR (subgroup with fasting insulin, n=555). HGS was analyzed as the combined HGS (CHGS) and the normalized CHGS (nCHGS=CHGS divided by body weight).

Results: At a mean age of 14.4 years, 276 participants (9.9%) had abdominal obesity, 56 (2.0%) had MetS, and 118 (20.9%) had IR. Individual components of MetS and IR were inversely associated with the nCHGS. The odds ratios (ORs) for MetS and IR decreased significantly with higher nCHGS after adjustment for sex, age, physical activity, and sedentary times. The optimal cut-off values that predicted MetS were 0.80 kg/kg (males) and 0.71 kg/kg (females), with significant associations with MetS (OR: 7.4 in males; 5.7 in females) and IR (OR: 3.3 in males; 3.2 in females) observed when nCHGS values were lower than those cut-offs.

Conclusion: HGS is associated with MetS and IR and might be a useful indicator of cardiometabolic risk factors in children and adolescents.

Key words: Handgrip strength, Cardiometabolic risk factors, Insulin resistance

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INTRODUCTION

Metabolic syndrome (MetS) is a clustering of cardiovascular risk factors: abdominal obesity, hypertension, impaired fasting glucose, elevated triglycerides, and decreased high-density lipoprotein cholesterol (HDL-C), with insulin resistance (IR) implicated as a possible underlying pathogenic link among the individual components. The presence of MetS in adults is associated with a 2- to 3-fold increase in the risk of cardiovascular morbidity and mortality[1] and a 3- to 5-fold increase in the risk of incident type 2 diabetes mellitus.[2] Its predictive value is less clear in children and adolescents due to a lack of consensus about diagnostic criteria,[3] instability in diagnosis continuity from childhood to adulthood,[4] complexities in the interplay between obesity and metabolic health indicators,[5] and sparse data about long-term cardiovascular outcomes. However, associations are clearly present between MetS risk factors (both clustered and individual) in early life and cardiovascular disease, MetS persistence, and type 2 diabetes mellitus in childhood.[6,7]

The components of health-related physical fitness are cardiorespiratory fitness, muscular fitness, body composition, and flexibility,

which together are integral to maintaining general health and preventing MetS in both obese and non-obese children.[8] The importance of muscular fitness in health is underscored by sarcopenia, a state of progressively decreasing muscle mass and function associated with aging and obesity. Secondary sarcopenia has been reported in younger populations through associations between cardiometabolic risk clustering and decreased muscle mass or strength in children and adolescents.[9] Handgrip strength (HGS) serves as a reliable and valid representation of upper limb[10] and whole body muscle strength,[11] with studies showing inverse associations between HGS and sarcopenic obesity[12] and cardiometabolic risk[13-15] in children and adolescents. However, reference HGS values in children and adolescents have not been established, and only a few studies have proposed cut-off values to identify those with increased cardiometabolic risk.[16-18] In this study, we aimed to confirm associations between HGS and MetS and measures of IR. We also aimed to propose optimal cut-off values to predict the presence of MetS and its components in a large, healthy, and population-based group of children and adolescents.

METHODS

Data resource

This study analyzed data from the 6th (2013–2015) and 7th (2016–2018) Korea National Health and Nutrition Examination Survey (KNHANES). KNHANES is an ongoing, cross-sectional survey conducted by the Korea Centers for Disease Control and Prevention (KCDC) since 1998. Each year, it assesses the health and nutritional status of a sample population of approximately 10,000 individuals selected according to a multi-stage clustered probability design. The participants are assigned sample weights to account for the complex survey design, non-responders, and post-stratification, which ensures that the data represent the larger Korean population. Participants complete a health interview, examination, and nutrition survey, through which detailed information is collected about socioeconomic status, health-related behaviors, quality of life, healthcare utilization, anthropometric measures, biochemical and clinical profiles of non-communicable diseases, and dietary intake. KNHANES received approval from the Institutional Review Board of the KCDC (No. 2013-07CON-03-4C, 2013-12EXP-03-5C, 2015-01-02-6C, 2018-01-03-P-A), and all participants provided informed written consent. The need for ethical approval for this study was waived by the Institutional Review Board of Kyung Hee University Medical Center (No. 2021-07-077) because we used anonymous data publicly available through the KNHANES website (https://knhanes.kdca.go.kr/).

Study participants

A total of 39,199 subjects participated in the KNHANES between 2014 and 2018. Among those participants, 3,689 were children and adolescents aged 10 to 18 years. Subjects with incomplete data for anthropometric measures (n = 273), HGS (n = 117), or laboratory test results (n = 434) were excluded. Those with inadequate fasting times (n = 62) or impaired fasting glucose (n = 6) were also excluded. Ultimately, we analyzed data for 2,797 children and adolescents (1,487 males and 1,310 females). IR was analyzed in a subset of 555 children whose fasting insulin level was tested.

Data collection

Demographic information (age and sex), medical history (current and past medical conditions including diabetes mellitus, hypertension, and dyslipidemia), and physical activity data (minutes per week of moderate to vigorous physical activity and hours per day of sedentary time) were obtained in interviews. Anthropometric measures, HGS measurements, blood pressure (BP) measurements, and laboratory tests were conducted by trained medical personnel in mobile examination centers according to standardized protocols. Height was measured to the nearest 0.1 cm and weight to the nearest 0.1 kg, and body mass index (BMI) was calculated as weight in kg divided by height in meters squared. Waist circumference (WC) was measured to the nearest 0.1 cm at the umbilical level using a measuring tape. HGS was measured in kg using a digital grip strength dynamometer (T.K.K. 5401; Takei, Niigata, Japan) in the standing position, feet hip width apart, arms naturally extending and hanging downward, and wrists in the neutral position. Grip strength was measured from both hands alternately with 30-second resting intervals to a total of three measurements each for the left and right hands. The maximum value from the left hand was summed with the maximum value from the right hand to calculate the combined HGS (CHGS, in kg). Furthermore, the CHGS was normalized for

body weight (nCHGS = CHGS in kg/body weight in kg) to account for its possible biasing effect on grip strength. BP was measured three times in the sitting position following 5 minutes of rest, and the means of the second and third measurements were recorded. Venous blood samples were drawn after an overnight fast to determine fasting plasma glucose, triglyceride, HDL-C, glycosylated hemoglobin (HbA1c), and insulin levels. Insulin levels were tested only during the 2015 survey year.

Definitions of obesity, metabolic syndrome, and insulin resistance in children and adolescents

Participants with BMI ≥ 95th percentile according to the KCDC national growth charts[19] were considered obese. MetS was defined according to the International Diabetes Federation (IDF) consensus for children and adolescents.[20] Those criteria mandate the presence of abdominal obesity and two or more additional clinical features. Abdominal obesity was defined as WC either ≥ 90th percentile[19] or ≥ the adult cut-offs (90 cm for males, 85 cm for females)[21] in children aged 10 to 15 years. Adult cut-offs for WC were used in adolescents aged 16 to 18. The additional clinical features of MetS were elevated triglycerides (≥ 150 mg/dL), low HDL-C (< 40 mg/dL for both sexes aged 10 to 15 and males aged 16 to 18; < 50 mg/dL for females aged 16 to 18), high BP (systolic BP [SBP] ≥ 130 mmHg or diastolic BP ≥ 85 mmHg), and impaired fasting glucose (≥ 100 mg/dL). Glucose homeostasis was evaluated using HbA1c. The measures of IR were fasting insulin level and homeostatic model assessment for insulin resistance (HOMA-IR = fasting plasma glucose [mg/dL] × fasting serum insulin [μIU/mL]/405). Participants were classified as having IR if the calculated HOMA-IR was ≥ 90th percentile.[22]

Statistical analysis

Statistical analyses for this study were performed in IBM SPSS 23.0 for Windows (IBM Corp., Armonk, NY, USA) using the complex samples option to account for the sample weights and incorporate the stratification and clustering of the design into the analyses. Variables were tested for normal distribution and described as weighted mean (± standard error [SE]) or median (interquartile range). Triglyceride level was log-transformed because it had a positively skewed distribution. Differences between two groups were analyzed by chi-square tests or t-tests. Both simple and multiple linear regression analyses were conducted to analyze associations between MetS components and IR (as dependent variables) and HGS (as the independent variable). A logistic regression was conducted to determine the odds ratios (ORs) of MetS and abdominal obesity according to HGS. Regression analyses were modeled to adjust for age, sex, BMI (only for CHGS), physical activity, sedentary time, household income, alcohol consumption, and smoking. To assess trends in individual and clustered MetS components and parameters of IR, binomial logistic and linear regression analyses were performed according to HGS in sex-specific quartile groups with adjustment for the mentioned covariates.

Receiver operating characteristics (ROC) curve analyses were conducted to assess the predictive power of HGS in identifying MetS. SAS version 9.4 software (SAS Institute Inc., Cary, NC, USA) and R Statistical Software version 3.3.3 (Foundation for Statistical Computing, Vienna, Austria) were used for ROC analyses. Sex-specific indices of sensitivity, specificity, and area under the curve (AUC) with 95% confidence intervals (CIs) were calculated. Appropriate cut-off values were determined from the maximum values of the Youden index: sensitivity+specificity–1. Both the positive and negative likelihood ratios were used to examine the potential diagnostic accuracy of HGS in discriminating between those with and without MetS and its components. Furthermore, the ability of the cut-off values to predict MetS and its components was tested with binomial logistic and multiple linear regression analyses. *P*-values < 0.05 were considered statistically significant.

RESULTS

Baseline characteristics of the study population

The characteristics of the subjects are summarized in Table 1. The mean age of the population was 14.4 years (SE, 0.1). Approximately 276 participants (9.9%) were obese according to the BMI criteria, without differences between males and females. The mean duration of reported moderate-vigorous physical activity per week was significantly greater in males, along with significantly fewer sedentary hours in males than females. A greater proportion of the male subjects were cigarette smokers compared with the female subjects.

Table 1. Characteristics of the participants

Baseline characteristics	Total (n=2,797)	Male (n=1,487)	Female (n=1,310)	*P*
Age (yr)	14.4±0.1	14.4±0.1	14.4±0.1	0.790
Height z-score	0.6±0.0	0.7±0.0	0.5±0.0	0.001
Weight z-score	0.4±0.0	0.4±0.0	0.3±0.0	0.030
BMI z-score	0.2±0.0	0.2±0.0	0.2±0.0	0.780
Obesity	276 (9.9)	152 (10.1)	124 (9.7)	0.720
Moderate–vigorous physical activity per week (min)	104.6±6.8	152.0±11.4	50.8±4.5	<0.001
Sedentary time (hr/day)	11.0±0.1	10.7±0.1	11.3±0.1	<0.001
Socioeconomic status				0.033
1st quartile	282 (10.1)	134 (9.0)	148 (11.3)	
2nd quartile	635 (22.8)	352 (23.7)	283 (21.7)	
3rd quartile	954 (34.2)	516 (34.8)	438 (33.5)	
4th quartile	919 (32.9)	482 (32.5)	437 (33.5)	
Alcohol consumption				0.200
None	2,299 (82.2)	1,199 (80.6)	1,100 (84.0)	
≤ Once per month	344 (12.3)	197 (13.2)	147 (11.2)	
2–4 Times per month	104 (3.7)	60 (4.0)	44 (3.4)	
> 2–3 Times per week	40 (1.4)	23 (1.5)	17 (1.3)	
Smoking (yes)	124 (4.4)	93 (6.3)	31 (2.3)	<0.001
Measure of handgrip strength				
Combined handgrip strength (kg)	51.9±0.5	60.4±0.6	42.4±0.3	<0.001
Normalized combined handgrip strength (kg/kg)	0.9±0.0	1.0±0.0	0.8±0.0	<0.001
Measure of metabolic syndrome components				
Waist circumference (cm)	70.8±0.2	73.3±0.3	68.0±0.3	0.001
Abdominal obesity	276 (9.9)	172 (11.6)	104 (7.9)	0.001
SBP (mmHg)	108.3±0.2	110.6±0.3	105.8±0.3	0.001
DBP (mmHg)	66.4±0.2	66.8±0.3	66.1±0.3	0.029
Elevated blood pressure	107 (3.7)	83 (5.5)	24 (1.8)	<0.001
Fasting glucose (mg/dL)	91.4±0.2	92.6±0.2	90.2±0.2	<0.001
Elevated fasting glucose	321 (10.8)	214 (13.9)	107 (7.4)	<0.001
Triglycerides (mg/dL)*	86.4±1.2	85.7±1.6	87.2±1.4	0.022
Elevated triglycerides	244 (8.4)	132 (8.7)	112 (8.0)	0.527
HDL-C (mg/dL)*	51.6±0.2	50.3±0.3	53.0±0.3	<0.001
Low HDL-C	419 (15.3)	182 (11.9)	237 (19.2)	<0.001
Metabolic syndrome	56 (2.0)	37 (2.5)	19 (1.4)	0.047
Measure of glucose and insulin resistance	(n=555)	(n=305)	(n=250)	
HbA1c (%)	5.4±0.0	5.4±0.0	5.3±0.0	0.002
Insulin (μIU/mL)	12.9±0.4	12.6±0.5	13.2±0.6	0.370
HOMA-IR	2.9±0.1	2.9±0.1	3.0±0.1	0.591
Insulin resistance	118 (20.9)	69 (22.4)	49 (19.3)	0.395

Values are presented as mean±standard error or number (%).
*Triglycerides and HDL-C were log transformed for the analyses.
BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HbA1c, glycosylated hemoglobin; HOMA-IR, homeostasis model assessment of insulin resistance.

Measurements of handgrip strength, metabolic syndrome, and insulin resistance

The mean CHGS was 60.4 kg (SE, 0.6) in males and 42.4 kg (SE, 0.3) in females. Normalized for body weight, the mean nCHGS was 1.0 kg/kg (SE, 0.0) in males and 0.8 kg/kg (SE, 0.0) in females. Both the mean CHGS and mean nCHGS were significantly higher in males than in females ($P<0.05$).

Of the 2,797 participants analyzed, 276 (9.9%) had abdominal

obesity, with a larger proportion of subjects being males (n = 172, 11.6%) than females (n = 104, 7.9%) ($P = 0.001$). Other MetS components of elevated BP, impaired fasting glucose, elevated triglycerides, and decreased HDL-C were observed in 107 participants (3.7%), 321 (10.8%), 244 (8.4%), and 419 (15.3%), respectively. According to the IDF criteria, 56 participants (2.0%) had MetS, and more of them were male (n = 37, 2.5%) than female (n = 19, 1.4%, $P = 0.047$). Among the indices of glucose and IR, mean HbA1c levels were slightly higher in males than in females ($P = 0.002$), and fasting insulin and calculated HOMA-IR did not differ by sex. In the subgroup of participants with fasting insulin measures, 118 (20.9%) met the criteria for IR (HOMA-IR > 90th percentile for sex and age).

Relationship between handgrip strength and metabolic syndrome

The results of the regression analyses of MetS, individual MetS components, and IR measures with HGS are shown in Table 2. When nCHGS was adjusted for sex and age (model 1), it was inversely as-

Table 2. Linear and binomial logistic regression models for metabolic syndrome components and handgrip strength

Independent variable	Dependent variable	Simple		Model 1		Model 2	
	Metabolic syndrome component						
CHGS		β	SE	β	SE	β	SE
	SBP	0.189†	0.011	0.102†	0.017	0.062*	0.026
	DBP	0.122†	0.010	0.057†	0.015	0.065†	0.021
	Fasting glucose	–0.004	0.008	–0.006	0.011	0.002	0.017
	Triglycerides	0.077	0.064	0.064	0.090	0.057	0.133
	HDL-C	–0.114†	0.010	–0.063†	0.016	–0.039	0.025
		OR	95% CI	OR	95% CI	OR	95% CI
	Abdominal obesity	1.024†	1.017–1.032	1.016*	1.001–1.031	1.022	0.998–1.046
	Metabolic syndrome	1.030†	1.014–1.047	1.016	0.992–1.040	1.019	0.973–1.067
nCHGS		β	SE	β	SE	β	SE
	SBP	3.861†	0.901	–3.402†	1.045	–5.892†	1.493
	DBP	3.731†	0.754	–0.378	0.853	0.574	1.239
	Fasting glucose	–1.788†	0.661	–2.648†	0.700	–1.487	1.108
	Triglycerides	–26.346†	4.745	–30.613†	5.215	–24.935†	7.772
	HDL-C	–0.022	0.841	4.703†	0.989	6.048†	1.473
		OR	95% CI	OR	95% CI	OR	95% CI
	Abdominal obesity	0.007†	0.003–0.018	0.001†	0.001–0.003	0.001†	0.001–0.003
	Metabolic syndrome	0.021†	0.004–0.104	0.006†	0.001–0.025	0.004†	0.001–0.061
	Glucose and insulin resistance						
CHGS		β	SE	β	SE	β	SE
	HbA1c	–0.001†	0.001	0.002	0.007	0.001	0.001
	Fasting insulin	–0.007	0.018	0.012	0.030	0.005	0.034
	HOMA-IR	–0.002	0.004	0.002	0.007	0.001	0.008
		OR	95% CI	OR	95% CI	OR	95% CI
	Insulin resistance	1.001	0.989–1.013	0.986	0.965–1.008	0.977	0.951–1.004
nCHGS		β	SE	β	SE	β	SE
	HbA1c	–0.084	0.051	–0.051	0.057	0.002	0.042
	Fasting insulin	–11.015†	1.539	–11.755†	1.808	–10.573†	1.884
	HOMA-IR	–2.538†	0.361	–2.715†	0.424	–2.436†	0.448
		OR	95% CI	OR	95% CI	OR	95%CI
	Insulin resistance	0.026†	0.008–0.086	0.010†	0.003-0.040	0.007†	0.001–0.043

Model 1 adjusted for age, sex, BMI for CHGS, and age and sex for nCHGS. Model 2 adjusted for age, sex, BMI, physical activity, sedentary time, household income, alcohol consumption, and smoking for CHGS and age, sex, physical activity, sedentary time, household income, alcohol consumption, and smoking for nCHGS.
*$P < 0.05$; †$P < 0.01$.
CHGS, combined handgrip strength; SE, standard error; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; OR, odds ratio; CI, confidence interval; nCHGS, normalized CHGS; HbA1c, glycosylated hemoglobin; HOMA-IR, homeostasis model assessment of insulin resistance; BMI, body mass index.

sociated with SBP, fasting glucose, and triglyceride levels and positively associated with HDL-C. When further adjusted for physical activity, sedentary time, household income, alcohol consumption, and cigarette smoking (model 2), the inverse associations between nCHGS and SBP, triglycerides, and decreased HDL-C remained significant. Moreover, the ORs for abdominal obesity and MetS decreased significantly as nCHGS increased, even after adjusting for covariates.

Relationship between handgrip strength and measures of glucose and insulin resistance

In regression analyses of CHGS and nCHGS with glucose and IR parameters, inverse associations of nCHGS with fasting insulin and HOMA-IR remained significant in the models that adjusted for age, sex, physical activity, sedentary time, household income, alcohol consumption, and cigarette smoking. Having a higher nCHGS was associated with significantly decreased ORs for IR in all models.

Trends in metabolic syndrome components and insulin resistance according to nCHGS quartile

Participants were grouped into sex-specific quartiles by nCHGS to analyze trends in the prevalence of MetS, abdominal obesity, and the individual MetS component measures (Fig. 1). The ORs of both MetS and abdominal obesity increased sequentially in consecutively lower nCHGS quartiles in both males and females (*P* for trend ≤0.001 for both). The mean triglyceride levels were higher for both males and females in the lower nCHGS quartiles. Furthermore, the mean SBP was higher and the mean HDL-C was lower (*P* for trend <0.05 for both) (Supplementary Table 1) for males in the lower nCHGS quartiles. Moreover, mean fasting insulin level and HOMA-IR both showed significant increasing trends in both males and females in the lower nCHGS quartiles (Fig. 2, Supplementary Table 2).

ROC curve analyses to find sex-specific cut-off values of nCHGS and analyses of metabolic syndrome and its components according to those cut-off values

A ROC curve analysis was conducted according to sex to identify optimal nCHGS cut-off values that predict the presence of MetS. The Youden index had maximum values of 0.38 for males and 0.54 for females when using 0.80 kg/kg for males (AUC, 0.74; 95% CI, 0.67–0.82) and 0.71 kg/kg for females (AUC, 0.81; 95% CI, 0.71–0.92) as the optimal cut-off values for nCHGS. The sensitivities, specificities, and positive and negative likelihood ratios are shown in Table 3, and the ROC curves are shown in Fig. 3.

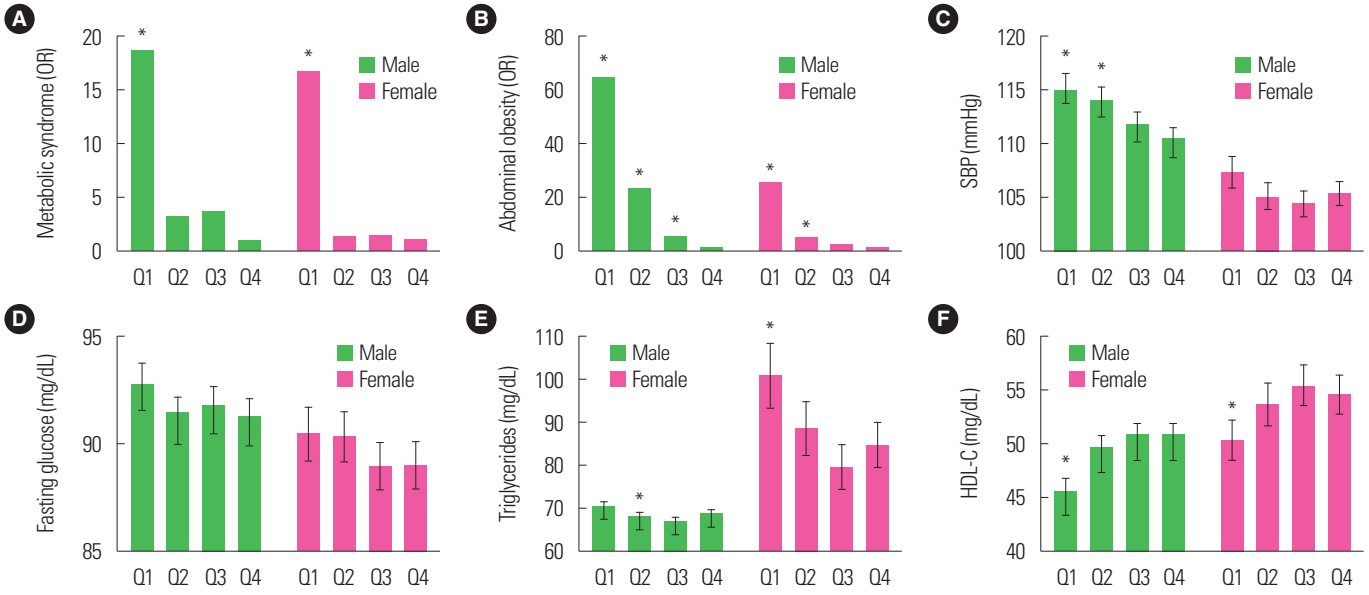

Figure 1. Metabolic syndrome and its components according to sex-specific quartiles of normalized handgrip strength. (A) Metabolic syndrome. (B) Abdominal obesity. (C) Systolic blood pressure (SBP). (D) Fasting glucose. (E) Triglycerides. (F) High-density lipoprotein cholesterol (HDL-C). Odds ratios (ORs) or actual measures of metabolic syndrome and its individual components by quartiles of normalized handgrip strength. The lowest quartile (Q1) to the highest quartile (Q4) are shown for each sex. The analyses were adjusted for age, physical activity, sedentary time, household income, alcohol consumption, and smoking. **P* for trend <0.05.

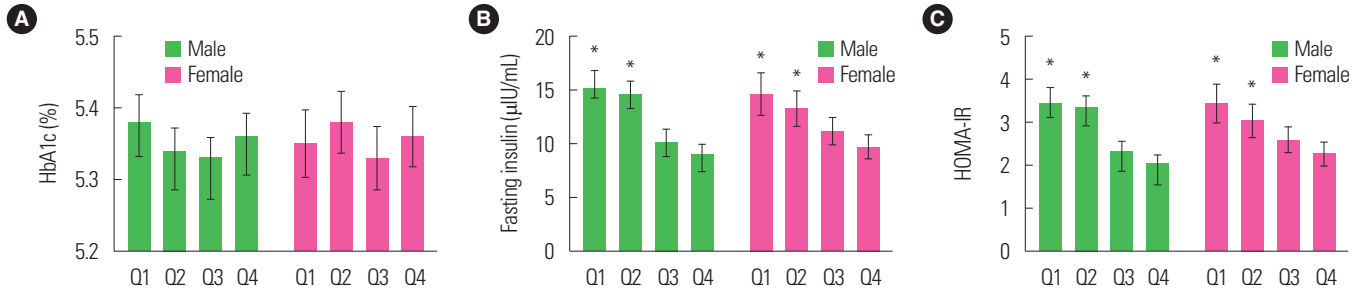

Figure 2. Measures of glucose homeostasis and insulin resistance according to sex-specific quartiles of normalized handgrip strength. (A) Glycosylated hemoglobin (HbA1c). (B) Fasting insulin. (C) Homeostasis model assessment of insulin resistance (HOMA-IR). Values for the glucose homeostasis and insulin resistance measures by quartiles of normalized handgrip strength from the lowest quartile (Q1) to the highest quartile (Q4) for each sex adjusted by age, physical activity, sedentary time, household income, alcohol consumption, and smoking. *P for trend <0.05.

Table 3. Cut-off values of normalized combined handgrip strength that predict the presence of metabolic syndrome

Output parameter	Male	Female
AUC (95% CI)	0.74 (0.67–0.82)*	0.81 (0.71–0.92)*
Cut-off value (kg/kg)	0.80	0.71
J-Youden	0.38	0.54
Sensitivity	78.2	75.4
Specificity	59.5	78.9
Positive likelihood ratio	1.93	3.58
Negative likelihood ratio	0.37	0.31

*P<0.01.
AUC, area under the curve; CI, confidence interval.

Those nCHGS cut-off values were used to classify our study subjects into high and low HGS groups. There were 339 males (22.8%) and 325 females (24.8%) whose nCHGS was lower than the cut-offs. Differences in their characteristics are shown in Supplementary Table 3. Differences in the measures of MetS components and the prevalence of MetS and its components according to the nCHGS cut-off values are shown in Supplementary Table 4. Both males and females with lower nCHGS showed significantly higher WC, fasting glucose, triglycerides, fasting insulin, and HOMA-IR and lower HDL-C (P < 0.05 for all). The ORs for presence of abdominal obesity, elevated triglycerides, low HDL-C, impaired fasting glucose (in females only), MetS, and IR (in females only) were all increased in those with nCHGS values below the cut-offs (P for all <0.05) after adjustment for age, physical activity, sedentary time, household income, alcohol consumption, and smoking (Supplementary Table 5).

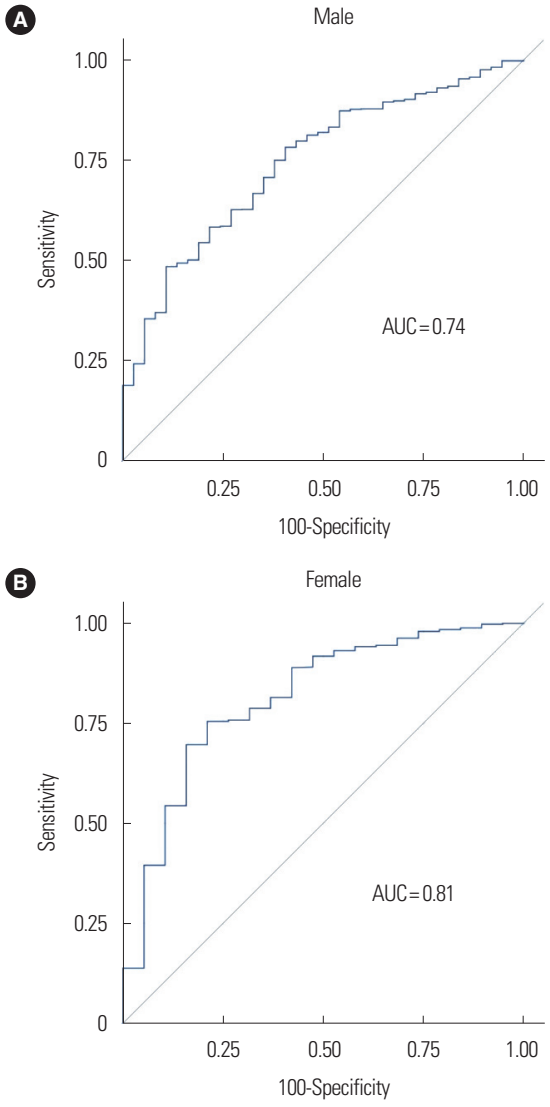

Figure 3. Receiver operating characteristic curves for normalized handgrip strength in predicting the presence of metabolic syndrome in males (A) and females (B). AUC, area under the curve.

DISCUSSION

In this population-based study of children and adolescents, HGS normalized for body weight was associated with presence of both clustered and individual MetS components and IR, despite adjustment for sex, age, physical activity, sedentary times, household income, alcohol consumption, and smoking. Significant associations were observed between MetS and IR and sequentially lower quartiles of nCHGS. Moreover, nCHGS cut-off points to differentiate between those with and without MetS were determined for this representative nationwide population.

The presence of abdominal obesity in our study population was 9.9%, of whom 2.0% met the criteria for MetS. This is comparable to the median prevalence of MetS of 2.1% reported using IDF criteria for a global population between 2014 and 2019[23] and considerably lower than the prevalence of 4.2% reported using the same IDF criteria for KNHANES participants aged 12 to 19 between 2011 and 2014.[24] Even though the number of participants with MetS was not high in our study, the inverse association between MetS and normalized HGS was significant. These results confirm the results of previous studies showing associations between low HGS and cardiometabolic risk factors in children and adolescents. Ramírez-Vélez et al.[14] reported greater ideal cardiovascular health metrics (nonsmoking; adequate physical activity; appropriate BMI; healthy diet; and normal BP, cholesterol, and glucose levels) in youth with high HGS. Data from previous population-based health and nutrition examination surveys have also generally reported a significant inverse association between HGS and MetS in children and adolescents.[25-27]

In terms of associations between individual MetS components and HGS, a previous study using KNHANES data reported that HGS was significantly and positively associated with both SBP and DBP in children and adolescents, independent of BMI and physical activity.[28] Another analysis of KHNANES data reported significantly lower handgrip-to-weight ratios in children and adolescents with abdominal obesity, hypertriglyceridemia, and low HDL-C than in those whose WC and laboratory values were in the normal range.[26] Yet another study found that lower quartiles of normalized HGS were associated with abdominal obesity, impaired fasting glucose (in males only), high BP (in females only), high triglycerides, and low HDL-C.[25] Our study results are similar: most individual components of MetS, with the exception of fasting glucose, were associated with lower normalized HGS. A possible reason for the lack of association between fasting glucose and HGS could be our exclusion of participants with overt diabetes mellitus or impaired fasting glucose. Fasting insulin and HOMA-IR levels were inversely associated with normalized HGS in our study. These results are similar to those in a previous study that examined HGS with measures of IR (fasting insulin and HOMA-IR) and glucose metabolism (fasting glucose and 2-hour glucose levels during a glucose tolerance test)[29] and found no association between HGS and fasting glucose level, despite inverse associations between HGS and fasting insulin, HOMA-IR, and 2-hour glucose levels. Another study that examined isometric strength of the abdominal and back muscles found inverse associations between muscle strength and fasting insulin, HOMA-IR, and HOMA-B. Measures of IR increase before development of overt abnormalities in fasting glucose. Thus, these study results suggest that normalized HGS could be a sensitive measure reflecting changes in IR before overt changes in fasting glucose can be measured.

In previous studies that determined HGS cut-off values for children and adolescents,[16-18] normalized HGS below the cut-offs was associated with the presence of more metabolic risk factors. We also report cut-offs for nCHGS in children and adolescents with greater and fewer cardiometabolic risk factors, including MetS components and IR. Our thresholds are not directly comparable to those in previous reports due to differences in the calculation of normalized HGS; however, the usefulness of normalized HGS as a marker of cardiometabolic health in children and adolescents is evident. In terms of the value of HGS as a predictor of cardiometabolic health, a previous longitudinal study demonstrated that a lower baseline relative HGS in children and adolescents was associated with greater cardiovascular disease risk scores 2 years later.[17] Studies about the long-term implications of HGS as a predictive marker for later development of cardiometabolic disease are scarce, especially in children and adolescents; therefore, more longitudinal and prospective studies are warranted.

HGS has been shown to be a reliable marker of both total muscle strength and upper body strength in children and adolescents.[10,11] Because skeletal muscle is the most abundant insulin-sensitive tis-

sue and is responsible for 20%–30% of resting oxygen consumption and 75%–95% of insulin-mediated glucose disposal,[30,31] decreases in muscle function could clearly contribute to the pathophysiology of MetS and IR. The mechanistic pathways through which muscles affect cardiometabolic health include their roles in glucose, protein, and fatty acid metabolism; secretion of myokines and metabolites; systemic inflammation; and oxidative stress.[32,33] Moreover, skeletal muscles actively interact with adipose tissues, bones, vasculature, and the brain in determining an individual's adiposity and exercise capacity,[34] which affect general health and disease. Although muscle strength and muscle mass do not necessarily correlate, especially in children and adolescents,[35] lean muscle mass as assessed by dual energy X-ray absorptiometry[36] and bioelectrical impedance[12,37,38] has been shown to be associated with HGS. Further prospective studies are needed to better delineate the relationships among HGS, muscle strength, muscle mass, and cardiometabolic risk.

This study has some limitations. Our analysis is cross-sectional, and the results cannot reflect causality. Furthermore, information about pubertal progression, which affects body composition in both sexes, was not available. HGS has been shown to increase steadily during the child–adolescent years in both males and females;[39] however, normative values and z-scores according to sex and age are unavailable for this population, making it difficult to establish HGS cut-offs. Furthermore, physical activity levels were adjusted using survey data and not an objective assessment of cardiorespiratory fitness. However, the study participants are representative of a general, healthy, nationwide population, and the results support and contribute to the body of evidence indicating the usefulness of HGS in identifying MetS and its components in children and adolescents. We analyzed the relationship between HGS and MetS and made efforts to identify possible HGS cut-off points to identify the presence of MetS components. We also explored the relationship between HGS and IR, which has been reported less frequently than the relationship with MetS in this group of children and adolescents.

Lower HGS normalized for body weight was associated with both clustered and individual components of MetS and measures of IR, suggesting that HGS could be a useful indicator of cardiometabolic risk factors associated with MetS. Furthermore, identification of thresholds for normalized HGS could help in identifying children with associated cardiometabolic risk factors. The importance of muscular fitness is emphasized in this study and warrants further research with regard to whether measures of HGS can play a role in screening, early identification, and clinical guidance to prevent MetS and IR in children and adolescents.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Study concept and design: JK; acquisition of data: HJ and JK; analysis and interpretation of data: HJ, JK, and JL; drafting of the manuscript: HJ; critical revision of the manuscript: JK and JL; statistical analysis: HJ, JK, and JL; administrative, technical, or material support: JK and JL; and study supervision: all authors.

SUPPLEMENTARY MATERIALS

Supplementary materials can be found online at https://doi.org/10.7570/jomes22053.

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