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ORIGINAL RESEARCH

Association between bioelectrical impedance analysis parameters and metabolic dysfunction–associated steatotic liver disease relative to handgrip strength in children and adolescents in Korea: A comparative study

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Abstract

Background: Investigations on the association among bioelectrical impedance analysis, handgrip strength, and metabolic dysfunction–associated steatotic liver disease (MASLD) in children and adolescents are limited. Therefore, the present study explored the relationship between bioelectrical impedance analysis parameters, handgrip, and MASLD in youth.

Methods: This study extracted 337 youths from population-based data. Pearson correlation analyses were conducted to assess the relationship between muscle-related bioelectrical impedance analysis and handgrip parameters. Logistic regression analysis investigated the associations among MASLD, bioelectrical impedance analysis, and handgrip strength. Areas under the receiver operating characteristic (ROC) curve were calculated to compare diagnostic performances of these markers in predicting MASLD.

Results: Grip strength, handgrip to weight, and handgrip to body mass index (BMI) were correlated with all muscle-related bioelectrical impedance analysis parameters, including the fat-free mass, appendicular muscle mass, skeletal muscle mass index, and muscle to fat ratio. Multivariable logistic regression analyses—adjusting for age, sex, energy intake, and nutrition—showed that skeletal muscle mass index, muscle to fat ratio, handgrip to weight, and handgrip to BMI were negatively associated with MASLD, whereas body fat mass and percentage of body fat were positively associated. The areas under the ROC curve of handgrip to weight, skeletal muscle mass index, muscle to fat ratio, body fat mass, and percentage of body fat in predicting MASLD were 0.71, 0.76, 0.81, 0.94, and 0.87, respectively.

Conclusions: Combining bioelectrical impedance analyses and handgrip assessments may be beneficial for MASLD screening in youth.

KEYWORDS
adolescent, bioelectrical impedance analysis, child, handgrip strength, metabolic dysfunction-associated steatotic liver disease

INTRODUCTION

Metabolic dysfunction–associated steatotic liver disease (MASLD), a chronic liver disease characterized by excessive fat accumulation in the liver and the development of metabolic risk factors in individuals without any history of significant alcohol consumption, is increasing in prevalence among adults, children, and adolescents.[1–3] Pediatric MASLD can progress to end-stage liver disease, including liver cirrhosis, in adulthood, and is closely linked with type 2 diabetes and cardiovascular disease.[3–5] Therefore, early assessment of MASLD is crucial.

Liver enzyme tests have been suggested as a simple and useful screening tool for MASLD, whereas ultrasonography is a noninvasive imaging tool.[4,6] In addition, anthropometric measurements including body mass index (BMI) and waist circumference (WC) have been suggested as a supplementary noninvasive screening tools for MASLD, based on the close relationship between obesity and MASLD.[4] Liver enzymes and ultrasonography remain central to diagnosis, but anthropometric indexes may serve as practical adjuncts in initial risk stratification and screening. However, BMI and WC cannot assess body composition, such as muscle and fat mass, limiting their utility in diagnosing metabolic diseases, including MASLD, particularly in individuals who are metabolically healthy with overweight or unhealthy with normal weight.[6–8] To overcome these limitations, bioelectrical impedance analysis has been indicated as a useful method for assessing body composition, including fat-free mass and body fat percentage.[6,9,10] bioelectrical impedance analysis involves the passage of a weak, alternating electrical current through the body, after which the resulting impedance is measured; the values vary based on the conductivity of different tissues, allowing for the estimation of fat and muscle mass.[11]

In body composition assessment, both muscle mass and muscle strength should be considered for comprehensive evaluation.[12,13] However, bioelectrical impedance analysis parameters are limited to assessing muscle strength and quality. Handgrip strength, measured using a dynamometer, is a simple, reliable, and cost-effective method for evaluating muscle strength that requires only minimal equipment and time investments.[13–16] Beyond its convenience, handgrip strength can predict cardiovascular mortality in adults and is a marker for overall health and functional capacity.[16,17] Lee et al.[18] previously reported that handgrip strength is negatively associated with steatotic liver disease in adults. The skeletal muscle is a primary site for glucose disposal; reduced muscle mass or function can worsen systemic metabolic health, promoting higher blood glucose and lipid levels, thereby fueling further liver fat deposition. Conversely, a fibrotic or fatty liver can release proinflammatory mediators that exacerbate muscle catabolism.[19] In addition, the concept of sarcopenia has gained increasing attention as a component of metabolic risk assessment in adults, given its strong association with insulin resistance, dyslipidemia, and hepatic steatosis. Rezende et al.[20] reported that sarcopenia can be found in children with chronic liver disease. However, research on the relationship between bioelectrical impedance analysis parameters and handgrip strength, and their combined predictive value for MASLD in children and adolescents, is lacking.

In this context, the present study aimed to investigate the association between bioelectrical impedance analysis parameters, handgrip strength, and MASLD in children and adolescents using data from the Korea National Health and Nutrition Examination Survey (KNHANES). The specific objectives of this study were to investigate (1) the association between bioelectrical impedance analysis parameters and handgrip strength and (2) the predictability of bioelectrical impedance analysis parameters and handgrip strength for identifying MASLD in children and adolescents.

METHODS

Ethics approval statement

This study was conducted in adherence with the Declaration of Helsinki and was approved by the Institutional Review Board (IRB) of Yonsei University Gangnam Severance Hospital (IRB no 3-2024-0397). Written informed consent was obtained from all participants for their participation in the KNHANES database.

Study design and participants

We conducted a comparison study in 337 children and adolescents in Korea using cross-sectional data from the KNHANES 2022. Our exposures of interest were fat-free mass, appendicular skeletal muscle mass, body fat mass, and percentage of body fat as body composition determinants assessed with an InBody 970 body composition analyzer (InBody). Our comparator was handgrip strength as a body composition determinant. Handgrip strength was assessed using a digital grip strength dynamometer (Model T.K.K.5401; Takei Co. Ltd). Our primary outcome was MASLD, defined as steatotic liver disease with at least one cardiometabolic risk factor, whereas cryptogenic steatotic liver disease is defined as steatotic liver disease without any identifiable cause, including any cardiometabolic risk factors.[5,21,22] Steatotic liver disease is classified as alanine aminotransferase (ALT) >26 IU/L in boys and >22 IU/L in girls without hepatitis B virus infection.[1,2,22,23] Cardiometabolic risk factors included overweight or obesity; abdominal obesity; fasting glucose ≥100 mg/dl or hemoglobin A_{1c} ≥5.7%; blood pressure thresholds of ≥130/85 mm Hg for participants aged 13 years and older, ≥130/80 mm Hg or ≥95th percentile for those younger than 13 years; triglyceride levels ≥150 mg/dl; and high-density lipoprotein cholesterol (HDL) levels <40 mg/dl.[21] Participants with ALT elevation but no cardiometabolic risk factors were considered to have cryptogenic steatotic liver disease and were excluded in this study. We hypothesize that there is a difference between body composition measured by bioelectrical impedance analysis and handgrip.

The details of the study design and flowchart outlining participant selection are presented in Supporting Information S1: Figure S1. KNHANES is a national survey conducted by the Korea Centers for Disease Control and Prevention under the National Health Promotion Act. Since 1998, the KNHANES has employed a cross-sectional design to assess health behaviors, medical examinations, nutrition status, and chronic diseases, using a multistage, stratified systematic sampling method. The survey uses a two-stage stratified sampling technique with sampling units and households as the primary and secondary sampling units, respectively.[24]

Study variables

Data regarding sex, age, and anthropometric parameters were obtained. Height was measured using a portable stadiometer (range, 850–2060 mm; Seritex Holtain Ltd), and weight was assessed using a calibrated balance beam scale (Giant 150 N; HANA). BMI was calculated as each individual's weight in kilograms divided by their height in meters squared (kg/m²). WC was measured at the narrowest point between the lower edge of the rib cage and iliac crest during normal exhalation. Height, weight, and BMI were expressed as the standard deviation scores (SDSs) based on the 2017 Korean National Growth Charts.[25] Participants were further classified in normal-weight (<85th percentile), overweight (85th to <95th percentile), or obese (≥95th percentile) groups according to their BMI. Blood pressure was measured in triplicate by trained nurses, and the mean systolic and diastolic blood pressure was calculated as the average of the second and third readings.

Parameters of bioelectrical impedance analyses and handgrip strength

Muscle-related bioelectrical impedance analysis parameters (including fat-free mass and appendicular skeletal muscle mass) and fat-related bioelectrical impedance analysis parameters (including body fat mass and percentage of body fat) were assessed. bioelectrical impedance analysis parameter markers were calculated as follows: skeletal muscle mass index = (appendicular skeletal muscle mass/weight) × 100, appendicular skeletal muscle mass index = appendicular skeletal muscle mass/height squared (kg/m^2), and muscle to fat ratio = appendicular skeletal muscle mass/sum of fat mass in the four limbs.[24,26,27]

Grip strength was defined as the average of three measurements of the handgrip strength (kg) of the dominant hand.[13,14] The handgrip to weight ratio was calculated as (grip strength/weight) × 100,[14,27,28] and the handgrip to BMI ratio was calculated as (grip strength/BMI) × 100.[27,30]

Laboratory analysis

Blood samples were collected from the antecubital vein after an 8-h fast, processed, and stored in a refrigerator. Serum levels of aspartate aminotransferase (AST) and ALT and fasting levels of glucose, total cholesterol, triglycerides, and HDL were measured using the Cobas 8000 (Roche).

Statistical analyses

Data were analyzed using SAS (version 9.4; SAS Inc) and R version 4.4.1 (The R Foundation for Statistical Computing), accounting for the complex survey design, which included clustering, stratification, and weighting within the KNHANES dataset. Sampling weights were applied to all analyses to ensure that the results accurately represented the Korean child and adolescent population. Differences in continuous variables were assessed using independent sample *t* tests, whereas the Rao–Scott–chi-square test was applied to assess categorical variables considering sampling weights. Continuous variables are presented as the weighted means with standard errors, whereas categorical variables are presented as weighted percentages with standard errors. Additionally, we performed Wilcoxon rank sum test, in which continuous variables are presented as median (IQR), and categorical variables were presented as percentages (standard error).

We additionally used bivariate correlation coefficients (Pearson *r*) to quantify the strength of agreement between bioelectrical impedance analysis (fat-free mass, appendicular skeletal muscle mass, body fat mass, fat-free mass, percentage of body fat) and handgrip as determinants of body composition. Logistic regression analysis was conducted to investigate the relationship between MASLD scores and various markers. Multivariable logistic regression analyses were performed after adjusting age, sex, and nutrition factors. Brier scores were calculated to evaluate the overall predictive performance of each body composition determinant for MASLD. Receiver operating characteristic (ROC) curves were plotted, and areas under the ROC curve (AUCs) were calculated to compare the diagnostic performance of markers in predicting MASLD. Sensitivity and specificity were further evaluated using the optimal cutoff values identified through Youden index. Pairwise comparisons of AUCs were conducted using the DeLong method. Statistical significance was set at a *P* value < 0.05.

RESULTS

Baseline characteristics of the participants

Table 1 presents the baseline characteristics of the enrolled participants according to their MASLD status. Overall, 8.6% of the total participants had MASLD. Age, weight SDS, BMI SDS, WC, systolic blood pressure, triglyceride levels, AST levels, ALT levels, grip strength, fat-free mass, appendicular skeletal muscle mass, appendicular skeletal muscle mass index, body fat mass, percentage of body fat, and the proportion of obese individuals were significantly higher in the MASLD group than in the control group. The handgrip to

TABLE 1 Baseline characteristics of the participants.

	Total	Normal (*n* = 308)	MASLD (*n* = 29)	*P*
Age	13.9 (0.2)	13.9 (0.2)	14.4 (0.5)	0.325
Sex (male), %	50.9 (3.5)	48.6 (3.7)	77.3 (9.2)	0.013
Height SDS	0.6 (0.1)	0.6 (0.1)	0.9 (0.2)	0.154
Weight SDS	0.4 (0.1)	0.2 (0.1)	2.2 (0.2)	<0.001
BMI SDS	0.1 (0.1)	−0.1 (0.1)	2.3 (0.2)	<0.001
BMI percentile, %				<0.001
Normal	75.8 (2.7)	82.1 (2.5)	6.5 (4.5)	
Overweight	11.8 (1.7)	10.4 (1.6)	27.6 (8.8)	
Obesity	12.4 (2.3)	7.5 (1.8)	65.9 (8.8)	
WC, cm	71.3 (0.7)	69.6 (0.7)	90.3 (2.0)	<0.001
Systolic blood pressure, mm Hg	107.0 (0.6)	106.5 (0.6)	112.5 (2.4)	0.020
Diastolic blood pressure, mm Hg	65.6 (0.5)	65.3 (0.5)	68.1 (1.1)	0.076
Glucose, mg/dl	91.6 (0.5)	91.7 (0.5)	90.5 (1.7)	0.473
Total cholesterol, mg/dl	163.4 (1.9)	162.5 (2.0)	173.3 (6.0)	0.129
Triglycerides, mg/dl	86.2 (2.8)	81.5 (2.7)	138.0 (7.9)	<0.001
HDL, mg/dl	57.6 (0.8)	58.6 (0.9)	46.3 (1.5)	<0.001
AST, mg/dl	18.8 (0.4)	17.7 (0.3)	31.0 (2.6)	<0.001
ALT, mg/dl	15.4 (0.9)	11.9 (0.3)	54.7 (6.0)	<0.001
Energy, kcal	1852.3 (42.4)	1823.8 (42.4)	2146.6 (123.9)	0.017
Carbohydrate, g	261.9 (6.8)	258.4 (6.8)	297.1 (22.0)	0.097
Protein, g	71.2 (2.0)	70.0 (2.0)	83.9 (5.9)	0.031
Fat, g	56.0 (1.7)	54.9 (1.7)	67.5 (6.1)	0.053
Grip strength, kg	25.0 (0.5)	24.7 (0.5)	29.2 (1.8)	0.022
Handgrip to weight, kg/kg	44.5 (0.6)	45.2 (0.6)	37.1 (1.4)	<0.001
Handgrip to BMI, kg/kg/m^2	1.2 (0.0)	1.2 (0.0)	1.0 (0.1)	0.012
Fat-free mass, kg	41.9 (0.7)	41.1 (0.7)	51.5 (2.2)	<0.001
appendicular skeletal muscle mass, kg	17.0 (0.3)	16.6 (0.3)	21.0 (1.0)	<0.001
Skeletal muscle mass index, %	30.0 (0.3)	30.3 (0.3)	26.7 (0.5)	<0.001
Skeletal muscle mass index, kg/m^2	17.2 (2.3)	13.4 (0.1)	58.4 (10.3)	<0.001
Muscle to fat ratio, kg/kg	3.0 (0.1)	3.1 (0.1)	1.9 (0.1)	<0.001
Body fat mass, kg	14.5 (0.4)	13.4 (0.4)	26.7 (1.2)	<0.001
Body fat, %	25.0 (0.5)	24.2 (0.5)	34.0 (0.7)	<0.001

Note: Values are presented as mean (standard error), and categorical data are represented as percentages (standard error). *P* value is assessed using Student *t* test and Rao–Scott–chi-square test

Abbreviations: ALT, alanine aminotransferase; AST, aspartate aminotransferase; BMI, body mass index; BP, blood pressure; HDL, high-density lipoprotein cholesterol; MASLD, metabolic dysfunction–associated steatotic liver disease; SDS, standard deviation score; WC, waist circumference.

weight, skeletal muscle mass index, muscle to fat ratio, and HDL levels were lower in the MASLD group than in the normal group.

In Wilcoxon rank sum test, weight SDS, BMI SDS, WC, systolic blood pressure, triglyceride levels, AST levels, ALT levels; energy, carbohydrate, protein, and fat intake; grip strength; fat-free mass; appendicular skeletal muscle mass; body fat mass; and percentage of body fat were higher in the MASLD group than in the normal group (Supporting Information S1: Table S1). HDL, handgrip to weight, skeletal muscle mass index, and muscle to fat ratio were lower in the MASLD group than in the normal group.

Correlation between handgrip and bioelectrical impedance analysis parameters and handgrip parameters

Pearson correlation analyses showed that appendicular skeletal muscle mass was positively correlated with fat-free mass, skeletal muscle mass index, appendicular skeletal muscle mass index, muscle to fat ratio, and body fat mass but negatively correlated with percentage of body fat (Table 2). Body fat mass was positively correlated with fat-free mass and appendicular skeletal muscle mass index but negatively correlated with skeletal muscle mass index and muscle to fat ratio. Percentage of body fat was negatively correlated with fat-free mass, skeletal muscle mass index, and muscle to fat ratio.

Grip strength correlated with fat-free mass ($r = 0.85$, $P < 0.001$), appendicular skeletal muscle mass ($r = 0.86$, $P < 0.001$), skeletal muscle mass index ($r = 0.58$, $P < 0.001$), appendicular skeletal muscle mass index ($r = 0.83$, $P < 0.001$), and muscle to fat ratio ($r = 0.57$, $P < 0.001$). The handgrip to weight ratio was correlated with fat-free mass ($r = 0.26$, $P < 0.001$), appendicular skeletal muscle mass ($r = 0.31$, $P < 0.001$), skeletal muscle mass index ($r = 0.71$, $P < 0.001$), appendicular skeletal muscle mass index ($r = 0.26$, $P < 0.001$), and muscle to fat ratio ($r = 0.71$, $P < 0.001$). Similarly, the handgrip to BMI ratio correlated with fat-free mass ($r = 0.58$, $P < 0.001$), appendicular skeletal muscle mass ($r = 0.63$, $P < 0.001$), skeletal muscle mass index ($r = 0.82$, $P < 0.001$), appendicular skeletal muscle mass index ($r = 0.78$, $P < 0.001$), and muscle to fat ratio ($r = 0.78$, $P < 0.001$).

Logistic regression analyses for MASLD

Univariable logistic regression analyses revealed that fat-free mass, appendicular skeletal muscle mass, body fat mass, and percentage of body fat were positively associated with MASLD, whereas skeletal muscle mass index, appendicular skeletal muscle mass index, muscle to fat ratio, handgrip to weight, and handgrip to BMI showed negative associations (Table 3). Multivariable logistic regression analyses, adjusted for age, sex, energy, protein intake, and fat intake, showed that fat-free mass (odds ratio [OR] = 1.10; 95% CI, 1.05–1.15), appendicular skeletal muscle mass (OR = 1.19; 95% CI, 1.07–1.33), and appendicular skeletal muscle mass index (OR = 3.39; 95% CI, 3.39–5.27) were positively associated with MASLD. Conversely, handgrip to weight (OR = 0.87; 95% CI, 0.81–0.92), handgrip to BMI (OR = 0.01; 95% CI, 0.00–0.11), skeletal muscle mass index (OR = 0.54; 95% CI, 0.45–0.66), and muscle to fat ratio (OR = 0.06; 95% CI, 0.02–0.21) showed negative associations. Fat-related parameters, including body fat mass (OR = 1.36; 95% CI, 1.22–1.52) and percentage of body fat (OR = 1.36; 95% CI, 1.22–1.51), were positively associated with MASLD.

Brier score and ROC curves for each parameter for MASLD

The Brier scores of the evaluated parameters ranged from 0.0053 to 0.078, with body fat mass showing the lowest score of 0.053 (Table 4). ROC curve analyses were conducted for variables found to be significantly associated with MASLD in multivariate logistic regression analyses (Table 4; Figure 1). Among the parameters, body fat mass had the highest predictive ability (AUC = 0.94; 95% CI, 0.91–0.97), followed by percentage of body fat (AUC = 0.87; 95% CI, 0.81–0.92), muscle to fat ratio (AUC = 0.81; 95% CI, 0.74–0.89), skeletal muscle mass index (AUC = 0.76; 95% CI, 0.68–0.85), and appendicular skeletal muscle mass (AUC = 0.75; 95% CI, 0.66–0.84).

Pairwise comparisons (Supporting Information S1: Table S2) revealed that body fat mass had a significantly superior predictive ability compared with all other parameters ($P < 0.001$ for all comparisons). Furthermore, the percentage of body fat demonstrated a significantly better predictive ability than the handgrip to weight ($P < 0.001$), handgrip to BMI ($P < 0.001$), skeletal muscle mass index ($P \leq 0.001$), and muscle to fat ratio ($P < 0.001$). The muscle to fat ratio showed significantly higher predictive ability than handgrip to weight ($P = 0.004$), handgrip to BMI ($P < 0.001$), appendicular skeletal muscle mass ($P = 0.382$), and skeletal muscle mass index ($P < 0.001$). Finally, skeletal muscle mass index was significantly better than handgrip to BMI ($P < 0.001$).

DISCUSSION

Overall, this study demonstrated significant correlations between the handgrip strength and muscle-related bioelectrical impedance analysis parameters in children and adolescents. Logistic regression analysis further showed that handgrip to weight, handgrip to BMI, and muscle-related bioelectrical impedance analysis parameters were negatively associated with MASLD, whereas fat-related parameters maintained significant positive associations after adjusting for age, sex, and nutrition factors. Among the parameters analyzed, bioelectrical impedance analysis parameters—including skeletal muscle mass index, muscle to fat ratio, body fat mass, and percentage of body fat—showed superior predictive ability compared with handgrip parameters. Furthermore, fat-related bioelectrical impedance analysis parameters were superior to muscle-related parameters for

TABLE 2 Correlation between bioelectrical impedance analysis parameters and handgrip parameters using Pearson correlation.

	Appendicular skeletal muscle mass r (95% CI)	P	Body fat mass r (95% CI)	P	Percentage of body fat r (95% CI)	P	Grip strength r (95% CI)	P	Handgrip to weight r (95% CI)	P	Handgrip to BMI r (95% CI)	P
Fat-free mass	0.99 (0.96–1.02)	<0.001	0.40 (0.27–0.53)	<0.001	−0.13 (−0.24 to 0.02)	0.026	0.85 (0.77–0.93)	<0.001	0.26 (0.15–0.37)	<0.001	0.58 (0.48–0.68)	<0.001
Appendicular skeletal muscle mass	–	–	0.36 (0.23–0.48)	<0.001	−0.17 (−0.28 to 0.06)	0.004	0.86 (0.78–0.94)	<0.001	0.31 (0.20–0.42)	<0.001	0.63 (0.53–0.73)	<0.001
Skeletal muscle mass index	0.54 (0.44–0.64)	<0.001	−0.54 (−0.63 to 0.44)	<0.001	−0.86 (−0.91 to 0.80)	<0.001	0.58 (0.49–0.68)	<0.001	0.71 (0.63–0.80)	<0.001	0.82 (0.74–0.89)	<0.001
Appendicular skeletal muscle mass index	0.96 (0.92–1.00)	<0.001	0.44 (0.31–0.56)	<0.001	−0.08 (−0.20 to 0.03)	0.166	0.83 (0.75–0.91)	<0.001	0.26 (0.15–0.37)	<0.001	0.54 (0.44–0.63)	<0.001
Muscle to fat ratio	0.48 (0.38–0.59)	<0.001	−0.56 (−0.65 to 0.48)	<0.001	−0.87 (−0.94 to 0.80)	<0.001	0.57 (0.45–0.69)	<0.001	0.71 (0.62–0.81)	<0.001	0.78 (0.69–0.87)	<0.001
Body fat mass	0.36 (0.25–0.46)	<0.001	–	–	0.83 (0.74–0.92)	<0.001	0.16 (0.07–0.26)	0.001	−0.48 (−0.56 to 0.39)	<0.001	−0.28 (−0.37 to 0.19)	<0.001
Percentage of body fat	−0.17 (−0.28 to 0.05)	0.005	0.83 (0.76–0.90)	<0.001	–	–	−0.29 (−0.40 to 0.17)	<0.001	−0.67 (−0.75 to 0.59)	<0.001	−0.61 (−0.71 to 0.52)	<0.001

Abbreviation: BMI, body mass index.

TABLE 3 Logistic regression analyses for metabolic dysfunction–associated steatotic liver disease.

	Unadjusted OR (95% CI)	*P*	Adjusted OR (95% CI)[a]	*P*
Grip strength	1.05 (1.01–1.10)	0.013	1.02 (0.95–1.10)	0.599
Handgrip to weight	0.92 (0.88–0.96)	<0.001	0.87 (0.81–0.92)	<0.001
Handgrip to BMI	0.28 (0.10–0.81)	0.019	0.01 (0.00–0.11)	<0.001
Fat-free mass	1.08 (1.04–1.11)	<0.001	1.10 (1.05–1.15)	<0.001
Appendicular skeletal muscle mass	1.15 (1.08–1.22)	<0.001	1.19 (1.07–1.33)	0.002
Skeletal muscle mass index	0.75 (0.67–0.85)	<0.001	0.54 (0.45–0.66)	<0.001
Appendicular skeletal muscle mass index	2.48 (1.78–3.45)	<0.001	3.39 (2.18–5.27)	<0.001
Muscle to fat ratio	0.21 (0.10–0.45)	<0.001	0.06 (0.02–0.21)	<0.001
Body fat mass	1.29 (1.20–1.39)	<0.001	1.36 (1.22–1.52)	<0.001
Percentage of body fat	1.22 (1.15–1.30)	<0.001	1.36 (1.22–1.51)	<0.001

Abbreviations: BMI, body mass index; OR, odds ratio.

[a]Adjusted for age, sex, energy, protein, and fat.

predicting MASLD, with body fat mass demonstrating the highest predictability, outperforming the other parameters.

In the present study, all muscle-related bioelectrical impedance analysis parameters correlated with all handgrip parameters. Bioelectrical impedance analysis estimates fat-free mass and skeletal muscle mass by measuring the impedance of an electrical current passing through the body; impedance varies based on the amount of water and electrolytes in the muscle vs fat tissues.[11] However, the accuracy of this technique may be influenced by hydration levels and body composition extremes, such as severe obesity or fluid imbalances. Additionally, bioelectrical impedance analyses do not directly reflect muscle strength. Conversely, handgrip strength testing evaluates muscle functionality and quality, making it a simple and reliable proxy for physical performance and overall muscle strength[7,31]; however, handgrip strength cannot directly quantify muscle mass. Therefore, when assessing metabolic diseases, it is important to consider both muscle quantity and quality, as each has specific limitations.[31,32] Based on the characteristics of both methods, our study indicates that bioelectrical impedance analyses and handgrip strength play complementary roles in the assessment of metabolic diseases, including MASLD, in children. One study in adults has reported that handgrip strength is strongly correlated with skeletal muscle strength in patients.[31] A prior Czech study also reported that handgrip strength is related to sarcopenic obesity in children.[12]

In the present study, the predictive ability of bioelectrical impedance analysis parameters were found to be superior to that of handgrip parameters for MASLD. Despite the utility of handgrip strength in the assessment of metabolic disease in various studies, it does not directly quantify muscle mass, and results may vary based on testing conditions such as hand dominance and posture during measurement.[13,18,29,31,32] Moreover, children may face challenges in performing handgrip strength tests accurately because of their weaker muscles, difficulties following instructions, less pronounced variations in muscle strength compared with adults, and the design of handgrip devices, which are typically suited to adult hand sizes, potentially making it difficult for children to exert their maximum force, thereby limiting the utility of the test in this population.[12,33] Conversely, bioelectrical impedance analysis is easy to apply in children, enabling objective assessments even in younger age groups and allowing measurements to be taken comfortably without physical exertion. Indeed, one Chinese study reported that skeletal muscle mass index is negatively associated with liver fat content in adults.[34] In a cross-sectional study, bioelectrical impedance analysis parameters added incremental value to anthropometric measurements in predicting steatotic liver disease in children.[6] In another observational study, the muscle to fat ratio demonstrated good predictive value for pediatric metabolic syndrome.[27] In adults, accumulating evidence suggests that sarcopenia is significantly associated with MASLD.[7,35,36] Although sarcopenia is increasingly recognized as a clinically relevant issue in children and adolescents, clear consensus regarding its definition—particularly the cutoff values for skeletal muscle mass index—is lacking in the pediatric population.[37] Further studies are required for clarifying the association between sarcopenia and MASLD in children.

In the present study, fat-related bioelectrical impedance analysis parameters were superior to muscle-related bioelectrical impedance analysis parameters in predicting MASLD. The AUC for the body fat mass was high (0.94), significantly superior to all other parameters. Moreover, the muscle to fat ratio, a combined index of appendicular skeletal muscle mass and fat mass, showed the highest predictive power among all muscle-related bioelectrical impedance analysis parameters. The superior predictive ability of fat-related parameters may be due to their direct reflection of visceral adiposity, a key contributor to hepatic fat accumulation

TABLE 4 Brier score and AUCs for each parameter for predicting metabolic dysfunction–associated steatotic liver disease.

	Brier score	Cutoff	AUC (95% CI)	P	Sensitivity (95% CI)	Specificity (95% CI)	Accuracy (95% CI)	Positive predictive value (95% CI)	Negative predictive value (95% CI)
Handgrip strength	0.077	>26.90	0.68 (0.58–0.77)	<0.001	0.61 (0.60–0.61)	0.68 (0.68–0.68)	0.67 (0.67–0.67)	0.14 (0.14–0.15)	0.95 (0.95–0.95)
Handgrip to weight	0.076	<43.77	0.71 (0.63–0.80)	<0.001	0.90 (0.90–0.90)	0.52 (0.52–0.52)	0.55 (0.55–0.55)	0.14 (0.14–0.15)	0.98 (0.98–0.98)
Handgrip to BMI	0.078	<1.32	0.60 (0.50–0.70)	0.039	0.96 (0.96–0.96)	0.35 (0.35–0.35)	0.40 (0.40–0.40)	0.12 (0.12–0.12)	0.99 (0.99–0.99)
Fat-free mass	0.072	>42.70	0.78 (0.69–0.86)	<0.001	0.85 (0.85–0.85)	0.65 (0.65–0.65)	0.66 (0.66–0.67)	0.18 (0.18–0.18)	0.98 (0.98–0.98)
Appendicular skeletal muscle mass	0.074	>16.45	0.75 (0.66–0.84)	<0.001	0.85 (0.85–0.85)	0.56 (0.56–0.56)	0.59 (0.59–0.59)	0.15 (0.15–0.15)	0.98 (0.98–0.98)
Skeletal muscle mass index	0.073	<26.83	0.76 (0.68–0.85)	<0.001	0.63 (0.62–0.63)	0.80 (0.80–0.80)	0.78 (0.78–0.78)	0.22 (0.22–0.22)	0.96 (0.96–0.96)
Muscle to fat ratio	0.069	<1.79	0.81 (0.74–0.89)	<0.001	0.63 (0.62–0.63)	0.85 (0.85–0.85)	0.83 (0.83–0.83)	0.27 (0.27–0.27)	0.96 (0.96–0.96)
Body fat mass	0.053	>18.40	0.94 (0.91–0.97)	<0.001	0.95 (0.95–0.95)	0.82 (0.82–0.82)	0.83 (0.83–0.83)	0.32 (0.32–0.32)	0.99 (0.99–0.99)
Percentage of body fat	0.065	>29.30	0.87 (0.81–0.92)	<0.001	0.88 (0.88–0.88)	0.75 (0.75–0.75)	0.76 (0.76–0.76)	0.24 (0.24–0.24)	0.99 (0.99–0.99)

Abbreviations: AUC, area under the receiver operating characteristic curve; BMI, body mass index.

and metabolic dysfunction.[4,6] Visceral fat further promotes lipolysis and releases free fatty acids, which are taken up by the liver and converted into triglycerides, thereby driving hepatic steatosis and insulin resistance. Muscle-related parameters shows an indirect relationship with nonalcoholic fatty liver disease (NAFLD), as they primarily reflect systemic metabolic health rather than direct hepatic fat deposition.[4,9,11] In one Chinese study, the association between hepatic steatosis and fat mass index was stronger than that with the appendicular skeletal muscle mass index in adults.[38] In pediatric populations, one study observed a stronger correlation between hepatic steatosis and the percentage of body fat compared with muscle-related bioelectrical impedance analysis parameters.[6]

Handgrip to weight and handgrip to BMI were found to be significantly associated with MASLD, although grip strength did not retain its significant association with MASLD after adjusting for age, sex, or nutrition factors. Simple handgrip strength may be high in individuals with high muscle and fat mass, making it important to evaluate handgrip strength after adjusting for body weight and BMI.[18,29] A US study also reported a negative association between handgrip to BMI with both NAFLD and advanced hepatic fibrosis in adults.[39] Similarly, a Korean study found that handgrip to BMI is negatively associated with hepatic steatosis index and NAFLD in adults.[18] In another pediatric study, handgrip to weight shows a negative correlation with metabolic syndrome.[29] Although handgrip to weight and handgrip to BMI demonstrated lower predictive power for MASLD in our study, their associations with MASLD and correlations with bioelectrical impedance analysis parameters highlight their potential to provide insights into muscle quality. Given that handgrip strength is a simple, practical, and easily implementable measurement, it could serve as a complementary tool to bioelectrical impedance analyses for the diagnosing pediatric MASLD.[16,17]

This study had several limitations. First, this was a cross-sectional study limited to Korean individuals, potentially restricting the generalizability of the findings. Second, steatotic liver disease was defined based on elevated ALT levels in the absence of hepatitis B virus infection, rather than using liver biopsy or imaging studies. Although this approach has been commonly applied in large-scale epidemiologic research, it may have reduced diagnostic accuracy, potentially leading to misclassification of MASLD, particularly in cases with normal liver enzymes. Third, other potential causes of liver enzyme elevation, such as hepatitis C, other viral infections, congenital heart disease–related liver conditions, Wilson's disease, autoimmune hepatitis, and drug-induced liver injury, were not accounted for, as they were not available in the KNHANES dataset. Fourth, confounding factors, such as physical activity, were not included in the analysis. Despite these limitations, this study utilized population-based data representative of a national cohort and simultaneously evaluated both bioelectrical impedance analysis parameters and handgrip strength in children, providing a comprehensive assessment of body composition and functional measures for predicting pediatric MASLD.

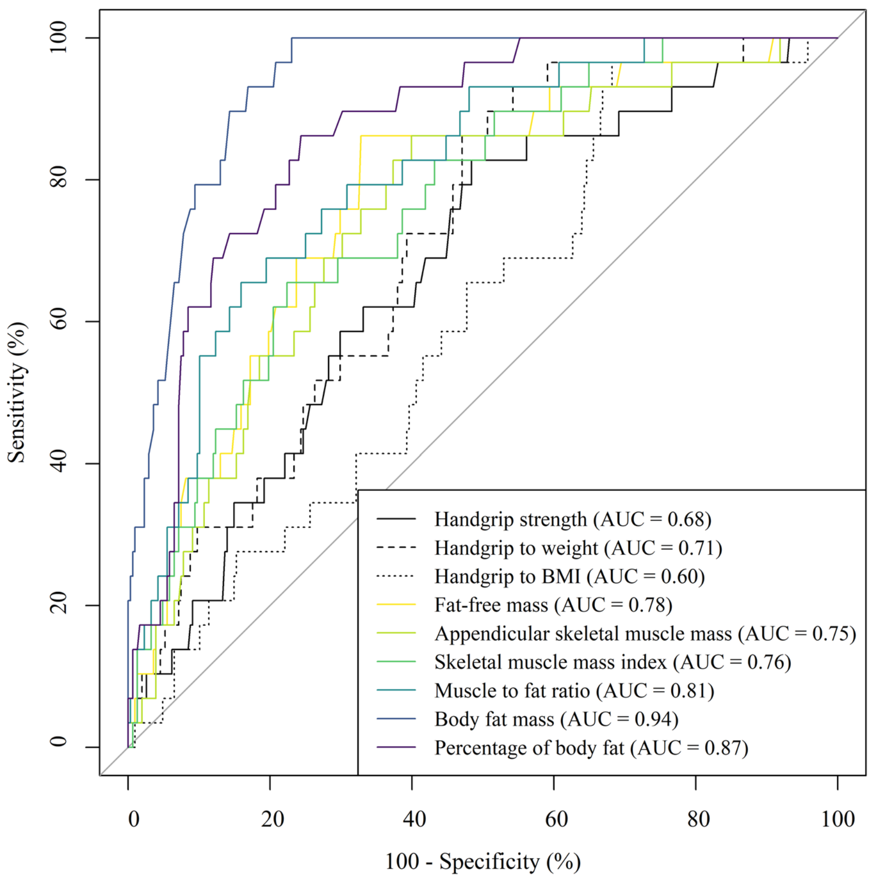

FIGURE 1 Receiver operating characteristic curve of the utility of bioelectrical impedance analysis parameters in predicting metabolic dysfunction–associated steatotic liver disease. AUC, area under the receiver operating characteristic curve; BMI, body mass index.

CONCLUSION

This study demonstrated that bioelectrical impedance analysis parameters are significantly associated with pediatric MASLD and could serve as useful predictors of this condition. Among the different bioelectrical impedance analysis parameters, fat-related indicators, particularly body fat mass, emerged as the strongest predictors of MASLD. Although handgrip parameters showed weaker associations with MASLD compared with bioelectrical impedance analysis parameters, they nevertheless exhibited a close relationship with bioelectrical impedance analysis parameters. Importantly, handgrip parameters provide a useful and easily accessible approach for assessing muscle strength and quality, which is difficult to evaluate using bioelectrical impedance analysis alone. Blood-based biomarkers and ultrasonography remain essential for diagnosing MASLD, but our findings indicate that bioelectrical impedance and handgrip strength measurements may offer complementary value beyond traditional screening approaches. Therefore, combining bioelectrical impedance analysis and handgrip parameters in the evaluation of pediatric MASLD could enhance screening and management strategies by facilitating a more comprehensive assessment. This study further highlights the clinical potential of incorporating both bioelectrical impedance and handgrip strength assessments into broader metabolic evaluations, emphasizing the importance of measuring both muscle quantity and quality to support more nuanced risk stratification in pediatric MASLD.

AUTHOR CONTRIBUTIONS

Kyungchul Song: Conceptualization; Methodology; Formal analysis; Investigation; Writing—original draft. **Eunju Lee**: Resources; Data curation; Formal analysis. **Hye Sun Lee**: Resources; Data curation; Formal analysis. **Hana Lee**: Resources; Data curation; Formal analysis. **Joon Young Kim**: Methodology. **Youngha Choi**: Methodology. **Hyun Wook Chae**: Writing—review and editing; Supervision.

CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY STATEMENT

The data used in this study are publicly available in the KNHANES website (https://knhanes.kdca.go.kr/knhanes/main.do).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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