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Original Article

Association between Bioelectrical Impedance Parameters, Magnetic Resonance Imaging Muscle Parameters, and Fatty Liver Severity in Children and Adolescents

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Background/Aims: To evaluate the associations between pediatric fatty liver severity, bioelectrical impedance analysis (BIA), and magnetic resonance imaging parameters, including total psoas muscle surface area (tPMSA) and paraspinal muscle fat (PMF).

Methods: Children and adolescents who underwent BIA and liver magnetic resonance imaging between September 2022 and November 2023 were included. Linear regression analyses identified predictors of liver proton density fat fraction (PDFF) including BIA parameters, tPMSA, and PMF. Ordinal logistic regression analysis identified the association between these parameters and fatty liver grades. Pearson's correlation coefficients were used to evaluate the relationships between tPMSA and muscle-related BIA parameters, and between PMF and fat-related BIA parameters.

Results: Overall, 74 participants aged 8 to 16 years were included in the study. In the linear regression analyses, the percentage of body fat was positively associated with PDFF in all participants, whereas muscle-related BIA parameters were negatively associated with PDFF in participants with obesity. PMF and the PMF index were positively associated with PDFF in normal-weight and overweight participants. In the ordinal logistic regression, percentage of body fat was positively associated with fatty liver grade in normal-weight and overweight participants and those with obesity, whereas muscle-related BIA parameters were negatively associated with fatty liver grade in participants with obesity. The PMF index was positively associated with fatty liver grade in normal/overweight participants. In the Pearson correlation analysis, muscle-related BIA parameters were correlated with tPMSA, and the fat-related BIA parameters were correlated with PMF.

Conclusions: BIA parameters and PMF are potential screening tools for assessing fatty liver in children. **(Gut Liver 2025;19:108-115)**

Key Words: Child; Fatty liver; Non-alcoholic fatty liver disease; Magnetic resonance imaging; Body composition

INTRODUCTION

Nonalcoholic fatty liver disease (NAFLD) is a chronic liver disorder marked by the excess fat accumulation in the liver, ranging from simple steatosis to nonalcoholic steatohepatitis and hepatic fibrosis.[1-3] The pathogenesis of pediatric NAFLD is closely linked to metabolic syndrome and cardiovascular disease, with key factors including central obesity and insulin resistance. These metabolic disturbances result in excessive fat accumulation in the liver, reflecting the hepatic manifestation of metabolic syndrome in children and adolescents with obesity.[2,4] In addition, the risks of cardiovascular disease and liver fibrosis are correlated with fatty liver severity.[5,6] NAFLD has high global

prevalence, affecting 52.5% of children with obesity.[7] In Korean children, its prevalence increased from 8.2% in 2009 to 16.8% in 2020.[8,9] For screening pediatric NAFLD, alanine aminotransferase (ALT) and ultrasonography are suggested; however, their use is restricted due to limited sensitivity, need for blood sampling, and high costs.[1,2,10]

Based on the relationship between obesity and NAFLD, anthropometric measurements, including body mass index (BMI), are used for NAFLD assessment.[2,11] A pediatric guideline suggests NAFLD screening administration for children with overweight and obesity.[11] However, this assessment is limited because NAFLD is associated with muscle and fat contents as well as body weight.[10,12] Considering this relationship, assessing body composition using bioelectrical impedance analysis (BIA) has been suggested as an alternative method for screening of obesity-related comorbidities, including NAFLD.[10,13] However, investigations on the relationship between BIA parameters and fatty liver severity in children are limited.

Body composition assessment using imaging has been suggested in previous studies.[14,15] El-Leithy and Kamal[15] reported that the total psoas muscle surface area (tPMSA) is correlated with handgrip strength and disease severity in patients with hepatic cirrhosis. A Japanese study reported that muscle and fat mass assessed using computed tomography were related to the prognosis of patients who underwent liver transplantation.[14] However, few studies have demonstrated the association of muscle and fat mass measured using magnetic resonance imaging (MRI) with other body composition measurement tools, including BIA, or their relationship with pediatric fatty liver disease.

This study aimed to explore the association of fatty liver grade with BIA and MRI muscle parameters, including tPMSA and paraspinal muscle fat (PMF), in children and adolescents. Additionally, we aimed to investigate the correlation between BIA parameters and tPMSA and PMF.

MATERIALS AND METHODS

1. Study population

This study was performed in accordance with Strengthening the Reporting of Observational Studies in Epidemiology guidelines and regulations. The Institutional Review Board of Yongin Severance Hospital approved this retrospective study, and the need for informed consent was waived (IRB number: 9-2023-0068).

This retrospective, cross-sectional study included children and adolescents (aged <18 years) who visited the pediatric endocrinology outpatient clinic of our hospital for evaluation of obesity-related complications including fatty liver and/or abnormal liver enzymes from September 2022 to October 2023. Patients who underwent both BIA and liver fat quantification using MRI were enrolled in the study. We excluded participants with other causes of fatty liver, including alcohol consumption and hepatitis B or C viral infections.

2. Anthropometric measurements, laboratory tests, and BIA

Height was measured to the nearest 0.1 cm, and body weight was recorded using an electronic scale with an accuracy of 0.01 kg. BMI was then calculated by dividing the weight in kilograms by the height in meters squared (kg/m^2). Height, weight, and BMI were expressed relative to the standard deviation scores (SDS) from the 2017 Korean national growth charts.[16] We measured waist circumference (WC) by positioning a tape measure horizontally at the midpoint between the lowest rib and the iliac crest.[10] Participants were categorized into three BMI groups: normal-weight (<85th percentile), overweight (85th to 95th percentile), or obese (≥95th percentile).[16]

Blood samples were collected from the antecubital vein following an 8-hour fast, then processed and promptly refrigerated. Serum aspartate transaminase and ALT levels were analyzed using an absorbance assay on a Roche Cobas 8000 c702 (Roche Diagnostics, Mannheim, Germany). The concentrations of hepatitis B surface antigen and anti-hepatitis C virus antibodies were also measured using the Roche Cobas 8000 c702 system.

For BIA parameters, skeletal muscle mass (SMM), fat-free mass (FFM), appendicular skeletal muscle mass (ASM), percentage of body fat (PBF), and visceral fat area (VFA) were measured using an InBody720 body composition analyzer (Biospace, Seoul, South Korea).

3. MRI acquisition and analysis of MRI parameters

Abbreviated liver fat quantification MRI was conducted on a 3-T system (Ingenia Elition X; Philips Medical Systems, Best, Netherlands) for patients who could cooperate without sedation, according to the clinical necessity in our institution. The sequences included axial single-shot fast spin-echo T2-weighted images and a three-dimensional volumetric multi-echo gradient sequence for proton density fat fraction (PDFF). The MRI settings for PDFF were as follows: repetition time, 5.7 milliseconds; echo time, 2.6 milliseconds; matrix, 160×160; slice thickness, 6 mm; flip angle, 3°; number of signal averages, 1; with six gradient echoes from 0.9 to 4.4 milliseconds. The total acquisition time was 15 seconds.[17,18]

To measure the liver PDFF value, an experienced board-certified pediatric radiologist drew four regions of interest

(ROIs) in the liver parenchyma at different axial slices of the PDFF map on a picture archiving and communication system. By drawing ROIs, the fat signal percentages of the liver were automatically calculated, and the mean measurement (%) value was utilized as a representative value. Fatty liver grades by PDFF were defined as in a previous study: normal for PDFF ≤6%, mild for PDFF >6%, moderate for PDFF >17.5%, and severe for PDFF >23.3%.[19] NAFLD was defined as a PDFF >6% in the MRI in the absence of other causes of fatty liver including alcohol consumption and hepatitis B or C viral infections.

The MRI muscle parameters, tPMSA and PMF, were evaluated. To measure tPMSA, the largest ROIs were separately drawn in the psoas muscles bilaterally on a single axial T2-weighted image at the mid L3 vertebra level, and the mean value (mm^2) was used. To measure PMF, the largest ROIs were drawn in the paraspinal muscles bilaterally on a single axial PDFF map at the mid L2 vertebra level, and the mean value (%) was used, as in a previous study.[20] The tPMSA index was calculated as tPMSA divided by height in meters squared (m^2), and the PMF index was calculated as PMF divided by height in meters squared (m^2).[21]

4. Statistical analysis

All continuous variables were presented as mean± standard deviation, whereas categorical variables were presented as numbers (percentages). Baseline characteristics were compared using the independent t-test for continuous variables and the chi-square test for categorical variables after dividing the participants into normal-weight, overweight, and obese groups. Linear regression analyses were conducted to identify predictors of liver PDFF, including variables such as BMI SDS, WC, tPMSA, PMF, SMM, FFM, PBF, and ALT. Ordinal logistic regression analyses were used to determine the association between independent variables and fatty liver grades using PDFF. Multivariable ordinal logistic regression analyses were performed after adjusting for age and sex. Odds ratios (ORs) with 95% confidence intervals and p-values were reported. Cutoff points for each parameter that maximize the sum of sensitivity and specificity were derived based on the Youden index. The Pearson correlation coefficients were calculated to assess the relationships between tPMSA and muscle-related BIA parameters (SMM, FFM, and ASM), and between PMF and fat-related BIA parameters (PBF and VFA). The results of the Pearson correlation are demonstrated in the forest plot. Statistical significance was set at p<0.05, and all analyses were performed using SAS (version 9.4; SAS Inc., Cary, NC, USA) and R, version 4.3.2 (The R Foundation for Statistical Computing; Vienna, Austria; http://www.R-project.org).

RESULTS

1. Baseline characteristics

During the study period, 727 patients visited our hospital for evaluation of obesity-related complications including fatty liver and/or abnormal liver enzymes, and 274 of these patients underwent BIA. Of the 274 participants, 74 were included because they underwent MRI. None of the participants were excluded from the study because they had no other causes of hepatic steatosis, including hepatitis viral infection or alcohol consumption. Table 1 shows the baseline characteristics of the participants. Mean age was 11.96±2.03 years, and among all participants, the participants with normal BMI, overweight, and obesity were 4, 13, and 57, respectively. The proportion of NAFLD among the participants in the normal-weight, overweight, and obesity groups were 83.78%, 76.47%, and 85.96%, respectively. Weight SDS, BMI SDS, WC, SMM, PBF, FFM, and ASM were higher in the participants with obesity than in normal-weight and overweight participants (p=0.022 for FMM, p=0.023 for ASM, p<0.001 for the others).

2. Linear regression analyses for liver PDFF

Table 2 shows the results from the linear regression analyses for liver PDFF. In logistic regression analyses, ALT was positively associated with PDFF in the total group (β=0.17, p<0.001) and obese group (β=0.16, p<0.001). PBF was positively associated with PDFF in the total group (β=0.69, p=0.002), normal-weight and overweight (β=1.33, p=0.037), and obese groups (β=0.76, p=0.007). SMM, FFM, ASM were negatively associated with PDFF in the total group (SMM: β=–0.41, p=0.002; FFM: β=–0.38, p=0.002; ASM: β=–0.79, p=0.003) and obesity group (SMM: β=–0.42, p=0.004; FFM: β=–0.40, p=0.004; ASM: β=–0.82, p=0.006). PMF and the PMF index were positively associated with PDFF in the normal-weight and overweight groups (PMF: β=6.17, p=0.036; PMF index: β=11.50, p=0.039).

3. Ordinal logistic regression analyses for fatty liver grade by PDFF

Table 3 shows the results from the ordinal logistic regression analyses for fatty liver grade by PDFF. In univariable logistic regression analyses, ALT was positively related with fatty liver grade in the total group (OR=1.11, p<0.001), and obese group (OR=1.15, p<0.001). PBF was positively associated with higher fatty liver grades in the total group (OR=1.11, p=0.002), normal-weight and overweight (OR=1.27, p=0.024), and obesity groups (OR=1.11, p=0.012). SMM, FFM, and ASM were negatively associated with fatty liver grade in the total group (SMM: OR=0.94,

Table 1. Characteristics of the Participants According to BMI

Characteristic	Total	Normal and overweight (n=17)	Obesity (n=57)	p-value
Age, yr	11.96±2.03	11.80±2.06	12.00±2.04	0.722
Male sex	46 (62.16)	9 (52.94)	37 (64.91)	0.372
Height SDS	0.99±1.15	0.54±1.25	1.13±1.09	0.065
Weight SDS	2.39±1.04	1.14±0.70	2.77±0.81	<0.001
BMI SDS	2.55±1.07	1.18±0.44	2.96±0.84	<0.001
BMI class				
Normal	4 (5.41)	4 (5.41)	0	
Overweight	13 (17.57)	13 (17.57)	0	
Obesity	57 (77.03)	0	57 (100.0)	
WC, cm	90.43±11.87	78.56±6.53	94.03±10.73	<0.001
AST, IU/L	34.26±29.21	35.94±24.75	33.75±30.60	0.789
ALT, IU/L	40.24±39.33	36.24±30.96	41.44±41.67	0.635
PBF, %	38.14±6.72	32.02±5.20	39.97± 6.03	<0.001
VFA, cm^2	122.70±42.67	77.90±25.66	136.06±37.35	<0.001
SMM, kg	40.07±11.42	34.52±10.12	41.73±11.33	0.021
FFM, kg	42.58±12.16	36.70±10.78	44.33±12.08	0.022
ASM, kg	16.89±5.66	14.18±5.15	17.70±5.60	0.023
tPMSA, mm^2	714.68±510.00	679.24±530.60	725.25±508.06	0.747
tPMSA index	286.20±184.34	278.55±181.30	288.48±186.76	0.847
PMF, %	3.77±1.79	3.41±1.13	3.88±1.94	0.219
PMF index	1.59±0.87	1.51±0.60	1.62±0.94	0.558
Liver PDFF, %	19.99±12.94	18.71±13.61	20.37±12.84	0.646
NAFLD	62 (83.78)	13 (76.47)	49 (85.96)	0.454
Fatty liver grade by PDFF				0.714
Normal (PDFF≤6%)	12 (16.22)	4 (23.53)	8 (14.04)	
Mild (6%<PDFF≤17.5%)	24 (32.43)	5 (29.41)	19 (33.33)	
Moderate (17.5%<PDFF≤23.3%)	9 (12.16)	1 (5.88)	8 (14.04)	
Severe (PDFF>23.3%)	29 (39.19)	7 (41.18)	22 (38.60)	

Data are presented as mean±SD or number (%).
BMI, body mass index; SDS, standard deviation score; WC, waist circumference; AST, aspartate aminotransferase; ALT, alanine aminotransferase; PBF, percentage of body fat; VFA, visceral fat area; SMM, skeletal muscle mass; FFM, fat-free mass; ASM, appendicular skeletal muscle mass; tPMSA, total psoas muscle surface area; PMF, paraspinal muscle fat; PDFF, proton density fat fraction; NAFLD, nonalcoholic fatty liver disease.

Table 2. Linear Regression Analyses for Liver PDFF

Variable	Total		Normal and overweight		Obesity	
	β (95% CI)	p-value	β (95% CI)	p-value	β (95% CI)	p-value
BMI SDS	0.53 (−2.30 to 3.37)	0.708	−5.62 (−22.37 to 11.13)	0.485	0.60 (−3.54 to 4.74)	0.773
WC	−0.14 (−0.39 to 0.12)	0.292	−0.55 (−1.65 to 0.56)	0.309	−0.22 (−0.54 to 0.10)	0.171
ALT	0.17 (0.10 to 0.23)	<0.001	0.21 (−0.00 to 0.42)	0.054	0.16 (0.09 to 0.23)	<0.001
PBF	0.69 (0.27 to 1.12)	0.002	1.33 (0.09 to 2.57)	0.037	0.76 (0.22 to 1.29)	0.007
VFA	0.00 (−0.07 to 0.07)	0.986	−0.03 (−0.33 to 0.26)	0.809	−0.01 (−0.10 to 0.08)	0.821
SMM	−0.41 (−0.65 to −0.16)	0.002	−0.61 (−1.27 to 0.05)	0.069	−0.42 (−0.70 to −0.14)	0.004
FFM	−0.38 (−0.62 to −0.15)	0.002	−0.57 (−1.19 to 0.06)	0.071	−0.40 (−0.66 to −0.13)	0.004
ASM	−0.79 (−1.29 to −0.29)	0.003	−1.15 (−2.46 to 0.16)	0.082	−0.82 (−1.40 to −0.24)	0.006
tPMSA	−0.00 (−0.01 to 0.00)	0.139	−0.01 (−0.02 to 0.00)	0.086	−0.00 (−0.01 to 0.00)	0.478
tPMSA index	−0.01 (−0.02 to 0.01)	0.485	−0.03 (−0.07 to 0.01)	0.102	0.00 (−0.02 to 0.02)	0.928
PMF	0.58 (−1.11 to 2.28)	0.496	6.17 (0.45 to 11.88)	0.036	0.00 (−1.79 to 1.79)	0.999
PMF index	2.21 (−1.24 to 5.66)	0.205	11.50 (0.65 to 22.36)	0.039	1.10 (−2.57 to 4.78)	0.549

PDFF, proton density fat fraction; CI, confidence interval; BMI, body mass index; SDS, standard deviation score; WC, waist circumference; ALT, alanine aminotransferase; PBF, percentage of body fat; VFA, visceral fat area; SMM, skeletal muscle mass; FFM, fat-free mass; ASM, appendicular skeletal muscle mass; tPMSA, total psoas muscle surface area; PMF, paraspinal muscle fat.

p=0.003; FFM: OR=0.95, p=0.003; ASM: OR=0.90, p=0.005) and obese group (SMM: OR=0.95, p=0.010; FFM: OR=0.95, p=0.009; ASM: OR=0.90, p=0.014). The PMF index was positively associated with fatty liver grade in the normal-weight and overweight groups (OR=7.65, p=0.047).

Table 3. Ordinal Logistic Regression Analyses for Fatty Liver Grade by PDFF

Variable	Total		Normal and overweight		Obesity	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Univariable ordinal logistic regression analyses						
BMI SDS	1.03 (0.70–1.53)	0.864	0.44 (0.04–3.44)	0.442	1.02 (0.58–1.79)	0.951
WC	0.98 (0.94–1.01)	0.187	0.91 (0.77–1.05)	0.189	0.97 (0.92–1.01)	0.114
ALT	1.11 (1.06–1.16)	<0.001	1.04 (1.00–1.12)	0.128	1.15 (1.08–1.23)	<0.001
PBF	1.11 (1.04–1.19)	0.002	1.27 (1.05–1.60)	0.024	1.11 (1.03–1.21)	0.012
VFA	1.00 (0.99–1.01)	0.798	0.99 (0.95–1.03)	0.616	1.00 (0.98–1.01)	0.639
SMM	0.94 (0.91–0.98)	0.003	0.90 (0.79–1.00)	0.065	0.95 (0.90–0.99)	0.010
FFM	0.95 (0.91–0.98)	0.003	0.91 (0.80–1.00)	0.066	0.95 (0.91–0.99)	0.009
ASM	0.90 (0.83–0.97)	0.005	0.83 (0.65–1.01)	0.078	0.90 (0.82–0.98)	0.014
tPMSA	1.00 (1.00–1.00)	0.426	1.00 (1.00–1.00)	0.147	1.00 (1.00–1.00)	0.923
tPMSA index	1.00 (1.00–1.00)	0.969	1.00 (0.99–1.00)	0.146	1.00 (1.00–1.00)	0.481
PMF	1.12 (0.89–1.43)	0.350	2.96 (1.12–11.91)	0.055	1.04 (0.82–1.34)	0.723
PMF index	1.45 (0.90–2.50)	0.147	7.65 (1.19–75.58)	0.047	1.26 (0.78–2.15)	0.355
Multivariable logistic regression analyses*						
BMI SDS	1.08 (0.73–1.59)	0.700	0.31 (0.02–3.01)	0.326	1.09 (0.61–1.98)	0.767
WC	1.00 (0.95–1.04)	0.815	0.95 (0.76–1.18)	0.651	0.98 (0.92–1.03)	0.412
ALT	1.10 (1.06–1.16)	<0.001	1.03 (0.98–1.11)	0.309	1.15 (1.08–1.23)	<0.001
PBF	1.10 (1.03–1.18)	0.007	1.23 (1.01–1.58)	0.059	1.11 (1.02–1.21)	0.022
VFA	1.00 (0.99–1.01)	0.697	1.00 (0.96–1.04)	0.935	1.00 (0.99–1.01)	0.938
SMM	0.93 (0.88–0.99)	0.027	0.91 (0.71–1.09)	0.337	0.91 (0.85–0.98)	0.011
FFM	0.94 (0.88–0.99)	0.026	0.92 (0.73–1.08)	0.349	0.92 (0.86–0.98)	0.011
ASM	0.88 (0.78–1.00)	0.047	0.87 (0.58–1.22)	0.441	0.85 (0.73–0.97)	0.020
tPMSA	1.00 (1.00–1.00)	0.624	1.00 (1.00–1.00)	0.437	1.00 (1.00–1.00)	0.997
tPMSA index	1.00 (1.00–1.00)	0.924	1.00 (0.99–1.00)	0.334	1.00 (1.00–1.00)	0.573
PMF	1.11 (0.87–1.42)	0.405	2.71 (0.97–10.66)	0.079	1.04 (0.81–1.33)	0.767
PMF index	1.30 (0.79–2.25)	0.313	5.58 (0.54–83.53)	0.158	1.19 (0.71–2.04)	0.512

PDFF, proton density fat fraction; OR, odds ratio; CI, confidence interval; BMI, body mass index; SDS, standard deviation score; WC, waist circumference; ALT, alanine aminotransferase; PBF, percentage of body fat; VFA, visceral fat area; SMM, skeletal muscle mass; FFM, fat-free mass; ASM, appendicular skeletal muscle mass; tPMSA, total psoas muscle surface area; PMF, paraspinal muscle fat.
*Adjusting for age and sex.

In multivariable logistic regression analyses after adjusting age and sex, ALT was positively related with fatty liver grade in the total group (OR=1.10, p<0.001), and obese group (OR=1.15, p<0.001). PBF was positively associated with higher fatty liver grades in the total group (OR=1.10, p=0.007) and obesity groups (OR=1.11, p=0.022). SMM, FFM, and ASM were negatively associated with fatty liver grade in the total group (SMM: OR=0.93, p=0.027; FFM: OR=0.94, p=0.026; ASM: OR=0.88, p=0.047) and obese group (SMM: OR=0.91, p=0.011; FFM: OR=0.92, p=0.011; ASM: OR=0.85, p=0.020).

4. Cutoff points for the parameters to predict NAFLD

Supplementary Table 1 shows the results of optimal cutoff points for the parameters which was significantly correlated with fatty liver grade in the multivariable ordinal logistic regression analyses. The cutoff points for PBF, SMM, FFM, and ASM were >34.90%, <42.15 kg, <44.85 kg, and <16.54 kg, respectively. The sensitivity for these values was 0.84, 0.69, 0.69, and 0.60, respectively, while the specificity was 0.67, 0.58, 0.58, and 0.67, respectively.

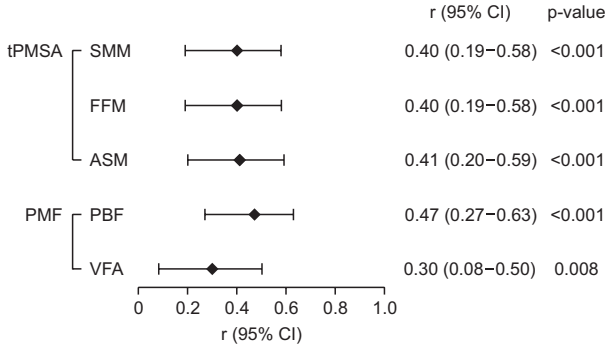

Fig. 1. Forest plot of the Pearson correlation of bioelectrical impedance analysis parameters with total psoas muscle surface area (tPMSA) and paraspinal muscle fat (PMF). SMM, skeletal muscle mass; FFM, fat-free mass; ASM, appendicular skeletal muscle mass; PBF, percentage of body fat; VFA, visceral fat area; CI, confidence interval.

5. Correlation of MRI muscle parameters with BIA parameters

Fig. 1 shows the forest plot of the correlation of tPMSA with muscle-related BIA parameters and of PMF with fat-related BIA parameters for all the participants. tPMSA was

positively correlated with SMM (r=0.40, p<0.001), FFM (r=0.40, p<0.001), and ASM (r=0.41, p<0.001) among the participants. PMF was positively correlated with PBF (r=0.47, p<0.001) and VFA (r=0.30, p=0.008) among the participants.

DISCUSSION

Our study demonstrated that PBF, PMF, and the PMF index were positively correlated with liver PDFF, whereas all muscle-related BIA parameters were negatively correlated with liver PDFF among children and adolescents. The univariable ordinal logistic regression analyses demonstrated that PBF and the PMF index were positively associated with fatty liver grade, whereas all muscle-related BIA parameters were negatively associated with fatty liver grade in children and adolescents. In addition, PBF and all muscle-related BIA parameters were significantly related with fatty liver grade even after adjusting age and sex. In the correlation analyses of the MRI muscle parameters, tPMSA was positively correlated with all muscle-related BIA parameters, whereas PMF was positively correlated with all fat-related BIA parameters.

The BIA parameters, PMF, and PMF index, were associated with fatty liver grade, whereas the BMI SDS and WC were not significantly related with fatty liver grade. Moreover, PBF, SMM, FFM, and ASM were significantly correlated with fatty liver grade even after adjusting age and sex. In pediatric fatty liver assessment, traditional measures, such as the BMI and WC, have limitations due to their inability to distinguish between muscle and fat mass, which can lead to misclassification of metabolic risk.[10,12,13,22] To overcome these limitations, investigations on relationship between body composition and fatty liver were conducted.[10,23,24] A meta-analysis reported that skeletal muscle index was negatively associated with NAFLD in adults.[13] In a Chinese study, BIA outperformed anthropometric indices in predicting NAFLD among children.[24] In a cross-sectional study, the predictability of waist-to-hip ratio for hepatic steatosis increased when combined with PBF or VFA.[10]

PBF and muscle-related BIA parameters were associated with fatty liver grade in the obesity group, not in the normal and overweight groups after adjusting age and sex. We divided the participants into normal and overweight group and obesity because differences in muscle and fat mass between normal and overweight, and obese children can impact obesity-related comorbidities including fatty liver.[8,11,25] In the obesity group, larger amounts of adipose tissue can have more significant adverse effects on fatty liver.[2,22,23] Consequently, the protective effects of muscle mass might become more apparent in this group. In a Korean study conducted in children who were overweight and obese, PBF was positively correlated with ALT elevation, whereas muscle-related BIA parameters, including SMM, FFM, and ASM, were negatively correlated with ALT elevation.[10] The association between muscle parameters and fatty liver grade in obese children underscores the importance of a comprehensive approach to managing pediatric NAFLD that includes both fat and muscle assessments.

PMF and the PMF index were positively associated with liver PDFF. PMF was associated with fatty liver grade in children with normal BMI and overweight status, whereas tPMSA did not show a significant relationship with fatty liver grade. This difference can be attributed to the nature of the measurements, wherein tPMSA primarily reflects muscle mass, which may not directly indicate liver fat content or overall adiposity.[20] In contrast, the PMF index measures fat infiltration in muscles, which is more closely associated with overall body fat and metabolic dysfunction, both of which are key factors in the development and severity of fatty liver disease.[10,20,23] In a previous cohort study, fat mass was a more effective predictor for NAFLD among children than muscle mass was.[23] In a Korean study, among children, tPMSA and PMF were positively associated with obesity but were not significantly associated with liver fat after adjusting for BMI.[20] More studies are required to clarify the association of fatty liver with tPMSA and PMF.

Muscle-related BIA parameters, including SMM, FFM, and ASM, correlated with tPMSA, whereas fat-related BIA parameters, including PBF and VFA, correlated with PMF although coefficients of correlation were not high. In a Japanese study, SMM was positively associated with tPMSA.[26] BIA devices are easily accessible outside medical facilities and provide a noninvasive body composition assessment method without radiation exposure.[10,26] Given that BIA showed strong correlations with tPMSA and PMF measured by MRI as well as with the severity of fatty liver, we propose that BIA could serve as a practical method for body composition assessment in the management of NAFLD.

This study has some limitations. First, its retrospective design and the fact that the population was limited to Koreans restrict the generalizability of the findings. Second, genetic and environmental factors, such as nutrition and physical activity, were not considered. Third, our study focused on children and adolescents attending a real-world clinic for the evaluation of obesity-related comorbidities, resulting in a relatively higher proportion of fatty liver even among children with normal BMI and those who were overweight, compared to the general population. Addition-

ally, participants with normal BMI and those who were overweight were combined due to the small sample sizes in these groups. This focus on a population predominantly affected by obesity led to a smaller number of normal-weight and overweight participants. Fourth, NAFLD was diagnosed using MRI rather than the gold standard of liver biopsy. However, MRI is the most accurate diagnostic tool for hepatic steatosis in imaging studies, as it provides the fatty liver grade using PDFF. Moreover, we assessed body composition using both BIA and MRI and provided insights into their relationship with NAFLD.

In conclusion, our study demonstrated an association between fatty liver grade and BIA parameters, including PBF and all muscle-related BIA parameters, as well as PMF and the PMF index, among children and adolescents. Moreover, PBF and all muscle-related BIA parameters were associated with fatty liver severity even after adjusting for age and sex, while anthropometric measurements were not. Fat-related BIA parameters correlated with PMF, and muscle-related BIA parameters correlated with tPMSA. Considering the noninvasive nature of BIA, its lack of radiation exposure, and its accessibility, these findings are particularly meaningful in the context of pediatric care and underscore the importance and practicality of considering body composition when assessing pediatric fatty liver. Additionally, our study provides a foundation for future research to explore the role of body composition assessments in the screening and management of NAFLD in children and adolescents.

CONFLICTS OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Study concept and design: K.S., H.J.S. Data acquisition: K.S., E.G.S., H.L., H.J.S. Data analysis and interpretation: K.S., H.J.S. Drafting of the manuscript: K.S. Critical revision of the manuscript for important intellectual content: H.J.S. Statistical analysis: E.L. Administrative, technical, or material support; study supervision: H.S.L., H.W.C., H.J.S. Approval of final manuscript: all authors.

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SUPPLEMENTARY MATERIALS

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