BMC Pediatrics

RESEARCH Open Access

Bioelectrical impedance analysis for measuring body composition and predicting low muscle mass in apparently healthy pediatric outpatients: a retrospective observational study

Qiongyao Hu[1], Qi Long[1], Wenqiao Wang[1] and Ming Ma[1*]

Abstract

Background The bioelectrical impedance analysis–derived phase angle is a proposed indicator of sarcopenia in adults. This study assessed the body composition of pediatric outpatients without underlying medical conditions to evaluate the predictive value of the phase angle in identifying low muscle mass, a risk factor for pediatric sarcopenia.

Methods Analyses were performed separately for each sex among 480 pediatric outpatients aged 5–18 years. Body composition variables were compared between low and normal body mass index-for-age z-score (BMIz) groups, including correlation analysis between the phase angle and other variables. The receiver operating characteristic curves of the phase angle, body mass index, and fat-free mass index (FFMI) were compared to predict a severely low appendicular skeletal muscle mass index (ASMI), defined as an ASMI below − 1 or − 2 standard deviations based on sex- and ethnicity-specific reference curves derived from dual-energy X-ray absorptiometry.

Results The low BMIz group showed a greater prevalence of a low fat-mass percentage and severely low ASMI, accompanied by notable changes in fat mass, muscle mass, height-squared adjusted indices, body water, protein, visceral fat area, and the phase angle ($P < 0.05$) compared with the normal BMIz group. The phase angle exhibited moderate correlations ($P < 0.001$) with the FFMI and ASMI (positive) and the visceral fat area and the extracellular water/total body water (ECW/TBW) ratio (negative) but no or negligible correlation with fat mass, fat-mass percentage, the fat mass index, or minerals. The phase angle' area under the curve for predicting a severely low ASMI was 0.743–0.785 (sensitivity: 62.3–80.4%; specificity: 67.0–75.0%). The area under the curve of the FFMI was 0.853–0.931 (sensitivity: 78.4–92.9%; specificity: 79.6–87.1%).

Conclusions Body composition can identify fat and muscle wasting in children with a normal BMIz. The phase angle moderately correlated with the FFMI, ASMI, visceral fat area, and ECW/TBW ratio. The phase angle is a reasonable, although not a surrogate, indicator of the sarcopenia risk in pediatric outpatients.

*Correspondence:
Ming Ma
maming73@zju.edu.cn

Full list of author information is available at the end of the article

Keywords Bioelectrical impedance analysis, Phase angle, Sarcopenia, Appendicular skeletal muscle mass index

Background

Simple anthropometric measurements, such as body mass index (BMI), are insufficient for distinguishing between fat mass (FM) and fat-free mass (FFM). Conversely, a normal BMI does not guarantee adequate muscle mass and FM in children; some children with a BMI-for-age z score (BMIz) between − 1 and − 1.99 are healthy, meeting dietary needs, lacking medical conditions, and showing no signs of malnutrition. This group represents approximately 13.59% of children with typical growth according to the Gaussian distribution pattern [1]. A comprehensive nutritional assessment should include an analysis of body composition to detect hidden malnutrition not evident from BMI alone and also place the burden of proof on clinicians to prevent the overdiagnosis of malnutrition.

Sarcopenia is adult malnutrition characterized by reduced skeletal muscle mass (SMM) and impaired muscle function. It slows growth and affects clinical outcomes, including increased hospitalization and ventilator dependency after liver transplantation [2], mortality in liver transplantation candidates [3], postoperative complications and hospital readmission in children with colectomy for ulcerative colitis [4], inflammatory bowel disease (IBD) severity [5], invasive fungal infection in children with acute lymphoblastic leukemia [6], and risk of metabolic dysfunction [7]. Evidence of sarcopenia in apparently healthy children is scarce but was recently identified in teenagers, who exhibited two phenotypes: a low soft lean mass (SLM) index with a low BMI and a low SLM-to-FM ratio with a high BMI and fat mass index (FMI) [8].

Body composition data can be obtained using bioelectrical impedance analysis (BIA), a quick, affordable, non-invasive, and radiation-free method that passes a harmless electrical current through the body. The body has two types of opposition to the current: capacitive reactance (Xc, ohms) from cell membranes and tissue interfaces corresponds to the cell membrane integrity and body cell mass (BCM); resistance (R, ohms) represents voltage decreases by extra and intracellular fluids. The bioelectrical impedance (Z, ohms) comprises Xc and R [$Z^2 = R^2 + Xc^2$] [9, 10]. Skeletal muscle, rich in water content, demonstrates high conductivity and correspondingly low impedance. In contrast, adipose tissue and bone are poor conductors with high impedance. The multifrequency BIA technique applies various frequencies (1–1000 kHz) of electric current to measure both extracellular water (ECW) and intracellular water (ICW); high-frequency electric current passes through both ECW and ICW, while low-frequency electric current only passes through ECW, thus differentiating ECW from total body water (TBW) [10].

Most of the estimates of body composition are based on impedance values and prediction equations calibrated against reference methods; the BIA-derived phase angle (PhA) is a less biased, assumption-free parameter describing the signal angle between Xc and R, calculated at a 50 kHz frequency through the formula: PhA (°) = Arctangent [(Xc/R) × (180°/π)] [11]. The PhA has been suggested to detect malnutrition in adults with cancer and Crohn's disease and correlate with clinical outcomes such as survival rate and inflammation [12–14]. Although no direct correlations were established between PhA and muscle mass or malnutrition in pediatric populations with Type 1 diabetes and IBD, studies documented a lower PhA indicative of compromised nutritional status, with distinct gender variations in BIA parameters observed within IBD subtypes [15, 16]. The PhA is decreased in adults with sarcopenia, and individuals with a lower PhA have an increased prevalence of sarcopenia [17–19]. However, only a few studies have investigated the role of the PhA in muscle mass (MM) in children.

Evidence indicates that PhA correlates with muscle mass and quality in male adolescents and with muscle mass in females [20], while another study reveals its association with physical performance in adolescent athletes without sex differentiation [21]. Despite this, many studies lack data on physical fitness or strength in children, reflecting the absence of consensus on pediatric sarcopenia diagnosis. This study aimed to (1) investigate body composition in children from the nutrition outpatient clinic to include a broader age range, and (2) elucidate the correlation between the PhA and other body-composition parameters, and determine the PhA's discriminative capacity for severely low muscle mass in these children and adolescents, particularly in the context of limited muscle strength assessment.

Methods

Participants

The study collected the electronic medical records of pediatric outpatients aged 5–18 years who had anthropometric and BIA measurements completed between June 2020 and December 2023 at the Department of Clinical Nutrition, Children's Hospital, Zhejiang University School of Medicine in Hangzhou, China. This study was approved by the Ethics Committee of Children's Hospital, Zhejiang University School of Medicine (No. 2023-IRB-0283-P-01). Informed consent was not required because of the study's retrospective nature.

Inclusion and exclusion criteria

The inclusion criteria were (1) Asian children, (2) without underlying medical conditions, and (3) for children with multiple body composition analysis results, only information from the first measurement was used. The exclusion criteria were (1) being overweight (BMIz ≥ + 1 standard deviation [SD]), obese (BMIz ≥ + 2 SD), or stunted (a height-for-age z-score [HAZ] ≤ − 2 SD according to the 2007 World Health Organization [WHO] criteria), which avoids the effect of short stature on body composition analysis [22]; (2) a history of prematurity, growth hormone deficiency, or growth hormone treatment; (3) disease conditions, including a cardiac surgery postoperative period, cardiac insufficiency, complex congenital heart disease, presence of ascites/edema, severe liver failure, renal failure or on dialysis, tumor, anorexia nervosa, neuromuscular disorders, inherited metabolic disorders, hypothyroidism, autoimmune disease, and chronic disease that affects height, weight, nutritional status, or disease that needs long-term treatment with glucocorticoids or diuretics; (4) presence of cardiac pacemakers, orthopedic prosthesis, electronic insulin pumps, or other metallic implants; (5) presence of abnormal limbs or trunks, including amputation, scoliosis, and atrophy; (6) fever > 38 °C when BIA was performed; and (7) athletes.

Anthropometric measurements

The children were dressed in light clothes, with jewelry removed, and stood barefoot during the weight and height measurements. Weight was measured using a digital scale (Seca; Germany) accurate to 0.1 kg. The height was measured using a vertical stadiometer (Seca; Germany) accurate to 0.1 cm. All measurements were recorded using a unified evaluation procedure. The BMI was calculated as weight/height^2 in kg/m^2. The WHO's AnthroPlus 1.0.4 software was used to calculate the BMIz and HAZ.

Body composition measurements

Body composition was measured in a unified procedure by rigorously trained dietitians using an InBody S10 Body Water Analyzer (InBody Co., Ltd., Seoul, Republic of Korea), which is a multifrequency (1, 5, 50, 250, 500, and 1000 kHz) tetrapolar eight-point tactile electrode system with a body composition analysis function [23]. However, not all children in the outpatient clinic met the fasting requirements prior to the measurement. The necessity of fasting in children is uncertain despite the empirical recommendation of a minimum 4-hour fasting period [23]. The fasting state does not influence the PhA in adults [24]. To minimize interference, we asked the children to empty their bladders, remove jewelry, dress in light clothes, and stand quietly for 10 min before the assessment. Tests were conducted between 8 a.m. and 5 p.m. at room temperature (22–27 °C). Information concerning name, ID number, age, sex, weight, and height was entered into the device. The corresponding touch-type detector electrodes were clamped to the thumb, middle finger, and ankle. The children stood barefoot with abducted upper (15°) and lower (shoulder width) extremities. The measurements took approximately 2–3 min. The output variables included FM, FMI, FM percentage (FM%), visceral fat area (VFA), FFM, SMM, appendicular SMM (ASM), ASM index (ASMI), trunk MM, TBW, ICW, ECW, BCM, protein, minerals, and the 50-kHz whole-body PhA. Details of the proprietary algorithms are not available for publication because of commercial sensitivities. The output variables, including the fat-free mass index (FFMI), were calculated using the following formulas:

$$\mathrm{FMI}\ \left(\mathrm{kg/m^2}\right) = \mathrm{FM/height^2}$$

$$\mathrm{FFMI}\ \left(\mathrm{kg/m^2}\right) = \mathrm{FFM/height^2}$$

$$\mathrm{ASMI}\ \left(\mathrm{kg/m^2}\right) = \mathrm{ASM/height^2}$$

$$\mathrm{ICW} = \mathrm{TBW} - \mathrm{ECW}$$

The physiological meaning of "BCM" measurements has no consensus. BCM could be interpreted as the protein-rich compartment affecting catabolic status [9] and was calculated using the formula BCM = protein + ICW.

Grouping

When only a single data point was available, a BMIz of ≤ − 1 SD indicated a diagnosis of malnutrition [25]. This study categorized children with a BMIz ≤ − 1 SD as having a low BMIz; children with a BMIz between − 1 SD and 1 SD were categorized as having a normal BMIz.

Reference values for FM%, SMM, and ASM are lacking for our study's ethnicity, sex, and age composition for the InBody S10 device. Therefore, we used the FM% reference ranges for Asian children implemented for the InBody S10 using an undisclosed proprietary algorithm. The standard values were 16% for boys aged 4–5.5 years, 15% for boys aged > 5.5 years, and 16% for girls aged 4–8 years. For girls, starting from the age of 8 years, the value begins at 17% and increases by 1% each year until it reaches 23% when girls are > 14 years of age. The upper and lower limits were calculated by adding or subtracting 5% of the standard values. An FM% below the lower limit or above the upper limit was categorized as a low or high FM%, respectively; an FM% within the limits was considered normal.

Differing cutoff points have been reported for the SMM and ASM [26]. Definitions of a low ASMI used either one

or two SDs below the mean value or the 5th percentile of the reference distribution in adults [27]. The InBody S10 uses a nontraditional and suboptimal method to define the SMM normal range as 90–110% of the standard values [28]. Therefore, lacking a more suitable alternative, we categorized ASMI based on the dual-energy X-ray absorptiometry (DXA)-measured (Hologic Inc.) reference values for Chinese children established by Liu et al. [29], which was supported by the strong agreement observed between InBody 720 BIA- and DXA-measured ASM in Chinese children [30]. We categorized an ASMI above the mean value as sufficient; an ASMI within the range of the mean to − 1 SD was considered insufficient. ASMIs below − 1 SD and − 2 SD were used to diagnose severely low ASMIs and for further analysis, respectively.

Statistical analysis

Two clinical medical staff members collected the data from patients' electronic medical records and BIA reports. Categorical variables are presented as frequencies and percentages and analyzed using the *chi*-squared test or Fisher's exact test. The integrated Bonferroni correction within IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA) was used for multiple comparisons of categorical variables, enabling the consideration of a $P < 0.05$ as statistically significant without requiring further correction. For continuous data, the distribution normality was assessed using the Shapiro–Wilk test. Normally distributed data are presented as the mean (SD) and were compared using Student's *t* test. Non-normally distributed data are presented as the median (25th percentile, 75th percentile; P25, P75) and were compared using the Mann–Whitney U test.

A standardized mean difference (SMD) < 0.1 was considered a good balance for baseline clinical characteristics between the low and normal BMIz groups. Propensity score matching (PSM) was performed to identify a subgroup of children with similar characteristics using the R package MatchIt (version 4.2.3; R Foundation for Statistical Computing; Vienna, Austria) with the nearest neighbor matching algorithm. The matching succeeded when the propensity score's logit difference between nearest neighbors was within a caliper width equal to 0.2 times its SD. The data distribution assessment and body composition comparison analyses were performed using the Storm Statistical Platform (www.medsta.cn/software) based on R version 4.3.0 (2023-04-21).

Correlation analysis was performed to evaluate the relationship between the PhA and other body parameters for each sex using the R package ppcor (version 4.2.3). Pearson correlation analysis was applied to normally distributed data; Spearman correlation analysis was applied to non-normally distributed data. As needed, partial correlation analysis was performed with age as a control variable. The correlation coefficients were categorized as "negligible" (0.00–0.29), "low" (0.30–0.49), "moderate" (0.50–0.69), "high" (0.70–0.89), and "very high" (0.90–1.0) [31].

Receiver operating characteristic (ROC) curves and the area under the curve (AUC) were used to assess the predictive capability of the PhA, FFMI, and BMI for severely low ASMI (based on ASMI − 1 SD or ASMI − 2 SD) using the R package pROC (version 4.2.3). The AUCs for diagnostic accuracy were 0.6–0.7 (acceptable), 0.7–0.8 (fair), 0.8–0.9 (good), and > 0.9 (excellent) [32]. The optimal cutoff values were determined mainly by the Youden index (the maximum value of [sensitivity + specificity − 1]). The product index (the maximum value of sensitivity × specificity) and Euclidean index (the minimum value of $[(1 - \text{sensitivity})^2 + (1 - \text{specificity})^2]$) were selectively used to determine optimal cutoff values using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA) and Microsoft Office Excel (2019) [33]. Comparison of the two ROC curves was based on the DeLong test using the R package pROC (version 4.2.3). A two-sided $P < 0.05$ was considered statistically significant.

Results

Patient characteristics and distribution of the BMIz, FM%, and ASMI

The study included 480 children aged 5–18 years, including 312 boys and 168 girls. The distribution of age is presented in Supplementary Table S1. Out of the 312 boys, 304 (97.4%) were aged 5–13 years, with a median age of 7.8 years (6.6, 10.1). Out of the 168 girls, 163 (97.0%) were aged 5–13 years, with a median age of 7.8 years (6.5, 10.3). The children's main complaints were reduced appetite, picky eating, and slow weight gain, as reported by the caregivers. Among the participants, 211 boys and 138 girls were categorized into the low BMIz group, and 101 boys and 30 girls were categorized into the normal BMIz group. Supplementary Table S2 shows the distribution of FM% and ASMI between the low and normal BMIz groups. The prevalence of a low BMIz was 67.6% in boys and 82.1% in girls. The low BMIz group displayed a significantly greater prevalence of low FM% (64.5% for boys and 73.2% for girls), severely low ASMI (≤ − 1 SD; 79.6% for boys, 76.8% for girls), and concurrent presence of both low indicators (47.4% for boys and 51.4% for girls) than the normal BMIz group ($P < 0.001$). One boy (1/211, 0.5%) in the low BMIz group exhibited normal FM% and sufficient ASMI. In addition, one girl (1/138, 0.7%) in the low BMIz group exhibited a high FM%. In the normal BMIz group, the proportion of individuals with adequate FM% and ASMI was 15.8% for boys and 13.3% for girls.

Comparison of BIA parameters between the normal and the low BMIz groups

In the PSM analysis, we explicitly included age as a confounding variable to calculate the propensity scores (see Table 1). Before PSM, the SMDs for age were 0.282 for boys and 0.284 for girls, respectively. After applying PSM to control for age, the SMDs decreased to 0.012 for boys and 0.015 for girls, respectively. The boys in the low BMIz group showed significant decreases in FM, FM%, FMI, FFM, FFMI, total SMM, trunk MM, upper limb skeletal muscle mass (ULSM), lower limb skeletal muscle mass (LLSM), ASMI, TBW, ICW, ECW, protein, BCM, and the PhA compared to the normal BMIz group ($P<0.001$). No significant difference was found in the mineral content ($P>0.05$) between these groups. The VFA and ECW/TBW ratio were significantly greater in the low BMIz group ($P<0.001$). The girls in the low BMIz group showed significant decreases in FM, FM%, FMI, FFMI, total SMM, trunk MM, ULSM, LLSM, ASMI, TBW, ICW, protein, BCM, and the PhA compared with the normal BMIz group ($P<0.05$). Although decreases in total FFM and ECW were observed in the low BMIz group, the differences were not statistically significant ($P=0.058$ and $P=0.051$, respectively). No significant difference was found in the mineral content or ECW/TBW ratio ($P>0.05$). The VFA was significantly higher in the low BMIz group ($P=0.048$).

Correlation coefficients between the PhA and body parameters

In the correlation analysis, age was treated as a control variable when it correlated with the PhA and certain body composition indicators, as shown in Table 2. For boys, partial correlation analysis was performed with age as a control variable after identifying age as a shared factor in the correlation between PhA and some of the BIA indices through bivariate analysis, and the PhA had moderate positive correlations with the FFMI ($r=0.586$, $P<0.001$) and ASMI ($r=0.669$, $P<0.001$), low positive correlations with FFM, SLM, SMM, TBW, ICW, protein, and BMI ($r=0.3$–0.49, $P<0.001$), moderate negative correlations with the VFA ($r=-0.650$, $P<0.001$) and the ECW/TBW ratio ($r=-0.687$, $P<0.001$), negligible correlations with age, height, FM%, and ECW ($r=0.00$–0.29, $P<0.001$), but no evidence of correlation with FM, trunk FM, FMI, or minerals ($P>0.05$). In girls, the PhA exhibited moderate positive correlations with the FFMI ($r=0.532$, $P<0.001$) and ASMI ($r=0.545$, $P<0.001$), a low positive correlation with BMI ($r=0.427$, $P<0.001$), and negligible positive correlations with FFM, SLM, SMM, TBW, ICW, ECW, and protein ($r=0.00$–0.29, $P<0.05$). Furthermore, the PhA in girls showed moderate negative correlations with the VFA ($r=-0.525$, $P<0.001$) and the ECW/TBW ratio ($r=-0.692$, $P<0.001$) but no evidence of correlations with age, height, FM, FM%, trunk FM, FMI, or minerals ($P>0.05$). In addition, the FFMI showed a strong positive correlation with ASMI ($r=0.867$ for boys and $r=0.837$ for girls, both were adjusted for age; $P<0.001$; data not shown in the table).

Predictive abilities of the PhA and nutritional indices for severely low ASMI

Defining severely low ASMI as an ASMI ≤ −1 SD achieved good predictive accuracy for the FFMI (AUC = 0.853 for boys and 0.889 for girls) and fair accuracy for the BMI (AUC = 0.798 for boys and 0.779 for girls) and PhA (AUC = 0.758 for boys and 0.767 for girls) ($P<0.001$) (see Table 3). The optimal cutoff values for the FFMI, BMI, and PhA were 12.8 kg/m^2, 14.4 kg/m^2, and 4.6° for boys and 12.0 kg/m^2, 13.4 kg/m^2, and 4.4° for girls, respectively. The sensitivities of these parameters for identifying severely low ASMI were 78.4%, 65.5%, and 66.4% for boys and 92.9%, 80.4%, and 80.4% for girls, with specificity rates of 79.6%, 81.6%, and 75.0% for boys and 75.9%, 67.9%, and 67.0% for girls, respectively. The FFMI had significantly greater AUC values than the BMI and PhA in both sexes ($P<0.05$).

In comparison, defining severely low ASMI as an ASMI ≤ −2 SD achieved excellent predictive accuracy for the FFMI (AUC = 0.926 for boys and 0.931 for girls), good predictive accuracy for the BMI (AUC = 0.860 for boys and 0.833 for girls), and fair accuracy for the PhA (AUC = 0.785 for boys and 0.743 for girls) ($P<0.001$). The optimal cutoff values for the FFMI, BMI, and PhA were 12.4 kg/m^2, 13.7 kg/m^2, and 4.4° (Euclidean index method) for boys and 11.8 kg/m^2, 13.5 kg/m^2, and 4.4° (by both the product index and Euclidean index methods) for girls, respectively. The sensitivities of these parameters for detecting severely low ASMI were 86.9%, 83.9%, and 70.4% for boys and 87.7%, 64.2%, and 62.3% for girls, respectively, with specificity rates of 83.2%, 77.9%, and 69.0% for boys and 87.1%, 88.7%, and 74.2% for girls, respectively. The FFMI had significantly greater AUC values than the BMI and PhA in both sexes ($P<0.05$).

Discussion

Prevalence of abnormal FM% and severe low ASMI

This study included children with reduced appetite, picky eating, or slow weight gain, revealed that in the normal BMIz group, a significant proportion (26.7–27.7%) had a low FM%, and 20.0–27.7% had a severely low ASMI (≤ −1 SD). DXA-derived ASMI ≤ −1 SD was defined as pre-sarcopenia [34]. Reduced muscle mass and strength in youth may predispose individuals to metabolic disorders, cardiovascular diseases, and potentially compromised bone health [35]. In the recent literature on the emerging issue of sarcopenia risk screening in seemingly healthy children and adolescents, we could not find directly

Table 1 Comparison of anthropometric and BIA parameters between the normal and low BMIz groups

Variable: mean (SD) or median (P25, P75)	Boys							
	Before Propensity Score Matching		Statistic	*P*	After Propensity Score Matching		Statistic	*P*
	Normal BMIz (*n* = 101)	Low BMIz (*n* = 211)			Normal BMIz (*n* = 99)	Low BMIz (*n* = 99)		
Age (years)	7.4 (6.2, 9.3)	8.3 (6.8, 10.3)	Z = −2.775	0.006	7.3 (6.2, 9.2)	7.3 (6.3, 9.2)	Z = −0.170	0.865
			SMD = 0.282				**SMD = 0.012**	
Height (cm)	124.2 (116.6, 136.2)	128.0 (119.8, 139.4)	Z = −1.819	0.069	123.0 (116.6, 135.8)	124.3 (116.0, 134.7)	Z = −0.594	0.552
Weight (kg)	23.7 (20.2, 29.0)	21.8 (19.2, 27.0)	Z = −2.365	0.018	23.6 (20.2, 29.0)	20.2 (18.2, 24.1)	Z = −4.184	< 0.001
BMI (kg/m^2)	15.16 (14.65, 15.91)	13.59 (13.04, 14.07)	Z = −12.526	< 0.001	15.15 (14.65, 15.86)	13.53 (13.02, 14.02)	Z = −11.435	< 0.001
FM (kg)	2.80 (2.30, 3.90)	2.10 (1.50, 2.70)	Z = −6.425	< 0.001	2.70 (2.30, 3.85)	1.90 (1.40, 2.55)	Z = −6.605	< 0.001
FM%	12.18 (3.66)	9.22 (2.96)	t = 7.643	< 0.001	12.30 (9.74, 14.23)	8.98 (7.49, 10.78)	Z = −6.254	< 0.001
FMI (kg/m^2)	1.83 (1.50, 2.25)	1.23 (0.98, 1.50)	Z = −8.669	< 0.001	1.83 (1.50, 2.26)	1.19 (1.00, 1.50)	Z = −7.782	< 0.001
VFA (cm^2)	15.40 (11.40, 17.70)	17.90 (15.70, 19.95)	Z = 5.756	< 0.001	15.40 (11.45, 17.70)	17.60 (15.35, 19.85)	Z = 4.976	< 0.001
FFM (kg)	20.50 (17.70, 25.00)	20.00 (17.45, 24.15)	Z = −1.247	0.212	20.50 (17.65, 24.70)	18.40 (16.50, 22.00)	Z = −3.216	0.001
FFMI (kg/m^2)	13.35 (12.94, 13.89)	12.25 (11.91, 12.76)	Z = −10.424	< 0.001	13.34 (12.93, 13.85)	12.24 (11.93, 12.60)	Z = −9.656	< 0.001
SMM (kg)	10.10 (8.50, 12.70)	9.70 (8.30, 12.20)	Z = −1.519	0.129	10.10 (8.45, 12.50)	8.70 (7.70, 10.95)	Z = −3.439	< 0.001
ULSM (kg)	1.44 (1.29, 1.73)	1.15 (1.02, 1.48)	Z=-6.559	< 0.001	1.43 (1.29, 1.71)	1.11 (1.00, 1.29)	Z=-7.379	< 0.001
Trunk MM (kg)	8.40 (7.30, 9.80)	7.70 (6.65, 9.45)	Z = −2.548	0.011	8.20 (7.25, 9.75)	7.20 (6.40, 8.45)	Z = −4.282	< 0.001
LLSM (kg)	5.22 (4.33, 6.83)	4.91 (3.96, 6.43)	Z=-1.840	0.066	5.11 (4.31, 6.61)	4.31 (3.80, 5.49)	Z=-3.853	< 0.001
ASMI (kg/m^2)	4.30 (4.00, 4.80)	3.80 (3.40, 4.25)	Z = −7.174	< 0.001	4.30 (4.00, 4.75)	3.60 (3.40, 4.00)	Z = −7.701	< 0.001
TBW (L)	14.90 (13.00, 18.20)	14.60 (12.75, 17.60)	Z = −1.388	0.165	14.90 (12.95, 18.05)	13.40 (12.05, 16.10)	Z = −3.371	< 0.001
ICW (L)	9.30 (8.10, 11.20)	9.00 (7.90, 10.90)	Z = −1.521	0.128	9.30 (8.05, 11.15)	8.20 (7.45, 9.90)	Z = −3.452	< 0.001
ECW (L)	5.80 (5.00, 7.00)	5.60 (4.90, 6.80)	Z = −1.177	0.239	5.70 (5.00, 6.90)	5.10 (4.65, 6.10)	Z = −3.220	0.001
ECW/TBW ratio	0.382 (0.005)	0.385 (0.005)	t = 4.721	< 0.001	0.382 (0.005)	0.384 (0.005)	t = 3.277	0.001
Protein (kg)	4.10 (3.50, 4.90)	3.90 (3.40, 4.70)	Z = −1.565	0.118	4.00 (3.50, 4.80)	3.60 (3.25, 4.20)	Z = −3.445	< 0.001
Minerals (kg)	1.54 (1.22, 1.89)	1.56 (1.32, 1.87)	Z = −0.374	0.709	1.54 (1.21, 1.88)	1.44 (1.20, 1.74)	Z = −1.488	0.137
BCM (kg)	13.30 (11.50, 16.10)	12.80 (11.30, 15.60)	Z = −1.537	0.124	13.30 (11.45, 15.95)	11.70 (10.70, 14.20)	Z = −3.461	< 0.001
PhA (°)	4.8 (0.5)	4.4 (0.4)	t = −6.656	< 0.001	4.8 (0.5)	4.4 (0.4)	t = −5.375	< 0.001
Variable: mean (SD) or median (P25, P75)	**Girls**							
	Before Propensity Score Matching		Statistic	*P*	After Propensity Score Matching		Statistic	*P*
	Normal BMIz (*n* = 30)	Low BMIz (*n* = 168)			Normal BMIz (*n* = 30)	Low BMIz (*n* = 105)		
Age (years)	7.8 (6.2, 9.1)	7.8 (6.6, 10.3)	Z = −1.031	0.302	7.8 (6.2, 9.1)	7.5 (6.3, 9.2)	Z = −0.045	0.964
			SMD = 0.284				**SMD = 0.015**	
Height (cm)	124.0 (116.3, 135.4)	125.5 (117.0, 139.1)	Z = −0.569	0.569	124.0 (116.3, 135.4)	124.1 (116.4, 133.4)	Z = −0.259	0.795
Weight (kg)	22.4 (19.3, 26.8)	20.5 (17.7, 25.6)	Z = −1.779	0.075	22.4 (19.3, 26.8)	20.0 (17.2, 23.8)	Z = −2.676	0.007
BMI (kg/m^2)	14.61 (14.35, 15.47)	13.16 (12.72, 13.68)	Z = −7.276	< 0.001	14.61 (14.35, 15.47)	13.02 (12.59, 13.55)	Z = −7.732	< 0.001
FM (kg)	3.10 (2.62, 4.42)	2.20 (1.60, 2.88)	Z = −4.227	< 0.001	3.10 (2.62, 4.42)	2.10 (1.40, 2.80)	Z = −4.673	< 0.001
FM%	13.90 (12.50, 16.53)	10.60 (7.82, 12.75)	Z = −5.080	< 0.001	14.33 (3.14)	10.22 (3.36)	t = 5.996	< 0.001
FMI (kg/m^2)	2.05 (1.81, 2.46)	1.38 (0.98, 1.76)	Z = −5.862	< 0.001	2.16 (0.58)	1.35 (0.49)	t = 7.663	< 0.001
VFA (cm^2)	16.20 (13.22, 20.48)	18.40 (15.53, 21.25)	Z = 2.102	0.036	16.20 (13.22, 20.48)	18.60 (16.00, 21.10)	Z = 1.974	0.048
FFM (kg)	19.55 (16.78, 23.50)	18.35 (16.33, 22.85)	Z = −0.990	0.322	19.55 (16.78, 23.50)	17.80 (15.60, 20.80)	Z = −1.892	0.058
FFMI (kg/m^2)	12.72 (12.50, 13.11)	11.81 (11.41, 12.19)	Z = −6.436	< 0.001	12.78 (0.50)	11.72 (0.61)	t = 8.747	< 0.001
SMM (kg)	9.55 (7.77, 11.80)	8.75 (7.45, 11.35)	Z = −1.112	0.266	9.55 (7.77, 11.80)	8.40 (7.10, 10.20)	Z = −2.025	0.043

Table 1 (continued)

Variable: mean (SD) or median (P25, P75)	Girls							
	Before Propensity Score Matching		Statistic	*P*	After Propensity Score Matching		Statistic	*P*
	Normal BMIz (*n* = 30)	Low BMIz (*n* = 168)			Normal BMIz (*n* = 30)	Low BMIz (*n* = 105)		
ULSM (kg)	1.26 (1.15, 1.46)	1.02 (0.87, 1.29)	Z=-3.875	< 0.001	1.26 (1.15, 1.46)	0.98 (0.86, 1.17)	Z=-4.753	< 0.001
Trunk MM (kg)	7.95 (6.50, 9.30)	7.15 (6.20, 8.90)	Z = − 1.415	0.157	7.95 (6.50, 9.30)	6.70 (5.90, 8.20)	Z = − 2.430	0.015
LLSM (kg)	4.70 (3.88, 6.26)	4.24 (3.53, 5.93)	Z=-1.501	0.133	4.70 (3.88, 6.26)	4.19 (3.31, 5.19)	Z=-2.456	0.014
ASMI (kg/m^2)	4.05 (3.73, 4.40)	3.50 (3.10, 3.90)	Z = − 4.282	< 0.001	4.12 (0.55)	3.44 (0.62)	t = 5.521	< 0.001
TBW (L)	14.25 (12.20, 17.22)	13.25 (11.85, 16.55)	Z = − 1.071	0.284	14.25 (12.20, 17.22)	13.10 (11.30, 15.20)	Z = − 1.974	0.048
ICW (L)	8.80 (7.53, 10.55)	8.25 (7.25, 10.28)	Z = − 1.108	0.268	8.80 (7.53, 10.55)	8.00 (7.00, 9.40)	Z = − 2.020	0.043
ECW (L)	5.45 (4.65, 6.68)	5.10 (4.53, 6.38)	Z = − 1.057	0.291	5.45 (4.65, 6.68)	5.00 (4.40, 5.80)	Z = − 1.949	0.051
ECW/TBW ratio	0.384 (0.381, 0.387)	0.384 (0.381, 0.387)	Z = 0.666	0.505	0.384 (0.005)	0.385 (0.005)	t = 0.827	0.410
Protein (kg)	3.85 (3.25, 4.55)	3.60 (3.12, 4.40)	Z = − 1.177	0.239	3.85 (3.25, 4.55)	3.40 (3.00, 4.10)	Z = − 2.061	0.039
Minerals (kg)	1.44 (1.23, 1.75)	1.42 (1.21, 1.81)	Z = − 0.056	0.955	1.44 (1.23, 1.75)	1.41 (1.19, 1.64)	Z = − 0.868	0.385
BCM (kg)	12.65 (10.72, 15.10)	11.80 (10.35, 14.65)	Z = − 1.143	0.253	12.65 (10.72, 15.10)	11.50 (10.00, 13.40)	Z = − 2.049	0.040
PhA (°)	4.7 (4.5, 4.8)	4.4 (4.1, 4.6)	Z = − 3.314	< 0.001	4.7 (4.5, 4.8)	4.3 (4.0, 4.5)	Z = − 3.679	< 0.001

Table legends: In the propensity score matching analysis, only age was considered as a confounding variable

Table 2 The correlation coefficients between the PhA and body parameters

Variable	Boys (*n* = 312)				Girls (*n* = 168)	
	Before adjustment		Adjustment for age		No adjustment	
	r	*P* value	*r*	*P* value	*r*	*P* value
Basic information						
Age	0.192	0.001	/	/	0.138	0.074
Height	0.194	0.001	/	/	0.090	0.244
BMI	0.477	< 0.001	0.457	< 0.001	0.427	< 0.001
Fat parameters						
FM	0.101	0.074	/	/	0.132	0.088
FM%	-0.165	0.003[a]	/	/	0.024	0.760
FMI	-0.028	0.623	/	/	0.112	0.150
Trunk FM	0.136	0.017	0.048	0.397	0.103	0.182
VFA	-0.650	< 0.001	/	/	-0.525	< 0.001
Muscle and fat-free mass parameters						
FFM	0.323	< 0.001	0.337	< 0.001	0.219	0.004
FFMI	0.601	< 0.001	0.586	< 0.001	0.532	< 0.001
SMM	0.355	< 0.001	0.398	< 0.001	0.256	0.001
ASMI	0.678	< 0.001	0.669	< 0.001	0.545	< 0.001
Hydration parameters						
TBW	0.334	< 0.001	0.357	< 0.001	0.235	0.002
ICW	0.356	< 0.001	0.400	< 0.001	0.258	0.001
ECW	0.298	< 0.001	0.281	< 0.001	0.199	0.010
ECW/TBW ratio	-0.687	< 0.001[a]	/	/	-0.692	< 0.001
Nutritional parameters						
Protein	0.357	< 0.001	0.400	< 0.001	0.254	0.001
Minerals	0.180	0.001	0.016	0.775	0.027	0.733

Table legends: As needed, partial correlation analysis was performed with age as a control variable for boys; [a] Pearson correlation analysis for normally distributed data; /, not adjusted

comparable data on the prevalence of low muscle mass among those with normal BMI [8, 34, 36]. This study underscores the necessity to extend the diagnostic focus beyond BMI to include assessments of muscle mass in children. It advocates for the implementation of routine screening for sarcopenic risk in both clinical and educational settings. The study also identified individuals with a low BMIz but sufficient FM% and ASMI or with a low

Table 3 Predictive abilities of the PhA and nutritional indices for severely low ASMI

	AUC	95% CI	*P* value	Cutoff	Sensitivity (%)	Specificity (%)	Comparison	Z	95% CI	*P* value
ASMI ≤ −1 SD							**ASMI ≤ −1 SD**			
Boys (n = 312)							**Boys (n = 312)**			
FFMI (kg/m^2)	0.853	0.810 to 0.896	< 0.001	12.8	78.4	79.6	FFMI vs. BMI	3.497	0.024 to 0.086	< 0.001
BMI (kg/m^2)	0.798	0.748 to 0.848	< 0.001	14.4	65.5	81.6	FFMI vs. PhA	3.260	0.038 to 0.153	0.001
PhA (°)	0.758	0.701 to 0.814	< 0.001	4.6	66.4	75.0	BMI vs. PhA	1.216	−0.025 to 0.107	0.224
Girls (n = 168)							**Girls (n = 168)**			
FFMI (kg/m^2)	0.889	0.837 to 0.941	< 0.001	12.0	92.9	75.9	FFMI vs. BMI	4.632	0.064 to 0.157	< 0.001
BMI (kg/m^2)	0.779	0.705 to 0.852	< 0.001	13.4	80.4	67.9	FFMI vs. PhA	3.114	0.045 to 0.199	0.002
PhA (°)	0.767	0.692 to 0.841	< 0.001	4.4	80.4	67.0	BMI vs. PhA	0.255	−0.080 to 0.104	0.798
	AUC	**95% CI**	***P* value**	**Cutoff**	**Sensitivity (%)**	**Specificity (%)**	**Comparison**	**Z**	**95% CI**	***P* value**
ASMI ≤ −2 SD							**ASMI ≤ −2 SD**			
Boys (n = 312)							**Boys (n = 312)**			
FFMI (kg/m^2)	0.926	0.898 to 0.954	< 0.001	12.4	86.9	83.2	FFMI vs. BMI	4.047	0.034 to 0.098	< 0.001
BMI (kg/m^2)	0.860	0.818 to 0.902	< 0.001	13.7	83.9	77.9	FFMI vs. PhA	5.554	0.091 to 0.191	< 0.001
PhA (°)	0.785	0.734 to 0.835	< 0.001	4.5	55.3	85.8	BMI vs. PhA	2.601	0.018 to 0.132	0.009
				4.5[a]	62.8	77.9				
				4.4[b]	70.4	69.0				
Girls (n = 168)							**Girls (n = 168)**			
FFMI (kg/m^2)	0.931	0.893 to 0.968	< 0.001	11.8	87.7	87.1	FFMI vs. BMI	4.156	0.051 to 0.143	< 0.001
BMI (kg/m^2)	0.833	0.772 to 0.894	< 0.001	13.5	64.2	88.7	FFMI vs. PhA	5.012	0.114 to 0.261	< 0.001
PhA (°)	0.743	0.666 to 0.819	< 0.001	4.5	51.9	87.1	BMI vs. PhA	1.998	0.002 to 0.179	0.046
				4.4[a, b]	62.3	74.2				

Table legends: The majority of the optimal cutoff values were determined by the Youden index method. [a] optimal cutoff value derived from the product index method; [b] optimal cutoff value derived from Euclidean index method

BMIz but high FM%, which emphasized the importance of avoiding the misdiagnosis of malnutrition in children who may appear thin but are otherwise healthy.

This section's limitations included selection bias of participants and a lack of quantified appetite data, longitudinal tracking of anthropometrics, and blood tests for nutritional markers. Future prospective studies with expanded sample sizes, adopting more comprehensive diagnostic tools for malnutrition, such as the Subjective Global Nutritional Assessment, are warranted to address these limitations.

Comparison of BIA parameters between the normal and low BMIz groups

After matching for age, the low BMIz group showed significantly lower FM, SMM, TBW, protein, and nutritional indicators (FM%, FMI, FFMI, ASMI, BCM, and the PhA) than the normal BMIz group across both sexes, consistent with our understanding that reduced energy intake depletes fat and muscle. The ECW/TBW ratio increased in the low BMIz group but only in boys. An increased ECW/TBW ratio may be explained by edema related to low protein levels or malnutrition [9, 37], which can lead to a significant loss of BCM [38]. The ECW/TBW ratio is a risk factor for malnutrition in adults with advanced cancer [39]; it is also linked to a greater risk of all-cause mortality in patients undergoing hemodialysis [40].

Regarding sex differences in body water distribution, a shift from ICW to ECW has been observed in men with cachexia but not in women, compared with age- and sex-matched healthy controls [41]. In that study, a decreased ECW/ICW ratio correlated with an increase in BMI only in men [41]. Because research is limited, sex-specific changes in water distribution remain unexplained in undernourished children.

The VFA values were slightly but significantly greater in the low BMIz group. The VFA is reduced in malnourished adults among pre-intestinal transplant recipients [42] and patients with ulcerative colitis [43]. However, variability in the VFA levels has been reported in different diseases. A greater VFA was found in patients with IBD with impaired nutrition, with or without sarcopenia [44], and in lean patients with type 2 diabetes compared with healthy lean controls [45]. Furthermore, pediatric patients with sarcopenia and autoimmune liver disease exhibited a greater VFA than patients without sarcopenia [46]. Compared to controls, children with end-stage liver disease or intestinal failure show reduced MM and more visceral fat [37]. Although treatment-oriented supplemental nutrition might lead to storing calories as fat after malnutrition is recognized, this situation was unlikely in the present study. Epigenetics has garnered attention over the past few decades; theories suggest that early-life malnutrition affects the etiology of metabolic diseases later in life. Visceral adipose tissue has been recognized in the

excessive release of free fatty acids and inflammatory adipokines [47]. Exposure to famine in utero or during childhood (0–9 years) is associated with a higher visceral adiposity index in women [47]. However, whether adults with a greater visceral adiposity index exhibit visceral fat accumulation during childhood is unknown. In addition, whether a slightly greater VFA poses a risk of metabolic dysfunction or provides protection remains unexplored.

One limitation of this section is the lack of real healthy controls, restricting its generalizability. The BMI, FM, FMI, FM%, BCM, and PhA values were lower in the normal BMIz group than in apparently healthy children in Chongqing, China [48] or the Motorik–Module (MoMo) study [38]. Moreover, the VFA values were lower than the published norms from the Czech Republic, which range from 30.3 to 44.9 cm^2 [49]. In addition, the sample size was too small to allow further stratification based on a narrower age range.

Correlation between the PhA and other body parameters

The PhA showed a negligible positive correlation with age and height in boys but not girls. This finding is consistent with the findings of the MoMo study, which indicated an elevation in boys' PhAs at the end of puberty, in contrast to the stabilization or slight reduction evident in girls at the onset of puberty [38]. We also identified a negligible negative correlation between the PhA and FM% in boys but not in girls, differing from a study that found an inverse correlation in females [50]. For the correlation between the PhA and minerals and trunk FM, age adjustment was essential for boys because of the differences in significance before and after partial Spearman correlation analysis. No evidence of correlation was observed between the PhA and total FM, trunk FM, or FMI in either sex, consistent with the literature [20]. The current evidence is insufficient to conclusively define the directionality of correlations concerning the PhA, FM, or FM-related indices; disparate results have been reported [51]. Our analysis found a negative correlation between the PhA and the VFA, and the ECW/TBW ratio for both sexes, consistent with existing data [51, 52]. The positive correlations between the PhA and FFM, SMM, BMI, FFMI, and ASMI identified in our study are widely supported [17, 50]. The evidence suggests that the PhA is an indicator of nutritional status, particularly for lean body mass rather than FM metrics, necessitating further analysis of its predictive capacity for sarcopenia.

Predictive abilities of the PhA and nutritional indices for severely low ASMI

We found the PhA has a fair performance for predicting severely low ASMI. Although judging sensitivity and specificity has no agreed-upon criteria, the PhA cutoffs were not ideal because the participants were considerably misclassified. The FFMI outperformed the BMI and PhA in predicting severely low ASMI. This result is not surprising since MM is the primary component of FFM; the FFMI showed a strong positive correlation with ASMI. Pediatric outpatients show a greater prevalence of a low FFMI than a low BMI [53]. The FFMI was recommended for diagnosing malnutrition at <17 kg/m^2 for men and <15 kg/m^2 for women, along with unintentional weight loss [54]. Furthermore, the BIA-measured FFMI showed strong positive correlations with both BIA- and DXA-measured ASMIs, suggesting it is a straightforward surrogate marker for low MM in adults [55]. Regarding the study's initial purpose, our analysis indicated that the PhA may be a reasonable, although not a surrogate, measure for assessing the sarcopenia risk in children.

The limitations of this section include the absence of muscle function assessments such as handgrip strength tests and 6-minute walk tests for children [26] since increases in MM do not always correspond to improved muscle strength [35, 56]. Another limitation concerns the accuracy of BIA; it might overestimate FFM at the individual level [30, 57]. Equations derived from BIA using advanced diagnostic tools, such as DXA, need to be validated for specific populations.

Conclusions

Our study found that underweight children frequently exhibit muscle wasting with or without fat wasting. The PhA moderately correlated with the FFMI and ASMI and exhibited a fair ability to predict severely low ASMI. BIA is a rapid and convenient approach for evaluating body composition in children at risk of sarcopenia.

Abbreviations

ASM	Appendicular skeletal muscle mass
ASMI	Appendicular skeletal muscle mass index
AUC	Area under the ROC curve
BCM	Body cell mass
BIA	Bioelectrical impedance analysis
BMI	Body mass index
BMIz	Body mass index-for-age z-score
DXA	Dual-energy X-ray absorptiometry
ECW	Extracellular water
FFM	Fat-free mass
FFMI	Fat-free mass index
FM%	Fat-mass percentage
FM	Fat mass
FMI	Fat mass index
HAZ	Height-for-age z-score
IBD	Inflammatory bowel disease
ICW	Intracellular water
IRB	Institutional review board
LLSM	Lower limb skeletal muscle mass
MM	Muscle mass
MoMo	Motorik–Module
P	P value
PhA	Phase angle
PSM	Propensity score matching
R	Resistance
ROC	Receiver operating characteristic curve
SD	Standard deviation

SLM	Soft lean mass
SMD	Standardized mean difference
SMM	Skeletal muscle mass
TBW	Total body water
ULSM	Upper limb skeletal muscle mass
VFA	Visceral fat area
WHO	World Health Organization
Xc	Capacitive reactance
Z	Bioelectrical impedance

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12887-025-05579-8.

Supplementary Material 1

Supplementary Material 2

Acknowledgements
The authors express their gratitude to colleagues from the Department of Clinical Nutrition, Children's Hospital, Zhejiang University School of Medicine for providing clinical data and technical assistance. We also thank the research participants in this study.

Author contributions
HQ contributed to the conception, design, acquisition, statistical analysis and interpretation of the data, and drafted the work; LQ contributed to the conception, design, and interpretation of the data, and critically revised the manuscript; WW contributed to the acquisition and statistical analysis of the data, and critically revised the manuscript; MM contributed to the conception, design of the research, and critically revised the manuscript. All authors read and approved the final manuscript.

Funding
This study was supported by the Young Scholar Research Grant from the Zhejiang Nutrition Society, China (ZN-YCHP2023-004).

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Children's Hospital, Zhejiang University School of Medicine (No. 2023-IRB-0283-P-01). Informed consent was not required because of the study's retrospective nature.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Clinical Nutrition, Children's Hospital, Zhejiang University School of Medicine, National Clinical Research Center for Child Health, 3333 Binsheng Rd, Hangzhou, Zhejiang 310052, China

Received: 30 March 2024 / Accepted: 11 March 2025
Published online: 16 April 2025

References

1. Bouma S. Diagnosing pediatric malnutrition. Nutr Clin Pract. 2016;32(1):52–67. https://doi.org/10.1177/0884533616671861
2. Mager DR, Hager A, Ooi PH, Siminoski K, Gilmour SM, Yap JYK. Persistence of sarcopenia after pediatric liver transplantation is associated with poorer growth and recurrent hospital admissions. JPEN J Parenter Enter Nutr. 2019;43(2):271–80. https://doi.org/10.1002/jpen.1414
3. Boster JM, Browne LP, Pan Z, Zhou W, Ehrlich PF, Sundaram SS. Higher mortality in pediatric liver transplant candidates with sarcopenia. Liver Transpl. 2021;27(6):808–17. https://doi.org/10.1002/lt.26027
4. Dedhia PH, White Y, Dillman JR, Adler J, Jarboe MD, Teitelbaum DH, Hirschl RB, Gadepalli SK. Reduced paraspinous muscle area is associated with postcolectomy complications in children with ulcerative colitis. J Pediatr Surg. 2018;53(3):477–82. https://doi.org/10.1016/j.jpedsurg.2017.09.006
5. Aljilani B, Tsintzas K, Jacques M, Radford S, Moran GW. Systematic review: sarcopenia in paediatric inflammatory bowel disease. Clin Nutr ESPEN. 2023;57:647–54. https://doi.org/10.1016/j.clnesp.2023.08.009
6. Suzuki D, Kobayashi R, Sano H, Hori D, Kobayashi K. Sarcopenia after induction therapy in childhood acute lymphoblastic leukemia: its clinical significance. Int J Hematol. 2018;107(4):486–9. https://doi.org/10.1007/s12185-017-2388-9
7. Burrows R, Correa-Burrows P, Reyes M, Blanco E, Albala C, Gahagan S. Low muscle mass is associated with cardiometabolic risk regardless of nutritional status in adolescents: a cross-sectional study in a Chilean birth cohort. Pediatr Diabetes. 2017;18(8):895–902. https://doi.org/10.1111/pedi.12505
8. Torres-Costoso A, Zymbal V, Janz KF, Martinez Vizcaino V, Baptista F. Body composition and musculoskeletal fitness: a cluster analysis for the identification of risk phenotypes for pediatric sarcopenia. Clin Nutr. 2023;42(7):1151–8. https://doi.org/10.1016/j.clnu.2023.05.008
9. Kyle U. Bioelectrical impedance analysis? Part I: review of principles and methods. Clin Nutr. 2004;23(5):1226–43. https://doi.org/10.1016/j.clnu.2004.06.004
10. Brantlov S, Ward LC, Jodal L, Rittig S, Lange A. Critical factors and their impact on bioelectrical impedance analysis in children: a review. J Med Eng Technol. 2017;41(1):22–35. https://doi.org/10.1080/03091902.2016.1209590
11. Marini E, Campa F, Buffa R, Stagi S, Matias CN, Toselli S, Sardinha LB, Silva AM. Phase angle and bioelectrical impedance vector analysis in the evaluation of body composition in athletes. Clin Nutr. 2020;39(2):447–54. https://doi.org/10.1016/j.clnu.2019.02.016
12. Bas D, Atahan C, Tezcanli E. An analysis of phase angle and standard phase angle cut-off values and their association with survival in head and neck cancer patients undergoing radiotherapy. Clin Nutr. 2023;42(8):1445–53. https://doi.org/10.1016/j.clnu.2023.06.020
13. Cioffi I, Marra M, Imperatore N, Pagano MC, Santarpia L, Alfonsi L, Testa A, Sammarco R, Contaldo F, Castiglione F, et al. Assessment of bioelectrical phase angle as a predictor of nutritional status in patients with Crohn's disease: a cross sectional study. Clin Nutr. 2020;39(5):1564–71. https://doi.org/10.1016/j.clnu.2019.06.023
14. Stobaus N, Pirlich M, Valentini L, Schulzke JD, Norman K. Determinants of bioelectrical phase angle in disease. Br J Nutr. 2012;107(8):1217–20. https://doi.org/10.1017/S0007114511004028
15. Wiech P, Bazalinski D, Salacinska I, Binkowska-Bury M, Korczowski B, Mazur A, Kozka M, Dabrowski M. Decreased bioelectrical impedance phase angle in hospitalized children and adolescents with newly diagnosed type 1 diabetes: a case-control study. J Clin Med. 2018;7(12). https://doi.org/10.3390/jcm7120516
16. Wiech P, Dabrowski M, Bazalinski D, Salacinska I, Korczowski B, Binkowska-Bury M. Bioelectrical impedance phase angle as an indicator of malnutrition in hospitalized children with diagnosed inflammatory bowel Diseases-A case control study. Nutrients. 2018;10(4). https://doi.org/10.3390/nu10040499
17. Di Vincenzo O, Marra M, Di Gregorio A, Pasanisi F, Scalfi L. Bioelectrical impedance analysis (BIA) -derived phase angle in sarcopenia: a systematic review. Clin Nutr. 2021;40(5):3052–61. https://doi.org/10.1016/j.clnu.2020.10.048
18. Akamatsu Y, Kusakabe T, Arai H, Yamamoto Y, Nakao K, Ikeue K, Ishihara Y, Tagami T, Yasoda A, Ishii K, et al. Phase angle from bioelectrical impedance analysis is a useful indicator of muscle quality. J Cachexia Sarcopenia Muscle. 2022;13(1):180–9. https://doi.org/10.1002/jcsm.12860
19. Kosoku A, Uchida J, Nishide S, Kabei K, Shimada H, Iwai T, Maeda K, Hanayama Y, Ishihara T, Naganuma T, et al. Association of sarcopenia with phase angle and body mass index in kidney transplant recipients. Sci Rep. 2020;10(1):266. https://doi.org/10.1038/s41598-019-57195-z
20. Martins PC, de Lima LRA, Berria J, Petroski EL, da Silva AM, Silva DAS. Association between phase angle and isolated and grouped physical fitness indicators in adolescents. Physiol Behav. 2020;217:112825. https://doi.org/10.1016/j.physbeh.2020.112825
21. Obayashi H, Ikuta Y, Fujishita H, Fukuhara K, Sakamitsu T, Ushio K, Kimura H, Adachi N. The relevance of whole or segmental body bioelectrical

impedance phase angle and physical performance in adolescent athletes. Physiol Meas. 2021;42(3). https://doi.org/10.1088/1361-6579/abed35
22. World Health Organization. Growth reference data for 5–19 years. Indicators. In. https://www.who.int/tools/growth-reference-data-for-5to19-years. Accessed 31 October, 2023; 2007.
23. Brantlov S, Jodal L, Lange A, Rittig S, Ward LC. Standardisation of bioelectrical impedance analysis for the Estimation of body composition in healthy paediatric populations: a systematic review. J Med Eng Technol. 2017;41(6):460–79 https://doi.org/10.1080/03091902.2017.1333165
24. Player EL, Morris P, Thomas T, Chan WY, Vyas R, Dutton J, Tang J, Alexandre L, Forbes A. Bioelectrical impedance analysis (BIA)-derived phase angle (PA) is a practical aid to nutritional assessment in hospital in-patients. Clin Nutr. 2019;38(4):1700–6. https://doi.org/10.1016/j.clnu.2018.08.003
25. Becker PJ, Nieman Carney L, Corkins MR, Monczka J, Smith E, Smith SE, Spear BA, White JV. Consensus statement of the academy of nutrition and dietetics/American society for parenteral and enteral nutrition: indicators recommended for the identification and Documentation of pediatric malnutrition (undernutrition). J Acad Nutr Diet. 2014;114(12):1988–2000. https://doi.org/10.1016/j.jand.2014.08.026
26. Ooi PH, Thompson-Hodgetts S, Pritchard-Wiart L, Gilmour SM, Mager DR. Pediatric sarcopenia: a paradigm in the overall definition of malnutrition in children?? JPEN J Parenter Enter Nutr. 2020;44(3):407–18. https://doi.org/10.1002/jpen.1681
27. Ge S, Du Q, Feng X, Liu Y, Wang H, Hai S, Shi X, Sun W, Ma A, Lv T, et al. Optimal cutoffs for the diagnosis of sarcopenia in older Chinese adults. Front Nutr. 2022;9853323. https://doi.org/10.3389/fnut.2022.853323
28. Gonzalez MC. Using bioelectrical impedance analysis for body composition assessment: sorting out some misunderstandings. JPEN J Parenter Enter Nutr. 2019;43(8):954–5. https://doi.org/10.1002/jpen.1702
29. Liu J, Yan Y, Xi B, Huang G, Mi J, China C, Adolescent Cardiovascular Health Study G. Skeletal muscle reference for Chinese children and adolescents. J Cachexia Sarcopenia Muscle. 2019;10(1):155–64. https://doi.org/10.1002/jcsm.12361
30. Huang Y, Wang X, Cheng H, Dong H, Shan X, Zhao X, Wang X, Xie X, Mi J. Differences in air displacement plethysmography, bioelectrical impedance analysis and dual-energy X-ray absorptiometry for estimating body composition in Chinese children and adolescents. J Paediatr Child Health. 2023;59(3):470–9. https://doi.org/10.1111/jpc.16327
31. Mukaka MM. Statistics corner: a guide to appropriate use of correlation coefficient in medical research. Malawi Med Journal: J Med Association Malawi. 2012;24(3):69–71.
32. White N, Parsons R, Collins G, Barnett A. Evidence of questionable research practices in clinical prediction models. BMC Med. 2023;21(1):339. https://doi.org/10.1186/s12916-023-03048-6
33. Hajian-Tilaki K. The choice of methods in determining the optimal cut-off value for quantitative diagnostic test evaluation. Stat Methods Med Res. 2018;27(8):2374–83. https://doi.org/10.1177/0962280216680383
34. Baptista F, Zymbal V, Janz KF. Predictive validity of handgrip strength, vertical jump power, and plank time in the identification of pediatric sarcopenia. Meas Phys Educ Exerc Sci. 2021;26(4):361–70. https://doi.org/10.1080/1091367x.2021.1987242
35. Orsso CE, Tibaes JRB, Oliveira CLP, Rubin DA, Field CJ, Heymsfield SB, Prado CM, Haqq AM. Low muscle mass and strength in pediatrics patients: why should we care? Clin Nutr. 2019;38(5):2002–15. https://doi.org/10.1016/j.clnu.2019.04.012
36. Marques M, Vieira F, Teles J, Baptista F. Growth and physical development of children at apparent risk of sarcopenia. Pediatr Res. 2024. https://doi.org/10.1038/s41390-024-03385-z
37. Mangus RS, Bush WJ, Miller C, Kubal CA. Severe sarcopenia and increased fat stores in pediatric patients with liver, kidney, or intestine failure. J Pediatr Gastroenterol Nutr. 2017;65(5):579–83. https://doi.org/10.1097/MPG.0000000000001651
38. Schmidt SC, Bosy-Westphal A, Niessner C, Woll A. Representative body composition percentiles from bioelectrical impedance analyses among children and adolescents. The MoMo study. Clin Nutr. 2019;38(6):2712–20. https://doi.org/10.1016/j.clnu.2018.11.026
39. Zheng K, Lu J, Liu X, Ji W, Liu P, Cui J, Li W. The clinical application value of the extracellular-water-to-total-body-water ratio obtained by bioelectrical impedance analysis in people with advanced cancer. Nutrition. 2022;96:111567. https://doi.org/10.1016/j.nut.2021.111567
40. Yajima T, Yajima K. Association of extracellular water/total body water ratio with protein-energy wasting and mortality in patients on hemodialysis. Sci Rep. 2023;13(1):14257. https://doi.org/10.1038/s41598-023-41131-3
41. Yoon SL, Grundmann O, Williams JJ, Gordan L, George TJ Jr. Body composition changes differ by gender in stomach, colorectal, and biliary cancer patients with cachexia: results from a pilot study. Cancer Med. 2018;7(8):3695–703. https://doi.org/10.1002/cam4.1665
42. Dowhan L, Moccia L, Remer EM, Lyu R, Kou L, Steiger E. Comparison of preintestinal transplant and posttransplant sarcopenia and visceral adiposity measurements using computed tomography in the diagnosis of malnutrition during a nutrition-focused physical examination. JPEN J Parenter Enter Nutr. 2022;46(5):1088–95. https://doi.org/10.1002/jpen.2383
43. Wang R, Ding X, Tian Z, Jing X. Body composition changes and related factors in patients with ulcerative colitis: a retrospective single-center study in China. Med Sci Monit. 2022;28:e933942. https://doi.org/10.12659/MSM.933942
44. Zhang Y, Zhang L, Gao X, Dai C, Huang Y, Wu Y, Zhou W, Cao Q, Jing X, Jiang H, et al. Impact of malnutrition and sarcopenia on quality of life in patients with inflammatory bowel disease: a multicentre study. J Cachexia Sarcopenia Muscle. 2023;14(6):2663–75. https://doi.org/10.1002/jcsm.13341
45. Goel R, Malhotra B, Rastogi A, Singh T, Bhansali A, Bhadada S. Body fat patterning in lean Asian Indians with diabetes: case-control study. Diabetes Metab Syndr. 2023;17(3):102728. https://doi.org/10.1016/j.dsx.2023.102728
46. Amevor AA, Yodoshi T, Trout AT, Dillman JR, Singh R, Jarvis R, Fei L, Liu C, Taylor A, Miethke A, et al. Sarcopenia is highly prevalent in children with autoimmune liver diseases and is linked to visceral fat and parent-perceived general health. Liver Int. 2022;42(2):394–401. https://doi.org/10.1111/liv.15108
47. Chen C, Zhao L, Ning Z, Li Q, Han B, Cheng J, Chen Y, Nie X, Xia F, Wang N, et al. Famine exposure in early life is associated with visceral adipose dysfunction in adult females. Eur J Nutr. 2019;58(4):1625–33. https://doi.org/10.1007/s00394-018-1707-0
48. Xiong KY, He H, Zhang YM, Ni GX. Analyses of body composition charts among younger and older Chinese children and adolescents aged 5 to 18 years. BMC Public Health. 2012;12:835. https://doi.org/10.1186/1471-2458-12-835
49. Kutac P, Bunc V, Sigmund M. Determination of body fat ratio standards in children at early school age using bioelectric impedance. Med (Kaunas). 2020;56(12). https://doi.org/10.3390/medicina56120641
50. Langer RD, da Costa KG, Bortolotti H, Fernandes GA, de Jesus RS, Goncalves EM. Phase angle is associated with cardiorespiratory fitness and body composition in children aged between 9 and 11 years. Physiol Behav. 2020;215112772. https://doi.org/10.1016/j.physbeh.2019.112772
51. Martins PC, Alves Junior CAS, Silva AM, Silva DAS. Phase angle and body composition: a scoping review. Clin Nutr ESPEN. 2023;56:237–50. https://doi.org/10.1016/j.clnesp.2023.05.015
52. Siddiqui NI, Khan SA, Shoeb M, Bose S. Anthropometric predictors of bioimpedance analysis (BIA) phase angle in healthy adults. J Clin Diagn Res. 2016;10(6):CC01. https://doi.org/10.7860/JCDR/2016/17229.7976
53. Zhu Y, Ye H, Feng Y, Pan LY, Fu HH, Liu YM, Fei J, Hong L. Assessment of nutritional status in paediatric outpatients using bioelectrical impedance analysis and anthropometric z-scores. J Paediatr Child Health. 2021;57(8):1274–80. https://doi.org/10.1111/jpc.15450
54. Cederholm T, Bosaeus I, Barazzoni R, Bauer J, Van Gossum A, Klek S, Muscaritoli M, Nyulasi I, Ockenga J, Schneider SM, et al. Diagnostic criteria for malnutrition - an ESPEN consensus statement. Clin Nutr. 2015;34(3):335–40. https://doi.org/10.1016/j.clnu.2015.03.001
55. Kawakami R, Tanisawa K, Ito T, Usui C, Miyachi M, Torii S, Midorikawa T, Ishii K, Muraoka I, Suzuki K, et al. Fat-free mass index as a surrogate marker of appendicular skeletal muscle mass index for low muscle mass screening in sarcopenia. J Am Med Dir Assoc. 2022;23(12):1955–61. https://doi.org/10.1016/j.jamda.2022.08.016
56. Granacher U, Goesele A, Roggo K, Wischer T, Fischer S, Zuerny C, Gollhofer A, Kriemler S. Effects and mechanisms of strength training in children. Int J Sports Med. 2011;32(5):357–64. https://doi.org/10.1055/s-0031-1271677

57. Liu L, Lu S, Ao LP, Liu JT, Cheng H, Huang WH, Yang L, Zhang GC, Mi J, Yang Y. Consistency between bioelectrical impedance analysis and dual-energy X-ray absorptiometry for body composition measurement in children aged 7–17 years. Zhonghua Liu Xing Bing Xue Za Zhi. 2021;42(3):475–81. https://doi.org/10.3760/cma.j.cn112338-20200812-01062

Publisher's note