

Relationships between musculoskeletal performance, body composition, and metabolic biomarkers in a pediatric population with obesity

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ABSTRACT

Background: Pediatric obesity is associated not only with metabolic alterations but also with impairments in musculoskeletal health, including reduced muscle function and impaired physical performance. However, the clinical relevance of muscle quality indices in this population remains insufficiently explored.

Objective: To investigate the association between relative hand grip strength (HGS) and body mass index standard deviation score (BMI-SDS) in relation to body composition, metabolic profile, and functional performance in children and adolescents with overweight and obesity.

Methods: This cross-sectional study included 71 children and adolescents aged 6–18 years evaluated between January and July 2025. We performed anthropometric, biochemical, dual-energy X-ray absorptiometry, and functional assessments. HGS was measured using a dynamometer, and relative muscle strength was expressed as the ratio between HGS and BMI-SDS (HGS/BMI-SDS). Participants were stratified according to the median HGS/BMI-SDS value. Correlations were analyzed using Spearman's correlation coefficient.

Results: Lower HGS/BMI-SDS was associated with higher fat-to-lean mass ratios (total body $p=0.03$; trunk $p=0.04$), higher waist-to-height ratio ($p=0.01$), and higher BMI-SDS ($p=0.02$). Metabolically, it was associated with higher non-HDL cholesterol ($p=0.006$) and a trend toward higher glycated hemoglobin (HbA1c) ($p=0.07$). HGS/BMI-SDS correlated positively with insulin sensitivity (Single-Point Insulin Sensitive Estimator (SPISE), $r=0.20$; $p=0.04$) and negatively with HbA1c ($r=-0.35$; $p=0.02$) and non-HDL cholesterol ($r=-0.40$; $p=0.09$). HGS was positively correlated with Pediatric Balance Scale scores ($r=0.44$; $p=0.0002$).

Conclusions: Relative HGS is associated with body composition, metabolic profile, and functional balance in pediatric obesity. The HGS/BMI-SDS ratio may represent a simple and clinically useful marker of musculoskeletal and metabolic health in children and adolescents with overweight and obesity.

KEYWORDS

Pediatric obesity, sarcopenia, muscle strength, body mass index, body composition, metabolic syndrome.

Introduction

Childhood obesity has emerged as one of the most pressing public health challenges worldwide. According to the World Health Organization (WHO), its prevalence has risen dramatically over recent decades. Europe remains among the most affected regions, where approximately one in four (25%) children live with overweight (including obesity) and one in ten (11%) with obesity, although there is recent evidence of stabilization in some countries^[1,2]. Italy ranks among the European countries with the highest prevalence of overweight and obesity in school-aged children, with a greater burden observed in southern regions, even though this gap is gradually narrowing^[2,3]. Although pediatric obesity has traditionally been studied primarily because of its cardiometabolic consequences^[4], increasing evidence indicates that excess adiposity also adverse-

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ly affects the musculoskeletal system, body composition, and physical function^[5,6].

The effects of obesity on musculoskeletal health extend beyond the increased mechanical load imposed by excess body weight. Adipose tissue is an active endocrine tissue that interacts with skeletal muscle and bone through adipokines, inflammatory cytokines, and hormonal pathways, contributing to chronic low-grade inflammation and altered musculoskeletal homeostasis^[7]. During childhood and adolescence, these

alterations may impair muscle development, with effects on muscle strength, mass, quality, and performance^[8,9]. Changes in muscle quantity and quality may contribute to the onset of sarcopenia, which in children with obesity may be associated with reduced motor competence, impaired mobility, decreased physical activity, and poorer functional performance than observed in normal-weight peers^[6,10].

The term sarcopenia was coined by Irwin Rosenberg in 1989 to refer to the decline in skeletal muscle mass that occurs with aging^[11]. Since its introduction, the concept of sarcopenia has undergone substantial refinement. A major milestone was the establishment of the European Working Group on Sarcopenia in Older People (EWGSOP), which broadened the definition by incorporating measures of muscle function in addition to muscle mass. According to the original EWGSOP consensus, the diagnosis of sarcopenia required the coexistence of reduced muscle mass and impaired muscle function, manifested as decreased strength and/or physical performance^[12]. The concept of secondary sarcopenia was introduced to describe muscle wasting associated with a range of conditions, including organ failure, cancer, eating disorders, and chronic diseases, which may also affect younger individuals.

A further nosological entity, more recently emerging in the literature, is sarcopenic obesity (SO), defined as the coexistence of excessive adiposity and reduced muscle mass and/or muscle function^[13]. This combination has been associated with a substantially greater risk of adverse health outcomes than either condition alone. In younger populations, low muscle mass and function have been linked to insulin resistance and an elevated risk of metabolic disorders^[14]. Nevertheless, no universally accepted definition of pediatric SO currently exists, and age- and sex-specific diagnostic criteria remain poorly standardized.

Several techniques are currently available for the assessment of muscle mass, such as computed tomography (CT) and magnetic resonance imaging (MRI). However, their routine clinical use is often limited by high cost, restricted availability, radiation exposure in the case of CT, and potential contraindications to imaging procedures in selected patients^[12]. Dual-energy X-ray absorptiometry (DXA) has emerged as the reference method for estimating muscle mass in both research and clinical practice. Its widespread use reflects its combination of accuracy, ease of use, relatively low cost, broad availability, and minimal radiation exposure compared with CT and MRI^[12].

Assessing muscle function is also essential in diagnosing sarcopenia, as muscle strength does not necessarily correlate directly with muscle mass. Several functional tests commonly used in adults can also be employed to evaluate muscle performance in older children and adolescents. These include the handgrip strength (HGS) test, the chair stand test, the Timed Up and Go (TUG) test, the six-minute walk test, the Stair Climb Power Test, and the 400-meter walk test^[15].

Muscle strength has recently emerged as an important indicator of overall health in pediatric obesity. HGS is a simple, inexpensive, and highly reproducible measure of muscle function that has been associated with physical fitness, cardiometabolic risk, and health-related quality of life in both adults and children^[15,16]. Children with obesity frequently exhibit greater absolute muscle strength because of the increased muscle mass

required to support excess body weight; however, when muscle strength is normalized for body size, this apparent advantage disappears, suggesting an association between obesity and impaired muscle quality rather than changes in muscle quantity alone^[6,17,18]. Accordingly, relative measures of HGS, including the grip strength-to-body mass index (BMI) ratio, have been proposed as practical indicators of muscle quality and have shown promising ability to identify children at increased risk of SO and adverse metabolic outcomes^[16].

Taken together, these findings highlight the need for a better understanding of the role of relative muscle strength as a potential marker of musculoskeletal and metabolic health in pediatric obesity. Therefore, the present study aimed to investigate associations between relative muscle strength, body composition, functional performance, and metabolic profile in children and adolescents with overweight and obesity.

Materials and methods

Study design and setting

This cross-sectional observational study was conducted between January and July 2025 at the Unit of Physical and Rehabilitation Medicine of the University of Campania “Luigi Vanvitelli,” Naples, Italy, in collaboration with the Pediatric Unit of the same university.

Children and adolescents aged to 6 to 18 years with a diagnosis of overweight or obesity were recruited during routine outpatient clinical evaluations. Body weight and height were measured using standardized procedures, and BMI was calculated as kg/m². The BMI standard deviation score (BMI-SDS) was calculated according to WHO reference standards. Waist circumference was measured at the end of a gentle expiration using a non-elastic flexible tape placed at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest, with the subject standing upright. Waist-to-height ratio was calculated as a surrogate marker of abdominal adiposity.

Clinical and functional assessment

Musculoskeletal and functional evaluations included assessment of joint range of motion using standardized goniometry and of muscle strength using HGS, which was measured using a calibrated hand dynamometer^[7,19]. Participants performed three maximal voluntary isometric contractions per hand, with adequate rests between trials. The mean value obtained from the dominant hand was used for analysis. Relative muscle strength was expressed as the ratio between HGS and BMI-SDS (HGS/BMI-SDS).

Functional performance was assessed using a standardized battery of tests, including the TUG test^[20], the 10-meter walk test^[21], and the Pediatric Balance Scale (PBS)^[22]. Fatigue was assessed using the Fatigue Severity Scale^[23].

Body composition

Body composition was assessed using DXA (FDX Visionary, BeamMed Ltd.). Total and regional fat mass, lean mass, and fat-to-lean ratios were obtained according to standardized manufacturer protocols. Regional analysis focused on trunk

and limb compartments to explore the relationship between fat distribution, muscle function, and metabolic profile.

Biochemical analysis

Fasting venous blood samples were collected in the morning after an overnight fast. Laboratory assessments included glycated hemoglobin (HbA1c), lipid profile, particularly non-high-density lipoprotein (non-HDL) cholesterol, and additional routine metabolic markers used in pediatric obesity assessment.

Statistical analysis

Normality of data distribution was assessed using the Shapiro–Wilk test. Continuous variables were expressed as mean ± standard deviation or median and interquartile range, as appropriate, while categorical variables were reported as frequencies and percentages.

Differences between male and female participants were analyzed using the Mann–Whitney U test. Participants were stratified according to the median value of the HGS/BMI-SDS ratio to compare body composition, functional performance, and metabolic parameters between groups.

Associations between variables were assessed using Spearman’s correlation coefficient. A two-tailed p value < 0.05 was considered statistically significant. Statistical analyses were performed using SAS OnDemand for Academics.

The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from parents or legal guardians, and assent from participants when appropriate. Ethical approval was granted by the Institutional Ethics Committee of the University of Campania “Luigi Vanvitelli” (approval No. 0015373/I, May 29, 2026).

Results

Participant characteristics

A total of 71 children and adolescents (36 females and 35 males) aged 6 to 18 years (11.54±2.62) were included in the study. All enrolled participants were able to complete the functional assessment protocol, including the PBS, the TUG test, and the 10-meter walk test. No significant differences between males and females were observed in age, anthropometric parameters, or main functional outcomes; therefore, subsequent analyses were performed on the whole cohort. Table I shows the characteristics of the study cohort.

Hand grip strength was used to calculate the HGS/BMI-SDS ratio, which showed a median value of 5.03. Based on this cut-off, participants were subsequently stratified into two groups (lower vs higher HGS/BMI-SDS) to allow comparison of various parameters according to relative muscle strength.

Participants in the lower HGS/BMI-SDS group presented higher waist-to-height ratio (p=0.02) and higher BMI-SDS (p=0.002), consistent with greater adiposity. From a metabolic perspective, this group also showed significantly higher glycated hemoglobin (HbA1c) levels (p=0.049) and a trend toward higher total cholesterol (p=0.06) and non-HDL cholesterol values (p=0.09), suggesting a less favorable cardiometabolic profile (Table II).

Moreover, the subjects with lower HGS/BMI-SDS also exhibited significantly worse body composition profiles compared with those with higher values. They showed higher fat-to-lean mass ratios both at total body level (p=0.04) and in regional compartments, including the trunk (p=0.03), upper limbs (p=0.04), and lower limbs (p=0.04). These findings indicate a more unfavorable body composition characterized by relatively greater adiposity and reduced lean mass (Table II).

Table I Anthropometric, metabolic, functional, and body composition parameters of the study sample.

PARAMETER	MEAN	SD
Age (years)	11.54	2.62
BMI (kg/m²)	34.08	8.23
BMI-SDS	3.36	0.78
Waist-to-height ratio	0.66	0.08
Total cholesterol (mg/dl)	149.10	27.72
HDL cholesterol (mg/dl)	40.98	6.27
Non-HDL cholesterol (mg/dl)	98.33	29.04
Triglycerides (mg/dl)	92.07	43.51
HbA1c (mmol/L)	37.01	2.56
Hand grip strength	17.25	7.87
PBS	55.07	2.54
Total body fat-to-lean mass	1.20	0.26
Trunk fat-to-lean mass	1.33	0.33
Upper limb fat-to-lean mass	1.14	0.51
Lower limb fat-to-lean mass	1.27	0.22

BMI: body mass index; BMI-SDS: body mass index standard deviation score; HDL: high-density lipoprotein; HbA1c: glycated hemoglobin; PBS: Pediatric Balance Scale score

Table II Differences between subjects with lower vs. higher HGS/BMI-SDS.

PARAMETER	LOWER HGS/ BMI-SDS	HIGHER HGS/ BMI-SDS	P-VALUE
BMI-SDS	3.66 ± 0.78	3.10 ± 0.61	0.002
Waist-to-height ratio	0.68 ± 0.07	0.65 ± 0.09	0.02
Total cholesterol (mg/dl)	155.03 ± 22.77	143.81 ± 30.84	0.06
HDL cholesterol (mg/dl)	41.00 ± 6.82	40.97 ± 5.85	0.96
Non-HDL cholesterol (mg/dl)	113.81 ± 22.00	103.41 ± 32.87	0.09
Triglycerides (mg/dl)	92.30 ± 47.83	91.86 ± 1.23	0.98
HbA1c (mmol/L)	38 ± 2.59	36 ± 2.27	0.049
Total body fat-to-lean mass	1.13 ± 0.28	1.12 ± 0.22	0.042
Trunk fat-to-lean mass	1.40 ± 0.37	1.26 ± 0.27	0.03
Upper limb fat-to-lean mass	1.23 ± 0.62	1.04 ± 0.35	0.046
Lower limb fat-to-lean mass	1.10 ± 0.20	0.98 ± 0.23	0.043

bHGS/BMI-SDS: ratio between handgrip strength and body mass index standard deviation score; BMI-SDS: body mass index standard deviation score; HDL: high-density lipoprotein; HbA1c: glycated hemoglobin; PBS: Pediatric Balance Scale score

Correlation analyses confirmed significant associations between relative muscle strength and both metabolic and functional parameters. The HGS/BMI-SDS ratio was found to be inversely correlated with waist-to-height ratio ($r=-0.30$, $p=0.01$), HbA1c ($r=-0.29$, $p=0.02$), total cholesterol ($r=-0.28$, $p=0.02$), and non-HDL cholesterol ($r=-0.26$, $p=0.02$), supporting a link between reduced relative muscle strength and worse metabolic profile (Figure 1).

The HGS/BMI-SDS ratio showed a significant positive correlation with the PBS ($r=0.44$, $p=0.0001$), indicating better postural control in children with higher muscle strength. In addition, PBS scores were inversely correlated with fat-to-lean mass ratios, including total body fat-to-lean mass ($r=-0.40$, $p=0.003$), trunk fat-to-lean mass ($r=-0.35$, $p=0.009$), upper limb fat-to-lean mass ($r=-0.41$, $p=0.002$), and lower limb fat-to-lean mass ($r=-0.35$, $p=0.009$) (Table III).

Functional mobility tests (TUG and 10-meter walk test) showed a tendency toward worse performance in the lower HGS/BMI-SDS group, although these differences did not reach statistical significance.

Discussion

The present study provides a multidimensional assessment of children and adolescents with overweight and obesity, integrating body composition, muscle strength, functional performance, and metabolic parameters. The main finding is that

Table III Spearman correlation of the Pediatric Balance Scale with hand grip strength and body composition.

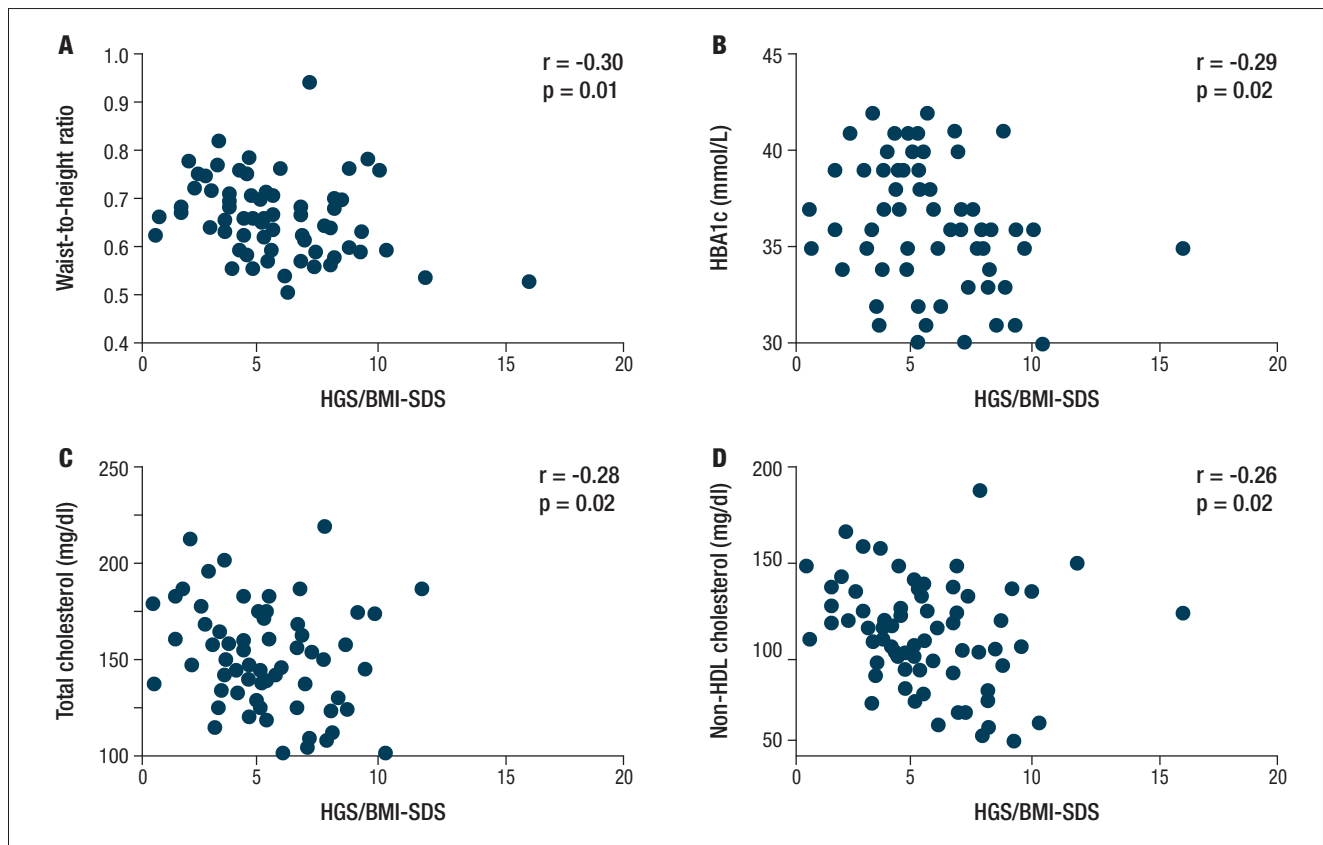
PARAMETER	SPEARMAN COEFFICIENT	P-VALUE
Hand grip strength/BMI-SDS	0.44	0.0001
Total body fat-to-lean mass	-0.40	0.003
Trunk fat-to-lean mass	-0.35	0.009
Upper limb fat-to-lean mass	-0.41	0.002
Lower limb fat-to-lean mass	-0.35	0.009

BMI-SDS: body mass index standard deviation score Balance Scale score

relative muscle strength, expressed as the HGS to BMI-SDS ratio (HGS/BMI-SDS), is significantly associated with body composition, metabolic profile, and postural balance. Lower HGS/BMI-SDS identifies a subgroup of patients with higher adiposity, reduced lean mass, a worse metabolic profile, and impaired functional performance.

These findings are consistent with previous studies reporting that reduced relative muscle strength is associated with greater adiposity and a less favorable cardiometabolic profile in pediatric populations [6,7,10,16,17]. HGS is widely adopted as a simple and reliable surrogate marker of overall muscle function. In pediatric populations, higher HGS has consistently been associated with better physical performance and a more favorable cardiometabolic profile, including lower adiposity and improved insulin sensitivity [6,7,10,16,17]. However, most of these

Figure 1 Correlation between HGS/BMI-SDS (the ratio between handgrip strength and body mass index standard deviation score) and cardiometabolic risk factors.



studies relied on absolute strength values, which are strongly influenced by body size and growth. Our results extend previous evidence in this setting by showing that normalization of HGS for BMI-SDS provides clinical information beyond the assessment of muscle quantity, better capturing the complementary dimension of muscle quality. The observed association between lower HGS/BMI-SDS and increased fat-to-lean mass ratios supports the concept of altered body composition in pediatric obesity, characterized not only by excess fat accumulation but also by relative impairment of lean mass function [7,10]. This is in line with emerging evidence suggesting that obesity during growth is associated with qualitative alterations in skeletal muscle, including reduced muscle efficiency and increased intramuscular fat infiltration [6,10,18,24]. These changes may contribute to reduced functional capacity even in the absence of established sarcopenia.

Of relevance is the relationship between relative muscle strength and metabolic profile. In our cohort, lower HGS/BMI-SDS was associated with higher non-HDL cholesterol, higher HbA1c, and lower insulin sensitivity as estimated by the SPISE index. These findings suggest that muscle quality may reflect systemic metabolic health and serve as an early marker of cardiometabolic risk in children with obesity. The observed associations agree with recent pediatric studies highlighting the role of muscular fitness as a determinant of metabolic risk clustering, although few studies have specifically investigated normalized strength indices [6,7,17].

Another important finding of this study is the significant association between muscle strength and functional balance. Higher HGS was positively correlated with PBS scores, while worse balance performance was associated with higher fat mass in both central and peripheral body compartments. These results support the hypothesis that excess adiposity negatively affects postural control and functional mobility, likely through alterations in biomechanics, proprioception, and neuromuscular control [25,26]. Importantly, these functional impairments may contribute to reduced physical activity levels, thereby perpetuating a cycle of worsening obesity and declining musculoskeletal health.

From a clinical perspective, the HGS/BMI-SDS ratio may represent a simple and practical tool to identify children with overweight and obesity who are at higher risk of musculoskeletal and metabolic impairment. Unlike imaging-based assessments, this index is inexpensive, non-invasive, and easily applicable in routine clinical settings. Its potential role is particularly relevant in pediatric populations, where early identification of functional decline is crucial to guide timely interventions, including structured physical activity programs and multidisciplinary rehabilitation approaches.

The present study has several limitations that should be acknowledged. First, its cross-sectional design does not allow causal inferences regarding the relationships between muscle strength, body composition, and metabolic outcomes. Longitudinal studies are needed to clarify whether reduced relative muscle strength precedes or arises as a result of worsening adiposity and metabolic impairment. Second, the sample size, although adequate for exploratory analyses, limits the generalizability of the findings. Third, pubertal stage was not system-

atically included in the analysis, despite its potential influence on muscle strength and body composition during growth. In addition, although DXA provides reliable estimates of body composition, it does not allow direct assessment of muscle quality or intramuscular fat infiltration, factors that could further refine the interpretation of our findings. A final limitation of this study is that physical activity levels were not assessed. Since physical activity influences muscle strength and metabolic health, residual confounding cannot be excluded. Future studies should incorporate standardized measures of physical activity.

The strengths of the study include the comprehensive and simultaneous assessment of multiple domains, including body composition, muscle strength, functional performance, and metabolic markers, as well as the use of both clinical and instrumental measures. This integrated approach provides a more complete characterization of pediatric obesity as a multisystem condition affecting both metabolic and musculoskeletal health.

Conclusions

In children and adolescents with overweight and obesity, relative hand grip strength (expressed as HGS/BMI-SDS) is significantly associated with body composition, metabolic profile, and functional balance. Lower values identify a subgroup of patients with higher adiposity, reduced lean mass, worse cardiometabolic profile, and impaired postural control.

These findings support the concept that muscle quality, rather than absolute muscle strength, may represent a key marker of musculoskeletal and metabolic health in pediatric obesity. The HGS/BMI-SDS ratio is a simple, non-invasive and easily applicable tool that may help clinicians identify children at higher risk of functional and metabolic impairment.

Further longitudinal studies are needed to confirm its predictive value and explore its potential role in guiding early preventive and rehabilitation interventions.

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