Preprints.org

Article

Not peer-reviewed version

Obesity, Fat-Free Mass Index, and Muscular Strength in Children: Independent Effects of Adiposity on Functional Performance in a Tertiary Pediatric Endocrinology Center

Bogdan Mihai Pascu * , Ana Maria Cula , Anca Bălănescu , Paul Cristian Bălănescu , Ioan Gherghina

Posted Date: 11 March 2026

doi: 10.20944/preprints202603.0882.v1

Keywords: childhood obesity; body composition; muscle strength; puberty; pediatric endocrinology

 doi:10.20944/preprints202603.0882.v1

Article

Obesity, Fat-Free Mass Index, and Muscular Strength in Children: Independent Effects of Adiposity on Functional Performance in a Tertiary Pediatric Endocrinology Center

Bogdan Mihai Pascu [1,2,3,*] Ana Maria Cula [1], Anca Bălănescu [1,3], Paul Cristian Bălănescu [1] and Ioan Gherghina [1,2]

[1] Pediatric Department, Faculty of Medicine, University of Medicine and Pharmacy "Carol Davila", 030167 Bucharest, Romania

[2] National Institute for Mother and Child Health "Alessandrescu-Rusescu", 020395 Bucharest, Romania

[3] Yuno Clinic, EASO COM Obesity Center, 020459 Bucharest, Romania

* Correspondence: bogdan-mihai.pascu@drd.umfcd.ro

Abstract

Background: Childhood obesity is associated with important alterations in body composition that may impair muscular strength and functional capacity. While higher body mass is often accompanied by greater absolute strength, the independent impact of adiposity on muscular strength after accounting for lean tissue remains insufficiently understood. The aim of this study was to examine the associations between adiposity, body composition, and muscular strength in children and adolescents, with particular focus on the independent effects of fat mass after adjustment for growth- and maturation-related factors. Methods: This cross-sectional study included 84 children and adolescents aged 5–18 years. Anthropometric measurements were used to calculate body mass index, waist-to-hip ratio, and waist-to-height ratio, with weight status classified according to World Health Organization BMI-for-age criteria. Body composition was assessed using bioelectrical impedance analysis (Tanita), providing estimates of body fat percentage and Tanita-derived muscle mass. Pubertal stage was assessed using Tanner classification. Muscular strength was evaluated using dominant handgrip strength, and habitual physical activity was recorded as hours per week. Associations between adiposity-related indices and muscular strength were explored using correlation and multiple linear regression analyses, with adjustment for age and Tanita-derived muscle mass. Results: Body mass index showed a positive association with handgrip strength, reflecting the contribution of overall body mass. Central adiposity indices demonstrated weak to modest associations with muscular strength. Body fat percentage showed only a limited association with handgrip strength in unadjusted analyses. However, in multivariable regression models adjusting for age and Tanita-derived muscle mass, higher body fat percentage emerged as an independent negative predictor of handgrip strength. Age did not show an independent association with muscular strength in adjusted models. Conclusions: Excess adiposity is independently and negatively associated with muscular strength in children and adolescents, even after accounting for age and Tanita-derived estimates of muscle mass. These findings suggest that increased fat mass may impair neuromuscular performance beyond its effects on body size or lean tissue. Pediatric obesity interventions should therefore focus not only on weight reduction but also on improving body composition and preserving functional strength.

Keywords: childhood obesity; body composition; muscle strength; puberty; pediatric endocrinology

---

1. Introduction

 doi:10.20944/preprints202603.0882.v1

Childhood obesity represents a major global health challenge, with increasing prevalence and well-established long-term consequences for metabolic and cardiovascular health [1–3]. While excess body weight has traditionally been assessed using body mass index (BMI), growing evidence indicates that obesity-related health risks are more closely linked to alterations in body composition and physical function than to body weight alone.

Skeletal muscle plays a fundamental role in metabolic regulation, insulin sensitivity, and physical performance. During childhood and adolescence, muscle mass and strength increase progressively under the influence of growth, hormonal maturation, and physical activity, with puberty representing a critical period for muscle development [4,5]. Disruptions in normal muscle development during this stage may have lasting effects on health outcomes later in life.

Lean tissue quantity is a key determinant of muscle strength; however, absolute fat-free mass is strongly influenced by body size and height. Fat-free mass index (FFMI), defined as fat-free mass normalized to height squared (kg/m²), provides a size-adjusted marker of lean mass and may better reflect muscular development during growth. The role of FFMI in relation to muscle strength in children with obesity remains insufficiently explored.

Although children with obesity often present with increased absolute lean mass due to greater mechanical loading, current evidence regarding muscle strength in this population is conflicting [6,7]. Some studies report preserved or even increased absolute muscle strength, whereas others demonstrate reduced relative strength and impaired muscle quality when adjusted for body size or lean mass [8,9]. Proposed mechanisms include fatty infiltration of skeletal muscle, chronic low-grade inflammation, and reduced levels of physical activity [10]. Consequently, the relationship between adiposity and muscle function in children remains controversial, particularly when pubertal development is taken into account.

Handgrip strength is a simple, reliable, and non-invasive marker of overall muscle strength and has been associated with cardiometabolic risk in pediatric populations [11,12]. However, data examining the association between detailed adiposity-related parameters, body composition, and muscle strength across different pubertal stages are limited.

The primary aim of this study was to evaluate the relationship between adiposity-related parameters and muscle strength in children and adolescents, using comprehensive anthropometric and body composition assessments while accounting for pubertal stage.

The secondary aim was to examine differences in muscle strength and body composition between normal-weight children and those with overweight or obesity.

2. Materials and Methods

2.1. Study Design and Participants

This cross-sectional observational study included 84 consecutive children and adolescents aged between 5 and 18 years who were evaluated during routine clinical assessments. Participants were recruited from the Department of Pediatric Endocrinology at the *"Alessandrescu-Rusescu" National Institute for Mother and Child Health (INSMC), Bucharest*. Recruitment was conducted over a defined period, from **15 July to 10 September 2025**.

Eligibility criteria included age ≥5 years, which was selected to ensure reliable assessment of body composition using bioelectrical impedance analysis (Tanita), as younger children are unable to comply adequately with standardized measurement protocols. Additional inclusion criteria were the availability of complete anthropometric, body composition, pubertal staging, and muscle strength data.

Exclusion criteria comprised the presence of chronic diseases, acute infections, or medical conditions known to affect growth, body composition, or muscle function, including endocrine disorders other than obesity, genetic syndromes, neuromuscular diseases, and the use of medications that could influence body composition or muscle strength.

 doi:10.20944/preprints202603.0882.v1

2.2. Anthropometric Measurements

Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, and body weight was measured to the nearest 0.1 kg using a calibrated digital scale, with participants wearing light clothing and no shoes. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). BMI values were converted to age- and sex-specific percentiles using the **Centers for Disease Control and Prevention (CDC) growth reference charts**. Participants were classified as underweight (<5th percentile), normal weight (5th–84th percentile), overweight (85th–94th percentile), or obese (≥95th percentile) according to CDC criteria [13]. Waist and hip circumferences were measured using a non-elastic measuring tape, following standardized procedures, and waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR) were calculated accordingly. Central adiposity was interpreted using WHtR, with a cut-off value of **≥0.50** considered indicative of increased cardiometabolic risk in pediatric populations, independent of age and sex [14,15].

2.3. Pubertal Assessment

Pubertal development was assessed by a trained clinician using Tanner staging, from stage I (prepubertal) to stage V (fully mature), based on standardized clinical criteria [16,17].

2.4. Body Composition Analysis

Body composition was assessed using bioelectrical impedance analysis (Tanita PRO DC430 MA device (Tanita Corporation, Tokyo, Japan)). The device provided manufacturer-derived estimates of body fat percentage, fat mass, fat-free mass, muscle mass, total body water percentage, and total body water volume. Measurements were performed according to the manufacturer's recommendations and international guidelines for bioelectrical impedance analysis, under standardized conditions.

All assessments were conducted in the morning, with participants in a fasting state, adequately hydrated, wearing light clothing, barefoot, and after bladder emptying, in order to minimize variability related to hydration status. Only children aged ≥5 years were included, as younger children may not reliably comply with standardized bioelectrical impedance measurement protocols.

Fat-free mass index (FFMI) was calculated as fat-free mass (kg) divided by height squared (m^2). Age- and sex-specific FFMI percentile categories were derived using published pediatric reference data, and participants were classified as <P10, P10–P49, P50–P89, or ≥P90 [6].

2.5. Muscle Strength Assessment

Muscle strength was assessed by measuring dominant handgrip strength using a calibrated handheld dynamometer (Jamar®, Patterson Medical, Warrenville, IL, USA). Handgrip strength was evaluated following standardized testing procedures. Participants were seated with the shoulder adducted and neutrally rotated, the elbow flexed at 90°, and the forearm in a neutral position.

Three maximal voluntary contractions were performed with the dominant hand, with brief rest intervals between trials. Participants were verbally encouraged to exert maximal effort during each attempt. The highest value obtained from the three measurements was recorded and expressed in kilograms (kg).

In addition to absolute handgrip strength, relative handgrip strength was calculated to account for differences in body size. Relative handgrip strength was defined as the ratio between absolute handgrip strength (kg) and body weight (kg), according to the following formula:

Relative handgrip strength = handgrip strength (kg) / body weight (kg).

This approach has been previously used to assess muscle strength relative to body mass in pediatric populations [19,20].

2.6. Physical Activity Assessment

 doi:10.20944/preprints202603.0882.v1

Physical activity level was assessed as the average number of hours per week of moderate-to-vigorous physical activity (MVPA). Information was obtained through self-report in older children and adolescents, or parental report for younger children, including those under 10 years of age.

Moderate-to-vigorous physical activity was defined as activities requiring at least moderate physical effort and resulting in increased heart rate and breathing, such as brisk walking, running, cycling, active play, or organized sports [18]. Weekly physical activity was recorded as total hours of MVPA performed outside of mandatory school physical education classes.

2.7. Statistical Analysis

Statistical analyses were performed using **Microsoft Excel 2016** (Microsoft Corporation, Redmond, WA, USA) with the **Analysis ToolPak add-in**. Continuous variables were expressed as mean ± standard deviation (SD). Data distribution was assessed visually and analytically, and group comparisons were conducted using **Student's t-test** for normally distributed variables or the **Mann–Whitney U test** for non-normally distributed variables, as appropriate.

Associations between adiposity-related parameters, body composition variables, and handgrip strength were evaluated using **Pearson's correlation coefficient** for normally distributed data or **Spearman's rank correlation coefficient** when normality assumptions were not met.

Multivariable linear regression analyses were performed to assess independent determinants of muscle strength. Absolute dominant handgrip strength (kg) and relative handgrip strength (handgrip strength/body weight) were used as dependent variables in separate models. Independent variables were selected a priori based on biological plausibility and previous literature and included **age**, **sex**, **pubertal stage (Tanner stage)**, **weekly physical activity**, and measures of adiposity and body composition.

Three regression models were constructed:

Model A: Absolute handgrip strength (kg) as the dependent variable, including body fat percentage and fat-free mass as key predictors.

Model B: Relative handgrip strength (handgrip strength/body weight) as the dependent variable, including body fat percentage and covariates.

Model C: Absolute handgrip strength (kg) as the dependent variable, including **fat-free mass index (FFMI)** instead of absolute fat-free mass, to account for body size and height.

All models were adjusted for age, sex, pubertal stage, and physical activity. A two-sided **p-value < 0.05** was considered statistically significant.

2.8. Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the National Institute for Mother and Child Health "Alessandrescu-Rusescu" (approval code no. 52/03.01.2023).

Written informed consent was obtained from parents or legal guardians, and assent was obtained from participants when appropriate.

2.9. Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. The dataset has not been deposited in a public repository due to ethical and privacy considerations involving pediatric participants.

2.10. Use of Generative Artificial Intelligence

Generative artificial intelligence was not used for study design, data collection, data analysis, or data interpretation. AI-based tools were used solely for language editing and formatting of the manuscript.

 doi:10.20944/preprints202603.0882.v1

3. Results

3.1. Characteristics of the Study Population

A total of 84 children and adolescents aged between 5 and 18 years were included in the study, comprising 27 females (32.1%) and 57 males (67.9%). Given the wide age range and the inclusion of both sexes and different stages of pubertal development, baseline characteristics were analyzed stratified by pubertal status, weight status, and sex.

Baseline characteristics according to pubertal status (prepubertal vs. pubertal) are presented in **Table 1A**, characteristics according to weight status are shown in **Table 1B**, and sex-specific characteristics are summarized in **Table 1C**.

Table 1A. Baseline characteristics according to pubertal status.

Variable	Prepubertal (Tanner I) (n = 27)	Pubertal (Tanner II–V) (n = 57)
Age (years)	7.78 ± 2.31	13.46 ± 2.32
Height (cm)	124.87 ± 16.11	159.91 ± 12.61
Weight (kg)	28.67 ± 14.67	59.66 ± 24.57
Body mass index (kg/m²)	**17.24 ± 4.30**	**22.64 ± 6.50**
Waist circumference (cm)	58.22 ± 14.22	75.03 ± 18.95
Hip circumference (cm)	66.69 ± 14.34	89.61 ± 15.89
Waist-to-hip ratio	0.87 ± 0.08	0.83 ± 0.11
Waist-to-height ratio	0.46 ± 0.07	0.47 ± 0.09
Physical activity (h/week)	**1.22 ± 1.77**	**2.84 ± 2.79**
Body fat (%)	20.00 ± 9.44	21.93 ± 11.73
Fat mass (kg)	6.76 ± 6.66	15.12 ± 15.51
Fat-free mass (kg)	21.93 ± 8.70	44.61 ± 13.04
Total body water (%)	58.53 ± 6.92	57.25 ± 8.70
Total body water (kg)	16.04 ± 6.38	32.71 ± 9.57
Muscle mass (%)	20.71 ± 8.30	42.33 ± 12.42
Fat-free mass index (FFMI, kg/m²)	**13.45 ± 1.72**	**17.05 ± 2.79**
Dominant handgrip strength (kg)	**6.98 ± 4.43**	**21.95 ± 9.64**
Relative handgrip strength (handgrip/body weight)	0.24 ± 0.11	0.38 ± 0.12

Data are presented as mean ± standard deviation.

Table 1B. Baseline characteristics according to weight status.

Variable	Underweight (5.	Normal weight (n = 42)	Overweight + Obesity (n = 37)
Age (years)	12.60 ± 3.05	10.79 ± 3.84	12.46 ± 3.01
Height (cm)	145.22 ± 20.10	139.91 ± 22.85	159.02 ± 14.81
Weight (kg)	30.50 ± 9.95	35.01 ± 15.05	68.97 ± 25.10
Body mass index (kg/m²)	**14.01 ± 1.51**	**16.85 ± 2.44**	**26.44 ± 5.45**
Waist circumference (cm)	53.20 ± 6.30	58.10 ± 9.93	84.93 ± 17.27
Hip circumference (cm)	66.40 ± 9.91	71.06 ± 13.26	97.07 ± 13.81
Waist-to-hip ratio	0.81 ± 0.07	0.83 ± 0.11	0.87 ± 0.09
Waist-to-height ratio	**0.37 ± 0.03**	**0.42 ± 0.04**	**0.53 ± 0.08**
Physical activity (h/week)	**2.60 ± 3.97**	**2.61 ± 3.76**	**1.96 ± 2.44**
Body fat (%)	5.24 ± 2.83	14.92 ± 4.60	30.74 ± 8.96
Fat mass (kg)	1.44 ± 0.61	5.14 ± 2.73	22.19 ± 16.01
Fat-free mass (kg)	29.06 ± 10.04	29.88 ± 13.20	46.88 ± 14.25
Total body water (%)	69.40 ± 2.07	62.41 ± 3.56	50.69 ± 6.55

Total body water (kg)	21.28 ± 7.35	21.94 ± 9.80	34.31 ± 10.43
Muscle mass (%)	27.50 ± 9.53	28.28 ± 12.58	44.50 ± 13.58
Fat-free mass index (FFMI, kg/m²)	**13.29 ± 1.63**	**14.33 ± 2.18**	**18.01 ± 2.62**
Dominant handgrip strength (kg)	**12.78 ± 6.49**	**13.36 ± 10.02**	**22.01 ± 10.50**
Relative handgrip strength (handgrip/body weight)	0.40 ± 0.16	0.34 ± 0.15	0.32 ± 0.12

Data are presented as mean ± standard deviation.

Table 1C. Baseline characteristics according to sex.

Variable	Girls (n = 27)	Boys (n = 57)
Age (years)	11.37 ± 3.47	11.75 ± 3.57
Height (cm)	145.95 ± 17.47	149.92 ± 23.12
Weight (kg)	46.31 ± 19.15	51.31 ± 28.98
Body mass index (kg/m²)	**20.80 ± 5.73**	**20.95 ± 6.72**
Waist circumference (cm)	66.24 ± 13.97	71.23 ± 21.13
Hip circumference (cm)	82.09 ± 16.10	82.31 ± 19.98
Waist-to-hip ratio	0.81 ± 0.09	0.86 ± 0.10
Waist-to-height ratio	0.45 ± 0.08	0.47 ± 0.09
Physical activity (h/week)	**1.94 ± 3.71**	**2.50 ± 2.99**
Body fat (%)	25.47 ± 10.62	19.34 ± 10.75
Fat mass (kg)	13.35 ± 9.69	11.99 ± 15.48
Fat-free mass (kg)	32.99 ± 10.76	39.37 ± 17.50
Total body water (%)	54.53 ± 7.75	59.15 ± 7.98
Total body water (kg)	24.14 ± 7.89	28.87 ± 12.85
Muscle mass (%)	31.30 ± 10.24	37.31 ± 16.70
Fat-free mass index (FFMI, kg/m²)	**14.96 ± 2.18**	**16.33 ± 3.27**
Dominant handgrip strength (kg)	**13.59 ± 7.53**	**18.82 ± 11.84**
Relative handgrip strength (handgrip/body weight)	0.29 ± 0.12	0.36 ± 0.13

Data are presented as mean ± standard deviation.

3.2. Weight Status and Body Composition

Based on CDC BMI-for-age percentile classification, 5 participants (6.0%) were classified as underweight, 42 (50.0%) as normal weight, and 37 (44.0%) as overweight or obese. Given the small number of underweight participants, comparative analyses focused on the normal-weight and overweight/obesity groups.

Children with overweight/obesity presented higher adiposity-related parameters compared with normal-weight participants, including body fat percentage (30.74 ± 8.96% vs. 14.92 ± 4.60%, $p < 0.001$) and fat mass (22.19 ± 16.01 vs. 5.14 ± 2.73 kg, $p < 0.001$). Central adiposity indices were also higher in the overweight/obesity group, including waist circumference (84.93 ± 17.27 vs. 58.10 ± 9.93 cm, $p < 0.001$) and waist-to-height ratio (0.53 ± 0.08 vs. 0.42 ± 0.04, $p < 0.001$). Fat-free mass (46.88 ± 14.25 vs. 29.88 ± 13.20 kg, $p < 0.001$) and FFMI (18.01 ± 2.62 vs. 14.33 ± 2.18 kg/m², $p < 0.001$) were higher in the overweight/obesity group. Differences in body composition and adiposity-related parameters according to weight status are summarized in **Table 2**.

Table 2. Body composition and adiposity parameters according to weight status.

Variable	Normal weight (n = 42)	Overweight + Obesity (n = 37)	p-value
Body mass index (kg/m²)	16.85 ± 2.44	26.44 ± 5.45	<0.001

doi:10.20944/preprints202603.0882.v1

Waist circumference (cm)	58.10 ± 9.93	84.93 ± 17.27	<0.001
Hip circumference (cm)	71.06 ± 13.26	97.07 ± 13.81	<0.001
Waist-to-hip ratio	0.83 ± 0.11	0.87 ± 0.09	0.008
Waist-to-height ratio	0.42 ± 0.04	0.53 ± 0.08	<0.001
Body fat (%)	14.92 ± 4.60	30.74 ± 8.96	<0.001
Fat mass (kg)	5.14 ± 2.73	22.19 ± 16.01	<0.001
Fat-free mass (kg)	29.88 ± 13.20	46.88 ± 14.25	<0.001
Fat-free mass index (FFMI, kg/m²)	14.33 ± 2.18	18.01 ± 2.62	<0.001
Absolute handgrip strength (kg)	13.36 ± 10.02	22.01 ± 10.50	<0.001
Relative handgrip strength (handgrip/body weight)	0.34 ± 0.15	0.32 ± 0.12	0.384
Body mass index (kg/m²)	16.85 ± 2.44	26.44 ± 5.45	<0.001
Waist circumference (cm)	58.10 ± 9.93	84.93 ± 17.27	<0.001
Hip circumference (cm)	71.06 ± 13.26	97.07 ± 13.81	<0.001
Waist-to-hip ratio	0.83 ± 0.11	0.87 ± 0.09	0.008
Waist-to-height ratio	0.42 ± 0.04	0.53 ± 0.08	<0.001
Body fat (%)	14.92 ± 4.60	30.74 ± 8.96	<0.001
Fat mass (kg)	5.14 ± 2.73	22.19 ± 16.01	<0.001

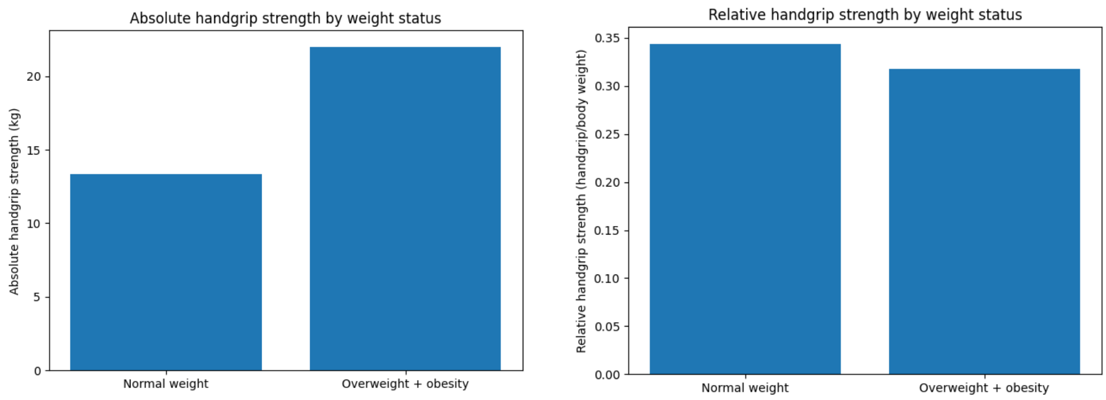
Data are presented as mean ± standard deviation. Comparisons were performed between normal-weight and overweight/obesity groups.

3.3. Handgrip Strength: Absolute versus Relative Measures

Absolute dominant handgrip strength differed between weight status groups. Children with overweight and obesity presented higher mean absolute handgrip strength compared with normal-weight participants (22.01 ± 10.50 kg vs. 13.36 ± 10.02 kg; $p < 0.001$).

When handgrip strength was expressed relative to body weight, relative handgrip strength values were lower in children with overweight and obesity compared with normal-weight participants (0.32 ± 0.12 vs. 0.34 ± 0.15), with no statistically significant difference between groups ($p = 0.384$).

These results remained consistent after adjustment for age and sex. Differences between absolute and relative handgrip strength measures according to weight status are presented in **Table 2** and illustrated in **Figure 1**.



(A) **(B)**

Figure 1. Comparison of absolute (A) and relative (B) dominant handgrip strength between normal-weight children and overweight/obesity children.

3.4. Correlation Analyses

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 11 March 2026 doi:10.20944/preprints202603.0882.v1

Correlation analyses revealed strong positive associations between dominant handgrip strength and growth- and maturation-related variables, including age ($r = 0.697$, $p < 0.001$), height ($r = 0.828$, $p < 0.001$), and pubertal stage ($r = 0.731$, $p < 0.001$). Fat-free mass showed the strongest positive correlation with handgrip strength ($r = 0.885$, $p < 0.001$).

Positive correlations were also observed between handgrip strength and BMI ($r = 0.561$, $p < 0.001$) as well as fat mass ($r = 0.347$, $p = 0.001$), reflecting the influence of overall body size on absolute muscle strength.

In contrast, body fat percentage was negatively correlated with relative handgrip strength (handgrip strength/body weight ratio) ($r = -0.381$, $p < 0.001$), indicating that higher adiposity was associated with reduced strength relative to body mass. This inverse association is illustrated in **Figure 2**.

In addition, fat-free mass index showed a strong positive association with absolute handgrip strength.This relationship is illustrated in Figure 3.

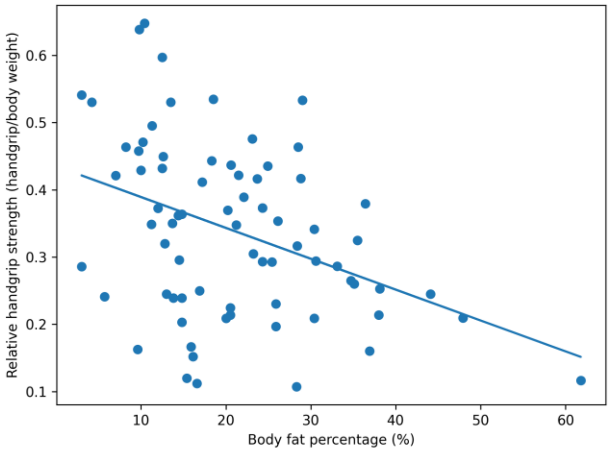


Figure 2. Association between body fat percentage and relative handgrip strength (handgrip strength/body weight ratio) in the study population. Higher adiposity was associated with lower relative muscle strength.

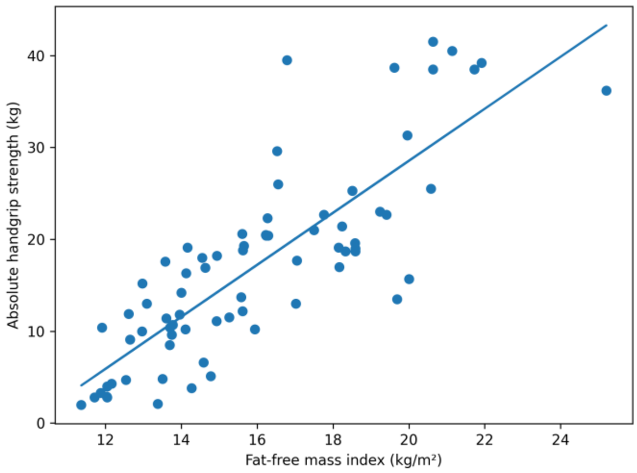


Figure 3. Association between fat-free mass index (FFMI) and absolute dominant handgrip strength in the study population. Higher FFMI was associated with greater muscle strength.

3.5. Multivariable Regression Analyses

Multivariable linear regression models were constructed to examine associations between adiposity-related parameters, body composition variables, and handgrip strength outcomes.

 doi:10.20944/preprints202603.0882.v1

In **Model A**, with absolute handgrip strength as the dependent variable and adjusted for age, sex, Tanner stage, physical activity, and fat-free mass, body fat percentage was negatively associated with handgrip strength (β = −0.203 kg per 1% increase in body fat, p = 0.0046). Fat-free mass was positively associated with handgrip strength (β = 0.707 kg per 1 kg increase, p < 0.001). The model explained 83.4% of the variance in absolute handgrip strength (R^2 = 0.834).

In **Model B**, using relative handgrip strength (handgrip strength/body weight) as the dependent variable and adjusted for age, sex, Tanner stage, and physical activity, body fat percentage was negatively associated with relative handgrip strength (β = −0.00412 per 1% increase in body fat, p = 0.00064).

In **Model C**, fat-free mass was replaced by fat-free mass index (FFMI). FFMI was positively associated with absolute handgrip strength (β = 2.21 kg per 1 kg/m² increase, p < 0.001), while Tanner stage was also associated with handgrip strength. Body fat percentage was not significantly associated with absolute handgrip strength in this model.

Results of the multivariable regression analyses are summarized in **Table 3**.

Table 3. Multivariable linear regression models for handgrip strength.

Model A: Absolute handgrip strength (kg) as the dependent variable

Predictor	β	95% CI	p-value
Body fat (%)	**−0.203**	**−0.341 to −0.064**	**0.0046**
Fat-free mass (kg)	**0.707**	**0.537 to 0.876**	**<0.001**
Age (years)	0.182	−0.041 to 0.405	0.11
Male sex	**2.41**	**0.92 to 3.90**	**0.002**
Tanner stage	**1.36**	**0.71 to 2.01**	**<0.001**
Physical activity (h/week)	0.21	−0.05 to 0.47	0.11

R^2 = 0.834.

Model B: Relative handgrip strength as the dependent variable (handgrip/body weight)

Predictor	β	95% CI	p-value
Body fat (%)	**−0.00412**	**−0.00643 to −0.00182**	**0.00064**
Male sex	**0.031**	**0.011 to 0.051**	**0.003**
Tanner stage	**0.018**	**0.006 to 0.030**	**0.004**
Physical activity (h/week)	0.003	−0.001 to 0.007	0.09

Model C: Absolute handgrip strength (kg) as the dependent variable with FFMI

Predictor	β	95% CI	p-value
Body fat (%)	−0.088	−0.253 to 0.077	0.291
FFMI (kg/m²)	**2.214**	**1.367 to 3.060**	**<0.001**
Age (years)	−0.343	−1.081 to 0.395	0.357
Male sex	2.874	−0.510 to 6.259	0.095
Tanner stage	**2.698**	**1.243 to 4.153**	**<0.001**
Physical activity (h/week)	0.396	−0.058 to 0.850	0.086

R^2 = 0.779, Adj. R^2 = 0.759.

3.6. Fat-Free Mass Index and Muscle Strength

Fat-free mass index (FFMI) differed according to weight status. Children with overweight and obesity presented higher mean FFMI values compared with normal-weight participants (18.01 ± 2.62 vs. 14.33 ± 2.18 kg/m², respectively) **Table 4**.

FFMI was positively associated with absolute dominant handgrip strength. This association is illustrated in **Figure 3**, which shows increasing absolute handgrip strength values across increasing FFMI levels in the study population.

Analysis of FFMI percentile categories showed differences in the distribution of FFMI according to weight status **Table 4**. A higher proportion of children with overweight and obesity were classified in the ≥P90 FFMI category, whereas most normal-weight participants were distributed within the P10–P49 percentile range.

In multivariable regression analyses in which fat-free mass was replaced by FFMI, FFMI was positively associated with absolute handgrip strength after adjustment for age, sex, pubertal stage, physical activity, and body fat percentage **Table 3**.

Table 4. Fat-free mass index values and percentile categories according to weight status.

Variable	Normal weight (n = 42)	Overweight + Obesity (n = 37)
FFMI (kg/m²)	**14.33 ± 2.18**	**18.01 ± 2.62**
FFMI < P10, n (%)	0 (0.0)	0 (0.0)
FFMI P10–P49, n (%)	39 (92.9)	2 (5.4)
FFMI P50–P89, n (%)	3 (7.1)	19 (51.4)
FFMI ≥ P90, n (%)	0 (0.0)	16 (43.2)

Data are presented as mean ± standard deviation.

4. Discussion

The present study examined the relationship between adiposity, body composition, and muscle strength in a pediatric population spanning a wide age range and different stages of pubertal development. The main finding was that increased adiposity was associated with reduced muscle strength when strength was expressed relative to body mass or evaluated after adjustment for lean tissue, despite higher absolute handgrip strength observed in children with overweight and obesity. These results highlight a dissociation between muscle quantity and muscle quality in pediatric obesity.

In agreement with previous reports, children with obesity exhibited higher absolute handgrip strength than their normal-weight peers, a finding largely attributable to greater body size and increased fat-free mass [8,9]. Increased mechanical loading associated with excess body weight may contribute to higher absolute muscle mass during growth. However, this apparent advantage did not translate into improved functional performance when strength was normalized to body weight or when adiposity-related parameters were included in multivariable models, indicating that greater muscle mass does not necessarily confer proportional functional benefit.

An important contribution of the present study is the inclusion of fat-free mass index (FFMI) as a height-adjusted marker of lean tissue. FFMI showed a strong positive association with absolute handgrip strength and remained a significant predictor in multivariable analyses, supporting its relevance as a robust indicator of lean mass during growth. Nevertheless, indicators of excess adiposity remained negatively associated with relative strength outcomes, suggesting that pediatric obesity is characterized not only by altered body composition but also by reduced muscle performance relative to body size.

The inverse association between body fat percentage and relative muscle strength observed in this study is consistent with previous literature describing impaired muscle function in children with obesity [9,13]. Several mechanisms may underlie this phenomenon. Fat infiltration into skeletal muscle may alter muscle architecture and reduce contractile efficiency, while obesity-related low-grade inflammation may impair muscle metabolism and regenerative capacity [10]. In addition, lower habitual physical activity levels, frequently reported in pediatric obesity, may further contribute to diminished functional performance.

Pubertal development emerged as a major determinant of muscle strength, as reflected by the strong associations between Tanner stage and handgrip strength. Importantly, the negative associations between adiposity and muscle strength persisted after adjustment for pubertal stage, indicating that these effects are not solely explained by differences in biological maturation. This finding is clinically relevant, as it suggests that excess adiposity may adversely affect muscle function independently of normal pubertal muscle development.

Handgrip strength is increasingly recognized as a practical and reliable marker of overall muscle function and has been associated with cardiometabolic risk in pediatric populations [11,12]. The present findings further support its use as a functional outcome measure in studies of pediatric obesity. Incorporating muscle strength assessment alongside traditional anthropometric indices and detailed body composition measures, including FFMI, may provide a more comprehensive evaluation of health status in children with excess adiposity.

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference regarding the relationship between adiposity and muscle strength. Second, the study included a relatively modest sample size recruited from a tertiary pediatric endocrinology center, which may introduce referral bias and limit the generalizability of the findings to the broader pediatric population. The unequal sex distribution and the wide age range of participants may also have influenced strength outcomes, despite statistical adjustment for pubertal stage.

Body composition was assessed using bioelectrical impedance analysis rather than imaging techniques such as dual-energy X-ray absorptiometry or magnetic resonance imaging, and therefore does not allow direct evaluation of muscle quality or intramuscular adipose tissue. In addition, physical activity was assessed through self- or parent-reported data, which may be subject to recall bias. Finally, muscle strength assessment relied solely on handgrip dynamometry and may not fully reflect global muscular performance.Overall, these findings emphasize that pediatric obesity should not be evaluated solely on the basis of body weight or BMI. Functional measures such as muscle strength, together with height-adjusted indices of lean mass, offer important insights into the health consequences of excess adiposity during growth.

5. Conclusions

In this cross-sectional study, increased adiposity was associated with reduced muscle strength in children and adolescents when strength was evaluated relative to body mass or adjusted for lean tissue. Although children with overweight and obesity exhibited higher absolute handgrip strength, this finding was largely explained by greater fat-free mass and overall body size. Measures of adiposity, particularly body fat percentage, remained negatively associated with functional strength outcomes after adjustment for age, sex, pubertal stage, physical activity, and body composition.

These results underscore the dissociation between muscle quantity and muscle quality in pediatric obesity and highlight the clinical relevance of functional muscle assessment. Integrating body composition analysis with simple strength measurements, such as handgrip strength, may improve the evaluation of obesity-related functional impairment and help guide more targeted interventions during growth.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the National Institute for Mother and Child Health "Alessandrescu-Rusescu" (approval code no. 52/3 January 2023).

Informed Consent Statement: Patient consent was waived due to the retrospective nature of the study and the use of anonymized data.

Data Availability Statement: The data presented in this study are available in the Supplementary Materials of this article.

Acknowledgments: During the preparation of this manuscript, the authors used ChatGPT (OpenAI, GPT-5, 2025) to assist with summarization of results, refinement of English phrasing, and supporting drafting. Access mode: via OpenAI ChatGPT Plus (web interface). No AI tools were used for data analysis, statistical computation, or figure generation. All AI-assisted content was reviewed and edited by the authors, who take full responsibility for the content of this publication. The authors also acknowledge that publication of this paper was supported by the University of Medicine and Pharmacy "Carol Davila", Bucharest, through the institutional program "Publish not Perish".

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Health Organization. **Obesity and overweight**. Geneva: World Health Organization; 2023.
2. Simmonds M, Llewellyn A, Owen CG, Woolacott N. **Predicting adult obesity from childhood obesity: a systematic review and meta-analysis**. *Obes Rev.* 2016;17(2):95–107.
3. Reilly JJ, Kelly J. **Long-term impact of overweight and obesity in childhood and adolescence**. *Int J Obes (Lond).* 2011;35(7):891–898.
4. Malina RM, Bouchard C, Bar-Or O. **Growth, Maturation, and Physical Activity**. 2nd ed. Champaign, IL: Human Kinetics; 2004.
5. Rogol AD, Roemmich JN, Clark PA. **Growth at puberty**. *J Adolesc Health.* 2002;31(6 Suppl):192–200.
1. Wells JCK. **Toward body composition reference data for children and adolescents**. *Adv Nutr.* 2014;5(3):320S–329S.
2. Tomlinson DJ, Erskine RM, Morse CI, Winwood K, Onambélé GL. **Obesity and skeletal muscle strength**. *Biogerontology*. 2016;17(3):467–483.
3. Thivel D, Ring-Dimitriou S, Weghuber D, et al. **Muscle strength and fitness in pediatric obesity**. *Obes Facts.* 2016;9(1):52–63.
4. Thivel D, O'Malley G, Metz L, et al. **Reduced muscle strength in children with obesity?** *Obes Rev.* 2022;23(6):e13427.
5. Hilton TN, Tuttle LJ, Bohnert KL, Mueller MJ, Sinacore DR. **Adipose tissue infiltration of skeletal muscle**. *Phys Ther.* 2008;88(11):1336–1344.
6. Ortega FB, Silventoinen K, Tynelius P, Rasmussen F. **Muscular strength and health outcomes**. *BMJ.* 2012;345:e7279.
7. Peterson MD, Zhang P, Saltarelli WA, Visich PS, Gordon PM. **Low muscle strength and cardiometabolic risk in adolescents**. *Am J Prev Med.* 2016;50(5):593–599.
8. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. **CDC growth charts: United States.** *Adv Data.* 2000;314:1–27.
9. Ashwell M, Gunn P, Gibson S. **Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis**. *Obes Rev.* 2012;13(3):275–286.
10. Browning LM, Hsieh SD, Ashwell M. **A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes**. *Nutr Res Rev.* 2010;23(2):247–269.
11. Marshall WA, Tanner JM. **Variations in pattern of pubertal changes in girls**. *Arch Dis Child.* 1969;44(235):291–303.
12. Marshall WA, Tanner JM. **Variations in pattern of pubertal changes in boys**. *Arch Dis Child.* 1970;45(239):13–23.
13. World Health Organization. **Guidelines on physical activity, sedentary behaviour and sleep for children and adolescents.**
Geneva: World Health Organization; 2020.
14. Peterson MD, Saltarelli WA, Visich PS, Gordon PM. **Strength capacity and cardiometabolic risk clustering in adolescents.** Pediatrics. 2014;133(4):e896–e903.
15. Wind AE, Takken T, Helders PJM, Engelbert RHH. **Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults?** European Journal of Pediatrics. 2010;169:281–287.

doi:10.20944/preprints202603.0882.v1

disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.