The Relationship of Handgrip Strength to Body Composition and Cardiopulmonary Fitness in Children and Young Adults

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Objective To investigate the relationship between handgrip strength (HGS) and sex, anthropometrics, body composition, and cardiovascular fitness has not been well studied in children, adolescents, and young adults.

Study design A single-center retrospective review of patients <25 years old without known heart disease and referred for clinical cardiopulmonary exercise testing was performed. Each patient underwent HGS testing, bioelectrical impedance body composition analysis, and cardiopulmonary exercise testing. Relationships between variables were assessed using the Pearson correlation coefficient, linear regression, cubic spline, and multivariable analysis. Comparisons by sex were performed using the Student *t* test.

Results The study included 316 patients without heart disease (age 15.1 ± 2.4 years old; 35% male). Male patients had greater peak dominant (34.4 ± 11.9 kg vs 27.8 ± 6.2 kg; $P < .001$) and nondominant (32.1 ± 11.1 kg vs 25.3 ± 6.0 kg; $P < .001$) HGS than female patients, with these differences more noticeable in the teenage years. Peak dominant HGS averaged 30.2 ± 9.3 kg and was correlated with age ($r = 0.49$, $P < .001$) and weight ($r = 0.56$, $P < .0001$); peak dominant HGS was even more strongly correlated with total body skeletal muscle mass (r = 0.80, $P < .001$), peak oxygen consumption (mL/min) (r = 0.69, $P < .0001$), and peak work rate (r = 0.70, $P < .001$).

Conclusions HGS is strongly associated with total and segmental skeletal muscle mass, peak work rate, and peak oxygen consumption. Sex-based differences in handgrip strength values emerge in mid-teenage years in parallel to expected pubertal changes. *(J Pediatr 2025;16:200144)*.

Handgrip strength (HGS) is a noninvasive, inexpensive, quantitative, and quick measure of musculoskeletal function suitable to use in routine clinical practice. Previous studies have described normative values of HGS on the basis of sex, handedness (ie, dominant vs nondominant hand), and age in both adult and pediatric populations.[1,2] HGS has high test-retest reliability, even in the pediatric population,[3] and has been correlated with total muscular and truncal strength.[4,5]

In pediatric patients, HGS is associated with bone density, spirometry, and lean mass.[6-8] In addition, metrics of cardiovascular health such as smoking status, body mass index, cardiorespiratory fitness determined by shuttle run testing, and diet are associated with greater HGS in adolescents.[9] Furthermore, HGS is a risk factor for unfavorable health outcomes and is associated with all-cause mortality and cardiovascular disease in both adults and adolescents.[10,11]

Other fitness outcomes evaluated in pediatric populations include peak oxygen consumption (VO_2peak), which is assessed with cardiopulmonary exercise testing (CPET). VO_2peak is generally regarded as the "gold standard" measure of exercise capacity and cardiorespiratory fitness.[12] In children and adolescents, VO_2peak is associated with lower adiposity[13] and greater lean mass.[14] VO_2peak is also an independent predictor of clinical outcomes, including mortality, in youth and young adults with and without disease.[15-17]

It is unclear how HGS relates to CPET metrics of cardiopulmonary fitness and body composition using bioelectrical impedance analysis (BIA) in healthy children and young adults. In addition, there has been limited research into normative HGS values in youth, with few data on sex differences. Improved information on expected values in healthy children, adolescents, and young adults will facilitate the application of HGS to less healthy populations.

BIA	Bioelectrical impedance
CPET	Cardiopulmonary exercise testing
DXA	Dual-energy x-ray absorptiometry
HGS	Handgrip strength
LBM	Lean body mass
SMM	Skeletal muscle mass
VO_2peak	Peak oxygen consumption

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The aims of our study are (1) to describe HGS values in a cohort of youth and young adults with no known cardiac diagnosis; (2) to assess the relationship of HGS with markers of fitness (CPET) and body composition (BIA); and (3) to describe differences in HGS by sex, age, and body size.

Methods

All patients referred for clinical CPET at Cincinnati Children's between January 2020 and June 2023 were reviewed. Inclusion criteria were (1) age <25 years; (2) completed a maximal effort CPET on a cycle ergometer; and (3) no known underlying cardiac diagnosis. Patients were considered healthy without heart disease if they met the following conditions: (1) were referred for CPET with common indications such as chest pain, palpitations, syncope/presyncope, dyspnea on exertion, or evaluation of a prolonged QT interval without a diagnosis of congenital long QT syndrome; (2) had no pathologic electrocardiographic changes during exercise; and (3) were not taking cardiovascular medication (**Supplemental Figure 1**; available at www.jpeds.com). This research was approved by the institutional review board at Cincinnati Children's Hospital Medical Center.

The HGS of both hands was measured using a hydraulic hand dynamometer (BL5001; B&L Engineering) with patients standing during the measurements and the tested arm positioned with the elbow at 90° of flexion. Each subject performed 3 maximum voluntary contractions for each hand. Each patient self-identified their dominant hand. Both peak measurements were recorded on each hand, and the peak dominant HGS was used for the analysis.

All patients underwent standardized CPET on a cycle ergometer (Corival; Lode) using a ramp protocol to reach exhaustion after approximately 10 minutes of exercise. The protocol consisted of setting an initial work rate based on patient's body surface area and baseline fitness level with linear increases to reach peak exercise after approximately 10 minutes. Patients were asked to keep a pedaling cadence of ~60 pedals/minute. A 12-lead electrocardiogram was recorded during the test (GE Medical Case 8000). Gas exchange was assessed continuously using breath-by-breath gas analysis with a metabolic cart (Ultima CardiO2; MGC Diagnostics). The test was judged to be maximal if the respiratory exchange ratio ≥1.1 and the maximal heart rate ≥85% of age-predicted maximal heart rate. The predicted VO_2peak for children (<18 years old) was calculated using 1 of the 2 estimating equations described by Cooper et al.[18] The predicted VO_2peak for adults (≥18 years old) was calculated using estimating equations from Wasserman et al.[19]

Body composition was measured by BIA (InBody 370; InBody) immediately before CPET, as described elsewhere.[20] Output variables from the InBody software included lean body mass (LBM), LBM of both the upper and lower extremities, LBM of the trunk, skeletal muscle mass (SMM), body fat mass, and body fat percentage.

Statistical Analysis

Data are summarized as mean ± SD for normally distributed continuous variables. A Student *t* test was performed to assess differences by sex and the Wilcoxon signed-rank test for non-normally distributed data was used where appropriate. All tests were 2-tailed, and the significance level was set at .05. To control for size, age, and sex, the z scores for HGS and VO_2peak were calculated on the basis of normative data.[1,2,21] Univariable analysis to assess relationships between peak dominant HGS with anthropometric data, body composition, and markers of fitness determined by CPET were assessed using the Pearson correlation coefficient and linear regression analysis. Comparison between SMM and peak dominant HGS by age was performed by a restricted cubic spline model. A stepwise multivariable linear regression modeling procedure with 0.1 as the significance level for entry and .05 as the significance level for retention in the model was constructed to determine independent predictors of peak dominant HGS. Candidate predictors for the model were age, weight, height, body mass index, SMM, trunk LBM, body fat percent, and body fat mass. Statistical analyses were performed using JMP 16 (SAS Institute Inc) and R, version 4.4.0 (R Foundation for Statistical Computing; www.R-project.org).

Results

A total of 2871 handgrip measurements were performed during the study period. Inclusion/exclusion criteria were met for 316 patients (**Supplemental Figure 2**; available at www.jpeds.com). Patient characteristics are shown in **Table I**. The mean age was 15.1 ± 2.4 years old (37% male; 93.4% <18 years old). The average height was 165.0 ±10.8 cm. The average weight was 60.8 ±16.6 kg. Indications for testing included syncope/presyncope (n = 170), chest pain (n = 53), palpitations (n = 41), a prolonged QT on resting electrocardiogram without a diagnosis of long QT syndrome (n = 35), dyspnea on exertion (n = 15), and exercise intolerance (n = 2).

Results of HGS, BIA, and CPET are shown in **Table I**. Hand dominance was right- and left-handed for 289 and 27 patients, respectively.

The correlations between peak dominant HGS and outcomes variables are presented in **Table II**. Peak dominant HGS was most strongly correlated with SMM ($r = 0.80$, $P < .001$), right arm SMM ($r = 0.79$, $P < .001$), left arm SMM ($r = 0.80$, $P < .001$), VO_2peak (mL/min) ($r = 0.69$, $P < .001$), and peak workload ($r = 0.70$, $P < .001$) (**Supplemental Figure 1**; available at www.jpeds.com). Although peak dominant HGS was also significantly correlated with age, metrics of body size, and other aspects of body composition, these associations were weaker: age ($r = 0.49$, $P < .001$), height ($r = 0.69$, $P < .001$), and weight ($r = 0.56$, $P < .001$). Unsurprisingly, peak nondominant HGS had a strong relationship with peak dominant HGS ($r = 0.98$, $P < .0001$). Peak dominant HGS was not significantly correlated with

Table I. Results of HGS, bioelectrical impedance analysis, and CPET in otherwise-healthy patients <25 years of age

Characteristics	Total cohort n = 316	Male patients n = 117	Female patients n = 199	*P* value
Age, y	15.1 ± 2.4	14.5 ± 2.6	15.4 ± 2.2	.001
Handgrip				
Peak R HGS, kg	30.1 ± 9.2	34.2 ± 11.7	27.7 ± 6.1	<.0001
Peak L HGS, kg	28.0 ± 9.2	32.3 ± 11.3	25.4 ± 6.1	<.0001
Peak dominant HGS, kg	30.2 ± 9.3	34.4 ± 11.9	27.8 ± 6.2	<.0001
Peak dominant HGS, z score	0.15 ± 1.0	0.14 ± 0.96	0.16 ± 1.1	.8
Peak nondominant HGS, kg	27.9 ± 8.9	32.1 ± 11.1	25.3 ± 6.0	<.0001
BIA				
Height, cm	165.0 ± 10.8	167.6 ± 14.6	163.5 ± 7.3	.001
Weight, kg	60.8 ± 16.6	61.3 ± 19.9	60.5 ± 14.2	.678
Skeletal muscle mass, kg	25.3 ± 6.3	28.2 ± 8.4	23.6 ± 3.8	<.0001
Body fat mass, kg	15.0 ± 10.3	10.9 ± 9.7	17.4 ± 9.9	<.0001
Body fat percentage, %	23.2 ± 10.3	16.5 ± 9.2	27.4 ± 8.8	<.0001
Body mass index, kg/m^2	22.1 ± 5.0	21.4 ± 4.9	22.6 ± 5.0	.036
Right arm lean mass, kg	2.3 ± 0.8	2.7 ± 1.0	2.1 ± 0.5	<.0001
Left arm lean mass, kg	2.3 ± 0.7	2.7 ± 1.0	2.1 ± 0.5	<.0001
Trunk lean mass, kg	20.3 ± 4.7	22.3 ± 6.3	19.1 ± 3.1	<.0001
Right leg lean mass, kg	7.0 ± 1.8	7.7 ± 2.3	6.5 ± 1.1	<.0001
Left leg lean mass, kg	6.9 ± 1.7	7.7 ± 2.3	6.5 ± 1.1	<.0001
CPET				
VO_2peak, mL/min	2163 ± 634	2489 ± 7649	1971 ± 460	<.0001
VO_2peak, mL/min/kg	36.4 ± 8.7	41.7 ± 8.7	33.3 ± 7.1	<.0001
VO_2peak (% predicted)	95.7 ± 19.2	88.9 ± 18.5	97.3 ± 19.1	<.0001
VO_2peak, z score	0.055 ± 1.35	0.01 ± 1.3	0.08 ± 1.4	.7
Peak HR, bpm	185.9 ± 9.3	185.6 ± 9.7	186.0 ± 9.1	.666
Peak workload, watts	151.3 ± 49.7	172.3 ± 62.7	138.94 ± 34.8	<.0001
Peak SBP, mm Hg	171 ± 21	174 ± 26	169 ± 18	.008
Peak RER	1.2 ± 0.01	1.2 ± 0.01	1.2 ± 0.01	.392
VAT, % of predicted VO_2peak	63.3 ± 15.8	60.4 ± 15.7	64.9 ± 15.6	.019

bpm, beats per minute; *HR*, heart rate; *L*, left; *R*, right; *RER*, respiratory exchange ratio; *SBP*, systolic blood pressure; *VAT*, ventilatory anerobic threshold.
Data are presented as mean ± SD. A Student *t* test was performed to assess differences between male and female patients. $P < .05$ was considered significant.

body fat mass, percent of predicted VO_2peak, or peak heart rate during exercise. When comparing the z score for peak dominant HGS and VO_2peak, there was a significant correlation ($r = 0.28$, $P < .0001$).

On multivariable analysis, we identified a model consisting of SMM, age, and weight as independently associated with peak dominant HGS (kilograms) (Table II) with a total model r^2 of 0.66. When using the z score for peak dominant HGS on multivariable analysis, age, sex, SMM, and height were independently associated with peak dominant HGS by z score with a total model r^2 of 0.20.

Subgroup Analysis

When evaluating peak dominant HGS by sex, there were significant differences in HGS between male and female patients (Table II). Male patients had greater peak dominant (34.4 ± 11.9 kg vs 27.8 ± 6.2 kg; $P < .001$) and nondominant HGS (32.1 ± 11.1 kg vs 25.3 ± 6.0 kg; $P < .001$) compared with female patients. At young ages, the HGS was similar between the sexes but diverged in the teenage years where the male patients continued to have greater HGS whereas the female patients began to plateau their HGS (Figure 1). When examining the relationship between measures of body size and peak dominant HGS by sex, male patients at greater weights and heights had a greater peak dominant HGS compared with female patients of similar size (Figure 2).

On evaluating further the relationship with age, we found there were significant associations between peak dominant HGS and SMM with age but not body fat percentage (Figure 1). When examining the relationship between peak dominant HGS and SMM, we found there was a strong association present, with previous sex-based differences becoming less pronounced (Figure 1). Segmental muscle mass represented as right arm muscle mass was significantly correlated with peak dominant HGS regardless of sex (Figure 2).

Discussion

In this study, we explored the relationship between HGS, body composition, and VO_2peak in children and young adults. Our final cohort included 316 patients (average age = 15.1 years old) with presumably normal hearts who underwent HGS, CPET, and BIA. On CPET, HGS had a positive relationship with absolute VO_2peak, VO_2peak z score, and peak work rate but not percent of predicted VO_2peak. In addition, HGS was strongly and positively correlated with both total and segmental SMM but not adiposity. Lastly, HGS correlated to age, height, and weight, and these

Table II. Relationship between peak dominant HGS and outcomes variables in otherwise-healthy patients <25 years of age

Univariable correlations	R	95% CI	*P* value
Age, y	0.49	0.40-0.57	<.001
Height, cm	0.69	0.61-0.73	<.001
Weight, kg	0.56	0.45-0.61	<.001
BMI, kg/m^2	0.27	0.17-0.38	<.001
SMM, kg	0.80	0.76-0.84	<.001
Body fat mass, kg	0.09	−0.02 to 0.20	.371
Body fat percentage	−0.17	−0.28 to 0.06	.014
R arm lean mass, kg	0.79	0.74-0.82	<.001
L arm lean mass, kg	0.78	0.73-0.82	<.001
VO_2peak, mL/min	0.69	0.63-0.74	<.001
VO_2peak, z score	0.28	0.15-0.51	<.001
VO_2peak, % predicted	−0.10	−0.21 to 0.01	.371
Peak workload, watts	0.70	0.64-0.75	<.001
Peak HR, bpm	−0.07	−0.18 to 0.04	.448
Peak SBP, mm Hg	0.49	0.40-0.57	<.001
VAT, %	−0.07	−0.18 to 0.04	.0448
Nondominant HGS	0.93	0.92-0.95	<.001
Multivariable analysis for peak HGS, kg	**β coefficient**	**Standard-β coefficient**	
SMM, per kg	0.19	0.82	0.85-1.6	<.001
Age, per year	0.20	0.19	0.40-1.18	<.001
Weight, per kg	0.041	−0.15	−0.17 to −0.009	.03
Height, per cm	0.071	−0.14	−0.26 to 0.019	.09
Sex, male	0.50	−0.09	−1.91 to −0.048	.1
Workload, per w	0.016	0.11	−0.01 to 0.051	.18
VO_2, z-score	0.38	0-0.01	−0.82 to 0.67	.85
Multivariable Analysis for peak HGS (z-score)	**β coefficient**	**Standard-β coefficient**	
Age, per year	0.033	−0.30	−0.19 to 0.069	<.001
Sex, male	0.083	0.25	0.11-0.43	.001
SMM, per kg	0.032	0.61	0.036-0.16	.002
Height, per cm	0.012	−0.27	−0.049 to −0.0019	.03
VO_2, z score	0.063	0.085	−0.06 to 0.19	.3
Workload, per w	0.0026	0.10	−0.0029 to 0.0072	.4
Weight, per kg	0.0068	0.01	−0.012 to 0.014	.9

BMI, body mass index.

Univariable analysis to assess relationships between peak dominant HGS with anthropometric data, body composition, and markers of fitness determined by CPET was assessed using the Pearson correlation coefficient. Stepwise multivariable linear regression (with 0.1 as the significance level for entry and 0.05 as the significance level for retention in the model) was applied to determine independent predictors of peak dominant HGS with candidate predictors for the model being age, sex, weight, height, SMM, and body fat mass with a $P < .05$. *P* value < .05 was considered significant.

differences became more pronounced by sex in the midteenage years.

The HGS values obtained in our study are consistent with previous research in pediatric populations.[1,22-24] An improved understanding of pediatric normative values is needed to apply HGS in other populations, such as those with congenital heart disease or oncologic processes. In addition, we have shown that HGS has a reasonable correlation with SMM as measured by BIA. This has multiple clinical implications. For one, not every exercise laboratory has convenient access to equipment to accurately measure body composition, such as a dual-energy x-ray absorptiometry (DXA) or BIA. HGS is a noninvasive, inexpensive, reliable, and easy-to-obtain marker of health that requires minimal staffing. This may make HGS a reasonable surrogate for SMM, which is especially important in low-income settings or in hospitals looking to minimize costs.

In addition, HGS has also been shown to have prognostic significance for all-cause mortality and cardiovascular diseases in adult patients.[11,25] An improved understanding of normative data will allow clinicians to see whether this same prognostic significance is present in pediatric populations. The ease of use and low cost of HGS should make this an attractive modality to incorporate in large multicenter longitudinal studies evaluating clinical outcomes in patients with chronic disease. Lastly, HGS is 1 of the 5 components of frailty (with slowness, fatigue, sarcopenia, and low physical activity as the other components).[2] Frailty has been shown to relate to negative patient outcomes in multiple disease populations but is rarely assessed in pediatric populations.[26-31] As HGS is further studied in pediatric patients, this hopefully will advance research and awareness of the other aspects of frailty in pediatric patients.

We were able to show that HGS is correlated with multiple markers of physical health. There were associations seen between total work and VO_2peak (mL/min and z score). Interestingly, however, there was not a significant association between HGS and the percent of predicted VO_2peak. This

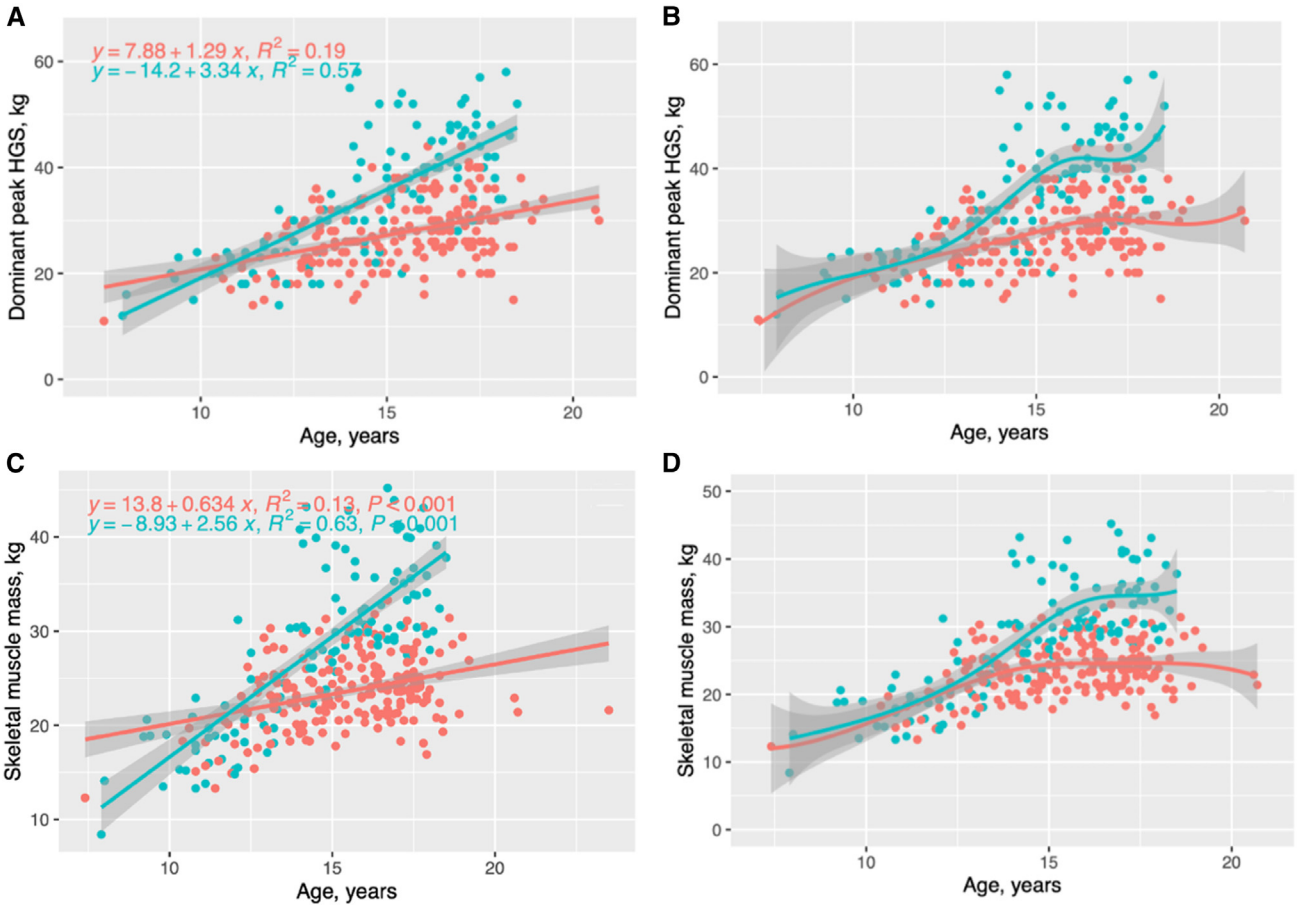

Figure 1. Relationship between age, peak dominant HGS, and SMM by sex. Relationship between age and peak dominant HGS by **A,** linear regression; **B,** by linear regression, age and peak dominant HGS by cubic spine; **C,** age and SMM assessed by BIA by linear regression; and **D,** age and SMM by cubic spline. *Blue* indicates male patients. *Red* indicates female patients. **A** and **C,** Analysis performed with linear regression analysis; *P* value < .05 was considered significant. **B** and **D,** Analysis performed by restricted cubic spine model; the *solid lines* and the *shaded area* represent the estimated regression coefficient beta and its 95% CI.

could reflect shortcomings in current prediction equations for VO_2peak. In contrast, this could also reflect that HGS measures a different category of fitness than VO_2peak and that the relationship between absolute VO_2peak and HGS is more reflective of patient size. Although this is intuitive in an otherwise healthy population, it is important to define this in healthy populations before it can be evaluated in pediatric patients with chronic disease, who may be smaller and more cachectic. In addition, as HGS seems to be a reasonable surrogate for SMM and SMM has been shown to improve the accuracy of pediatric prediction equations for VO_2peak.[32] there may be a role for incorporating HGS into VO_2peak prediction equations as a cheaper alternative to BIA. This needs to be confirmed in other studies before widespread implementation.

Lastly, there were noteworthy sex-based differences in HGS. For one, HGS was similar between sexes at younger ages but diverged in early to middle teenage years (Figure 1). This was also the period in which size and SMM changes were apparent, with taller and heavier male patients having a greater HGS compared with their similarly sized female counterparts. The divergence in HGS around this age is likely secondary to the expected pubertal changes in body composition that differ between male and female patients. In the later teenage years, male patients had an increase in SMM with stable-to-decreased adiposity, whereas women had a smaller increase in SMM and a larger increase in adiposity, consistent with previous research.[33] Interestingly, male and female patients with similar SMM had minimal differences in HGS, implying that total SMM is a sex-independent driver of HGS (Figure 1). This is supported by multivariable analysis. This has performance and trainability implications in that improvements in both muscular strength and SMM should result in increased HGS regardless of sex. If larger studies confirm that HGS is a modifiable risk factor in pediatric populations, this study offers more evidence for the importance of a comprehensive exercise training program for clinical populations at risk of frailty-related negative outcomes, such as congenital heart disease.

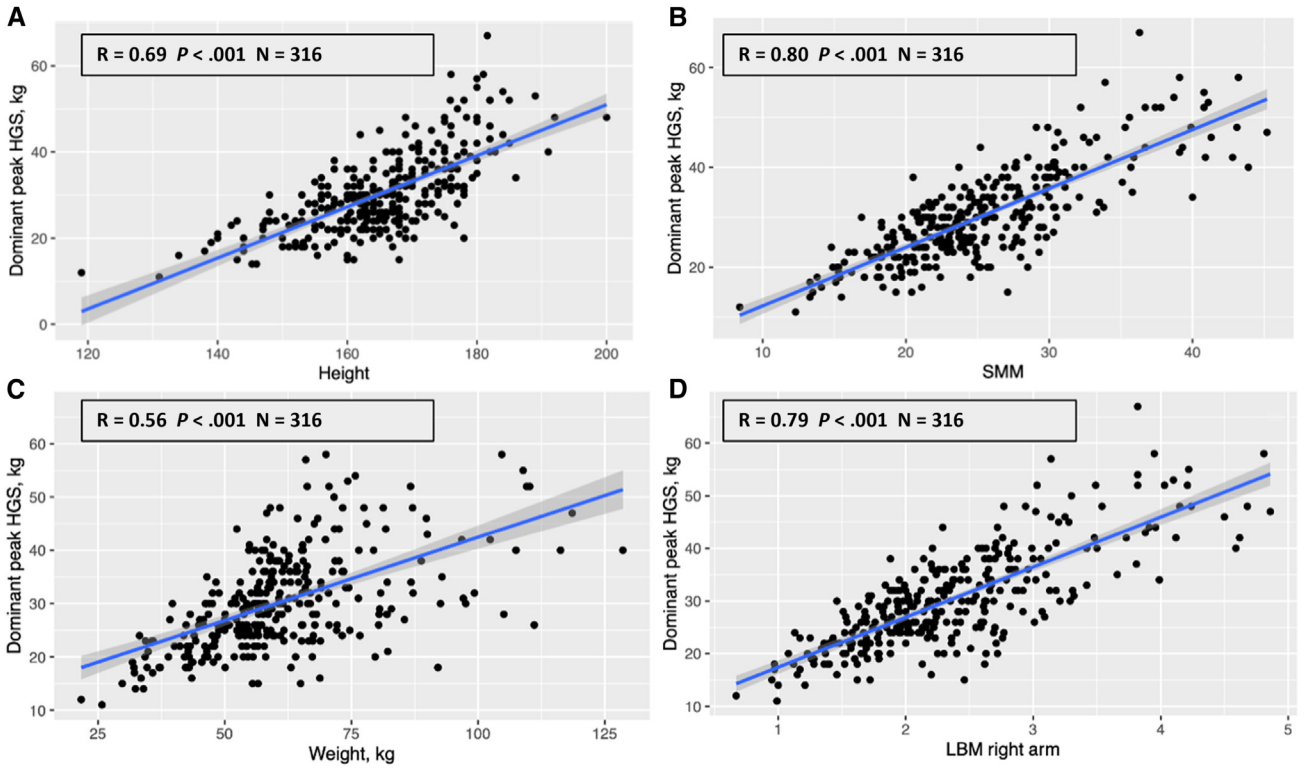

Figure 2. Relationship between dominant peak HGS and **A,** height; **B,** SMM; **C,** weight; and **D,** right arm muscle mass (LBM) assessed by BIA. Analysis performed with linear regression analysis. *P* value < .05 was considered significant.

There were several limitations to this study. First, this population consisted of a group of patients with presumably healthy hearts presenting for exercise testing secondary to nonspecific symptoms. Although no patient was identified as having cardiac pathology, this clinical cohort may not be generalizable to a healthy nonhospital-based population and those with pulmonary and/or orthopedic limitations were not part of the exclusion criteria. Second, all CPETs were performed on a cycle ergometer, which may underestimate actual VO_2peak in the very young or those not used to cycling. Third, we did not have Tanner staging or other data on the specific stage of puberty in this cohort. Lastly, we acknowledge that DXA is the preferred gold standard for the measurement of body composition analysis; however, DXA is located far from the exercise laboratory, resulting in an inconvenient situation for the patient. BIA has shown excellent agreement with DXA and has increasingly been used in clinical and research situations in children.[34-36] ■

CRediT authorship contribution statement

Carter G. Richardson: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Alexander R. Opotowsky:** Writing – review & editing, Visualization, Validation, Supervision, Formal analysis, Data curation, Conceptualization. **Clifford Chin:** Writing – review & editing, Supervision, Conceptualization. **Wayne A. Mays:** Writing – review & editing, Supervision, Conceptualization. **Sandra K. Knecht:** Writing – review & editing, Validation, Supervision, Formal analysis, Data curation, Conceptualization. **Adam W. Powell:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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