

ORIGINAL ARTICLE

Association between Segmental Muscle Mass and Handgrip Strength in Healthy Young Adult Males: A Cross-Sectional Study

Shane Emmanuel James¹, Isaac Lim Wan Cheng¹, Faizal Abdul Manaf², Brinnell Caszo³, Justin Gnanou^{3*}

¹*School of Pharmacy, IMU University, 57000 Kuala Lumpur, Malaysia.*

²*Department of Defense Fitness, National Defense University of Malaysia, 57000 Kuala Lumpur, Malaysia.*

³*School of Medicine, IMU University, 57000 Kuala Lumpur, Malaysia.*

Corresponding Author

Justin Gnanou,

School of Medicine, IMU University, 57000 Kuala Lumpur, Malaysia.

Email: justingnanou@gmail.com

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Abstract

Background: Body composition assessment using bioelectrical impedance analysis (BIA) provides valuable insights into nutritional status by estimating body protein and fat composition. BIA also uses predictive equations to estimate muscle mass across different body segments, including the right arm, left arm, trunk, right leg, and left leg. Handgrip strength (HGS), measured using a handheld dynamometer, is a widely accepted indicator of muscle strength; however, it primarily reflects upper-limb strength and is often used as a surrogate for overall muscle strength. This study examined the relationship between BIA-estimated segmental muscle mass and HGS in healthy young males. **Methods:** Forty healthy male participants aged 18–25 years with a normal body mass index were recruited. Total and segmental muscle mass were assessed using a BIA analyser, and HGS was assessed on the dominant hand with a handheld dynamometer. Pearson's correlation analysis was performed to evaluate the associations between BIA-estimated total and segmental muscle mass and HGS. The Holm procedure was applied to control the family-wise error rate across the six correlation tests. **Results:** BIA-estimated total muscle mass was positively correlated with HGS ($r = 0.461$, $p = 0.003$). Significant positive correlations were also observed between HGS and BIA-estimated muscle mass in all body segments. The strongest correlation was found for the left arm ($r = 0.521$, $p < 0.001$), whereas the weakest was observed for the right leg ($r = 0.373$, $p = 0.018$). However, formal statistical comparison of dependent correlations was not performed, and the 95% confidence intervals for these correlations overlapped. **Conclusion:** HGS was significantly associated with both total and segmental BIA-estimated muscle mass in healthy young males. Although muscle mass across all five assessed body segments was significantly associated with HGS, the magnitude of these associations appeared to differ across anatomical regions, with numerically stronger associations observed for the arm segments and weaker associations for the lower-limb segments. These segmental comparisons should be interpreted as exploratory.

Keywords: Bio-impedance analysis, body composition analysis, body segments, handgrip strength, muscle mass, muscle strength.



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Introduction

Analyzing body composition provides an objective method to estimate the body's proportions of protein and fat, offering crucial insights into nutritional status and functional abilities. The percentage body fat reflects long-term energy reserves, while the protein percentage indicates muscle mass. Several methods, such as anthropometry, densitometry, and bioelectrical impedance analysis (BIA), are utilized to assess body composition. Among these, BIA is increasingly favoured due to its simplicity and cost-effectiveness. This technique predicts protein content and muscle mass across different body regions. It's a painless method that measures how much the body's tissues resist an electric current [1]. Since different tissues have varying water content and conductivity, BIA can estimate the body's composition by analyzing the way an electrical current travels through the body [2]. More resistance means more fatty tissue, and thus provides the body fat percentage. The rest would be the fat-free mass, which mainly consists of skeletal muscle. Using algorithms, BIA can provide total body muscle mass as well as segmental muscle mass measurements. Notably, BIA-derived estimates of muscle mass provide information about overall muscle quantity, which is associated with muscular strength [3].

Muscle strength, an indicator of various health aspects, including cardiovascular disease and cognitive function [4], can also be gauged through handgrip strength (HGS). HGS measures the force generated by the hand muscles when grasping and holding an object. It indicates the maximum strength a person can produce when squeezing something with their hand [5]. This strength is typically measured using a hand dynamometer, which gauges the force exerted during the squeeze [6]. During assessment, the dynamometer is typically used with the participant seated and the elbow flexed at approximately 90 degrees, with the handle adjusted to the individual's hand size [7]. Depending on the study protocol, HGS may be

assessed using repeated trials, with the highest recorded force commonly used as the representative value [8]. This simple, standardized procedure is widely used in clinical, research, and fitness settings to assess upper body strength, providing reliable insights into a person's physical capabilities and tracking changes over time.

HGS is widely used as a simple and practical measure of muscle strength and physical function. Although the handgrip task primarily involves the muscles of the hand and forearm, force generation during maximal gripping also involves musculature extending through the upper limb and requires stabilization of the proximal segments of the body [5,9,10,11]. Consequently, HGS has been proposed as a surrogate measure of more generalized muscular strength. However, because HGS represents a localized functional task, its relationship with muscle mass may not be uniform across different anatomical regions.

Muscle mass is distributed throughout the body, and segmental body composition assessment provides an opportunity to examine whether muscle mass in regions not directly involved in handgrip force generation is also associated with HGS. Previous studies have reported associations between HGS and muscle characteristics of the upper limb, including forearm muscle size, as well as associations between HGS and muscle mass in other regions of the body [12-15]. These findings suggest that HGS may reflect aspects of overall muscular status beyond the muscles directly involved in gripping. However, the relative strength of the association between HGS and muscle mass across distinct body segments remains less clearly characterized. In particular, the extent to which trunk and lower-limb muscle mass is associated with HGS, compared with upper-limb muscle mass, warrants further investigation. Examining these relationships may provide a better understanding of whether HGS reflects muscle mass more broadly distributed throughout the body or whether its association is

stronger for anatomically proximal and functionally related muscle segments.

Therefore, the present study aimed to examine the relationship between HGS and BIA-estimated total as well as segmental muscle mass in healthy young adult males, including the right arm, left arm, trunk, right leg, and left leg. By comparing the strength of these associations across body segments, the study sought to clarify whether the relationship between HGS and BIA-estimated muscle mass differs according to anatomical region.

Materials and methods

Study participants

Forty male participants aged 18 to 25 years old with a BMI range of 18.5 – 24.9 kg/m² and without any medical conditions from the student population of the university were recruited via advertisement for this study. The absence of medical conditions was ascertained by self-report during screening. To achieve more accurate and reliable data, volunteers were reminded to maintain optimal hydration levels and abstain from any form of vigorous exercise or physical activities within the 24 hours of the study. Additionally, the subjects were advised against making significant alterations to their dietary habits or daily protein intake and to abstain from alcohol consumption during the 24 hours leading up to the collection. Participants were required to provide written informed consent and received a thorough briefing on the study. The study was conducted in accordance with the World Medical Association Declaration of Helsinki. Ethical approval was obtained from the Joint Research and Ethics Review Committee of the university (BP I-01-2024(01)).

Sample size calculation

The sample size was determined a priori based on an expected moderate effect size of 0.50, with 80% statistical power and a two-tailed significance level of 0.05, yielding a minimum required sample size of 34 participants. To allow

for potential participant attrition, the recruitment target was conservatively increased to 50 participants. A total of 40 participants completed the study and were included in the final analysis. The sample size calculation was based on a single correlation and did not account for the six correlation tests performed.

HGS measurement

HGS was assessed using a Baseline® Smedley Digital Hand Dynamometer (Model 12-0286), Fabrication Enterprises, Inc., White Plains, NY, USA. Participants were instructed to sit upright with elbows bent at right angles on both sides. Participants held the hand dynamometer in the tested hand, keeping the wrist in a neutral position. The forearm was positioned in neutral rotation, and the wrist was held in slight extension (0–30 degrees), consistent with the American Society of Hand Therapists (ASHT) recommendations. A 30-second rest period was provided between trials. To ensure measurement precision, the dynamometer handle was adjusted to align its base with the palm's heel rest, and the handle was positioned between the four fingers before commencing the test. The handle was set at the second grip position for all participants. Measurements were obtained from the participant's dominant hand. Three measurements were performed, and the highest value recorded across the three trials was used as the handgrip strength value for subsequent analysis. Among the 40 participants, 37 were right-hand dominant, and three were left-hand dominant. All measurements were performed by the same trained examiner. The recorded results, measured in kilograms, were taken from the dynamometer and rounded to the nearest 0.1 kg.

Segmental body composition and BIA-estimated muscle mass measurement

To estimate muscle mass in different body segments of the legs, arms, and trunk, the TANITA Segmental Body Composition Analyzer (Tanita InnerScan V BC-545N) was utilized. Measurements were performed using the same

device and standardized measurement procedure was followed for all participants, such as time of day, fasting status, and clothing, and the manufacturer's recommended procedures were followed. Participants were assessed in the morning after an overnight fast, wearing lightweight clothing, and after voiding. All measurements were performed at approximately the same time of day.

Briefly, the participants were instructed to hold the grip electrodes with their thumbs at the top and the other fingers wrapping around the grip electrodes. The participants' information, such as their height, weight, age, and sex, was entered into the machine. Subsequently, subjects spread their legs one foot apart and fully stretched their arms in front of them while standing on the footpad (electrodes) of the analyzer. Upon pressing the "START" button, the instrument began the measurement, and the results were obtained from the instrument.

Data were analyzed using IBM SPSS Statistics v30 (IBM Corp., Armonk, NY, USA) software and are presented as mean $\pm$ standard deviation. The normality of continuous variables was assessed using the Shapiro–Wilk test. The relationships between handgrip strength and BIA-estimated total and segmental muscle mass were assessed using scatterplots to evaluate linearity, and the data were examined for extreme or influential observations. Influential observations were assessed using Cook's distance, with values greater than $4/n$ considered potentially influential. As the variables showed no statistically significant departure from normality and the relationships were reasonably linear without influential outliers, Pearson's correlation coefficient was used to examine the associations between handgrip strength and BIA-estimated whole-body and segmental muscle mass. Because six correlation tests were performed, the Holm procedure was applied to control for the family-wise error rate. Formal statistical comparison of dependent correlations (e.g., Steiger's test) was not performed; therefore, segmental comparisons

were considered exploratory. Both unadjusted and Holm-adjusted p-values were considered when interpreting the correlation results. Statistical significance was set at $p < 0.05$.

Results

The study population comprised 40 male students. Table 1 provides the participants' mean age, anthropometric characteristics, and body composition. The mean age of the participants was 20.600 ± 1.614 years. Heights ranged from a minimum of 160 cm to a maximum of 185 cm, while the body weight varied between 52 kg and 80 kg. All participants had BMIs within the normal range. The mean BIA-estimated muscle mass was 52.430 ± 5.365 kg, and the mean HGS was 38.600 ± 7.543 kg.

BIA-estimated segmental muscle mass in the study population

Table 2 summarizes the mean BIA-estimated muscle mass in various body segments in our study population. The trunk segment has the highest muscle mass (28.915 kg), followed by the legs, with the right leg averaging slightly more (9.253 kg) than the left leg (9.103 kg). The arms have the lowest muscle mass, with the right arm averaging 2.673 kg and the left arm 2.488 kg.

Relationship between HGS (kg) and BIA-estimated whole-body muscle mass (kg)

Figures 1 (a-f) present scatter plots showing the correlation between HGS and BIA-estimated muscle mass in various body segments. Overall, our study showed a positive correlation between BIA-estimated total muscle mass and HGS, which was statistically significant ($r = 0.461$, 95% CI: 0.175–0.676, $p = 0.003$). Significant positive correlations were also observed for all five segmental muscle mass measures (r ranging from 0.373 to 0.521; Table 3).

Discussion

In the present study, BIA-estimated total muscle mass demonstrated a moderate positive correlation with dominant-hand HGS, supporting the established association between muscle quantity and muscle strength [3,17–19]. Analysis of individual body segments revealed that the strength of this association varied across anatomical regions. The strongest correlation was observed between left arm muscle mass and dominant-hand HGS ($r = 0.521$), followed by right arm muscle mass ($r = 0.478$), whereas the weakest correlation was observed for right leg muscle mass ($r = 0.373$). However, these segmental comparisons were exploratory, and formal statistical comparison of dependent correlations was not performed, and the 95% confidence intervals for these correlations overlapped. The apparent differences in the strength of associations should therefore be interpreted with caution. The relatively stronger associations observed for the arm segments may be expected because HGS is a task that directly involves the muscles of the hand and forearm and requires coordinated force generation across the upper limb. Previous studies have demonstrated associations between HGS and forearm muscle size and ultrasound-measured muscle thickness of the hand and forearm [12,13]. Although the muscle mass estimated by BIA represents the entire arm segment rather than the hand and forearm musculature alone, greater upper-limb muscle mass may reflect greater muscular capacity within the limb and therefore have a closer association with grip performance. In contrast, the comparatively weaker correlations observed for the lower-limb muscle-mass segments may reflect their less direct involvement in the handgrip task. Nevertheless, previous research has demonstrated an association between HGS and lower-limb strength, indicating that the relationship between grip strength and musculature outside the upper limb may still be relevant [15]. The trunk showed an intermediate correlation ($r = 0.438$), which is

consistent with previous evidence reporting an association between trunk muscle strength and HGS, although the mechanisms underlying this relationship remain uncertain [16]. It is important to note that the left arm showed the numerically strongest correlation ($r = 0.521$), despite HGS being assessed on the dominant hand, with 37 participants being right-hand dominant and three being left-hand dominant. Thus, the difference between the left- and right-arm correlations should not be interpreted as evidence that the left arm has a stronger functional relationship with HGS. Rather, the overall pattern of relatively stronger associations for both arm segments may reflect the closer anatomical and functional relationship between upper-limb musculature and the handgrip task. Importantly, the present study did not directly assess individual muscle activation, neuromuscular recruitment, or the biomechanical contribution of specific body segments during HGS. Therefore, the physiological mechanisms underlying the observed segmental differences cannot be established from the present data.

The pattern observed in our study is broadly consistent with previous research demonstrating associations between HGS and muscle mass or muscle characteristics in different populations. Studies examining forearm muscle size and ultrasound-measured muscle thickness have reported positive associations with HGS, supporting the closer relationship between upper-limb muscle characteristics and grip performance [12,13]. Similarly, a study of older Asian adults reported associations between HGS and regional muscle mass, while other studies have demonstrated associations between HGS and overall muscle mass or fat-free mass [14,17–19]. The present findings extend these observations by demonstrating that, in healthy young adult males, BIA-estimated muscle mass across all assessed body segments was significantly associated with dominant-hand HGS, while the magnitude of the associations varied across anatomical regions. However, the present study cannot determine whether greater muscle mass in any particular

body segment leads to greater HGS. The observed relationships should therefore be interpreted as associations, and longitudinal or experimental studies would be required to determine whether changes in segmental muscle mass are accompanied by corresponding changes in HGS.

Despite the valuable insights gained from this study, several limitations should be acknowledged. First, the sample size was relatively small, which may limit the generalizability of the findings to broader populations and may reduce the precision of the estimated correlations. In addition, the a priori sample size calculation was based on a single correlation and did not account for the six correlation tests performed, which may have affected statistical power for the Holm-adjusted analyses. Second, muscle mass was estimated using BIA rather than directly assessed using reference methods such as dual-energy X-ray absorptiometry (DXA) or magnetic resonance imaging (MRI) [20]. BIA is a practical and non-invasive approach for estimating body composition, but its estimates depend on device-specific predictive equations and may be influenced by factors such as hydration status [1,2]. Hydration status was not objectively assessed in the present study, which may have influenced BIA estimates. Consequently, measurement-related variation in BIA-estimated muscle mass may have affected the observed associations with HGS. Third, the study population consisted exclusively of healthy young adult males, and therefore the findings may not be generalizable to females, older adults, or populations with chronic disease or altered body composition. Physical activity, nutritional status, and other lifestyle characteristics were not assessed, and the small sample size precluded multivariable adjustment for potential confounders. Future studies involving larger and more diverse populations, together with more precise assessment of muscle mass and relevant lifestyle factors, would help to determine whether the segment-specific pattern observed in the

present study is reproducible across different populations.

Conclusion

This study demonstrated significant positive associations between handgrip strength and both total and segmental BIA-estimated muscle mass in healthy young adult males. Although muscle mass across all five assessed body segments was significantly associated with handgrip strength, the strength of these associations varied across anatomical regions, with relatively stronger associations observed for the arm segments and weaker associations for the lower-limb segments. These findings indicate that handgrip strength is associated with muscle mass across multiple body regions, although the strength of this association may vary according to anatomical location. Longitudinal or experimental studies are needed to determine whether changes in segmental muscle mass are accompanied by corresponding changes in handgrip strength, and whether the segmental pattern observed in the present study is reproducible across different populations, including females, older adults, and individuals with chronic disease or altered body composition.

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Conflicts of interest

The authors declare no conflict of interest

Authors' contribution

SEJ and ILC contributed equally to data collection, statistical analysis, and manuscript preparation. FAM and BC contributed to conceptualization, review, and editing, with BC

also involved in funding acquisition. JG conceived and designed the study, acquired funding, supervised the study, and was a major contributor to writing the manuscript.

Table 1. Basic Anthropometric and Body Composition Parameters of the Study Population

Characteristics	Mean	± SD
Age (years)	20.600	1.614
Height (cm)	173.650	6.079
Weight (kg)	66.542	7.794
BMI (kg/m ²)	22.025	1.879
Total body water (%)	55.598	4.166
Body fat (%)	16.673	3.869
BIA-estimated muscle mass (kg)	52.430	5.365
Handgrip strength (kg)	38.600	7.543

Table 2. BIA-estimated Segmental Muscle Mass of the Study Population

BIA-estimated Segmental Muscle Mass	Mean	±SD
Right arm muscle mass (kg)	2.673	0.346
Left arm muscle mass (kg)	2.488	0.356
Trunk muscle mass (kg)	28.915	2.453
Right leg muscle mass (kg)	9.253	1.338
Left leg muscle mass (kg)	9.103	1.262

Table 3. Correlations between handgrip strength and total and segmental BIA-estimated muscle mass

BIA-estimated muscle mass (kg)	r	95% CI	p	Holm-adjusted p-value
Total muscle mass	0.461	0.175–0.676	0.003	0.012
Right arm	0.478	0.196–0.687	0.002	0.010
Left arm	0.521	0.250–0.716	<0.001	<0.005
Trunk	0.438	0.146–0.660	0.005	0.015
Right leg	0.373	0.070–0.613	0.018	0.018
Left leg	0.434	0.142–0.657	0.005	0.015

r, Pearson correlation coefficient; CI, confidence interval; Holm-adjusted p-values were calculated to control the family-wise error rate for the six correlation tests. The Holm-adjusted p-value for the right leg correlation ($p = 0.018$) is reported as the unadjusted value because it was the last comparison in the Holm sequence and remained significant after adjustment.

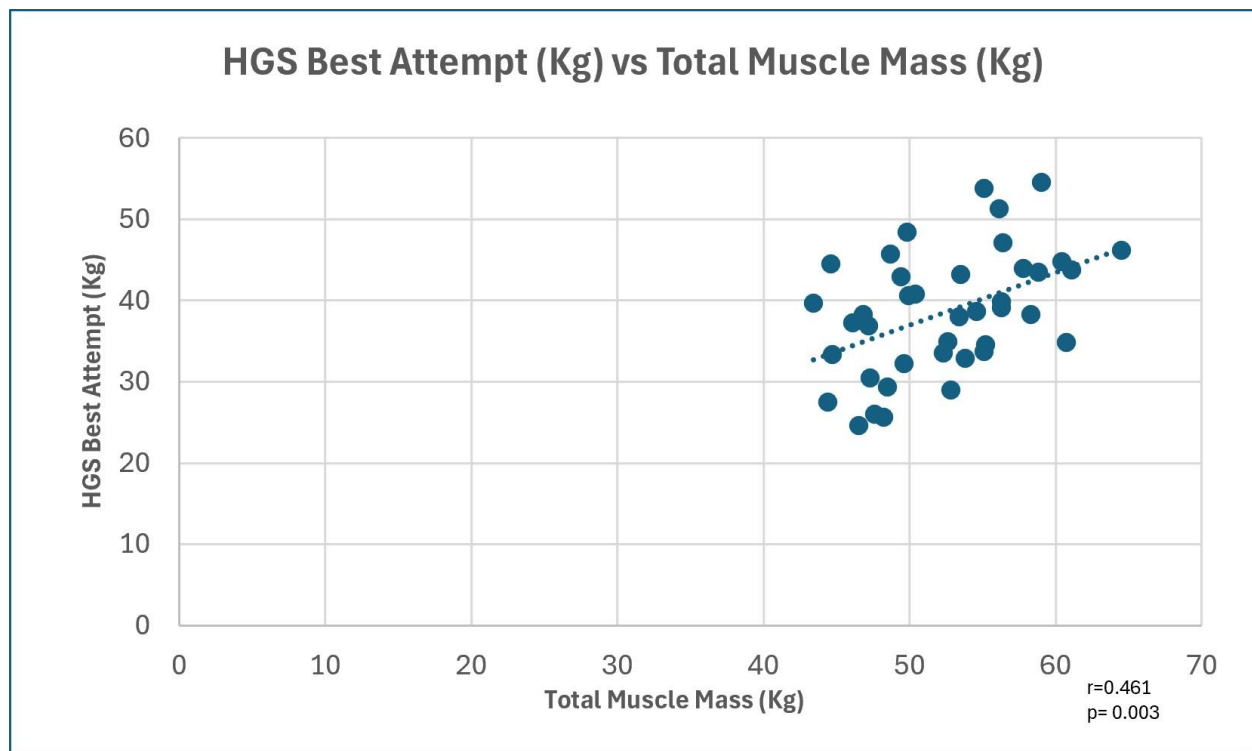


Figure 1a. Correlation analysis of the best attempt at handgrip strength (kg) versus total muscle mass (kg). Pearson's $r = 0.461$, $p = 0.003$, $n = 40$.

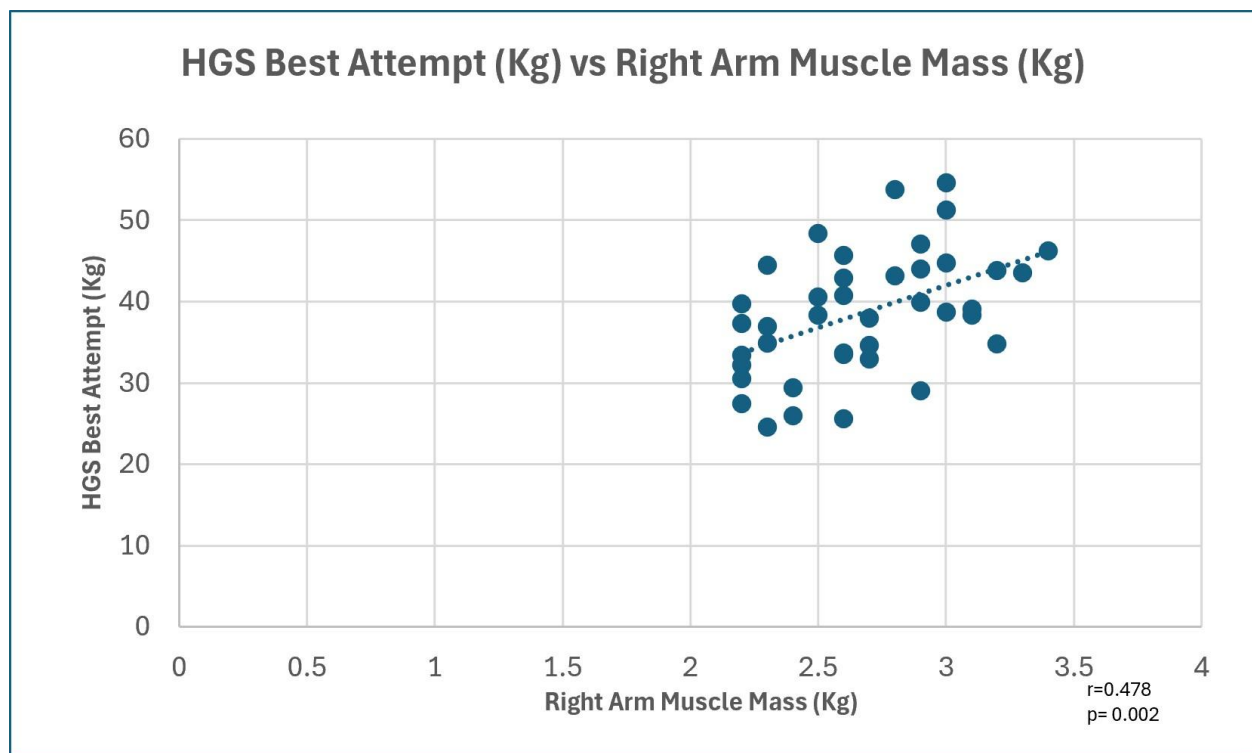


Figure 1b. Correlation analysis of the best attempt at handgrip strength (kg) versus trunk muscle mass (kg). Pearson's $r = 0.438$, $p = 0.005$, $n = 40$.

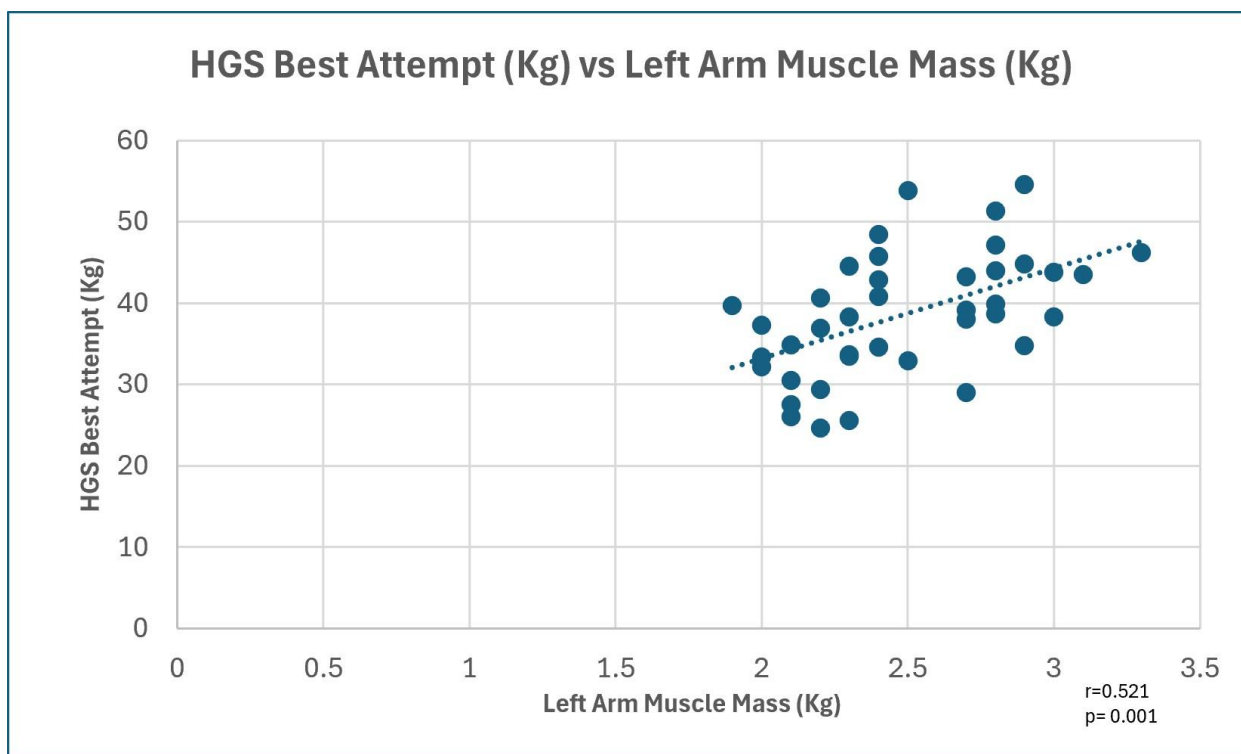


Figure 1c. Correlation analysis of the best attempt at handgrip strength (kg) versus total muscle mass (kg). Pearson's $r = 0.478$, $p = 0.002$, $n = 40$.

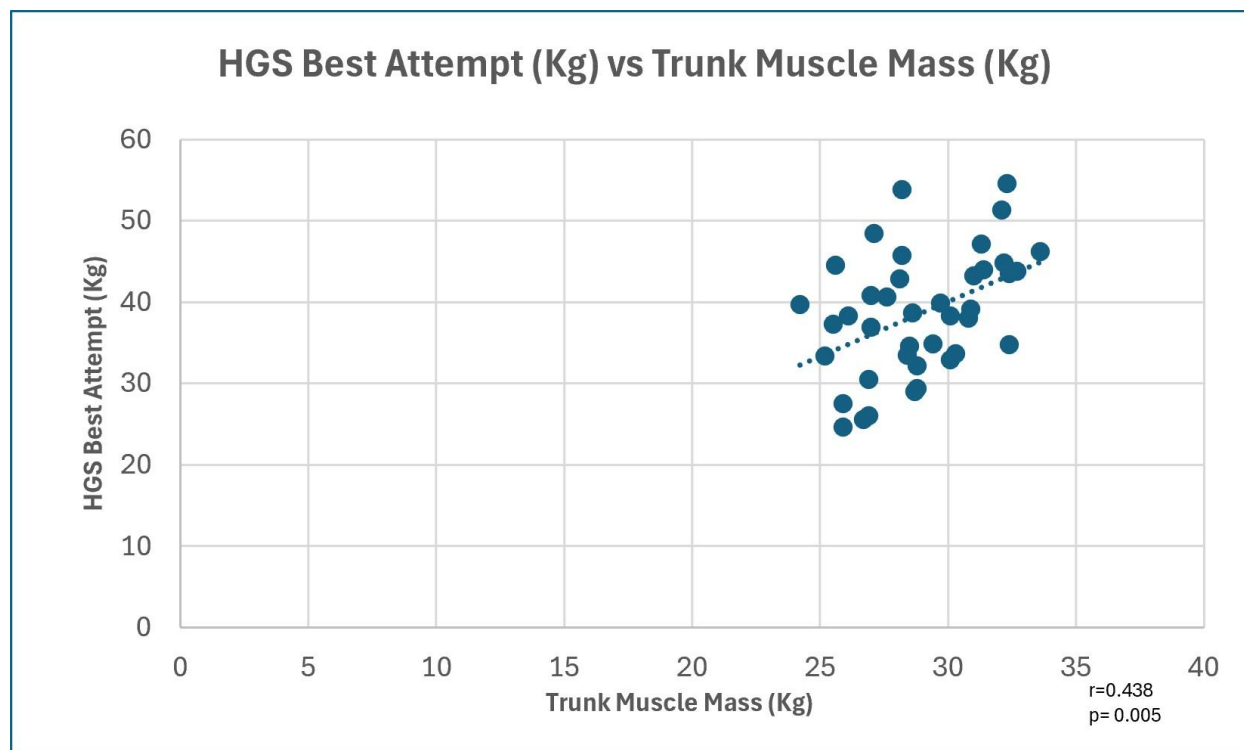


Figure 1d: Correlation analysis of the best attempt at handgrip strength (kg) versus total muscle mass (kg). Pearson's $r = 0.521$, $p < 0.001$, $n = 40$.

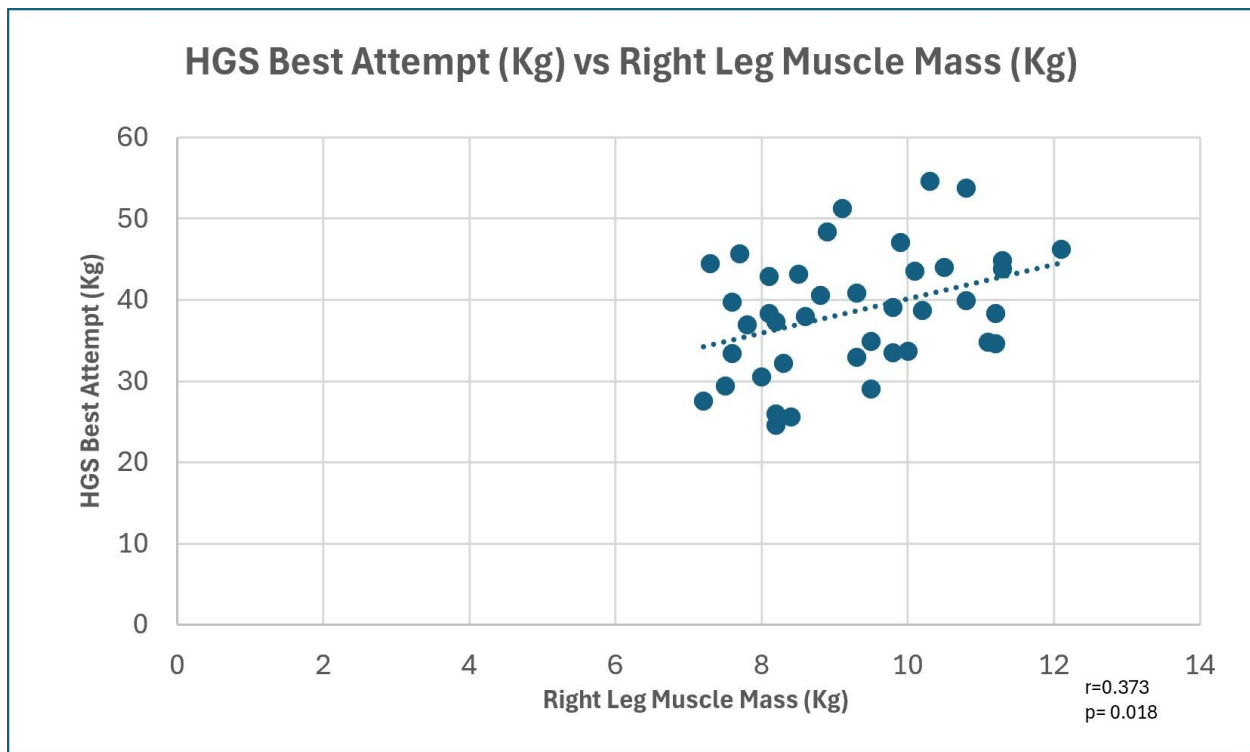


Figure 1e: Correlation analysis of the best attempt at handgrip strength (kg) versus total muscle mass (kg). Pearson's $r = 0.373$, $p = 0.018$, $n = 40$.

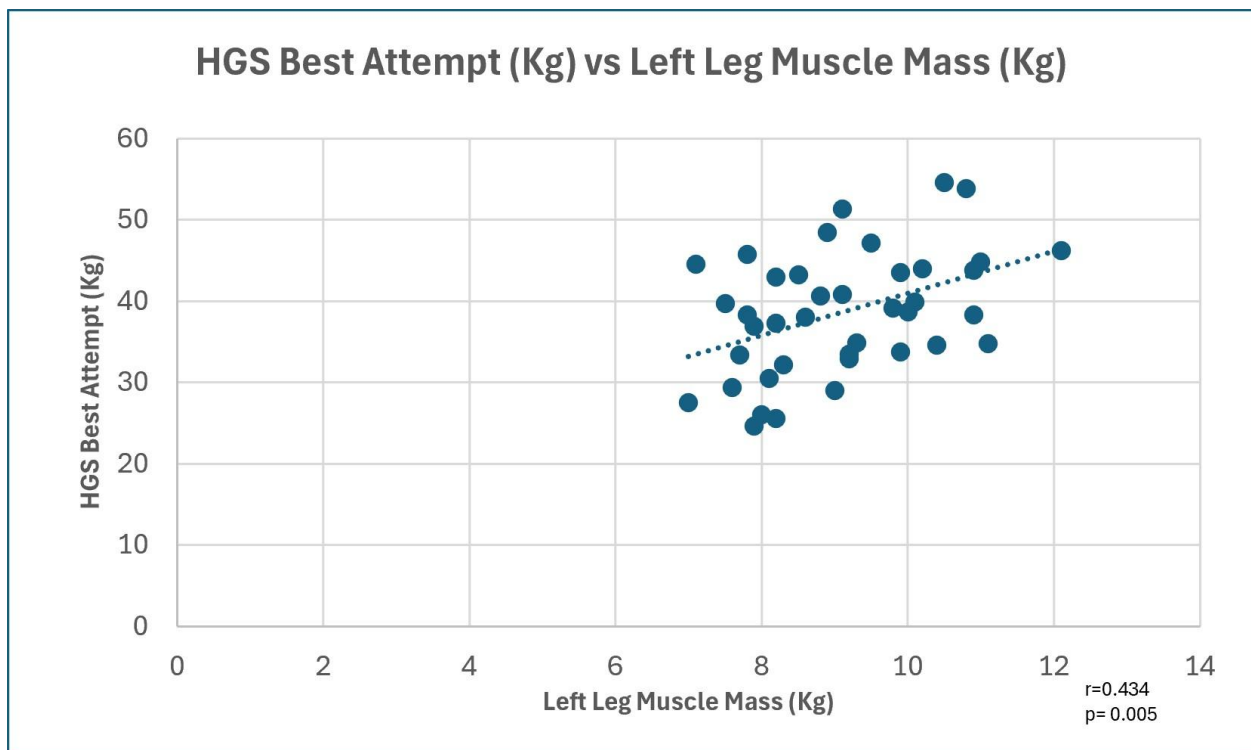


Figure 1f: Correlation analysis of the best attempt at handgrip strength (kg) versus total muscle mass (kg). Pearson's $r = 0.434$, $p = 0.005$, $n = 40$.

Figure 1(a-f). Correlation analysis of total and segmental muscle mass with best-attempt hand grip strength.

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