Association Between Muscle Mass Quantity and Quality and Muscle Strength in Adults with Obesity

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Research Article

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Abstract

Background: This cross-sectional study aimed to verify the association between muscle quantity and quality and muscle strength in obese adults.

Methods: Lean mass (LM) and intracellular water (ICW) were obtained using bioelectrical impedance. Muscle quantity was expressed in kg for LM, while muscle quality was determined by ICW and the ratio of ICW/LM. Maximum strength was measured by the one-repetition maximum test (1RM) in bench press and leg press exercises at 45º. The score for total strength (Z-score) was given by the average of scores for each test. The statistical analysis included Spearman's correlation, whose results were expressed as correlation coefficients (r); crude and adjusted linear regression, expressed as adjusted coefficients of determination (R^2); Bayesian Information Criterion (BIC); and Akaike Information Criteria (AIC).

Results: Sixty-nine adults of both sexes with a mean age of 34 (± 7.1) years participated in the study. A strong positive correlation was found between the amount of LM and muscle strength ($r = 0.83$; $p < 0.001$). There was also a positive correlation between ICW and the ratio of ICW/LM, indicators of muscle quality, and muscle strength, resulting in strong ($r = 0.83$ $p < 0.001$) and moderate ($r = 0.40$ $p < 0.001$) magnitudes, respectively. Additionally, ICW had better predictive power for muscle strength (R2 adjusted = 0.98; AIC: 161.8483; BIC: 175.253).

Conclusion: Muscle quantity and quality presented good predictive capacity for muscle strength. Assessing muscle quality can provide further clarification on how the muscle is able to produce strength in adults with obesity.

Introduction

Muscle mass is a metabolically active tissue that plays an important role in the body [1], and it has a positive impact on basal metabolic rate, lipid oxidation, daily energy expenditure, and on weight loss and control as a consequence [2]. Peak muscle mass is reached in early adulthood, and it gradually declines around the fourth decade of life, accelerating after the age of 50 [3].

Aside from age, reduced muscle mass is influenced by genetic factors, an unhealthy lifestyle, and obesity [3], and it gives rise to frailty, physiological imbalance with pro-inflammatory conditions [4], and reduced levels of muscle strength [3]. Strategies to reverse this situation include changes in eating habits and physical exercise [5] while focusing on improving body composition, especially increasing muscle mass [1]; promoting gains in muscle strength and cardiorespiratory capacity [6]; and reducing pro-inflammatory markers [7].

The association between the amount of muscle mass and muscle strength has been made evident in the literature [8, 9]. However, recent studies suggest that muscle quality, among other aspects, can better explain the decline in muscle strength levels [10, 11]. Muscle quality is defined as the capacity to generate force relative to the volume of contractile tissue [12]. In this sense, some studies point to intracellular water (ICW) and the ICW/lean mass (LM) ratio as indicators of muscle quality [10, 11] since water makes up most of the LM [10]. In fact, older adults, women, and individuals with obesity have less LM and, consequently, a lower amount of total body water (TBW) [10].

Although the literature presents information pointing to ICW and the ICW/LM ratio as indicators of muscle quality, few studies have investigated these indicators in the adult population with obesity. Given the evident scenario of reduced muscle mass and its implications for the health of the adult population with obesity, expanding assessment strategies for parameters related to muscle mass quantity and quality and their association to muscle strength is important. Therefore, the aim of this study is to verify the association between muscle quantity and quality and muscle strength in adults with obesity.

Materials And Methods

This is a cross-sectional study that used baseline data from a randomized clinical trial targeting obese adults. The study was approved by the Committee for Ethics in Research on Human Beings of the [University Name] (protocol 2448,674) and is registered in the Brazilian Registry of Clinical Trials (RBR-3c7rt3). Data for this analysis were collected in April 2018. All volunteers signed an informed consent form.

Adults of both sexes between the ages of 20 and 50 years with grade I and II obesity, as determined by BMI (30-34.9 kg/m² and 35-39.9 kg/m², respectively), participated in the study. Individuals who had not regularly participated in a physical exercise program (< 2 times a week) in the three months prior to the study, who were non-smokers or had not smoked for over a year, who did not consume excessive alcohol (≤ 7 drinks per week for women and ≤ 14 drinks per week for men), who did not use medication to control obesity, and who did not undergo surgical procedures for weight loss were considered eligible to participate in the study. The sample selection process was non-probabilistic. A description of the sampling procedure and the methodological details of the clinical trial is provided in the protocol study [13].

Study participants underwent a body composition assessment using octopolar, multi-frequency bioelectrical impedance (BIA) equipment, model InBody® 720 (Biospace, Los Angeles, CA, USA), in accordance with the manufacturer's instructions. Therefore, the recommendations for the use of BIA in clinical practice were followed [14]. Participants were instructed not to consume alcoholic or caffeinated beverages in the 12 hours prior to the test and not to practice physical activity the day before. On the day of measurement, participants were asked to abstain from food and fluids for four hours prior to the assessment. Women in their menstruation period were rescheduled. During the assessment, the participants remained in an orthostatic position holding two levers, with their feet placed under a platform. All evaluations were conducted in the morning by experienced evaluators. For the examination, the participants wore bathing suits and were barefoot and were not wearing earrings and/or rings or other metals. The following variables were obtained: body mass (BM) (kg), lean mass (LM) (kg), total body water (TBW) (L), intracellular water (ICW) (mL), and extracellular water (ECW) (mL). Additionally, the ICW/LM ratio (mL/kg) was calculated.

Maximum strength was determined by the one-repetition maximum test (1RM) in bench press and leg press exercises at 45º [15]. The participants performed a warm-up set of six to 10 repetitions with approximately 50% of the estimated load for the first experimental trial before each exercise. After two minutes, three 1RM attempts were performed between intervals of three to five minutes. The test ended when there was a difference of 2 kg in the bench press and 4 kg in leg the press at 45º between a successful and an unsuccessful attempt. The highest load lifted was considered as the final value, expressed in kilograms (kg). The participant's form and technique to perform each exercise were standardized and continuously monitored. To familiarize the participants with the test, all the participants performed the protocol in at least three distinct sessions with a minimum interval of 48 hours. The maximum load recorded was used to calculate the strength score for the lower and upper limbs (by subtracting the individual value from the mean value and dividing the difference by the standard deviation value). The total strength score (Z-score) was given by the average of the scores for each of the variables (RMleg and RMsup).

The variables sex (male and female), skin color (white and non-white), and age (in years) of the participants were collected from a questionnaire and used as adjustment variables. Usual protein intake (g/day) and water intake (L/day) were also considered. These data were obtained from a 24-hour dietary recall applied on three non-consecutive days, which was given in the form of an interview on the previous day's food and water intake, quantities, portions in household measures, preparation method, and ingredients used. The "Multiple Pass Method" technique was used to reduce possible biases in data collection on food consumption [16]. Energy and nutrient consumption were estimated (NDSR 2017 software; NCC Food and Nutrient Database, University of Minnesota, USA), and data were entered into the software according to the "Manual on Assessing Food Consumption in Population Studies" [17]. Moreover, the level of physical activity, objectively measured by accelerometry, was also considered as an adjustment variable. The participants used an accelerometer (ActiGraph GT3X +) on their right hip for seven consecutive days, removing it only for activities related to sleep, bathing, or water. The ActiLife software was used to analyze the data, where a minimum of 10 hours of daily use of the device for at least four days, including three days during the week (Monday to Friday) and one day on the weekend, was considered valid. The time spent on light, moderate, and vigorous physical activity was calculated from the proposed cutoff points which had been previously validated [18, 19], and the values were adjustedaccording to the number of valid days and hours of use. Total physical activity (sum of the time spent on light, moderate, and vigorous activities) was expressed in minutes per day.

Statistical analysis

For the descriptive analysis, interquartile ranges, mean, and standard deviation were used. Data normality was verified by the Shapiro Wilk test. Spearman's test was used to observe the correlation between the muscle quality and quantity variables and muscle strength. Correlations were evaluated by their coefficients (r) and classified as weak ($0 \leq r \geq 0.299$), moderate ($0.300 \leq r \geq 0.499$), or strong ($0.500 \leq r \geq 1.000$) [20].

Simple and multiple linear regression analyses were employed to test the association between muscle quality variables and exposure. The independent variables were tested separately in the crude analysis. Two levels with hierarchical linear modeling into the model were tested in the adjustment: (I) sex, skin color, age, and BMI; (II) moderate to vigorous physical activity, habitual water consumption, daily protein consumption, and extracellular water. Only one independent variable was used per model. Variables with a p value > 0.20 were removed according to the backward technique.

Regression coefficients (ß) and their respective 95% confidence intervals (95%CI), standardized regression coefficients and adjusted determination coefficients (R^2), and the variance inflation factor (VIF) as a multicollinearity indicator were estimated. Additionally, the Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC) values for each model were determined. The STATA® software (StataCorp LLC, Texas, USA) version 14.0 was used for all the analyses. Statistical significance was established when $p < 0.05$.

Results

Sixty-nine adults (27 males) participated in the study. The mean age was 34 years (± 7.1), and the mean BMI was 33.5 kg/m2 (± 2.8). Table 1 presents the descriptive values for the main characteristics of the sample and the variables.

Table 1		
Sample characterization of adults with obesity (n = 69).		
	Interquartile ranges p.25; p.75	**Mean (±SD)**
Intracellular water - ICW (mL)	21.7; 30.7	26.6 (± 5.9)
Lean Mass - LM (kg)	44.5; 63.2	54.9 (± 12.1)
ICW/LM ratio	0.483; 0.487	0.485 (± 0.003)
RM lower (kg)	177.2; 305.5	240.0 (± 77.4)
RM upper (kg)	37.7; 67.7	53.1 (± 20.9)
Strength Z-score	-0.75; 0.80	0.01 (± 0.9)
Age (years)	29.0; 39.0	34.6 (± 7.1)
BMI (kg/m²)	31.5; 34.5	33.5 (± 2.8)
Water intake (L/day)	833; 1.916	1.412 (± 749)
Protein intake (g/day)	78.0; 118.5	97.6 (± 25.0)
Total Body Water - TBW (%)	29.2; 51.2	42.3 (± 15.4)
MVPA (min/day)	34; 74	58.5 (± 34.0)
	N	**%**
Sex (Female)	42	60.8
Skin color (white)	55	79,7

p.25: 25th percentile; p.75: 75th percentile; SD: standard deviation; RM: repetition maximum.

n: absolute frequency; %: relative frequency.

RM: repetition maximum.

MVPA: moderate- to-vigorous physical activity.

Figure 1 presents the scatter plots which demonstrate the correlations between the variables. A positive correlation was found between the amount of lean mass and the muscle strength score (r = 0.83 p < 0.001). There was also a positive correlation between intracellular water and the ratio between intracellular water and lean mass, indicators of muscle quality, and muscle strength, revealing strong (r = 0.83 p < 0.001) and moderate (r = 0.40 p < 0.001) magnitudes, respectively.

<insert figure 1>

Table 2 shows the association between muscle quantity and quality indicators and muscle strength among obese adults. As for the amount of lean mass, an increase of 1 kg to this variable implied an increase of 0.04 in the muscle strength Z-score ($p<0.001$). On the other hand, an increase of 1 mL in intracellular water implied an increase of 0.06 in the muscle strength Z-score ($p<0.001$). A 1-unit increase in the ICW/LM ratio implied an increase of 0.83 in the outcome ($p=0.01$). Both the amount of muscle mass and intracellular water presented the best explanatory capacities for muscle strength, as each of the models adjusted for these variables explained 98% of the variability in muscle strength (adjusted $R2=0.98$). Finally, the intracellular water variable exhibited the lowest values for the Akaike information criterion (AIC) and the Bayesian information criterion (BIC), thus verifying that its predictive power for muscle strength is better in comparison to the other two indicators.

Table 2

Association between muscle quantity and quality and muscle strength Z-score (n = 69).

	β	β standardized	SE	Adjusted R^2	p-value	VIF	AIC	BIC
LM								
Crude model	0.86	10.7	0.75	0.75	<0.001	-	446.458	450.926
Adjusted model	0.04	0.58	0.45	0.98	0.001	3.94	251.823	265.228
ICW								
Crude model	0.87	5.31	0.36	0.75	<0.001	-	345.733	350.201
Adjusted model	0.06	0.42	0.24	0.98	<0.001	3.94	161.8483	175.253
ICW/LM								
Crude model	0.42	0.001	0.001	0.18	<0.001	-	-578.376	-573.908
Adjusted model	0.83	0.004	0.001	0.29	0.001	2.87	-461.982	-451.946

Note: VIF = Variance Inflation Fator; BIC = Bayesian Information Criterion; AIC: Akaike Information Criterion.

Discussion

The aim of this study was to examine the association between muscle quantity and quality and muscle strength in adults with obesity. The main finding showed that muscle mass quantity and quality can be used to predict muscle strength in the adult population with obesity. This finding is important as there is considerable heterogeneity between subjects regarding strength and muscle mass ratios, and it reveals the involvement of the muscle's intrinsic aspects in the ability to generate force, in addition to the quantity.

The association between the amount of muscle mass and muscle strength found in the results was expected, even in an obese population. Although the relationship between muscle quantity and muscle strength cannot be ignored, there is a consensus that this relationship is not quite clear and that losses or gains in strength are only partially explained by decreases or increases in muscle mass. Producing force depends on neural, neuromuscular, and muscle tissue characteristics [21], while muscle tissue modulates the functional capacity of skeletal muscle through muscle architecture, composition, metabolism, fat infiltration, and fibrosis [22]. When maximum muscle strength is normalized to body mass in individuals with obesity, for example, they seem to be weaker, and this relative weakness can be caused by different determinants, including changes in muscle morphology [23]. Thus, it is reasonable to assume that it is more difficult to establish a direct relationship between the amount of muscle mass and muscle strength as body fat increases.

Although the results of the study indicate an association between both muscle quantity and quality and muscle strength, intracellular water (quality indicator) demonstrated the best predictive power for muscle strength. This information reiterates the importance of assessing muscle quality, as it aggregates different components of the functional structure and better represents the variability of muscle performance. In the specific case of ICW, it is usually proportional to the total amount and size of muscle fibers in the segment [24], and it has a good correlation with muscle function and strength [25]. Obesity and age tend to increase the extracellular space and reduce the concentration of intracellular water, which directly affects the muscle's functional properties. Thus, the excess fat mass that normally coexists with low muscle mass and function tends to reduce muscle quality and muscle strength as a consequence [26], thereby increasing the risk for health problems such as metabolic syndrome, hospitalization, and higher mortality [27]. Furthermore, excess fat mass favors the infiltration of ectopic fat into the muscle (myosteatosis), which can facilitate the transition process of muscle fibers from type II to type I and reduce contractile function, power, and mobility [28].

In addition to assessing muscle quality using ICW, the ratio of intracellular water to lean mass was also investigated. An association between this muscle quality indicator and muscle strength was also observed, but to a lesser extent. Serra-Prat et al. [10] examined a sample of older adults with obesity and also found a positive association between ICW/LM and muscle strength [10]. The ICW/LM ratio is based on the hypothesis of reduced muscle cells or reduced hydration, which is plausible in the obese population. Regardless of the reason, the altered cell volume determined by ICW seems to be an important metabolic signal that regulates cell and muscle functions [11]. However, little is known about muscle quality indicators, including the ICW/LM ratio in the adult population with obesity. The few studies that exist were conducted with older adults and even considered the presence of predisposing factors in this population (cellular dehydration and MM reduction). Therefore, it is still not possible to clearly determine the impact of excess body fat on muscle quality through ICW/LM.

In this context, the literature reports that uniformity and clarity are still needed to define muscle quality and the measurement method [29]. Despite these gaps, the findings of this study contribute to amplifying the view of the muscle's functional qualities in the adult population with obesity. For reasons that have been widely explained, decreases in muscle strength tend to occur faster than decreases in muscle mass. However, this condition may be even more evident in the obese population when intrinsic aspects of muscle function are considered. The recommendation in this case is to consider muscle quality in the preliminary assessments and in prescribing physical exercises for subjects with obesity, which should focus on improving body composition and reducing body weight qualitatively. High muscle quality, even in subjects with low muscle mass, can reduce the risk of functional deficiencies [30] associated with age and excess body fat.

Finally, assessing muscle quality in younger populations is also relevant given the possibility to alleviate aging complications. Many determinants of muscle function, such as obesity, physical activity, eating habits, cardiovascular and metabolic diseases, play an early role and have significant impacts on muscle strength and quality [31, 22]. It is therefore necessary to consider reduced muscle strength and poor muscle quality as population problems that precede senescence. There have been reports of a high prevalence (84%) of poor muscle quality in the obese population (18–75 years), which was mainly attributed to low specific strength, and age, sex, and BMI were independent predictors [32].

This study broadens the perspective for analyzing muscle strength predictors by adopting muscle quantity and different muscle quality indicators (ICW and ICW/ML ratio). This study is unique in that it examines the adult population with obesity, whose relation to this particular topic has not been thoroughly examined, and in its analyses adjusted for important determinants such as physical activity and protein consumption. Moreover, the use of BIA deserves attention since it is portable, accessible, and considered to be appropriate for determining the amount of body water. It can be used daily in the clinical environment to assess both muscle quality and quantity.

Muscle quantity and quality demonstrated good predictive capacity for muscle strength in obese adults. In this population, muscle mass and muscle strength are extremely important for good functional and metabolic capacity and for preventing health problems. Since it represents aspects of the muscle's functional structure, assessing muscle quality can enhance quantitative analyses of muscle mass and provide further clarification on the muscle's capacity to produce strength.

Declarations

Ethical approval:

The study was approved by the Committee for Ethics in Research on Human Beings of the Federal University of Santa Catarina (protocol 2448,674). All procedures were performed in accordance with the ethical standards set out in the Declaration of Helsinki of 1964 and its subsequent amendments. In addition, all subjects gave their informed consent before being included in the study, with anonymity being guaranteed at all stages.

Author Contributions:

ARS: was responsible for designing and writing the protocol, conducting the research, analyzing data, interpreting results, and creating tables and writing the manuscript. JB: was responsible for designing and writing the protocol, conducting the research, interpreting results, and creating tables and writing the manuscript. FR and GTB: interpreted results, creating tables and writing the manuscript. AMG and GFDD: designing and writing the protocol and provided feedback on the report.

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Conflict of interest:

We declare that there are no potential conflicts of interest associated with this publication.

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Figures

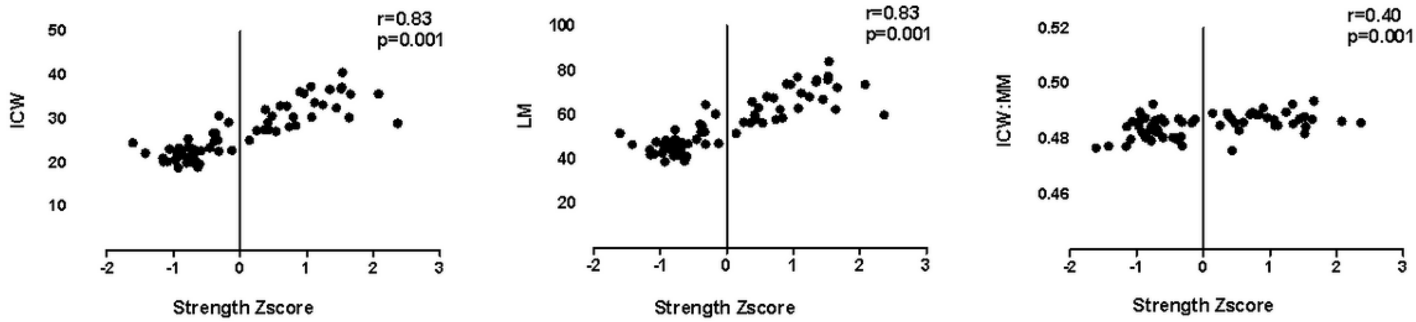

Figure 1

Scatter plots demonstrating the correlation between intracellular water, lean mass, and the ICW/LM ratio and the muscle strength z-score in adults with obesity (n=69).