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Original Research

Effects of Resistance Training on Muscle Quality Index, Muscle Strength, Functional Capacity, and Serum Immunoglobulin Levels between Obese and Non-obese Older Women

PAULO ROBERTO SILVA JUNIOR†[1], DAHAN DA CUNHA NASCIMENTO‡[1,2,6], IVO VIEIRA DE SOUSA NETO†[3], SILVANA SCHWERZ FUNGHETTO‡[4], RAMIRES ALSAMIR TIBANA‡[1], JAMES W. NAVALTA‡[7], FABIANI LAGE RODRIGUES BEAL‡[5,6] and JONATO PRESTES‡[1]

[1]Department of Physical Education, Catholic University of Brasilia (UCB), Brasilia, DF, BRAZIL; [2]Department of Physical Education, Center University of Distrito Federal (UDF), Brasilia, DF, BRAZIL; [3]Laboratory of molecular analysis, Graduate program of Sciences and Technology of Health, University of Brasilia, DF, BRAZIL; [4]Department of Nursing, University of Brasilia (UNB), Brasilia, DF, BRAZIL; [5]Department of Nutrition, Health and Medicine School, Catholic University of Brasilia, UCB, Brasilia, DF, BRAZIL; [6]Department of Gerontology, Catholic University of Brasilia, UCB, Brasilia, DF, BRAZIL; [7]Department of Kinesiology and Nutrition Sciences, University of Nevada, Las Vegas, NV, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 14(7): 707-726, 2021. Considering the negative impact of obesity on neuromuscular and immune systems, we sought to compare the effects of a 10-week resistance training (RT) program on muscle quality index (MQI), muscle strength, functional capacity, and immunoglobulins in older women with and without obesity. Thirty-nine older women participated in the present study (age: 69.02 ± 6.16, fat (%): 38.80% ± 6.28) and underwent a linear RT program performed on two non-consecutive days of the week. Body composition, functional tests, immunoglobulins, muscle quality of upper and lower limbs and absolute muscular strength of the upper and lower limbs were measured. Both groups displayed an increased statistically significant difference in MQI between pre-post training, however obese participants showed a lower field and laboratory MQI when compared to non-obese participants at the same time-points. Obese participants displayed an increased statistically significant 30-second chair stand test, with no differences for non-obese participants. Obese participants showed a higher statistically significant difference for immunoglobulin M when compared to the non-obese group at post-training. Finally, both groups displayed an increased statistically significant difference in muscle strength between pre-post-training. However, obese participants showed a statistically significant lower 10-RM low row score when compared to non-obese participants at post-training. Obese older women showed a lower field and laboratory MQI when compared to non-obese post-training, besides a lower 10-RM low row score which reinforces that obesity blunts the beneficial effects of RT on muscle quality and strength.

KEY WORDS: Obesity, older adults, physical activity, immune system

*Corresponding Author: Paulo Silva; Email:pauloroberto2823@gmail.com

INTRODUCTION

In the next decade the number of people 60 years of age or older will increase 46% worldwide, and it is estimated that by the year 2030 there will be 1.4 billon elderly in the world, surpassing the number of young people. This scenario is due to a combination of factors, such as decreased fertility rates, mortality, increased in life expectancy, and improved health services (50). Although the aging process itself results in decreased functional capacity, obesity associated with insufficient physical activity levels significantly elevates the degree of impairment of the physiological systems in elderly participants. Therefore, aging and obesity together result in decreased capacity to perform activities of daily living, physical disability, cognitive impairment, balance and gait disturbances (9, 10, 15).

Recently, Silva et al. (12) demonstrated that older sarcopenic obesity participants demonstrated attenuated 16 week resistance training (RT) adaptations with respect to muscle strength and functional capacity. In addition, Villareal et al. (52) demonstrated that obese older participants displayed a lower muscle quality index and physical function when compared with non-obese older participants. The possible explanation is that older obese participants, present a greater proportion of intermuscular adipose tissue to contractile elements, demonstrating that fat is a determinant of muscle function and quality in later life (32).

Acknowledging this, muscle quality index (MQI) or muscle strength per unit of muscle mass, has been recognized as an important surrogate for physical function and mortality in older individuals (8, 25). This simple measure provides an estimate of the contribution of neuromuscular factors affecting muscle strength as well as loss of muscle strength during the aging process (21). For a better evaluation of MQI, field (ratio of handgrip strength to body mass index [BMI]) and laboratory-based (ratio of handgrip strength to the entire arm muscle in kilograms measured by DXA) estimates were previously compared and demonstrated a strong relationship, inferring that field-based MQI may be implemented as an initial assessment tool for older adults, due to the ease of assessment, cost and relevance (35).

Furthermore, considering that age and adipose tissue potentially have a negative impact on MQI (35) and considering that MQI may be a better indicator for physical performance in older adults than muscle strength (8, 36), additional research is necessary to better characterize the impact of chronic RT on both field and laboratory-based estimates between obese and non-obese older adults (47).

Among the possible behavioral changes to be implemented during aging, resistance training (RT) is a popular and efficient form of exercise recommended by health organizations, such as the American College of Sports Medicine (1, 28), and the National Strength and Conditioning Association (19). Resistance training is considered an important non-pharmacologic tool capable of inducing significant positive effects on MQI, muscle strength and mass, functional capacity and inflammation in older people (1, 38), which contributes to better health and well-being.

On the other hand, excess adipose tissue is responsible for generating chronic low grade inflammation (48), while adipose tissue cells, especially viscerally located, are considered to be an immune organ (45).

Regarding the immune system, humoral immunity is an essential mechanism of defense, acting as the primary barriers against antigens. Furthermore, obesity may also act in specific immune responses generated by humoral immunity (44). This immune activity is organized by molecules from blood and mucous secretion known as immunoglobulins (Igs) (14). The Igs are a class of glycoprotein molecules (antibodies) produced by B lymphocytes (plasmocytes) in the event of an immune response to an antigen. It has been reported that serum immunoglobulins play a crucial role in the first line of defense against harmful environmental factors, which can be relevant to producing enhanced immune responses in obese elderly individuals.

The different classes of Igs are IgA, IgD, IgE, IgG and IgM, while IgA is designed to defend the exterior of the intestinal mucosa against microscopic pathogens, and blocks parasitic bacteria in the intestinal lumen (30). IgG is highly present in blood and exerts immune functions in the complement system (4). Lin et al. (29) suggest that lower serum IgG levels may be found in individuals with components of metabolic syndrome. IgM is an antibody activated by a previous contact with antigens (17). Marzullo et al. (31) reported that IgM levels are significantly decreased in patients with obesity in association to significant increments in leukocyte counts. However, previous data have shown that adaptive immune system in athletes and healthy individuals can be altered by exercise programs through up-regulating serum immunoglobulins, which play an important role in strengthening humoral immunity (23). The link between different Igs with RT in obese and non-obese older adults has been neglected. This information would be valuable to elucidate potential mechanisms induced by exercise training that could attenuate harmful alterations inherent to the immune system.

Considering the negative impact of the aging process and obesity on both the neuromuscular and immune systems, the overall aim was to compare the effects of 10-weeks of RT on muscle quality, functional capacity, muscle strength and immunoglobulins between older women with and without obesity. The initial hypothesis is that obesity blunts the beneficial effects of RT on muscle quality, muscle strength, functional capacity, and immunoglobulins.

METHODS

Participants

A total of 157 elderly women were assessed for eligibility; 104 were excluded (did not meet inclusion criteria), 14 dropped out before completion the study and thus 39 elderly women completed the RT program. The sample consisted of older women (≥ 60 years) who were recruited on a voluntary basis from the Catholic University of Brasilia following advertisements and lectures. Sedentary and physically active women with controlled essential hypertension were included. Participants that declared to have any immune and/or inflammatory disease were excluded. The Institutional Research Ethics Committee of the Catholic University of Brasilia approved all procedures and measurements (protocol number:

45648115.8.0000.5650/2016). The study design and employed procedures were in accordance with the ethical standards of the Declaration of Helsinki (41). Each participant was fully informed about the risks and benefits associated with participation and provided signed consent. Each participant was interviewed and responded to a health history questionnaire (43). Participants then completed an exercise electrocardiogram, resting blood pressure measurements, body composition assessment by dual-energy x-ray absorptiometry (DXA), and orthopedic evaluation by a physiotherapist. Obesity was considered as a body fat percentage ≥ 38%(6) accordance with specifications proposed in the literature and none of the participants in this study were sarcopenic according to Cruz-Jentoft et al 2019 (11). During the study, participants maintained the prescribed use of their medications (20) and were encouraged to maintain their usual diet, and to avoid unusual physical activity during the 10-week RT program.

Protocol

Ten Repetitions Maximum Tests: First, participants completed a 2-week familiarization prior to the RT 10-repetition maximum test (10 RM). During the familiarization period, older adults completed 2 sessions per week, performing 2 sets of 15 submaximal repetitions with a 1-minute rest interval between sets and exercises (15).

The week after familiarization, upper and lower body strength was evaluated by ten-repetition maximum (10-RM) strength testing. Participants were tested for 10-RM at the same time of day for the following exercises in this order: machine leg press, machine chest press, machine leg extension, machine low row, and machine leg curl (Righetto Fitness Equipment®, Sao Paulo, Brazil). In brief, participants warmed-up on each exercise with 5-10 submaximal repetitions. All procedures were in accordance with a previously published study (3).

Two experienced RT professionals supervised the tests. Furthermore, participants were evaluated by an experienced physiotherapist before the 10-RM testing and study participation. Previous studies from our research group demonstrated a high test and retest reliability for this type of test $r > 0.97$ (16, 37).

Resistance training program: There were two groups of training and because of this, the RT sessions were scheduled between the hours of 8:00 AM and 10:00 AM (morning class, N = 21), and 1:00 PM and 3:00 PM (afternoon class, N = 18). There was no randomization of groups for period of training.

The program lasted 10-weeks, with two weekly sessions, and an interval of at least 24 hours between sessions. The periodization scheme was in accordance and adapted with our previous research described in detail elsewhere (34, 38).

Briefly, older women were instructed to lift and lower loads at a constant velocity, taking ~2 sec for the concentric and 2 sec for the eccentric phase. In the first 3 weeks, three sets of 12–14 repetition maximum (RM) with a 60-sec rest interval were performed; from weeks 4–6, three sets of 10–12 RM with a 80-sec rest interval were performed; from weeks 7–8, three sets of 8–10

RM with a 100-sec rest interval were performed; and from weeks 9–10, three sets of 6–8 RM with a 120-sec rest interval were performed. When subjects performed more than three repetitions in the third set beyond the RM zone prescribed the loads were adjusted. During sessions, participants commonly reported tiredness and difficulty to complete the proposed repetition range on the third set. In all weeks, repetitions were performed close to concentric failure at the intensities indicated. The loads were monitored in each session. The list and order of the used exercises were as follows: 1) machine leg press; 2) machine chest press; 3) machine leg extension; 4) machine low row; and 5) machine leg curl. Training volume for each exercise was calculated as the product of number of repetitions by the load lifted. All sessions were supervised by experienced RT professionals with a high supervision ratio of 1:1 to favor greater strength gains and for safety.

Handgrip strength: Handgrip strength (HGS) was evaluated using a validated handgrip Hydraulic dynamometer (Saehan Corp®, SH5001, S. Korea) (40). Three measures on the right and left hand were obtained and the highest value was recorded. Verbal encouragement was used for all participants with 1-minute rest intervals between measurements. Measurements for handgrip strength were scheduled between the hours of 8:00 AM and 10:00 AM and 1:00 PM and 3:00 PM after familiarization period for pre-training and 2 days after the last training session (post-training).

Functional tests: The functional tests performed were the 6-minute walk test, 30-second chair-stand, and the timed-up-and-go test(26). Measurements for functional tests were scheduled between the hours of 8:00 AM and 10:00 AM and 1:00 PM and 3:00 PM after familiarization period for pre-training and 2 days after the last training session (post-training).

Muscle quality index: To calculate upper body MQI, the highest reading from each hand was divided by the participant's BMI (46) (field-based approach) and by lean mass (measured in kg) from both arms evaluated by DXA (laboratory-based approach) (22, 35). To calculate the lower body MQI, the 10 RM obtained from the leg extension exercise was divided by the participant's lean mass from both legs (measured in kg) evaluated by DXA (22). In addition, previous research supported strength corrected for BMI over absolute strength measures (39, 46, 49), as a field-based approach with handgrip normalized by BMI can predict performance on objective measures of physical function similar to a laboratory based-approach (46).

Body composition analysis and anthropometric measurements: Body composition analysis was evaluated using DXA (General Electric-GE model 8548 BX1L, year 2005, Lunar DPX type, software Encore 2005; Rommelsdorf, Germany). Briefly, the apparatus was operated by a technically trained professional who performed a complete body scan with the participant in the supine position. DXA calibration was performed, and a phantom was used to check this calibration daily before body composition was evaluated. Legs were secured using non-elastic straps at the knee and ankles, and the arms were aligned along the trunk with the palms facing the thighs. Body mass (kg) was measured using a scale (W200 LCD Portable Welmy), and a conventional stadiometer was used to measure height (m). Body mass index was calculated by the traditional equation (body mass/height^2). Measurements for body composition analysis and

anthropometric measurements were scheduled between the hours of 8:00 AM and 10:00 AM and 1:00 PM and 3:00 PM after familiarization period for pre-training and 2 days after the last training session (post-training).

Immunoglobulin quantification: To measure Igs, blood samples were drawn from the antecubital vein 48h after the end of experimental period. A 4 mL blood sample was collected, centrifuged at 2,500 rpm for 15 minutes for serum, and posteriorly stored at −70°C at the laboratory. The quantification of immunoglobulins was measured by the equipment BN™ II System with the method of nephelometric analyzer using the BN Prospec Nephelometer Analyzer and commercially available kits from Dade Behring, Marburg, Germany. Analysis of immunoglobulins was provided by an experienced laboratory (Sabin Institute). The CV of intra- and inter-assays were < 5%. For sample collection, a voucher was distributed for participants, and were requested for participants to attend Sabin Institute between the hours of 8:00 AM and 10:00 AM 2 days after the last training session (post-training).

Statistical Analysis

Descriptive statistics were expressed as means and standard deviation (SD). Normality was assessed by Shapiro-Wilk's and a Two-way ANCOVA was conducted to examine the effects of group (obese and non-obese) on MQI, functional capacity, muscle strength and immunoglobulin concentration after controlling for baseline percent body fat values (51). Baseline percent body fat was included as a covariate because it negatively impacts MQI, absolute muscle strength, relative muscle strength and immunoglobulin levels (24, 49). In addition, a Two-way ANOVA without controlling for baseline percent body fat values as covariate was also conducted because adaptations in obese elderly women are attenuated and compromises improvements in strength gains and functional capacity (12). Thus, using percent body fat as covariate would probably hinder important chronic differences between obese and non-obese participants. Furthermore, an analysis of simple main effects and main effects for group and pre-post training were performed. For the nonparametric variables (disease), a $\chi 2$ for proportions with Fisher's exact test (expected cell frequencies less than five) was applied. An alpha level of $\alpha \leq .05$ was considered significant and all calculations were performed using SPSS (version 19.0). Furthermore, to illustrate significant findings displayed on Tables 2, 3, 4, 5 and 6 (body composition data), figures and results can be found in the Supplemental Appendix Material.

RESULTS

Baseline characteristics

General characteristics and medications between obese and non-obese older adult's women are presented in Table 1. Considering the baseline characteristics, obese participants displayed a significantly higher body weight and BMI than non-obese participants, but no differences were verified for other characteristics. Table 1.

Table 1. Participants' baseline characteristics[a].

	Obese (N = 25)		Non-Obese (N = 14)		*P*
Age, years	67.76 (5.50)		71.28 (6.82)		0.087
Body weight, kg	72.00 (10.32)†		58.80 (8.55)		0.001
Height, m	1.55 (0.05)		1.54 (0.06)		0.567
BMI, kg/m²	29.55 (3.38)†		24.56 (3.41)		0.001
Disease	**Yes**	**No**	**Yes**	**No**	**X²**
Diabetes mellitus type 2	2 (8)	23 (92)	3 (21.4)	11 (78.6)	0.221
Hypertension	19 (76)	6 (24)	8 (57.1)	6 (42.9)	0.229

Note: [a]Values are expressed as means ± DP and frequency and percentage values. X² = qui-square. BMI = body mass index; †Significantly different between groups ($p < 0.05$).

Field muscle quality index controlling for percent body fat as a covariate

There was no statistically significant interaction between group and pre-post training on field MQI handgrip [$F(1, 73) = .000$, $p = .99$], whilst controlling for baseline percent body fat. (Please see the Post-training *M*adj column[c] in Table 2).

After a main effect analysis, obese participants showed a lower statistically significant difference in field MQI handgrip of -0.46 (95% CI, -0.73 to -0.20, p = 0.001) and a lower field MQI handgrip of -0.44 (95% CI, -0.71 to -0.18, $p = 0.001$) at post-training when compared with non-obese participants. (Please see the Post-training *M*adj column[c] in Table 2).

There was no statistically significant interaction between group and pre-post training on field MQI leg press [$F(1, 72) = .001$, $p = .97$], field MQI chest press [$F(1, 72) = 0.02$, $p = .87$], field MQI 10-RM leg extension [$F(1, 72) = .07$, $p = .78$], field MQI low row [$F(1, 72) = .34$, $p = .55$] and field MQI leg curl [$F(1, 72) = .02$, $p = .87$], whilst controlling for baseline percent body fat. (Please see the Post-training *M*adj column[c] in Table 2).

However, a main effect for pre-post training was observed and obese participants displayed a higher statistically significant difference at post-training for field MQI leg press of .43 (95% CI, .30 to .56, p = .001), field MQI press of .35 (95% CI, .27 to .44, $p = .001$), field MQI leg extension of .43 (95% CI, .24 to .61, $p = .001$), field MQI low row of .26 (95% CI, .17 to .35, $p = .001$), and field MQI leg curl of .30 (95% CI, .16 to .43, $p = .001$) when compared to pre-training. (Please see the Post-training *M*adj column[c] in Table 2).

In addition, a main effect for pre-post training was observed for non-obese participants. Non-obese participants displayed a higher statistically significant difference at post-training for field MQI leg press of .43 (95% CI, .26 to .61), p = .001), field MQI chest press of .36 (95% CI, .25 to .48, $p = .001$), field MQI leg extension of .47 (95% CI, .22 to .71, $p = .001$), field MQI low row of .30 (95% CI, .19 to .42, $p = .001$), and field MQI leg curl of .31 (95% CI, .13 to .50, $p = .001$) when compared to pre-training. (Please see the Post-training *M*adj column[c] in Table 2).

Field muscle quality index removing percent body fat as a covariate

After removing body fat percent as covariate, no statistically significant interaction between group and pre-post training on field MQI handgrip [$F(1, 74) = .009$, $p = .92$] was noted. (Table 2[b]).

After removing body fat percent as a covariate, there was no a statistically significant interaction between group and pre-post training on field MQI leg press [$F(1, 73) = .000$, $p = .99$], field MQI chest press [$F(1, 73) = .01$, $p = .90$], field MQI leg extension [$F(1, 73) = .06$, $p = .80$], field MQI low row [$F(1, 73) = .27$, $p = .60$], or field MQI leg curl [$F(1, 73) = .0.009$, $p = .92$] (Table 2[b]).

After a main effect analysis, obese participants showed a lower statistically significant difference at pre-training for field MQI chest press of -.11 (95% CI, -.21 to -.01, $p = .03$), lower field MQI low row of -.23 (95% CI, -.34 to -.12, $p = .001$) and lower field MQI leg curl test -.28 (95% CI, -.45 to -.10, $p = .002$) when compared to non-obese participants. (Table 2[b]).

Furthermore, obese participants showed a lower statistically significant difference at post-training for field MQI chest press of -.12 (95% CI, -.22 to -.01, $p = .02$), lower field MQI leg extension of -.25 (95% CI, -.47 to -.03, $p = .02$), lower field MQI low row of -.27 (95% CI, -.38 to -.16, $p = .001$) and lower field MQI leg curl of -.29 (95% CI, -.46 to -.11, $p = .001$) when compared to non-obese participants. (Table 2[b]).

Additionally, obese participants displayed a higher statistically significant difference at post-training for field MQI leg press of .43 (95% CI, .30 to .56), p = .001), field MQI chest press of .35 (95% CI, .27 to .44, $p = .001$), field MQI leg extension of .43 (95% CI, .24 to .61, $p = .001$), field MQI low row of .26 (95% CI, .17 to .35, $p = .001$), and field MQI leg curl of .30 (95% CI, .16 to .43, $p = .001$) when compared to pre-training. (Table 2[b]).

Non-obese participants displayed a higher statistically significant difference at post-training for field MQI leg press of .43 (95% CI, .26 to .60), p = .001), field MQI chest press of .35 (95% CI, .24 to .48, $p = .001$), field MQI leg extension of .46 (95% CI, .21 to .71, $p = .001$), field MQI 10-RM low row of .30 (95% CI, .18 to .42, $p = .001$), and field MQI leg curl of .31 (95% CI, .11 to .50, $p = .002$) when compared to pre-training. (Table 2[b]).

Laboratory muscle quality index controlling for percent body fat as a covariate

There was no statistically significant interaction between group and pre-post training on upper extremity right handgrip MQI [$F(1,72) = .003$, $p = .85$], and lower extremity MQI [$F(1,72) = .000$ $p = .99$], whilst controlling for baseline percent body fat. However, a statistically significant interaction between group and pre-post training on upper extremity left handgrip MQI [$F(1,72) = 5.55$, $p = .02$] was verified. Therefore, an analysis of main effects for group and pre-post training were verified. (Please see the Post-training *M*adj column[c] in Table 2).

After a main effect analysis, obese participants displayed a higher statistically significant difference at post-training upper extremity left handgrip MQI of 1.29 (95% CI, .76 to 1.81, $p = .001$) and lower extremity MQI of .79 (95% CI, .36 to 1.21, $p = .001$) when compared to pre-training. (Please see the Post-training *M*adj column[c] in Table 2).

After a main effect analysis, non-obese participants displayed a higher statistically significant difference at post-training upper extremity left handgrip MQI of 2.32 (95% CI, 1.62 to 3.01, p = .001) and lower extremity MQI of .78 (95% CI, .22 to 1.35, p = .001) when compared to pre-training. (Please see the Post-training *M*adj column[c] in Table 2).

Laboratory muscle quality index removing percent body fat as a covariate

After removing body fat percent as a covariate, there was no statistically significant interaction between group and pre-post training on upper extremity right handgrip MQI [F(1,73) = .04, p =.82], and lower extremity MQI [F(1,73) = .000, p =.99]. However, a statistically significant interaction between group and pre-post training on upper extremity left handgrip MQI [F(1,73) = 5.59, p =.02] was verified. (Table 2[b]).

After a main effect analysis, obese participants displayed a lower statistically significant difference at pre-training for left handgrip MQI of -.84 (95% CI, -1.49 to -.19, p = .012) and post-training of -.74 (95% CI, -1.40 to -.08, p = .027) when compared to non-obese participants. In addition, these participants displayed a lower statistically significant difference at post-training for right handgrip MQI of -.80 (95% CI, -1.42 to -.19, p = .011) when compared to non-obese participants. (Table 2[b]).

After a main effect analysis, obese participants displayed a higher statistically significant difference at post-training for upper extremity left handgrip MQI of 1.29 (95% CI, .76 to 1.81, p = .001) and lower extremity MQI of .78 (95% CI, .36 to 1.21, p = .001) when compared to pre-training. (Table 2[b]).

After a main effect analysis, non-obese participants displayed a higher statistically significant difference at post-training for upper extremity left handgrip MQI of 2.32 (95% CI, 1.62 to 3.01, p = .001) and lower extremity MQI of .79 (95% CI, .22 to 1.35, p = .006) when compared to pre-training. (Table 2[b]).

Functional tests controlling for percent body fat as a covariate

There was no statistically significant interaction between group and pre-post training on timed-up-and-go test [F(1, 73) = .08, p = .76], 30-second chair stand test [F(1, 73) = .28, p = .59], 6-minute walking test [F(1, 73) = 1.35, p = .24], whilst controlling for baseline percent body fat. (Table 3[c]).

After a main effect analysis, obese participants showed a higher statistically significant difference of 1.95 (95% CI, 0.48 to 3.42, p = 0.01) at post-training vs. pre-training for 30-second chair stand test, but no differences were verified for other variables. (Table 3[c]).

Table 2. Pre- vs. post-training outcome measures for muscle quality index between obese and non-obese older adults women[a].

Obese (*N* = 25)				
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
Field muscle quality index				
Relative handgrip strength, kg/BMI	1.68 (0.33)	1.77 (0.31)	1.88 (0.08)	1.96 (0.08)
Relative leg press strength, kg/BMI	1.33 (0.21)	1.76 (0.22)†	1.36 (0.05)	1.80 (0.05)†
Relative chest press strength, kg/BMI	0.75 (0.11)	1.10 (0.13)†	0.79 (0.03)	1.15 (0.03)†
Relative leg extension strength, kg/BMI	1.31 (0.32)	1.74 (0.26)†	1.38 (0.07)	1.80 (0.07)†
Relative low row strength, kg/BMI	1.16 (0.15)	1.42 (0.12)†	1.22 (0.03)	1.48 (0.03)†
Relative leg curl strength, kg/BMI	1.33 (0.24)	1.63 (0.22)†	1.44 (0.05)	1.74 (0.05)†
Laboratory muscle quality index				
Right handgrip strength, kg strength/kg mass‡	5.76 (0.94)	5.88 (0.86)	6.14 (0.22)	6.25 (0.22)
Left handgrip strength, kg strength /kg mass‡	4.06 (0.85)	5.35 (1.06)†	4.12 (0.22)	5.41 (0.22)†
Lower extremity force, kg strength/kg mass‡	3.02 (0.73)	3.81 (0.56)†	2.94 (0.17)	3.73 (0.18)†
Non-Obese (*N* = 14)				
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
Field muscle quality index				
Relative handgrip strength, kg/BMI	2.15 (0.48)*	2.22 (0.52)*	1.80 (0.12)	1.88 (0.12)
Relative leg press strength, kg/BMI	1.46 (0.24)	1.90 (0.23)†	1.40 (0.08)	1.84 (0.07)†
Relative chest press strength, kg/BMI	0.86 (0.22)*	1.23 (0.17)*†	0.78 (0.05)	1.15 (0.05)†
Relative leg extension strength, kg/BMI	1.53 (0.37)*	2.00 (0.39)*†	1.42 (0.11)	1.89 (0.11)†
Relative low row strength, kg/BMI	1.39 (0.14)*	1.70 (0.23)*†	1.30 (0.05)	1.60 (0.05)†
Relative leg curl strength, kg/BMI	1.61 (0.28)*	1.92 (0.31)*†	1.41 (0.08)	1.73 (0.08)†
Laboratory muscle quality index				
Right handgrip strength, kg strength/kg mass‡	6.61 (1.16)*	6.62 (1.03)*	5.94 (0.32)	5.97 (0.32)
Left handgrip strength, kg strength /kg mass‡	3.84 (0.97)	6.16 (0.66)*†	3.75 (0.32)	6.07 (0.32)†
Lower extremity force, kg strength/kg mass‡	3.01 (0.84)	3.80 (0.93)†	3.15 (0.26)	3.94 (0.26)†

Note: [a]Values are expressed as means and standard deviation for pre-training and means and adjusted means (*M*adj) for post-training. [b]Not corrected for percent body fat, [c]Corrected for percent body fat, BMI = body mass index, *Significantly different between groups ($p < 0.05$), †Significantly different between pre-training vs post-training ($p < 0.05$). ‡Upper extremity strength was defined as ratio of grip strength (measured in kg of force) to arm lean mass (measured in kg) and lower extremity specific force as ratio of quadriceps (measured in kg of force) to leg lean mass (measured in kg).

Functional tests removing percent body fat as a covariate

After removing body fat percent as a covariate, no statistically significant interaction between group and pre-post training on timed-up-and-go test [$F(1, 74) = .04$, $p = .83$], 30-second chair stand test [$F(1, 74) = .30$, $p = .58$], 6-minute walking test [$F(1, 74) = 1.26$, $p = .26$] were observed. (Table 3[b]).

After a main effect analysis, obese participants showed a higher statistically significant difference in 30-second chair stand test of 1.96 (95% CI, 0.49 to 3.42, $p = 0.009$) at post-training vs. pre-training, but no differences were verified for other variables. (Table 3[b]).

Table 3. Pre- vs. post-training outcome measures for functional tests between obese and non-obese older adults women[a].

Obese (*N* = 25)				
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
Time-up and go, s	6.69 (0.72)	6.39 (0.63)	6.43 (0.15)	6.13 (0.15)
30- second chair stand, reps	14.16 (2.74)	16.12 (2.48)†	14.30 (0.62)	16.26 (0.61)†
Six-minute walking test, m	491.97 (39.93)	484.79 (49.22)	500.36 (10.63)	492.90 (10.52)
Non-Obese (*N* = 14)				
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
Time-up and go, s	6.40 (0.79)	6.02 (0.58)	6.87 (0.23)	6.49 (0.22)
Chair stand, reps	15.64 (2.20)	16.92 (2.84)	15.38 (0.92)	16.67 (0.91)
Six-minute walking test, m	504.21 (45.63)	520.80 (44.08)	489.27 (15.76)	506.27 (15.58)

Note: [a]Values are expressed as means and standard deviation for pre-training and means and adjusted means (*M*adj) for post-training. [b]Not corrected for percent body fat, [c]Corrected for percent body fat, *Significantly different between groups ($p < 0.05$), †Significantly different between pre-training vs post-training ($p < 0.05$).

Immunoglobulins controlling for percent body fat as a covariate

There was no statistically significant interaction between group and pre-post training on immunoglobulin A [F (1, 73) = 0.10, p = .74], immunoglobulin G [F (1, 73) = 0.52, p = .47], and immunoglobulin M [F (1, 73) = 0.00, p = .96], whilst controlling for baseline percent body fat. (Table 4[c]).

After a main effect analysis, obese participants showed a higher statistically significant difference at post-training adjusted marginal means for immunoglobulin M 54.88 (95% CI, 1.63 to 108.13, p = 0.044) when compared to non-obese group. (Table 4[c]).

Immunoglobulins removing percent body fat as a covariate

After removing body fat percent as a covariate no statistically significant interaction between group and pre-post training on immunoglobulin A [F (1, 74) = 0.12, p = .72], immunoglobulin G [F (1, 74) = 0.56, p = .45], and immunoglobulin M [F (1, 74) = .007, p = 0.93], were observed. After simple main effects analysis for group and pre-post training no differences were verified. (Table 4[b]).

Muscle strength variables controlling for percent body fat as a covariate

For absolute handgrip strength, there was no statistically significant interaction between group and pre-post training on absolute right handgrip strength [F(1, 73) = .004, p = .94] and left absolute handgrip strength test [F(1, 73) = .007, p = .93], whilst controlling for baseline percent body fat. (Table 5[c]).

There was no statistically significant interaction between group and pre-post training on absolute 10-RM leg press test [F(1, 72) = .33, p =.56], absolute 10-RM chest press test [F(1, 72) = 0.26, p = .61], absolute 10-RM leg extension test [F(1, 72) = .03, p = .85], absolute 10-RM low row test [F(1, 72) = .018, p = .89] and absolute 10-RM leg curl test [F(1, 72) = .069, p = .79], whilst controlling for baseline percent body fat. (Table 5[c]).

Table 4. Pre- vs. post-training outcome measures for immunoglobulins between obese and non-obese older adults women[a].

	Obese (*N* = 25)			
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
IgA, mg/dl	234.36 (93.65)	261.94 (121.61)	248.51 (30.03)	275.60 (29.72)
IgG, mg/dl	1218.00 (211.99)	1248.16 (222.36)	1266.91 (68.24)	1295.37 (67.54)
IgM, mg/dl	90.12 (59.12)	94.14 (69.38)	103.83 (13.15)	107.37 (13.01)*
	Non-Obese (*N* = 14)			
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
IgA, mg/dl	270 (146.49)	277.57 (156.95)	245.55 (44.52)	253.08 (44.01)
IgG, mg/dl	1386.78 (424.49)	1315.28 (338.15)	1299.79 (101.17)	1230.61 (100.02)
IgM, mg/dl	74.39 (34.81)	76.22 (36.03)	50.01 (19.49)	52.48 (19.27)

Note: [a]Values are expressed as means and standard deviation for pre-training and means and adjusted means (*M*adj) for post-training. [b]Not corrected for percent body fat, [c]Corrected for percent body fat, Ig = immunoglobulin. *Significantly different between groups ($p < 0.05$).

After a main effect analysis, obese participants showed a lower statistically significant difference for absolute 10-RM low row test of -5.64 (95% CI, -10.31 to -.97, $p = .018$) at pre-training and a lower statistically significant test of -5.34 (95% CI, -10.31 to -.97, $p = .024$) at post- training when compared to non-obese participants. (Table 5[c]).

After a main effect analysis, obese participants displayed a higher statistically significant difference at post-training for absolute 10-RM leg press test of 12.63 (95% CI, 7.97 to 17.30), p = .001), absolute chest press test of 10.03 (95% CI, 7.35 to 12.70, $p = .001$), absolute leg extension test of 12.15 (95% CI, 6.14 to 18.17, $p = .001$), absolute 10-RM low row test of 7.41 (95% CI, 4.71 to 10.11, $p = .001$), and absolute 10-RM leg curl test of 8.92 (95% CI, 3.86 to 12.71, $p = .001$) when compared to pre-training. (Table 5[c]).

After a main effect analysis, non-obese participants displayed a higher statistically significant difference for absolute 10-RM leg press test of 10.40 (95% CI, 4.23 to 16.57), p = .001), absolute chest press test of 8.89 (95% CI, 5.35 to 12.43, $p = .001$), absolute leg extension test of 11.24 (95% CI, 3.28 to 19.19, $p = .001$), absolute 10-RM low row test of 7.11 (95% CI, 3.54 to 10.68, $p = .001$), and absolute 10-RM leg curl test of 7.32 (95% CI, 1.46 to 13.17, $p = .001$) when compared to pre-training. (Table 5[c]).

Muscle strength variables removing percent body fat as a covariate

After removing body fat percent as a covariate, no statistically significant interaction between group and pre-post training on absolute right handgrip strength [$F(1, 74) = .006$, $p = .93$] and left absolute handgrip strength test [$F(1, 74) = .007$, $p = .93$] were verified. (Table 5[b]).

After removing body fat percent as a covariate, there was no statistically significant interaction between group and pre-post training on absolute 10 RM leg press test [$F(1, 73) = .24$, $p = .62$], absolute 10-RM chest press test [$F(1, 73) = .018$, $p = .89$], absolute 10-RM leg extension test [$F(1, 73) = .02$, $p = .87$], absolute 10-RM low row test [$F(1, 73) = .005$, $p = .94$], absolute 10-RM leg curl test [$F(1, 73) = .06$, $p = .80$]. (Table 5[b]).

After a main effect analysis, obese participants displayed a higher statistically significant difference at post-training for absolute 10-RM leg press test of 12.59 (95% CI, 7.66 to 17.53, p = .001), absolute chest press test of 10.01 (95% CI, 7.31 to 12.72, p = .001), absolute leg extension test of 12.12 (95% CI, 6.04 to 18.21, p = .001), absolute 10-RM low row test of 7.38 (95% CI, 4.50 to 10.26, p = .001), and absolute 10-RM leg curl test of 8.28 (95% CI, 3.86 to 12.70, p = .001) when compared to pre-training. (Table 5[b]).

After a main effect analysis, non-obese participants displayed a higher statistically significant difference at post-training for absolute 10-RM leg press test of 10.56 (95% CI, 4.04 to 17.08, p = .002), absolute chest press test of 8.93 (95% CI, 5.36 to 12.51, p = .001), absolute leg extension test of 11.35 (95% CI, 3.30 to 19.39, p = .006), absolute 10-RM low row test of 7.21 (95% CI, 3.39 to 11.02, p = .001), and absolute 10-RM leg curl test of 7.36 (95% CI, 1.51 to 13.21, p = .014) when compared to pre-training. (Table 5[b]).

Table 5. Pre- vs. post-training outcome measures for muscle strength between obese and non-obese older adults women[a].

	Obese (*N* = 25)			
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
Right handgrip strength, kg	26.16 (4.54)	26.84 (4.24)	26.52 (1.19)	27.14 (1.20)
Left handgrip strength, kg	23.36 (5.37)	24.48 (4.38)	23.29 (1.19)	24.22 (1.20)
10 RM leg press, kg	39.23 (6.93)	51.83 (9.70)†	35.88 (1.96)	48.52 (1.98)†
10 RM chest press, kg	22.27 (4.54)	32.19 (4.58)†	21.29 (1.12)	31.32 (1.13)†
10 RM leg extension, kg	38.91 (10.16)	51.04 (9.66)†	36.60 (2.52)	48.76 (2.55)†
10 RM low row, kg	34.28 (4.90)	41.60 (4.94)†	32.18 (1.13)	39.60 (1.14)†
10 RM leg curl, kg	39.38 (8.13)	47.55 (7.72)†	38.46 (1.86)	46.75 (1.88)†
	Non-Obese (*N* = 14)			
	Pre-training *M* (SD)	**Post-training *M* (SD)[b]**	**Pre-training *M*adj (SE)[c]**	**Post-training *M*adj (SE)[c]**
Right handgrip strength, kg	27.21 (5.35)	27.71 (6.21)	26.57 (1.76)	27.09 (1.74)
Left handgrip strength, kg	24.85 (4.81)	25.78 (5.25)	24.97 (1.76)	25.89 (1.74)
10 RM leg press, kg	36.14 (8.69)	46.70 (9.50)†	42.05 (2.90)	52.45 (2.86)†
10 RM chest press, kg	21.05 (5.20)	29.99 (4.80)†	22.78 (1.66)	31.67 (1.64)†
10 RM leg extension, kg	37.78 (10.96)	49.13 (12.84)†	41.85 (3.74)	53.09 (3.69)†
10 RM low row, kg	34.14 (4.32)	41.35 (5.98)†	37.83 (1.67)	44.94 (1.65)*†
10 RM leg curl, kg	39.27 (7.03)	46.63 (7.54)†	40.88 (2.75)	48.21 (2.72)†

Note: [a]Values are expressed as means and standard deviation for pre-training and means and adjusted means (*M*adj) for post-training. [b]Not corrected for percent body fat, [c]Corrected for percent body fat,*Significantly different between groups (p < 0.05), †Significantly different between pre-training vs post-training (p < 0.05).

DISCUSSION

The major new findings from this study are: *1*) Obese and non-obese participants displayed an increased statistically significant difference in MQI between pre-post training moments, however obese participants showed a lower field and laboratory MQI when compared to non-obese participants at the same time-points. *2*) Obese participants displayed an increased

statistically significant performance on the 30-second chair stand test, with no differences for non-obese participants. *3*) Obese participants showed a higher statistically significant difference for immunoglobulin M when compared to non-obese group at post-training moment. *4*) Finally, obese and non-obese participants displayed an increased statistically significant difference in muscle strength tests between pre-post-training. However, obese participants showed a statistically significant lower 10-RM low row score when compared to non-obese participants at post-training whilst controlling for percent body fat.

Recent observations provide evidence that obesity has considerable negative effects on muscle structure due to excessive intramuscular lipid accumulation and inflammatory profile, which consequently interferes in force generation and hypertrophy, potentially mitigating gains in physical function and muscle quality (5, 47)**.** Our results partially corroborate with Silva et al. (12), which reported that gains in absolute muscle strength after 16 weeks of RT were attenuated in elderly women with sarcopenic obesity. Besides, in our study, only obese participants presented an improvement in physical functional.

However, it is interesting to highlight that Silva et al. (12) did not use a statistical model controlling for a confounding variable such as percent body fat and using percent body fat as a covariate hindered important RT chronic differences between obese and non-obese participants. Furthermore, body weight and body mass index were statistically higher for obese participants at pre- and post-training when compared to non-obese participants (Supplemental Appendix Material).

An additional factor that should be considered in this study is that most participants in both groups did not display improvements in handgrip strength. We infer that a prolonged training or different types of periodization are necessary, and for handgrip, a dissimilar effect in upper and lower body response in older obese and non-obese participants might occur. Furthermore, handgrip strength might not be used as a proxy of global muscle strength, independent of age and health status of the participant (18, 56). In addition, the decline of muscle strength between the lower and upper body is different (2, 42). Thus, caution is need when generalizing handgrip strength as a predictor of global muscle strength, especially in older adults.

Furthermore, the addition of knee extension strength is recommended. A previous study (55) showed the superiority of knee extension strength over handgrip in explaining variance in health characteristics as social support (care support and dependent living) and nutritional characteristics (lower BMI). As a consequence, results from this study raise the importance of evaluating lower body muscle quality as part of a comprehensive geriatric assessment.

Additionally, obese participants at pre-post training displayed a lower field and laboratory MQI when compared to non-obese participants. Both groups presented improved MQI after 10 weeks of RT. MQI is a better indicator for physical function performance in older adults than strength (36). An increase in field and laboratory lower body MQI might be partially correlated with the improvement in the 30-second chair stand test presented by obese participants. Also, the results from the present study corroborates previous research that a field based estimate of MQI may

be implemented as an initial assessment tool for older adults, due to ease of the assessment, cost and relevance in daily clinical practice (35).

The rationale for evaluating Igs was based on previous studies demonstrating that immune system alteration contributes to increased morbidity and mortality in the older population. The Igs are affected by various physiological and pathological states, thus being an excellent marker of an elderly person's general health. Here, we demonstrate that serum Igs do not change after exercise training (pre x post training), suggesting limited RT effects on the adaptive immune system in obese and non-obese participants. However, obese older women displayed higher IgM levels post training when compared with non-obese older women. Obesity is often associated with increased susceptibility to infection with a number of different pathogens (29). Consequently, obesity itself may exacerbate certain other infections. Considering our findings, and a possible explanation, we speculate that higher IgM in the obese older women group might play a critical role in the obesity-associated autoimmune process and may reflect a compensatory mechanism associated with a disease phenotype. The present work represents an essential first step in understanding Igs as keys biochemical markers in older individuals. Igs have the potential to serve as an add-on to improve existing biomarkers of disease predisposition, as well as the establishment, prognosis and response to exercise.

Studies have shown that hyperleptinemia, higher BMI, and obesity are associated with lower immunoglobulin responsiveness due to leptin resistance (7, 24). However, it is important to emphasize that both factors (i.e aging and obesity) are associated with inflammation and immune dysregulation, including pathogenic antibody production by functionally altered B cells, which likely affects immunoglobulin responses. Furthermore, it is possible that wide heterogeneity of older and different clinical phenotypes can interfere with the pharmacokinetics of immunoglobulin (24). Researchers should be careful when mixing elderly people with and without obesity in their analysis, because these states represent complex conditions which can lead to misleading interpretations of exercise responses as reported by Silva et al. (12).

The discussion of our findings regarding Igs is not an easy task because the majority of previous studies were conducted on athlete and healthy individuals. Nevertheless, similar to the present results, Mohamed and Taha (33) reported not changes in different serum immunoglobulins in obese women (age: 35–45 years) after RT (12 weeks using free weights and dumbbells at 80% of the one repetition maximum). One suggested explanation is the possibly there was no IGs discharge in lymphatic sites, which might have obscured the effects of exercise training on Igs in the circulation. Therefore, it is possible that lymphocytes can migrate from the bloodstream into other tissues that requires greater action of Igs (i.e skeletal muscle) after RT, which decreases the secretion of serum Igs. These hypotheses are speculative, and more studies are needed to understand this complex outcome.

On the other hand, the absence of a difference between pre-training vs post-training in serum Igs may be attributed to other factors. Karacabey et al. (27) reported that the production of Igs have been associated with central nervous system stimulation and the increase of catecholamine and neuropeptide secretion. Moreover, synergic interactions between metabolism and

immunity affect many underpinning systems. It has been demonstrated that age-related loss of skeletal muscle mass is associated with the presence of a catabolic state, which consequently can induce protein degradation to generate glucose in order to maintain energy metabolism (13). In this process, there may sometimes be a lack of substrate for the production of important molecules, including immunoglobulins (54) and altered metabolic patterns provide opportunities to therapeutically target the immune aging process. Therefore, trainers and physicians are advised to analyze several factors that can modulate Igs in obese older women.

Although RT is recommended for obese older women, there is no evidence to suggest what frequency and duration is more effective for MQI, functional capacity and serum immunoglobulin levels. Researchers should aim to fill this gap in order to clarify the appropriate stimulus to modify these variables, along with investigating acute variables (intensity, volume, rest period) modulated by training in order to potentiate exercise effects and highlight the cornerstone mechanisms involved. In addition, recent reviews revealed that isolated exercise training without caloric restriction has a limited ability to modify the RT adaptive responses. Lifestyle interventions with diet-induced adiposity loss and combined training (aerobic and resistance training) inclusion may be required in older obese participants.

Some limitations of the present study should be highlighted, such as the lack of diet control and a small sample size of older women. Additionally, the present research provides valuable insights involved in the aging process and other immune clinical markers, hormonal profile and circulating metabolic measures should be investigated to clarify the adjacent mechanisms related to Igs. Besides, when evaluating chronotype individual predisposition, it is important to determine the participant's predisposition towards morningness or eveningness by a self-assessment questionnaire (53), as time of training affect performance, strength, oxidative stress, motivation and immunoglobulins.

In summary, obese older women showed a lower field and laboratory muscle quality index when compared to non-obese post-training, besides 10-RM low row score whilst controlling for percent body fat, which reinforces that obesity can blunt the beneficial effects of RT on muscle quality and strength. Furthermore, while obese older women displayed higher IgM levels post training when compared with non-obese older women, the two groups displayed similar serum immunoglobulin levels in response to RT, which suggests limited adaptive immune system in both conditions. Our results provide important insights into the RT adaptations in obese and non-obese older women and can be useful to clinicians and coaches for the effective design of RT programs.

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REFERENCES

1. American College of Sports M. American college of sports medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 41(3):687-708, 2009.

2. American College of Sports M, Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, Minson CT, Nigg CR, Salem GJ, Skinner JS. American college of sports medicine position stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 41(7):1510-1530, 2009.

3. Apel JM, Lacey RM, Kell RT. A comparison of traditional and weekly undulating periodized strength training programs with total volume and intensity equated. J Strength Cond Res 25(3):694-703, 2011.

4. Aschermann S, Lux A, Baerenwaldt A, Biburger M, Nimmerjahn F. The other side of immunoglobulin g: Suppressor of inflammation. J Clin Exp Immunol 160(2):161-167, 2010.

5. Barbat-Artigas S, Rolland Y, Zamboni M, Aubertin-Leheudre M. How to assess functional status: A new muscle quality index. J Nutr Health Aging 16(1):67-77, 2012.

6. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, Garry PJ, Lindeman RD. Epidemiology of sarcopenia among the elderly in new mexico. Am J Epidemiol 147(8):755-763, 1998.

7. Bouhajja H, Bougacha-Elleuch N, Lucas N, Legrand R, Marrakchi R, Kaveri SV, Jamoussi K, Ayadi H, Abid M, Mnif-Feki M, Fetissov SO. Affinity kinetics of leptin-reactive immunoglobulins are associated with plasma leptin and markers of obesity and diabetes. Nutr Diabetes 8(1):32, 2018.

8. Brown JC, Harhay MO, Harhay MN. The muscle quality index and mortality among males and females. Ann Epidemiol 26(9):648-653, 2016.

9. Chien MH, Guo HR. Nutritional status and falls in community-dwelling older people: A longitudinal study of a population-based random sample. PLoS One 9(3):e91044, 2014.

10. Corona LP, Pereira de Brito TR, Nunes DP, da Silva Alexandre T, Ferreira Santos JL, de Oliveira Duarte YA, Lebrao ML. Nutritional status and risk for disability in instrumental activities of daily living in older brazilians. Public Health Nutr 17(2):390-395, 2014.

11. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyere O, Cederholm T, Cooper C, Landi F, Rolland Y, Sayer AA, Schneider SM, Sieber CC, Topinkova E, Vandewoude M, Visser M, Zamboni M, Writing Group for the European Working Group on Sarcopenia in Older P, the Extended Group for E. Sarcopenia: Revised european consensus on definition and diagnosis. Age Ageing 48(4):601, 2019.

12. de Oliveira Silva A, Dutra MT, de Moraes W, Funghetto SS, Lopes de Farias D, Dos Santos PHF, Vieira DCL, Nascimento DDC, Orsano VSM, Schoenfeld BJ, Prestes J. Resistance training-induced gains in muscle strength, body composition, and functional capacity are attenuated in elderly women with sarcopenic obesity. Clin Interv Aging 13:411-417, 2018.

13. de Sousa Neto IV, Carvalho MM, Marqueti RC, Almeida JA, Oliveira KS, Barin FR, Petriz B, de Araujo HSS, Franco OL, Durigan JLQ. Proteomic changes in skeletal muscle of aged rats in response to resistance training. Cell Biochem Funct 2020.

14. Delves PJ, Roitt IM. The immune system. First of two parts. NEJM 343(1):37-49, 2000.

15. Deschamps V, Astier X, Ferry M, Rainfray M, Emeriau JP, Barberger-Gateau P. Nutritional status of healthy elderly persons living in dordogne, france, and relation with mortality and cognitive or functional decline. Eur J Clin Nutr 56(4):305-312, 2002.

16. Dos Santos ES, Asano RY, Filho IG, Lopes NL, Panelli P, Nascimento Dda C, Collier SR, Prestes J. Acute and chronic cardiovascular response to 16 weeks of combined eccentric or traditional resistance and aerobic training in elderly hypertensive women: A randomized controlled trial. J Strength Cond Res 28(11):3073-3084, 2014.

17. Ehrenstein MR, Notley CA. The importance of natural igm: Scavenger, protector and regulator. Nature Rev Immunol 10(11):778-786, 2010.

18. Felicio DC, Pereira DS, Assumpcao AM, de Jesus-Moraleida FR, de Queiroz BZ, da Silva JP, de Brito Rosa NM, Dias JM, Pereira LS. Poor correlation between handgrip strength and isokinetic performance of knee flexor and extensor muscles in community-dwelling elderly women. Geriatr Gerontol Int 14(1):185-189, 2014.

19. Fragala MS, Cadore EL, Dorgo S, Izquierdo M, Kraemer WJ, Peterson MD, Ryan ED. Resistance training for older adults: Position statement from the national strength and conditioning association. J Strength Cond Res 33(8):2019-2052, 2019.

20. Gomides RS, Costa LA, Souza DR, Queiroz AC, Fernandes JR, Ortega KC, Junior DM, Tinucci T, Forjaz CL. Atenolol blunts blood pressure increase during dynamic resistance exercise in hypertensives. Br J Clin Pharmacol 70(5):664-673, 2010.

21. Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, Simonsick EM, Tylavsky FA, Visser M, Newman AB. The loss of skeletal muscle strength, mass, and quality in older adults: The health, aging and body composition study. J Gerontol A Biol Sci Med Sci 61(10):1059-1064, 2006.

22. Hairi NN, Cumming RG, Naganathan V, Handelsman DJ, Le Couteur DG, Creasey H, Waite LM, Seibel MJ, Sambrook PN. Loss of muscle strength, mass (sarcopenia), and quality (specific force) and its relationship with functional limitation and physical disability: The concord health and ageing in men project. J Am Geriatr Soc 58(11):2055-2062, 2010.

23. Hejazi K, Hosseini SR. Influence of selected exercise on serum immunoglobulin, testosterone and cortisol in semi-endurance elite runners. Asian J Sports Med 3(3):185-192, 2012.

24. Hodkinson JP. Considerations for dosing immunoglobulin in obese patients. Clin Exp Immunol 188(3):353-362, 2017.

25. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. J Am Geriatr Soc 50(5):889-896, 2002.

26. Jones CJ, Rikli RE. Measuring functional. J Active Aging 1(24-30)2002.

27. Karacabey K, Peker I, Saygın Ö, Cıloglu F, Ozmerdivenli R, Bulut V. Effects of acute aerobic and anaerobic exercise on humoral immune factors in elite athletes. Biotechnol Biotechnol Equip 19(1):175-180, 2005.

28. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, Fleck SJ, Franklin B, Fry AC, Hoffman JR, Newton RU, Potteiger J, Stone MH, Ratamess NA, Triplett-McBride T, American College of Sports M. American college of sports medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 34(2):364-380, 2002.

29. Lin D, Bridgeman MB, Brunetti L. Evaluation of alterations in serum immunoglobulin concentrations in components of metabolic syndrome, obesity, diabetes, and dyslipidemia. BMC Cardiovasc Disord 19(1):319, 2019.

30. Macpherson AJ, McCoy KD, Johansen FE, Brandtzaeg P. The immune geography of iga induction and function. Mucosal Immunol 1(1):11-22, 2008.

31. Marzullo P, Minocci A, Giarda P, Marconi C, Tagliaferri A, Walker GE, Scacchi M, Aimaretti G, Liuzzi A. Lymphocytes and immunoglobulin patterns across the threshold of severe obesity. Endocrine 45(3):392-400, 2014.

32. McGregor RA, Cameron-Smith D, Poppitt SD. It is not just muscle mass: A review of muscle quality, composition and metabolism during ageing as determinants of muscle function and mobility in later life. Longev Healthspan 3(1):9, 2014.

33. Mohamed GS, Taha MM. Comparison between the effects of aerobic and resistive training on immunoglobulins in obese women. Bull Fac Phys Ther 21(1):11, 2016.

34. Nascimento DDC, da Silva CR, Valduga R, Saraiva B, de Sousa Neto IV, Vieira A, Funghetto SS, Silva AO, Oliveira SDC, Pereira GB, Willardson JM, Prestes J. Blood pressure response to resistance training in hypertensive and normotensive older women. Clin Interv Aging 13:541-553, 2018.

35. Nascimento DDC, Prestes J, de Sousa Diniz J, Beal PR, Alves VP, Stone W, Beal FLR. Comparison of field- and laboratory-based estimates of muscle quality index between octogenarians and young older adults: An observational study. J Exerc Rehab 16(5):458-466, 2020.

36. Park SW, Goodpaster BH, Strotmeyer ES, Kuller LH, Broudeau R, Kammerer C, de Rekeneire N, Harris TB, Schwartz AV, Tylavsky FA, Cho YW, Newman AB, Health A, Body Composition S. Accelerated loss of skeletal muscle strength in older adults with type 2 diabetes: The health, aging, and body composition study. Diabetes Care 30(6):1507-1512, 2007.

37. Prestes J, da Cunha Nascimento D, Tibana RA, Teixeira TG, Vieira DC, Tajra V, de Farias DL, Silva AO, Funghetto SS, de Souza VC, Navalta JW. Understanding the individual responsiveness to resistance training periodization. Age 37(3):9793, 2015.

38. Prestes J, Shiguemoto G, Botero JP, Frollini A, Dias R, Leite R, Pereira G, Magosso R, Baldissera V, Cavaglieri C, Perez S. Effects of resistance training on resistin, leptin, cytokines, and muscle force in elderly post-menopausal women. J Sports Sci 27(14):1607-1615, 2009.

39. Prestes J, Tibana RA. Muscular static strength test performance and health: Absolute or relative values? Revista Assoc Med Brasileira 59(4):308-309, 2013.

40. Reis MM, Arantes PMM. Medida da força de preensão manual: Validade e confiabilidade do dinamômetro saehan. Fisioterapia Pesquisa 18(2):176-181, 2011.
41. Rickham PP. Human experimentation. Code of ethics of the world medical association. Declaration of helsinki. Br Med J 2(5402):177, 1964.

42. Samuel D, Rowe P. An investigation of the association between grip strength and hip and knee joint moments in older adults. Arch Gerontol Geriatr 54(2):357-360, 2012.

43. Schulc E, Gothe RM, Them C, Tufan I, Mueller G. Self-reported questionnaire of functional health of home-dwelling elderly people living in austria: Based on the patient questionnaire of the standardized assessment of elderly people in primary care. J Nurs Meas 25(2):238-256, 2017.

44. Sheridan PA, Paich HA, Handy J, Karlsson EA, Hudgens MG, Sammon AB, Holland LA, Weir S, Noah TL, Beck MA. Obesity is associated with impaired immune response to influenza vaccination in humans. Int J Obes 36(8):1072-1077, 2012.

45. Song YS, Lee SK, Jang YJ, Park HS, Kim JH, Lee YJ, Heo YS. Association between low sirt1 expression in visceral and subcutaneous adipose tissues and metabolic abnormalities in women with obesity and type 2 diabetes. Diabetes Res Clin Pract 101(3):341-348, 2013.

46. Straight C, Brady A, Schmidt M, Evans E. Comparison of laboratory-and field-based estimates of muscle quality for predicting physical function in older women. J Aging Res Clin Pract 2(3):276-279, 2013.

47. Straight CR, Brady AO, Evans EM. Muscle quality in older adults: What are the health implications? Am J Lifestyle Med 9(2):130-136, 2015.

48. Sun S, Ji Y, Kersten S, Qi L. Mechanisms of inflammatory responses in obese adipose tissue. Ann Rev Nutr 32:261-286, 2012.

49. Tibana RA, Tajra V, César D, de Farias DL, Teixeira TG, Prestes J. Comparação da força muscular entre mulheres brasileiras com e sem síndrome metabólica. ConSci Saúde 10(4):708-714, 2011.

50. Valença TDC, Santos WdS, Lima PV, Santana EdS, Reis LAd. Deficiência física na velhice: Um estudo estrutural das representações sociais. Escola Anna Nery 21(1)2017.

51. Van Breukelen GJ. Ancova versus change from baseline: More power in randomized studies, more bias in nonrandomized studies [corrected]. J Clin epidemiol 59(9):920-925, 2006.

52. Villareal DT, Banks M, Siener C, Sinacore DR, Klein S. Physical frailty and body composition in obese elderly men and women. Obes Res 12(6):913-920, 2004.

53. Vitale JA, Weydahl A. Chronotype, physical activity, and sport performance: A systematic review. Sports Med 47(9):1859-1868, 2017.

54. Von Ah Morano AE, Dorneles GP, Peres A, Lira FS. The role of glucose homeostasis on immune function in response to exercise: The impact of low or higher energetic conditions. J Cell Physiol 235(4):3169-3188, 2020.

55. Yeung SSY, Reijnierse EM, Trappenburg MC, Blauw GJ, Meskers CGM, Maier AB. Knee extension strength measurements should be considered as part of the comprehensive geriatric assessment. BMC Geriatr 18(1):130, 2018.

56. Yeung SSY, Reijnierse EM, Trappenburg MC, Hogrel JY, McPhee JS, Piasecki M, Sipila S, Salpakoski A, Butler-Browne G, Paasuke M, Gapeyeva H, Narici MV, Meskers CGM, Maier AB. Handgrip strength cannot be assumed a proxy for overall muscle strength. J Am Med Dir Assoc 19(8):703-709, 2018.