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Higher Body Mass Index Values Do Not Impact Physical Function and Lower-Extremity Muscle Strength Performance in Active Older Individuals

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ABSTRACT

International Journal of Exercise Science 15(3): 330-340, 2022. This study examined the potential impact of BMI on physical function and lower-extremity muscle strength (leg extension and flexion peak torque) performance in active/trained older individuals. Sixty-four active/trained older individuals were enrolled, and later allocated to groups according to BMI categories (normal [≤ 24.9 kg/m^2], overweight [25 to 29.9 kg/m^2] and obese [≥ 30 kg/m^2]). Sixty-four active/trained older individuals were enrolled, and later allocated to groups according to BMI categories (normal [≤ 24.9 kg/m^2], overweight [25 to 29.9 kg/m^2] and obese [≥ 30 kg/m^2]). Assessments were conducted in two separate visits to the laboratory. In the first visit, participants underwent measures of height, body mass, and peak torque leg extension and flexion using an isokinetic dynamometer. On visit two, participants performed the 30-second Sit and Stand test (30SST), Timed Up and Go (TUG), and 6-minute Walk (6MW) tests. ANOVA one-way was used to analyze the data and significance was set at $P < .05$. One-way ANOVAs did not reveal significance differences among BMI categories for leg extension peak torque (F(2,61) = 1.11; P = 0.336), leg flexion peak torque (F(2,61) = 1.22; P = 0.303), 30SST (F(2,61) =1.28; P = 0.285), TUG (F(2,61) = 0.238; P = 0.789), and 6MW (F(2,61) = 2.52; P = 0.089)]. Our findings indicated that for older individuals who exercise regularly, physical function tests which mimic ordinary activities of daily living, are not impacted by BMI status. Thus, being physically active may counteract some of the negative effects of high BMI observed in the older adult population.

KEY WORDS: Activities of daily living, body composition, elderly, functional fitness, leg strength

INTRODUCTION

Body mass index (BMI) is widely used in research and clinical settings as a measure to categorize individuals as underweight, normal weight, overweight or obese that takes into consideration mass (weight) and height (52). Although some researchers suggest that BMI can be a predictor of body fatness (31, 44), others suggest that BMI is a poor marker of body fat and cannot distinguish between fat and lean body mass (39, 48). Nonetheless, BMI is a practical and simple measurement with strong associations among health outcomes in different populations, including older adults (5, 8, 14, 22, 51). Despite its popularity, the influence of BMI on fitness and functional performance in the elderly remains unclear based on the findings of previous studies. For example, high BMI values have been associated with increased risk for chronic diseases (20, 22, 47, 50, 51), poor muscle quality (6, 46), and diminished physical functioning (13, 23) among older adults. Previous studies conducted in older Americans and Asians have further suggested a negative association between BMI and muscle grip strength (20, 32, 43). In contrast, however, Hardy et al. (18) reported that men with higher BMI values performed better in handgrip strength testing. Previous studies examining muscle strength have focused primarily on handgrip assessment, and there are limited data regarding the potential effect of body fatness (i.e. BMI) on physical function and direct measures of lower-extremity muscle strength. Importantly, such measures are strongly associated with independence in activities of daily living (e.g., activities requiring walking) among the older adult population (4). Furthermore, studies examining the impact of BMI on different health outcomes have been conducted in inactive, sedentary or non-trained older populations (9, 20, 29). Thus, it remains unclear whether higher BMI values negatively impact health-related outcome measures such as physical function and more objective measures of lower-extremity muscle strength in active/trained older individuals.

Sufficient levels of physical function and lower-extremity strength are important factors for successful healthy aging and reduce the risk of falls, a major public health concern due to its negative consequences to individuals and society (25, 26). Despite its popularity, the influence of BMI on fitness and functional performance of older adults remains unclear based on the findings of previous studies. Thus, the present study may help expand our understanding on the potential impact of BMI on health-related outcomes in different sub-populations of older individuals (i.e., active vs. sedentary). To this end, the purpose of the present study was to examine the potential impact of BMI on physical function and lower-extremity muscle strength (leg extension and flexion peak torque measured using an isokinetic dynamometer) performance in active/trained older individuals. Based on previous findings, we hypothesized that higher BMI (overweight, obese) values would negatively impact physical function and strength performance in this population.

METHODS

Participants

This cross-sectional study protocol was approved by a university Institution Review Board (IRB protocol number: 04242218.2.0000.5659) and all participants provided written informed consent prior to data collection. Further, this study was conducted fully in accordance to the ethical standards of the Declaration of Helsinki, and the ethical standards of the International Journal of Exercise Science (33). Sixty-four active elderly individuals (86% females) were recruited and enrolled to participate in this study (Figure 1). Participants were recruited from the fitness program for seniors offered by the School of Physical Education and Sports of Ribeirão Preto, University of São Paulo, Brazil (EEFERP-USP in *Portuguese*). Enrolled participants had been engaged in the program for at least 3 months prior to data collection and regularly exercised at least 3 times per week, 60 minutes per session. During the program participants engaged in whole body functional training which included aerobic exercises such as walking and cycling, as well as resistance training using body weight exercises and free weights, with the main goal to improve individual's functional capacity. Stretching exercises were performed as part of the warm up and cool down on every session. Inclusion criteria included: a) member of the referred fitness program, b) aged ≥ 60 years, c) fully ambulatory, and d) no risk of malnutrition. Participants were excluded if they: a) did not complete all stages of the study, b) voluntarily withdraw from participation; or c) suffered any condition that could influence their ability to perform the selected assessments (e.g., knee and hip prostheses, tumors, back pain).

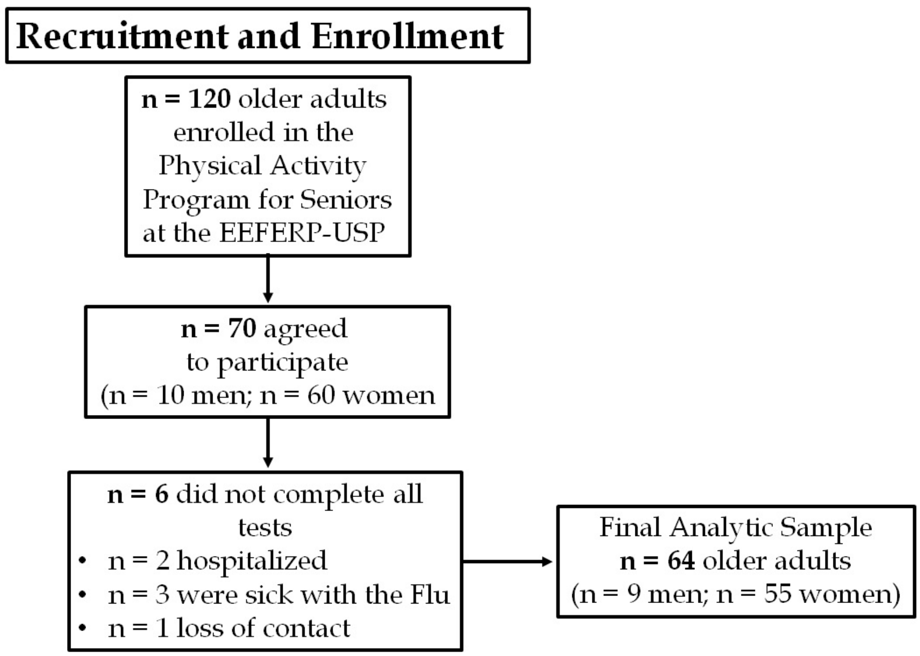

Figure 1. Process of sample recruitment and enrollment

Protocol
All assessments were conducted in a laboratory research setting at the School of Physical Education and Sports of Ribeirão Preto, Brazil, and were conducted in two non-consecutive days. During the first day, participants read and signed the informed consent, completed the questionnaires and underwent anthropometric measures of height and weight. In addition, participants underwent the lower-extremity muscle strength assessment in the isokinetic dynamometer. In the second day, participants performed the physical function tests (i.e., 30SST, TUG and 6MW). Overall, assessments took an average of 30 minutes per day of visit.

Body mass index (BMI): BMI was calculated based on participants body mass (kg) divided by their height (m^2) (12). Body mass was assessed using an analogic scale (Marte LS200, *Santa Rita do Sapucaí*, MG, Brazil) and height was assessed using a wall mounted stadiometer (Seca, Chino, CA, United States) collected by two experienced research staff. For body mass and height assessment, participants were asked to remove their shoes and heavy clothes and remain as static as possible. BMI values were used to allocate participants into three categories: normal weight (≤ 24.9 kg·m^{-2}), overweight (25 to 29.9 kg·m^{-2}) and obese (≥ 30 kg·m^{-2}) according to widely used criteria (52).

Physical function: Physical function was assessed using a collection of measures which included: a) 30-second Sit and Stand (30SST) to assess lower-extremity functional strength; b) Timed Up and Go (TUG) as a measure of dynamic balance and; c) 6-minute Walk Test (6MW) to assess aerobic capacity and walking ability. These tests have been shown to be valid and reliable assessments in the older adult population and were administered following standardized procedures (36). A 5-minute rest between tests performed was adopted for participant recovery.

Lower-extremity muscle strength: Lower-extremity muscle strength was assessed as leg extension and flexion peak torque with an angular velocity of 60°·s^{-1} using an isokinetic dynamometer (Biodex System 4 Pro) following standard procedures (3). Briefly, a protocol of one familiarization series with ten submaximal repetitions and 60-second resting intervals was adopted. The employed testing protocol consisted of three series of four valid maximal repetitions of leg extension and flexion with 60-seconds rest in between trials. The highest peak torque values achieved were used as the representative performance scores and expressed in N·m.

Other measurements: Demographic information was gathered for the purpose of sample characterization using a questionnaire developed specifically for the purpose of the present study. Questions included gender, age, educational attainment, and race. Further, participants nutritional status was determined using the widely adopted Mini Nutritional Assessment (MNA), which is a valid instrument developed to assess potential risk of malnutrition in older adults (21, 27). The MNA was used to identify potential participants at risk of malnutrition or malnourished.

Statistical Analysis

Descriptive statistics (mean, median, standard deviation) were used for general sample characterization. In addition, separate one-way analyses of variance tests (ANOVAs) were used to examine potential differences in 30SST, TUG, and 6MW as well as leg extension and flexion peak torque among BMI categories (normal weight vs. overweight vs. obese), with partial eta-squared (η_p^2) used as a measure of effect size. Data were analyzed using SPSS version 25 (IBM Corporation, Armory, N.Y) and significance was set at $P < 0.05$.

RESULTS

Detailed information on demographic and health characteristics of the sample are provided in Table 1. Briefly, mean (SD) age of the participants was 65.0 (6.1) years with BMI values of 27.8 (4.2) kg·m^{-2}. All participants reported no difficulties to perform activities of daily living (ADL; data not shown) and were also classified as normal nutrition status according to the MNA.

Table 1. Demographic, anthropometric, and nutritional characteristics of the sample overall and separated by body mass index categories.

	BMI Categories			
	Overall (n = 64)	Normal (n = 20)	Overweight (n = 26)	Obese (n = 18)
Age, years	65 (6.1)	66.1 (7.4)	62.6 (5.9)	64.3 (4.6)
Gender, female/male	55/9	15/5	22/4	18/0
Education, *n* (%)				
College degree	15 (23.4)	5 (25.0)	8 (30.8)	2 (11.1)
Race, *n* (%)				
Caucasian	49 (76.6)	14 (70.0)	19 (73.1)	16 (88.9)
African-descent	5 (7.8)	2 (10.0)	3 (11.5)	---
Hispanic	10 (15.6)	4 (20.0)	4 (15.4)	2 (11.1)
Body mass, kg	71.4 (11.6)	59.7 (7.5)	71.9 (7.1)	64.3 (6.3)
Height, cm	160.31 (7.5)	160.1 (8.1)	161.7 (7.6)	158.5 (6.9)
BMI, kg $\cdot m^{-2}$	27.8 (4.2)	23.2 (1.6)	27.4 (1.4)	33.3 (2.0)
MNA, score	13.5 (.78)	13.4 (.82)	13.6 (.70)	13.4 (.85)

Note: Data are present as mean (standard deviation). BMI: Body Mass Index; kg: kilogram; cm: centimeters; MNA: Mini Nutritional Assessment; Normal: ≤ 24.9 kg $\cdot m^{-2}$; Overweight: 25 to 29.9 kg $\cdot m^{-2}$; Obese: ≥ 30 kg $\cdot m^{-2}$

Because of the known differences between males and females on physical functional, and muscular strength (peak torque extension and flexion), the data were first analyzed in terms of potential differences between sex according to BMI categories. Two-way ANOVA did not reveal significant differences ($p > 0.05$) between males and females in the selected dependent variables (data not shown) as a function of BMI categories. Thus, the subsequent analysis was conducted considering males and females as one group.

Table 2 depicts the mean values observed for the physical function and lower-extremity muscle strength tests separated by BMI category, and respective results of the one-way ANOVAs. Briefly, all physical function and lower-extremity muscle strength performance scores were not significantly different among BMI categories in our sample of older active/trained individuals ($P > 0.05$).

Table 2. Mean and standard deviation performance values of physical function and leg muscle strength tests separated by BMI categories and results of the one-way analyses of variance tests.

	BMI Categories					
	Normal (n = 20)	Overweight (n = 26)	Obese (n = 18)	F	p	η_p^2
TUG, sec	5.65 (1.35)	5.77 (1.61)	5.94 (1.11)	0.210	0.81	.007
30SST, rep	16.20 (3.99)	15.65 (5.36)	13.89 (2.99)	1.437	0.24	.045
6MW, m	498.20 (87.52)	499.54 (84.43)	449.44 (59.03)	2.527	0.08	.077
Peak Flexion, N $\cdot$m	53.25 (21.15)	59.51 (22.18)	51.84 (16.72)	0.907	0.40	.029
Peak Extension, N $\cdot$m	96.43 (24.80)	109.47 (37.83)	95.90 (32.21)	1.221	0.30	.033

Note: BMI: Body Mass Index; TUG: Timed Up and Go; 30SST: 30-second Sit and Stand; 6MW: 6-minute Walk Test; Peak Flexion: Peak torque flexion; Peak Extension: Peak torque extension; N $\cdot$m: Newtons per meter. Normal: ≤ 24.9 kg $\cdot m^{-2}$; Overweight: 25 to 29.9 kg $\cdot m^{-2}$; Obese: ≥ 30 kg $\cdot m^{-2}$

Subsequent analysis examining peak torque extension and flexion relative to body weight as a function of BMI revealed significant differences in both peak torque extension and flexion. Peak torque extension (Normal weight: 152.93 ± 55.60 vs. Overweight 144.72 ± 51.87 vs. Obese 108.80 ± 45.93, (F2,61) = 3.944; p = 0.025). Peak torque flexion (Normal weight: 88.02 ± 32.42 vs. Overweight 82.21 ± 27.77 vs. Obese 62.11 ± 19.45, (F2,61) = 4.673; p = 0.013)). Follow up Bonferroni post-hoc analysis revealed significant differences for peak torque extension (p = 0.025) and flexion (p = 0.013) between the normal weight and obese groups – favorable to the normal weight group.

DISCUSSION

This study examined potential differences in physical function and lower-extremity muscle strength performance as a function of BMI categories in a sample of active older individuals. Our results generally indicated no significant differences among BMI categories on physical function performance tests (i.e. 30SST, TUG, 6MW) or lower-extremity muscle strength (i.e. leg extension and flexion peak torque) in this population. However, it is important to note that the performance in the 6MW (walking endurance) was found to be marginally significant between BMI groups. Overall, our findings suggest that, our sample of active older adults presented with similar performance scores in functional and strength testing regardless of BMI classification (i.e. normal, overweight, obese). Subsequent analysis conducted for peak torque extension and flexion but relative to body weight demonstrated that active older adults classified as normal weight, presented with higher relative peak torque extension and flexion than those classified as obese. Overall, our findings partially corroborate our hypothesis that high BMI values (overweight, obese) would negatively impact physical performance in active older individuals. In terms of the performance in the selected functional tests, our sample ranged from 12 to 19 repetitions on the 30SST, 5.7 to 4.3 seconds on the TUG, and 512 to 640 meters in the 6MW. The normative values of the Senior Fitness Test (36, 37) used to compared the results of our sample vary across age and sex groups. Considering the mean age of our sample (i.e., 65 years old), the normative values for the 65-69 years old category for the 30SST range from 12 to 18 repetitions for males and 12 to 16 for females; for the TUG the range is 4.3-5.7 seconds for males and 4.8-6.4 seconds for females, and the 6WM the range is 540-640 meters for males and 457-589 for females. Taking the normative values into consideration, our sample would be classified as "average" for the 30SST and TUG, and "above average" for the 6MW. In addition, the mean relative values for peak torque extension and flexion were 1.37 Nm/kg and 0.78 Nm/kg, respectively which is in the range of the normative values. For instance, the normative values for extension is 1.5 Nm/kg around the age of 60-65, decreasing to 1.2 Nm/kg for individuals older than 80 years (34, 40). In terms of peak torque flexion, the literature shows values of 0.64 Nm/kg around the age of 60-65 (10, 40). Taken together, the performance of our sample in the functional tests as well as in lower extremity muscular strength seem to be within the normal values observed in the literature.

The literature provides equivocal results on the association between BMI and health-related outcomes. For example, Hardy et al. (18) reported positive relationship between BMI scores and handgrip strength performance. In contrast, Shin et al. (42) demonstrated that high BMI scores negatively impacted physical performance in their sample of obese adults. Furthermore, previous findings have suggested that older adults classified as normal weight had higher muscle strength compared to their counterparts classified as obese (14, 15, 19, 20, 41). Our findings of relative (to body weight) peak torque and peak flexion, which are objective measures of muscular strength, corroborate the idea that BMI values may negatively affect muscular performance among older adults. In fact, we observed that normal weight BMI individuals presented with significantly higher relative peak torque extension and flexion values compared to their counterparts in the obese group. However, our findings on functional tests showed no significant differences among different BMI categories. Of note, the association between high BMI values, mobility limitation (24), chronic disease - particularly cardiovascular disease (22, 47, 50, 51), and mortality risk (7, 28) have also been observed by researchers. Collectively, the findings of these previous investigations (24, 28, 42, 47, 50) suggested that high BMI values may be associated with negative health outcomes and reduced performance in physical function tests. However, the relationship among BMI, health measures, and functionality may depend upon the population being analyzed and the selected variables examined, and whether or not the results taken into account one's body weight. In particular, our study enrolled active/trained older individuals compared to previous studies in which inactive/non-trained individuals were recruited (5, 30, 41). Our participants were engaged in whole body functional exercise training involving aerobic and resistance training for at least 3 months, 3 times per week, with 60 minutes duration per session, with a focus on functional capacity. Based on this information it is clear that our participants were trained and highly active. Thus, it is possible that BMI status does not impact physical function tests (that mimic ordinary activities of daily living) in elderly individuals who exercise regularly. This is reinforced by findings from previous studies demonstrating that being physically active on a regular basis significantly attenuates the negative impact of being overweight or obese in terms of morbidity and functionality (16, 35). For instance, a recent study conducted in 220 older adults showed that high physically active individuals presented with lower waist and hip circumference, lower body fat percent, better physical fitness (assessed using upper and lower body strength, static and dynamic balance, flexibility and endurance tests) and a better lipid profile than their counterparts reporting low levels of physical activity (35). Similarly, researchers examining the influence of being overweight on functional capacity of 24 active older women (exercise regularly twice a week), concluded that physically active overweight older women do not present with poor performance of total functional capacity, however, they tend to present lower hip and upper body flexibility (1). Collectively, these studies provided cross-sectional evidence that being physically active seems to positively impact anthropometric indicators, physical fitness, and lipid profile among older adults.

The present study was not without limitations, therefore our findings should be interpreted with caution. First, BMI is used to estimate body fatness in large populations but it is not a direct measure of body fatness on an individual level. On this point, it is well-known that factors such as age and amount of muscle mass can influence BMI values. Previous studies, however, have shown that BMI is moderately-to-strongly correlated with more direct methods of body fat obtained from valid methods such as bioelectrical impedance and dual energy X-ray absorptiometry (2, 49). Our study further comprised a disproportionate number of females (86%). This could have impacted our findings as previous work has underscored that BMI, comorbidities and muscle mass differ by sex (44). BMI assessment has also being shown to be of concern in research including older adults (17). To minimize this issue we objectively measured height and weight in our sample using a stadiometer and analogic scale, respectively instead of self-report, which can cause bias and misclassification of the participants (11). Another factor not observed in our study was sarcopenic obesity, which is a condition that affects the risk of developing a series of adverse health events (38), due to the low muscle mass accompanied by obesity (45). Physically active/trained older individuals are generally not affected (38). Furthermore, we only examined the impact of BMI on a small collection of physical function tests. It would be important to investigate the potential influence of BMI and body fatness in active/trained individuals on a large array of tests in order to acquire a broader understanding in this subpopulation. Future studies should attempt to objectively assess body composition (preferably using a gold standard approach) and allocate groups based on body fat quantification using a larger and heterogeneous sample. Despite our current limitations, we were able to provide valuable information suggesting that high values BMI do not negatively affect performance in selected physical function or lower extremity muscle strength tests in older active/trained individuals.

Our findings suggested that high BMI values do not significantly affect performance in physical function or lower extremity muscle strength tests in active/trained older individuals. However, relative peak torque and peak flexion, known measures of muscle strength, of normal weight individuals was found to be significant higher compared to obese individuals. Thus, independent of BMI classification (i.e., normal weight, overweight or obese), active/trained older adults presented with similar performances in physical function and lower extremity muscle strength tests, except when muscle strength is analyzed relative to individual's body weight. These findings indicated that being physically active/trained may counteract some of the negative effects of high BMI observed in the older adult population. Despite the overall lack of association between BMI and physical functioning/muscular strength testing in this population, it is important to highlight that overweight and obese categories of BMI have been associated with a large array of adverse health outcomes in older adults including variety of chronic diseases and conditions.

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REFERENCES

1. de Almeida AS, Fontes PA, Reinaldo JM, Neta M de LF, Sampaio RAC, Silva RJDS, et al. Influence of overweight on functional capacity of physically active older women. Rev Bras Cineantropometria e Desempenho Hum 22, 2020.

2. Amani R. Comparison between bioelectrical impedance analysis and body mass index methods in determination of obesity prevalence in Ahvazi women. Eur J Clin Nutr , 2007.

3. Aquino M de A, Leme LEG, Amatuzzi MM, Greve JMDA, Terreri ASAP, Andrusaitis FR, et al. Isokinetic assessment of knee flexor/extensor muscular strength in elderly women. Rev Hosp Clin Fac Med Sao Paulo 57(4): 131–4, 2002.

4. Arrieta H, Rezola-Pardo C, Echeverria I, Iturburu M, Gil SM, Yanguas JJ, et al. Physical activity and fitness are associated with verbal memory, quality of life and depression among nursing home residents: Preliminary data of a randomized controlled trial. BMC Geriatr 18(1): 1–13, 2018.

5. Bahat G, Muratli S, Ilhan B, Tufan A, Tufan F, Aydin Y, et al. Body mass index and functional status in community dwelling older Turkish males. Aging Male, 2015.

6. Brady AO, Straight CR, Schmidt MD, Evans EM. Impact of body mass index on the relationship between muscle quality and physical function in older women. J Nutr Heal Aging, 2014.

7. Buys DR, Roth DL, Ritchie CS, Sawyer P, Allman RM, Funkhouser EM, et al. Nutritional risk and body mass index predict hospitalization, nursing home admissions, and mortality in community-dwelling older adults: Results from the UAB study of aging with 8.5 years of follow-up. Journals Gerontol - Ser A Biol Sci Med Sci 69(9), 2014.

8. Carvalho J, Oliveira J, Magalhães J, Ascensão A, Mota J, Soares JMC. Força muscular em idosos I — Será o treino generalizado suficientemente intenso para promover o aumento da força muscular em idosos de ambos os sexos? Rev Port Ciências do Desporto 2004(1): 51–7, 2004.

9. Cohen A, Baker J, Ardern CI. Association between body mass index, physical activity, and health-related quality of life in Canadian adults. J Aging Phys Act 24(1): 32–8, 2016.

10. Deborah Hebling Spinosoa, Nise Ribeiro Marquesb, Dain Patrick LaRochec, Camilla Zamfollini Hallald, Aline Harumi Karukae, Fernanda Cristina Milanezie, Gonçalvese M. Hip, Knee, and Ankle Functional Demand During Habitual and Fast Pace Walking in Younger and Older Women Authors: 2014.

11. Flegal KM, Kit BK, Graubard BI. Bias in Hazard Ratios Arising from Misclassification According to Self-Reported Weight and Height in Observational Studies of Body Mass Index and Mortality. Am J Epidemiol 187(1), 2018.

12. Garrow JS, Webster J. Quetelet's index (W/H2) as a measure of fatness. Int J Obes, 1985.

13. Geirsdottir OG, Chang M, Jonsson P V., Thorsdottir I, Ramel A. Obesity, physical function, and training success in community-dwelling nonsarcopenic old adults. J Aging Res, 2019.

14. Graf CE, Pichard C, Herrmann FR, Sieber CC, Zekry D, Genton L. Prevalence of low muscle mass according to body mass index in older adults. Nutrition 34: 124–9, 2017.

15. Günther CM, Bürger A, Rickert M, Crispin A, Schulz CU. Grip Strength in Healthy Caucasian Adults: Reference Values. J Hand Surg Am, 2008.

16. Hainer V, Toplak H, Stich V. Fat or fit: what is more important? Diabetes Care. 32 Suppl 2, 2009.

17. Han L, You D, Ma W, Astell-Burt T, Feng X, Duan S, et al. National Trends in American Heart Association Revised Life's Simple 7 Metrics Associated with Risk of Mortality among US Adults. JAMA Netw Open 2(10), 2019.

18. Hardy R, Cooper R, Aihie Sayer A, Ben-Shlomo Y, Cooper C, Deary IJ, et al. Body Mass Index, Muscle Strength and Physical Performance in Older Adults from Eight Cohort Studies: The HALCyon Programme. PLoS One, 2013.

19. Hiol AN, von Hurst PR, Conlon CA, Mugridge O, Beck KL. Body composition associations with muscle strength in older adults living in Auckland, New Zealand. PLoS One 16(5 May): 1–12, 2021.

20. Huang C, Niu K, Momma H, Kobayashi Y, Guan L, Chujo M, et al. Breakfast consumption frequency is associated with grip strength in a population of healthy Japanese adults. Nutr Metab Cardiovasc Dis, 2014.

21. Kaiser MJ, Bauer JM, Ramsch C, Uter W, Guigoz Y, Cederholm T, et al. Validation of the Mini Nutritional Assessment short-form (MNA®-SF): A practical tool for identification of nutritional status. J Nutr Heal Aging , 2009.

22. Karanikas I, Karayiannis D, Karachaliou A, Papanikolaou A, Chourdakis M, Kakavas S. Body composition parameters and functional status test in predicting future acute exacerbation risk among hospitalized patients with chronic obstructive pulmonary disease. Clin Nutr 40(11), 2021.

23. Kim S, Leng XI, Kritchevsky SB. Body Composition and Physical Function in Older Adults with Various Comorbidities. Innov Aging, 2017.

24. Koster A, Penninx BWJH, Newman AB, Visser M, Van Gool CH, Harris TB, et al. Lifestyle factors and incident mobility limitation in obese and non-obese older adults. Obesity, 2007.

25. Lieber RL, Roberts TJ, Blemker SS, Lee SSM, Herzog W. Skeletal muscle mechanics, energetics and plasticity Daniel P Ferris. J Neuroeng Rehabil 14(1): 1–16, 2017.

26. van Lummel RC, Evers J, Niessen M, Beek PJ, van Dieën JH. Older adults with weaker muscle strength stand up from a sitting position with more dynamic trunk use. Sensors (Switzerland) 18(4): 1–12, 2018.

27. Machado RSP, Coelho MASC, Veras RP. Validity of the portuguese version of the mini nutritional assessment in brazilian elderly. BMC Geriatr, 2015.

28. MacMahon S, Baigent C, Duffy S, Rodgers A, Tominaga S, Chambless L, et al. Body-mass index and cause-specific mortality in 900 000 adults: Collaborative analyses of 57 prospective studies. Lancet, 2009.

29. Mainous AG, Tanner RJ, Rahmanian KP, Jo A, Carek PJ. Effect of Sedentary Lifestyle on Cardiovascular Disease Risk Among Healthy Adults With Body Mass Indexes 18.5 to 29.9 kg/m 2. Am J Cardiol, 2019.

30. Mathis AL, Rooks RN, Tawk RH, Kruger DJ. Neighborhood Influences and BMI in Urban Older Adults. J Appl Gerontol, 2017.

31. Meeuwsen S, Horgan GW, Elia M. The relationship between BMI and percent body fat, measured by bioelectrical impedance, in a large adult sample is curvilinear and influenced by age and sex. Clin Nutr, 2010.

32. Merchant RA, Kit MWW, Lim JY, Morley JE. Association of central obesity and high body mass index with function and cognition in older adults. Endocr Connect, 2021.

33. Navalta JW, Stone WJ, Lyons TS. Ethical Issues Relating to Scientific Discovery in Exercise Science. Int J Exerc Sci 12(1): 1–8, 2019.

34. Pereira JC, Neri SGR, Vainshelboim B, Gadelha AB, Bottaro M, De Oliveira RJ, et al. Normative Values of Knee Extensor Isokinetic Strength for Older Women and Implications for Physical Function. J Geriatr Phys Ther 42(4): E25--E31, 2019.

35. Rajabi H, Sabouri M, Hatami E. Associations between physical activity levels with nutritional status, physical fitness and biochemical indicators in older adults. Clin Nutr ESPEN 45, 2021.

36. Rikli RE, Jones CJ. Development and validation of a functional fitness test for community- residing older adults. J Aging Phys Act, 1999.

37. Rikli RE, Jones CJ. Development and validation of criterion-referenced clinically relevant fitness standards for maintaining physical independence in later years. Gerontologist 53(2): 255–67, 2013.

38. Roh E, Choi KM. Health Consequences of Sarcopenic Obesity: A Narrative Review. Front. Endocrinol. (Lausanne), 2020.

39. Romero-Corral A, Somers VK, Sierra-Johnson J, Thomas RJ, Collazo-Clavell ML, Korinek J, et al. Accuracy of body mass index in diagnosing obesity in the adult general population. Int J Obes 32(6), 2008.

40. Šarabon N, Kozinc Ž, Perman M. Establishing Reference Values for Isometric Knee Extension and Flexion Strength. Front Physiol 12(October), 2021.

41. Shen S, Li J, Guo Q, Zhang W, Wang X, Fu L, et al. Body mass index is associated with physical performance in suburb-dwelling older Chinese: A cross-sectional study. PLoS One 10(3): 1–11, 2015.

42. Shin H, Liu PY, Panton LB, Ilich JZ. Physical performance in relation to body composition and bone mineral density in healthy, overweight, and obese postmenopausal women. J Geriatr Phys Ther, 2014.

43. Smith L, White S, Stubbs B, Hu L, Veronese N, Vancampfort D, et al. Depressive symptoms, handgrip strength, and weight status in US older adults. J Affect Disord, 2018.

44. Srikanthan P, Horwich TB, Tseng CH. Relation of Muscle Mass and Fat Mass to Cardiovascular Disease Mortality. Am J Cardiol 117(8), 2016.

45. Stenholm S, Harris T, Rantenen T, Visser M, Kritchevsky SB, Ferrucci L. Sarcopenic obesity-definition,etiology and consequences. Curr Opin Clin Nutr Metab Care 11(6), 2008.

46. Valenzuela PL, Maffiuletti NA, Tringali G, De Col A, Sartorio A. Obesity-associated poor muscle quality: Prevalence and association with age, sex, and body mass index. BMC Musculoskelet Disord, 2020.

47. WANG YF, TANG Z, GUO J, TAO LX, LIU L, LI H Bin, et al. BMI and BMI Changes to All-cause Mortality among the Elderly in Beijing: a 20-year Cohort Study. Biomed Environ Sci, 2017.

48. Wannamethee SG, Shaper AG, Lennon L, Whincup PH. Decreased muscle mass and increased central adiposity are independently related to mortality in older men. Am J Clin Nutr 86(5), 2007.

49. Wohlfahrt-Veje C, Tinggaard J, Winther K, Mouritsen A, Hagen CP, Mieritz MG, et al. Body fat throughout childhood in 2647 healthy Danish children: Agreement of BMI, waist circumference, skinfolds with dual X-ray absorptiometry. Eur J Clin Nutr 68(6): 664–70, 2014.

50. Yu J, Tao Y, Dou J, Ye J, Yu Y, Jin L. The dose-response analysis between BMI and common chronic diseases in northeast China. Sci Rep, 2018.

51. Yun H-R, Kim HW, Chang TI, Kang EW, Joo YS, Nam KH, et al. Increased Risk of Chronic Kidney Disease Associated With Weight Gain in Healthy Adults: Insight From Metabolic Profiles and Body Composition. Front Med 8, 2021.

52. WHO | Mean Body Mass Index (BMI). WHO, 2017.