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Original Research

Muscle Mass Adjusted by Body Height is not Correlated with Mobility of Middle-Aged and Older Adults

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A B S T R A C T

Background: Low muscle mass and obesity are associated with mobility disability, cardiometabolic diseases, and loss of independence. Three skeletal muscle indices (SMIs) are proposed to adjust the body size of individuals. However, it is unknown which index is better correlated with mobility. Additionally, it remains unclear whether low muscle mass or abdominal obesity has a greater impact on the mobility and cardiometabolic health of older adults.

Objectives: This study explored the association between different SMIs {appendicular skeletal muscle mass [ASM] adjusted by body height [Ht], body weight [Wt], or body mass index [BMI (kg/m^2)]} and mobility/cardiometabolic health. The roles of low muscle mass and abdominal obesity in the mobility and cardiometabolic health of individuals were also identified.

Methods: Four-hundred and twenty-seven community-dwelling middle-aged and older adults underwent body composition assessments [dual-energy x-ray absorptiometry and waist circumference (WC)], grip strength, and mobility (timed up-and-go test and chair stand test). Spearman's rank correlation coefficient and regression models were used to examine research questions. This study was registered in the Thai Clinical Trials Registry (registration number: TCTR20210521007).

Results: All SMIs were positively correlated with the grip strength (ASM/Ht^2: $r = 0.392$; ASM/Wt: $r = 0.439$; ASM/BMI: $r = 0.569$). Regarding mobility, only ASM/Ht^2 wasn't relevant. After adjusting for age, sex, and WC, ASM/BMI was the only SMI associated with grip strength ($\beta = 0.274$). When age and sex were controlled, WC, but not SMI, was associated with mobility and cardiometabolic health.

Conclusions: ASM/Ht^2 did not correlate with mobility in middle-aged and older adults, whereas ASM/Wt and ASM/BMI did. Abdominal obesity has a greater impact on mobility and cardiometabolic health than low muscle mass in middle-aged and older adults. We recommend using ASM/BMI to identify the low muscle mass of individuals. In addition, clinicians should note the important role of abdominal obesity when considering mobility in middle-aged and older adults.

Keywords: sarcopenia, definition, abdominal obesity, function, skeletal muscle index

Introduction

Healthy life expectancy and physical independence are valued increasingly as the world ages, and the elderly population continues to grow. Cardiometabolic diseases not only decrease the quality of life of individuals but also increase their risk of disability-adjusted life years, hospitalization, and mortality [1–3]. Mobility (i.e., the ability to move from one place to another, such as walking, stair climbing, or chair rising) is another important component of the overall well-being of the elderly. Impaired mobility decreases functional independence and increases the risk of falls, frailty, disability, hospitalization, and mortality in the elderly [4,5].

Obesity is a hallmark of age-related changes in body composition. It is a risk factor for cardiometabolic diseases and contributes to the development of functional impairment and physical disability [6,7]. Many indicators are used to define obesity, including BMI, waist circumference (WC), and body fat percentage (BF%) [8]. However, these indicators have slightly different implications. Both BMI and BF% do not provide

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information about depots of fat. WC is more correlated with visceral fat than either BMI or BF% [6]. It is known that visceral fat is associated with risks of cardiometabolic diseases, whereas subcutaneous fat is less harmful [6,9]. Indeed, a meta-analysis demonstrated that a 1-cm increment in WC increases the risk of cardiovascular diseases by 2% [10]. WC is also found to have a greater association with muscle function than other indices of obesity (BMI and BF%) [11].

In addition to obesity, low muscle mass also plays a critical role in cardiometabolic health and mobility [12]. Because muscle mass is correlated with body size, it is adjusted for body size when identifying low muscle mass. Body size–adjusted skeletal muscle mass, also known as skeletal muscle index (SMI), was used to define the low muscle mass of individuals by the Asian Working Group for Sarcopenia and the European Working Group on Sarcopenia [13,14]. To date, 3 SMIs have been proposed: appendicular skeletal muscle mass (ASM) adjusted by body height (ASM/Ht^2), body weight (ASM/Wt), and BMI (ASM/BMI) [13–18]. Although Ht, Wt, and BMI are the proposed ways of adjustment, the preferred adjustment method and whether the same adjustment can be used for all populations continue to be debatable. ASM/Ht^2 is the most widely used index for defining low muscle mass [13]. However, ASM/BMI showed a better correlation with muscle strength, physical function, and recurrent falls than ASM/Ht^2 and ASM/Wt in older adults [16,19,20]. For young and middle-aged adults with BMI $\geq$35, ASM/Wt, but not ASM/Ht^2 or ASM/BMI, is associated with difficulties in activities of daily living [21]. Taken together, the relationship between different SMIs and mobility remains unclear and is likely population-specific.

Although low muscle mass and abdominal obesity both contribute to the impairment of mobility and cardiometabolic health, it is unclear which one plays a more critical role in mobility and cardiometabolic health. Understanding the role of abdominal obesity and low muscle mass in mobility and cardiometabolic health will help in planning interventions. For example, if abdominal obesity plays a more critical role in mobility and cardiometabolic health than low muscle mass, calorie restriction and aerobic exercise are recommended to manage abdominal obesity [22]. If low muscle mass plays a more important role in mobility and cardiometabolic health than abdominal obesity, a high-protein diet and resistance exercise are recommended to increase muscle mass [23]. This study aimed to investigate which body size–adjusted SMI has a better correlation with mobility and cardiometabolic health and to identify which factors (low muscle mass or abdominal obesity) play an independent role in mobility and cardiometabolic health.

Methods

Participants

This study invited community-dwelling middle-aged and older adults ($\geq$45 y) to participate. Exclusion criteria were conditions that prevented individuals from performing physical activity tests, such as sprain, chest pain, or lesions in the central nervous system. A total of 435 individuals were assessed for eligibility; 8 people did not meet the inclusion and exclusion criteria. Therefore, 427 individuals from northern Taiwan participated in this study (Figure 1). All methods were carried out in accordance with the principles stated in the Declaration of Helsinki. This study was approved by the institutional review board of National Yang Ming Chiao Tung University (IRB number: YM-109007F) and was registered in the Thai Clinical Trials Registry (registration number: TCTR20210521007). All participants underwent assessment after signing the consent form.

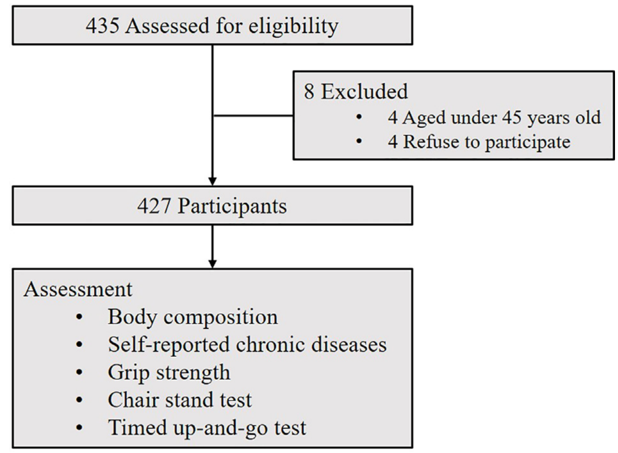

FIGURE 1. Flow chart of the study.

Outcome variables

Body composition

ASM and Wt were determined using dual-energy x-ray absorptiometry (Lunar iDXA; GE Medical System). The dual-energy x-ray absorptiometry system was calibrated each day before assessments by placing the calibration block in line with the laser, as indicated by the diagram on the screen. After successful calibration, participants were asked to remove items that were made of metal and lay down on the equipment by instructions without any movement for 15 min. Ht and WC were measured by tape measure. Participants were asked to stand in front of a wall-mounted tape measure without shoes [24]. WC was measured at the midway level between the lowest rib and the iliac crest using an anthropometric tape, twice [25]. If the difference between the first and the second measurements was >0.5 cm, a third measurement was performed. The mean of measurements was recorded [25]. The technical measurement error for WC was 0.003 cm based on our pilot study, where the WC of 73 participants was measured, and the technical measurement error was calculated as the SD of the 3 measurements divided by the mean of the 3 measurements. BMI was calculated as Wt divided by Ht^2 [26].

Muscle strength, mobility, and cardiometabolic health

Muscle strength was determined by measuring grip strength [14] using a hand dynamometer (Jamar) as described previously [13]. The grip strength of both hands was tested 3 times each, and the highest value was used for the analysis. Many validated tests are available for assessing mobility in older adults, and the 8-foot timed up-and-go test (TUG) and chair stand test (CST) are 2 suitable assessments for community-dwelling middle-aged and older adults [27]. In the CST, participants sat on a chair with their arms crossed over the chest. When the assessors said "go," participants stood up fully and sat down repeatedly as fast as possible for 30 s. The number completed in 30 s was recorded. In the TUG, participants were asked to stand up from a chair, walk 8 feet, turn around, walk back to the chair, and sit down as fast as possible. The time required to complete the tests was recorded [26]. The cardiometabolic health of individuals was determined based on whether they had been diagnosed with hypertension (HTN), type 2 diabetes mellitus (T2DM), and dyslipidemia.

Definition of abdominal obesity and low muscle mass

Abdominal obesity was defined as WC ≥90 cm for men and 80 cm for women (Ministry of Health and Welfare, Taiwan). BMI and BF% were not chosen as indicators of obesity because WC is more correlated with visceral fat than BMI and BF% [6]. Low muscle mass was identified according to the following criteria: *1*) ASM/Ht^2 <7.0 for men; ASM/Ht^2 <5.4 for women [13]; or *2*) ASM/Wt <29.1% for men; ASM/Wt <23.0% for women [17]; or *3*) ASM/BMI <0.789 for men; ASM/BMI <0.512 for women [15]. The definition of low muscle mass determined by ASM/Ht^2 and ASM/Wt is 2 SDs below the mean value of healthy young adults [13,17]. The cut-off point for low muscle mass determined by ASM/BMI is based on clinically relevant weakness [15]. Participants who met the definitions of both abdominal obesity and low muscle mass were defined as having low muscle mass and abdominal obesity. According to the definition stated above, all participants were divided into 4 groups: normal body composition group (N group, without abdominal obesity and low muscle mass), low muscle mass alone group (LM group, with low muscle mass but without abdominal obesity), abdominal obesity alone group (O group, with abdominal obesity but without low muscle mass), and low muscle mass plus abdominal obesity group (LMO group, with both abdominal obesity and low muscle mass).

Statistical analyses

Statistical analyses were performed by SPSS 25.0 (Statistical Package for the Social Sciences). Data were presented as mean ± SD or percentage. The Kolmogorov-Smirnov test was used to examine the normality distribution of data. One-way analysis of variance and the χ^2 test were used to compare the differences among N, LM, O, and LMO groups. The Bonferroni test was used as a post hoc test. The correlation between grip strength/mobility and SMI was assessed using Spearman's rank correlation coefficient. Multiple regression analysis was used to identify independent associations of abdominal obesity and low muscle mass with muscle strength, mobility, and cardiometabolic health. Age and sex were a covariate in the multiple regression model because they were significantly different between N, LM, O, and LMO groups. Statistical significance was set at $P < 0.05$.

Statistical power was performed by G*Power (latest version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf). The effect size [standardized regression coefficient (β)] was set at 0.1. The number of predictors was set at 4. The type I error was set at 0.05, and the type II error was set at 0.05 (Power: 95%). The estimated total sample size was 191. In order to increase the credibility of this study, we recruited 427 participants.

Results

Characteristics of participants

Among the 427 participants (66.0 ± 9.0 y old), 303 (71%) were women and 124 (29%) were men. The mean BMI, WC, and BF% were 25.5 ± 3.8 kg/m^2, 85.7 ± 10.3 cm, and 36.0% ± 7.5%, respectively. Compared with men, women were younger (men: 69.4 ± 8.7 y old; women: 64.7 ± 8.8 y old), had lower values of WC (men: 88.0 ± 9.7 cm; women: 84.8 ± 10.4 cm), and had higher values of BF% (men: 28.7% ± 5.7%; women: 39.0% ± 5.9%). The mean ASM/Ht^2, ASM/Wt, and ASM/BMI were 6.7 ± 1.0, 26.5% ± 3.9%, and 0.658 ± 0.135, respectively. Compared with men, women had lower values of ASM/Ht^2 (men: 7.5 ± 1.0 kg/m^2; women: 6.3 ± 0.8 kg/m^2), ASM/Wt (men: 30.0±3.7%; women: 25.0% ± 3.0%), and ASM/BMI (men: 0.808 ± 0.112; women: 0.597 ± 0.086). The mean grip strength, TUG, and CST were 26.4 ± 7.3 kg, 6.1 ± 1.7 sec, and 17.9 ± 5.9 times, respectively. Compared with men, women had lower grip strength (men: 32.6 ± 6.7 kg; women: 23.5 ± 5.6 kg). The performance in TUG and CST was similar between men and women. Compared with men, women had a lower prevalence of HTN (men: 48.7%; women: 31.8%) and a higher prevalence of dyslipidemia (men: 2.6%; women: 9.3%).

When muscle mass was adjusted for Ht (ASM/Ht^2), 26.7% of the participants belonged to the normal body composition group (N group, without abdominal obesity and low muscle mass), 11.9% of the participants belonged to the low muscle mass group (LM group, with low muscle mass but without abdominal obesity), 56.0% of the participants belonged to the abdominal obesity alone group (O group, with abdominal obesity but without low muscle mass), and 5.4% of the participants belonged to the low muscle mass plus abdominal obesity group (LMO group, with both abdominal obesity and low muscle mass). The mean age of individuals in the LM group was greater than that in the N and O groups. The LM group had the highest percentage of men, and the O group had the highest percentage of women (Table 1).

When muscle mass was adjusted by Wt (ASM/Wt), 33.5% of participants belonged to the N group, 5.1% of participants belonged to the LM group, 42.4% of participants belonged to the O group, and 19.0% of participants belonged to the LMO group. The mean age of individuals in the LM group was greater than those in the N, O, and LMO groups. The LM group had the highest percentage of men, and the O group had the highest percentage of women (Table 1).

When muscle mass was adjusted by BMI (ASM/BMI), 30.0% of the participants belonged to the N group, 8.7% of the participants belonged to the LM group, 48.9% of the participants belonged to the O group, and 12.4% of the participants belonged to the LMO group. The mean age of individuals in the LM group was greater than those in the N, O, and LMO groups. The mean age of individuals in the LMO group was greater than that in the O group. The LM group had the highest percentage of men, and the O group had the highest percentage of women (Table 1).

Correlation of different SMIs with muscle strength, mobility, and cardiometabolic health

ASM/Ht^2

Ht-adjusted SMI (ASM/Ht^2) was positively correlated with grip strength ($r = 0.392$, $P < 0.001$), but its correlations with TUG and CST performance were not significant (Figure 2). When categorizing participants into the N, LM, O, and LMO groups based on WC and ASM/Ht^2, the performance of grip strength, CST, and TUG was poorer in the O group than in the N group ($P < 0.05$), whereas the performance did not differ between the N,

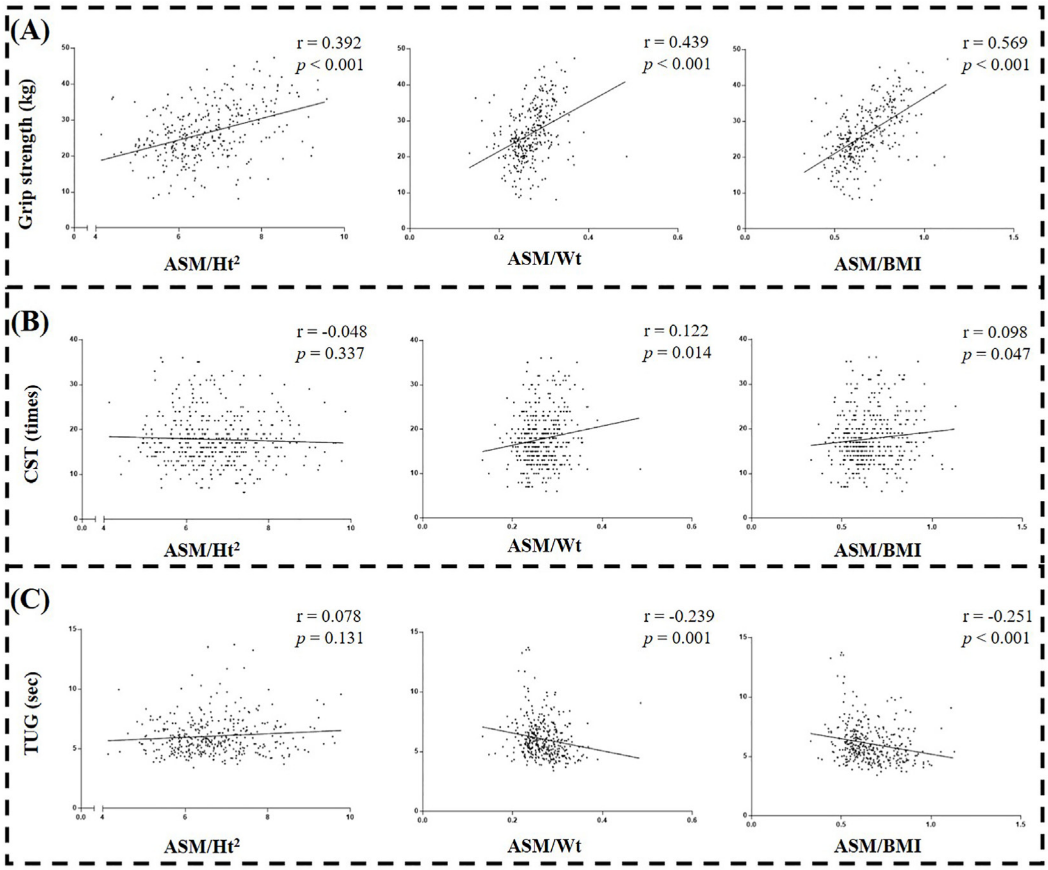

FIGURE 2. Spearman's rank correlation coefficient between skeletal muscle index (SMI) and grip strength/mobility. (A) Correlation of SMI and grip strength. (B) Correlation of SMI and chair stand test (CST). (C) Correlation of SMI and timed up-and-go test (TUG). ASM, appendicular skeletal muscle mass; BMI, body mass index; Ht, body height; Wt, body weight.

LM, and LMO groups (Figure 3). Regarding cardiometabolic health, the prevalence of HTN was >40% in the O and LMO groups, which was higher than that in the N (26.5%) and LM (29.8%) groups. The prevalence of dyslipidemia was higher in the O (9.9%) and LMO (13.6%) groups than in the N (2.9%) and LM (2.1%) groups ($P < 0.05$). More than 50% of the participants in the O and LMO groups and <40% of the participants in the N and LM groups had ≥1 cardiometabolic disease (Table 1).

ASM/Wt

Wt-adjusted SMI (ASM/Wt) was positively correlated with grip strength ($r = 0.439$, $P < 0.001$) and CST ($r = 0.122$, $P = 0.014$) and negatively correlated with TUG ($r = –0.239$, $P = 0.001$) (Figure 2). When categorizing participants into the N, LM, O, and LMO groups based on WC and ASM/Wt, we found that compared with the N group, the LM group had poorer performance in the TUG; the O group had poorer performance in the grip strength, CST, and TUG; and the LMO group had poorer performance in the CST and TUG ($P < 0.05$) (Figure 3). Regarding cardiometabolic health, the prevalence of HTN was >40% in the LM, O, and LMO groups, which was higher than that in the N group (24.2%). The prevalence of T2DM was >15% in the LM and O groups. The prevalence of dyslipidemia was highest in the O group (12.7%). More than 50% of the participants in the LM, O, and LMO groups and <40% of the participants in the N group had ≥1 cardiometabolic disease (Table 1).

ASM/BMI

BMI-adjusted SMI (ASM/BMI) was positively correlated with grip strength ($r = 0.569$, $P < 0.001$) and CST ($r = 0.098$, $P = 0.047$) and negatively correlated with TUG ($r = –0.251$, $P < 0.001$) (Figure 2). When categorizing participants into the N, LM, O, and LMO groups based on WC and ASM/BMI, we found that compared with the N group, the O and LMO groups had poorer CST and TUG performance. The TUG performance of the LMO group was poorer than that of the O group ($P < 0.05$) (Figure 3). Regarding cardiometabolic health, the prevalence of HTN, T2DM, and dyslipidemia differed between the groups ($P < 0.05$). More than 50% of the participants in the LM and LMO groups had HTN; >10% of participants in the LM, O, and LMO groups had T2DM; and 11.9% of the participants in the O group had dyslipidemia. More than 50% of the participants in the LM, O, and LMO groups and <30% of the participants in the N group had ≥1 cardiometabolic disease (Table 1).

Factors associated with muscle strength, mobility, and cardiometabolic health

Regression models were used to examine the independent roles of abdominal obesity and low muscle mass in muscle strength, mobility, and cardiometabolic health. When age, sex, WC, and ASM/Ht^2 were entered into the model, WC was negatively associated with the performance of CST and TUG ($P <$

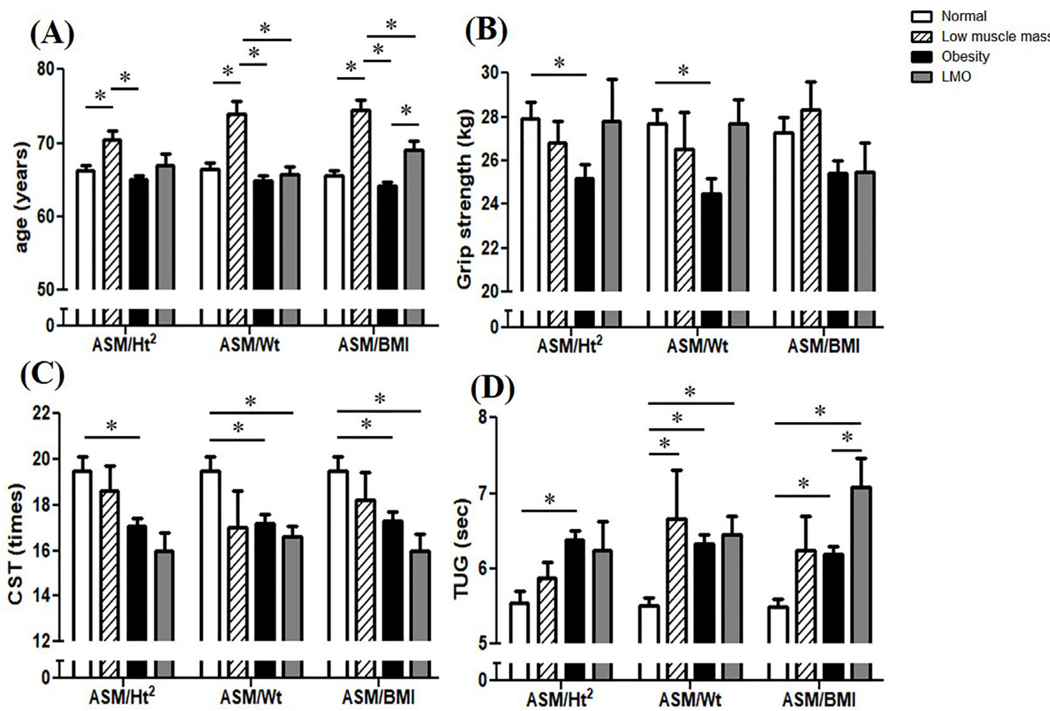

FIGURE 3. Age (A), grip strength (B), and the performance in the chair stand test (CST) (C), and timed up-and-go test (TUG) (D) of participants with different body composition. Data were presented as mean ± SE. ASM, appendicular skeletal muscle mass; BMI, body mass index; Ht, body height; SE, standard error; Wt, body weight.

0.001). ASM/Ht^2 was not independently associated with grip strength, CST, or TUG ($P > 0.05$). When age, sex, WC, and ASM/Wt were entered into the model, WC was positively associated with grip strength ($\beta = 0.103$, $P = 0.031$) and negatively associated with the performance of CST and TUG ($P < 0.05$). ASM/Wt was not independently associated with grip strength, CST, or TUG ($P > 0.05$). When age, sex, WC, and ASM/BMI were entered into the model, WC was positively associated with grip strength ($P = 0.001$) and negatively associated with the performance of CST and TUG ($P < 0.001$). ASM/BMI was positively associated with grip strength ($\beta = 0.274$, $P < 0.001$). ASM/BMI was not independently associated with the performance of CST and TUG ($P > 0.05$). Regarding the factors for cardiometabolic health, WC, but not SMI, was an independent factor for having ≥1 cardiometabolic disease (Table 2).

Discussion

This study aimed to identify which body size–adjusted SMI had the best correlation with muscle strength/mobility/cardiometabolic health in community-dwelling middle-aged and older individuals. The roles of abdominal obesity and low muscle mass in muscle strength/mobility/cardiometabolic health were also examined. Three examined SMIs were positively correlated with grip strength, but only ASM/Wt and ASM/BMI were relevant to the mobility of middle-aged and older individuals. Only ASM/BMI was positively correlated with grip strength when controlling for age, sex, and WC. Abdominal obesity, but not muscle mass (regardless of adjusting for Ht, Wt, or BMI), was associated with mobility and cardiometabolic health after controlling age and sex.

Grip strength is often used to represent an individual's muscle strength because it is easy to assess and has a moderate correlation with the muscle strength of other body components [28]. In the current study, grip strength was correlated with ASM/Ht^2, ASM/Wt, and ASM/BMI in middle-aged and older adults. Interestingly, we found that when age, sex, and WC were controlled for, only ASM/BMI was positively correlated with grip strength. Similarly, Kinoshita et al. [19] showed that individuals with low ASM/BMI but not ASM/Ht^2 or ASM/Wt had a higher risk of low grip strength. The better correlation between ASM/BMI and grip strength than that between ASM/Ht^2 or ASM/Wt and grip strength is likely because Ht is generally positively associated with Wt, which is composed of a mass of muscle, fat, bone, and organs. Therefore, when muscle mass is compared among individuals, it should be adjusted by BMI.

An important finding of this study was that the association between SMI and mobility was found in ASM/Wt and ASM/BMI; ASM/Ht^2 was not associated with mobility, although it is the current most commonly used index for identifying low muscle mass [13,14]. The finding of this study was similar to the previous reports that examined SMI and mobility. For example, Stoklossa et al. [21] reported that ASM/Wt, but not ASM/Ht^2, was positively correlated with physical independence in adults with obesity. ASM/BMI, but not ASM/Ht^2, was also found relevant to the mobility of older adults [15,19,29]. Taken together, though still limited in number, an increasing body of research findings (including the current study) support the use of Wt- or BMI-adjusted SMI to identify low muscle mass, as it correlates more strongly with individuals' mobility. The observation regarding the significance of Wt- or BMI-adjusted SMI is likely attributed to the fact that mobility is more closely linked to individuals' body mass or the severity of obesity.

We noticed that sex influenced grip strength and TUG performance when age, WC, and SMI were controlled, with women

TABLE 1
Basic characteristics and cardiometabolic health according to the different definitions of low muscle mass

	ASM/Ht^2					ASM/Wt					ASM/BMI				
	N	LM	O	LMO	*P*	N	LM	O	LMO	*P*	N	LM	O	LMO	*P*
Participants (%)	114 (26.7)	51 (11.9)	239 (56.0)	23 (5.4)		143 (33.5)	22 (5.1)	181 (42.4)	81 (19.0)		128 (30.0)	37 (8.7)	209 (48.9)	53 (12.4)	
Men (%)	45 (39.5)	28 (54.9)	43 (18.0)	8 (34.8)	<0.001	56 (39.2)	17 (77.3)	28 (15.5)	23 (28.4)	<0.001	43 (33.6)	30 (81.1)	32 (15.3)	19 (35.8)	<0.001
Age (y)	66.2 ± 8.8	70.4 ± 9.5[1,2]	65.0 ± 8.9	66.9 ± 7.5	0.001	66.5 ± 9.0	73.9 ± 8.0[1,2,3]	64.9 ± 8.9	65.7 ± 8.7	<0.001	65.5 ± 8.6	74.5 ± 7.9[1,2,3]	64.1 ± 8.5	69.1 ± 9.0[2]	<0.001
Men	69.1 ± 8.3	73.0 ± 8.8	67.2 ± 9.0	70.6 ± 6.7	0.053	69.4 ± 8.8	74.5 ± 6.8[2]	65.2 ± 9.0	70.9 ± 7.4	0.004	68.3 ± 8.8	74.1 ± 7.1[1,2]	65.6 ± 9.1	71.4±6.8	0.001
Women	64.3 ± 8.6	67.4 ± 9.7	64.5 ± 8.8	64.9 ± 7.4	0.495	64.6 ± 8.7	71.8 ± 12.1	64.9 ± 8.9	63.6 ± 8.3	0.237	64.1 ± 8.2	76.0 ± 11.1[1,2]	63.9 ± 8.4	67.9 ± 9.9	<0.001
Body fat (%)	31.2 ± 6.2[2,3]	30.2 ± 7.7[2,3]	39.3 ± 5.9	38.5 ± 7.2	<0.001	30.4 ± 6.7[2,3]	33.6 ± 5.6[2,3]	38.2 ± 5.2[3]	41.6 ± 7.0	<0.001	30.6 ± 7.0[2,3]	31.7 ± 5.4[2,3]	39.1 ± 5.7	39.9 ± 7.3	<0.001
Men	26.2 ± 4.2[2,3]	26.6 ± 7.1[2,3]	31.6 ± 4.0	34.5 ± 5.2	<0.001	24.9 ± 5.1	31.4 ± 3.2[1]	30.1 ± 3.9[1,3]	34.4 ± 3.6[1]	<0.001	24.1 ± 5.6	29.7 ± 3.2[1,3]	30.9 ± 4.2[1]	34.0 ± 3.7[1]	<0.001
Women	34.4 ± 5.0[2,3]	34.7 ± 5.8[2,3]	41.0 ± 4.8	40.6 ± 7.4	<0.001	34.0 ± 5.0	41.3 ± 5.2[1]	39.7 ± 3.9[1,3]	44.5 ± 5.9[1]	<0.001	33.9 ± 5.0	40.4 ± 4.1[1]	40.6 ± 4.5[1,3]	43.2 ± 6.7[1]	<0.001
HTN (%)	27 (26.5)	14 (29.8)	93 (42.7)	8 (40.0)	0.029	31 (24.2)	10 (47.6)	68 (41.0)	33 (45.8)	0.004	24 (20.7)	17 (51.5)	77 (39.7)	24 (54.5)	<0.001
Men	18 (42.9)	9 (34.6)	23 (62.2)	5 (62.5)	0.115	19 (37.3)	8 (47.1)	16 (64.0)	12 (60.0)	0.109	12 (29.3)	15 (55.6)	18 (60.0)	10 (66.7)	0.017
Women	9 (15.0)	5 (23.8)	70 (38.7)	3 (25.0)	0.005	12 (15.6)	2 (50.0)	52 (36.9)	21 (40.4)	0.004	12 (16.0)	2 (33.3)	59 (36.0)	14 (48.3)	0.004
T2DM (%)	6 (5.7)	5 (10.4)	36 (16.2)	4 (18.2)	0.050	6 (4.6)	5 (22.7)	29 (17.5)	11 (14.1)	0.004	6 (5.1)	5 (14.3)	34 (17.5)	6 (12.0)	0.017
Men	2 (4.7)	4 (15.4)	8 (20.0)	2 (25.0)	0.154	2 (3.8)	4 (23.5)	5 (20.0)	5 (21.7)	0.051	2 (4.9)	4 (14.3)	6 (20.0)	4 (22.2)	0.185
Women	4 (6.5)	1 (4.5)	28 (15.4)	2 (14.3)	0.189	4 (5.1)	1 (20.0)	24 (17.0)	6 (10.9)	0.071	4 (5.2)	1 (14.3)	28 (17.1)	2 (6.3)	0.045
Dyslipidemia (%)	3 (2.9)	1 (2.1)	22 (9.9)	3 (13.6)	0.036	4 (3.1)	0 (0.0)	21 (12.7)	4 (5.1)	0.005	4 (3.4)	0 (0.0)	23 (11.9)	2 (4.0)	0.007
Men	0 (0.0)	0 (0.0)	3 (7.5)	0 (0.0)	0.115	0 (0.0)	0 (0.0)	3 (12.0)	0 (0.0)	0.010	0 (0.0)	0 (0.0)	3 (2.6)	0 (0.0)	0.030
Women	3 (4.8)	1 (4.5)	19 (10.4)	3 (21.4)	0.189	4 (5.1)	0 (0.0)	18 (12.8)	4 (7.3)	0.214	4 (5.2)	0 (0.0)	20 (12.2)	2 (6.3)	0.236
With ≥1 cardiometabolic disease (%)	33 (33.0)	18 (38.3)	115 (53.7)	10 (55.6)	0.003	40 (31.7)	11 (52.4)	89 (54.9)	36 (51.4)	0.001	33 (28.9)	18 (54.5)	99 (52.4)	26 (60.5)	<0.001
Men	18 (43.9)	12 (46.2)	28 (75.7)	6 (75.0)	0.015	21 (42.0)	9 (52.9)	21 (84.0)	13 (65.0)	0.005	14 (35.0)	16 (59.3)	23 (76.7)	11 (73.3)	0.002
Women	15 (25.4)	6 (28.6)	87 (49.2)	4 (40.0)	0.008	19 (25.0)	2 (50.0)	68 (49.6)	23 (46.0)	0.005	19 (25.7)	2 (33.3)	76 (47.8)	15 (53.6)	0.007

Data were presented as mean ± SD or percentage.

Note: valid data available for the status of HTN was from 387 participants; valid data available for the status of T2DM and dyslipidemia were from 397 participants; valid data for the status of with ≥1 cardiometabolic disease was from 379 participants.

Abbreviations: ASM, appendicular skeletal muscle mass; BMI, body mass index; Ht, body height; HTN, hypertension; LM, the low muscle mass but without abdominal obesity; LMO, with both abdominal obesity and low muscle mass; N, without abdominal obesity and low muscle mass; O, with abdominal obesity but without low muscle mass; SD, standard deviation; T2DM, type 2 diabetes mellitus; Wt, body weight.

[1] Significantly different from the normal (N) group.

[2] Significantly different from the abdominal obesity alone (O) group.

[3] Significantly different from the low muscle mass plus abdominal obesity (LMO) group.

TABLE 2
Multiple regression models for factors associated with grip strength, mobility, and cardiometabolic health

Dependent variables	Independent variables	β (95% CI)	*P* value
Grip strength	Age	–0.350 (–0.359, –0.225)	<0.001
	Women	–0.606 (–11.041, –8.156)	<0.001
	WC	0.028 (–0.041, 0.082)	0.520
	ASM/Ht^2	0.093 (–0.031, 1.414)	0.061
Grip strength	Age	–0.359 (–0.365, –0.232)	<0.001
	Women	–0.593 (–11.063, –7.708)	<0.001
	WC	0.103 (0.007, 0.139)	0.031
	ASM/Wt	0.088 (–3.992, 36.668)	0.115
Grip strength	Age	–0.323 (–0.335, –0.203)	<0.001
	Women	–0.434 (–8.780, –4.953)	<0.001
	WC	0.137 (0.038, 0.157)	0.001
	ASM/BMI	0.274 (8.495, 21.341)	<0.001
CST	Age	–0.282 (–0.249, –0.123)	<0.001
	Women	–0.062 (–2.228, 0.608)	0.262
	WC	–0.235 (–0.192, –0.075)	<0.001
	ASM/Ht^2	0.030 (–0.510, 0.861)	0.615
CST	Age	–0.283 (–0.249, –0.124)	<0.001
	Women	–0.023 (–1.942, 1.345)	0.721
	WC	–0.186 (–0.168, –0.044)	0.001
	ASM/Wt	0.084 (–7.164, 32.157)	0.212
CST	Age	–0.278 (–0.248, –0.120)	<0.001
	Women	–0.043 (–2.463, 1.357)	0.569
	WC	–0.212 (–0.177, –0.064)	<0.001
	ASM/BMI	0.043 (–4.421, 8.184)	0.558
TUG	Age	0.556 (0.092, 0.125)	<0.001
	Women	0.247 (0.571, 1.275)	<0.001
	WC	0.248 (0.026, 0.056)	<0.001
	ASM/Ht^2	0.077 (–0.043, 0.311)	0.137
TUG	Age	0.548 (0.091, 0.123)	<0.001
	Women	0.236 (0.472, 1.293)	<0.001
	WC	0.296 (0.033, 0.065)	<0.001
	ASM/Wt	0.038 (–3.314, 6.687)	0.508
TUG	Age	0.545 (0.090, 0.123)	<0.001
	Women	0.201 (0.274, 1.231)	0.002
	WC	0.275 (0.031, 0.060)	<0.001
	ASM/BMI	–0.013 (–1.773, 1.446)	0.842
Having ≥1 cardiometabolic disease	Age	1.059 (1.030, 1.089)	<0.001
	Women	1.084 (0.513, 1.661)	0.789
	WC	1.065 (1.037, 1.094)	<0.001
	ASM/Ht^2	1.213 (0.908, 1.622)	0.191
Having ≥1 cardiometabolic disease	Age	1.055 (1.027, 1.084)	<0.001
	Women	0.936 (0.536, 2.129)	0.852
	WC	1.075 (1.045, 1.105)	<0.001
	ASM/Wt	2.913 (0.001, 15353.516)	0.807
Having ≥1 cardiometabolic disease	Age	1.054 (1.025, 1.083)	<0.001
	Women	0.786 (0.573, 2.821)	0.554
	WC	1.071 (1.044, 1.099)	<0.001
	ASM/BMI	0.611 (0.044, 8.581)	0.715

In the multiple regressions, men was set as the reference.
Abbreviations: ASM, appendicular skeletal muscle mass; BMI, body mass index; CI, confidence interval; CST, chair stand test; Ht, body height; TUG, timed up-and-go test; WC, waist circumference; Wt, body weight.

exhibiting lower grip strength and TUG performance compared with men. The potential explanation for lower grip strength in women compared with men, even when SMI is controlled, is that men exhibit greater distribution percentages of type II fibers, whereas women exhibit greater distribution percentages of type I fibers [30]. Because type II muscle fibers generate greater force than type I muscle fibers, this difference in fiber distribution contributes to the observed disparity. Another explanation for the lower grip strength in women compared with men, even when controlling for age, WC, and SMI, is that women are known to have a higher percentage of body fat than men [31]. The higher level of body fat is associated with lower muscle quality (i.e., force production per unit of muscle mass) [32]. The contributing factors to poorer TUG performance in women compared with men, even when age, WC, and SMI are controlled, include shorter stride length and greater sensitivity to determinants of slow gait speed [31,33]. Stride length is associated with leg length, and women are generally shorter than men. In addition, Sialino et al. [33] found that women have higher sensitivity and greater exposure to determinants of low gait speed, such as lower physical activity, pain, and depressive symptoms, compared with men [33]. However, because this study did not record participants' physical activity levels, pain, and levels of depression, further investigation is necessary to examine the explanation.

Surprisingly, when we used age, sex, WC, and SMI in the model, WC, but not SMI, was independently associated with mobility. Similar to our findings, Hwang et al. [34] showed that obesity, but not low muscle mass, is associated with lower physical aspects of quality of life in community-dwelling middle-aged and older adults. The potential explanation for the independent association between mobility and obesity is that mobility is not only positively associated with skeletal muscle mass but also negatively associated with loading on the muscles. Supporting this explanation, prospective follow-up studies demonstrated that abdominal obesity predicts mobility disability in older adults [35,36]. Collectively, the findings of our study and others suggest that abdominal obesity plays a more significant and independent role in the mobility of the elderly than skeletal muscle mass does.

Obesity, especially abdominal obesity, is a well-known risk factor for cardiometabolic diseases [6]. In addition to obesity, low muscle mass is associated with cardiometabolic abnormalities [12,37]. The skeletal muscle is a key organ that uptakes blood lipids and glucose for storage and usage. Low muscle mass increases the risk of dyslipidemia even after adjusting for age, sex, and physical activity level [12,37]. Supporting the relationship between low muscle mass and cardiometabolic abnormalities, the current study found that individuals with low muscle mass (LM and LMO groups) had a higher prevalence of cardiometabolic diseases than individuals with normal body composition (N group). Nevertheless, when considering low muscle mass and obesity simultaneously, WC, but not SMI, was an independent factor for cardiometabolic health. Similar to this finding, Ryan et al. [38] found that although low muscle mass was associated with lipid metabolism, this relationship did not exist after adjusting for fat mass. One explanation for the more significant role of central obesity in cardiometabolic health than that of low muscle mass is that obesity negatively affects muscle mass. Excess adipose tissue could infiltrate skeletal muscles and result in muscle protein degradation [39]. Indeed, abdominal adipose tissue was found to be an independent predictor of low muscle mass [38]. Taken together, central obesity plays a more significant role in cardiometabolic health than low muscle mass does.

The limitation of this study is that the physical function of participants in this study is not impaired. More than 90% of participants completed the TUG test within 8.5 s, which suggests a low risk of falls [40]. In addition, the prevalence of low grip strength is 23.2% and 15.6% in men and women, respectively [13]. Therefore, the results of this study may not be generalized to other population groups, such as individuals who are really frail. Last, the majority of our participants are women. Thus, the credibility of applying our findings to middle-aged and older men might be lower.

In conclusion, abdominal obesity plays a more critical role in mobility and cardiometabolic health than low muscle mass among community-dwelling middle-aged and older adults. Muscle mass adjusted by Wt and BMI was positively correlated with mobility, but muscle mass adjusted by Ht didn't correlate with mobility in middle-aged and older adults. Our findings suggest the importance of adiposity prevention and using mobility-relevant SMI when assessing muscle mass in community-dwelling middle-aged and older adults.

Low muscle mass has received lots of attention when discussing mobility. Our results remind clinicians of the important role of obesity when considering mobility in middle-aged and older adults. This study found that muscle mass adjusted by BMI is correlated with mobility and is a predictor of grip strength. Thus, we recommend using BMI as the body-size adjustment when identifying low muscle mass and using ASM/BMI as a parameter for the effectiveness of intervention on muscle mass. According to our findings, resistance exercise, together with a high-protein diet, is suggested for community-dwelling middle-aged and older adults without abdominal obesity. For community-dwelling middle-aged and older adults with abdominal obesity, resistance exercise, together with a high-protein calorie-restricted diet, is suggested.

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Author contributions

The authors' responsibilities were as follows – C-NC, K-JH: conceptualized the study; K-YC, C-NC, K-JH: coordinated and managed the project; S-CC, K-YC: collected the data and helped interpret the data; C-NC, K-JH: analyzed and interpreted the data, and wrote the manuscript; and all authors: read and approved the final manuscript.

Conflict of interest

The authors report no conflicts of interest.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

References

[1] G.A. Roth, G.A. Mensah, C.O. Johnson, G. Addolorato, E. Ammirati, L.M. Baddour, et al., Global burden of cardiovascular diseases and risk factors, 1990-2019: update from the GBD 2019 study, J Am. Coll. Cardiol. 76 (25) (2020) 2982–3021.

[2] E.M. Enogela, R. Jones, T.W. Buford, D.E. Vance, P.L. Fazeli, Cardiometabolic diseases and quality-of-life outcomes in adults with HIV in the deep south: a cross-sectional study, J Assoc. Nurses AIDS Care 34 (2) (2023) 171–181.

[3] X. Cao, L. Zhang, X. Wang, Z. Chen, C. Zheng, L. Chen, et al., Cardiovascular disease and all-cause mortality associated with individual and combined cardiometabolic risk factors, BMC Public Health 23 (1) (2023) 1725.

[4] S. Studenski, S. Perera, K. Patel, C. Rosano, K. Faulkner, M. Inzitari, et al., Gait speed and survival in older adults, JAMA 305 (1) (2011) 50–58.

[5] G. Abellan van Kan, Y. Rolland, S. Andrieu, J. Bauer, O. Beauchet, M. Bonnefoy, et al., Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force, J Nutr. Health Aging. 13 (10) (2009) 881–889.

[6] K. Direk, M. Cecelja, W. Astle, P. Chowienczyk, T.D. Spector, M. Falchi, et al., The relationship between DXA-based and anthropometric measures of visceral fat and morbidity in women, BMC Cardiovasc. Disord. 13 (2013) 25.

[7] E. Wong, C. Stevenson, K. Backholer, H. Mannan, K. Pasupathi, A. Hodge, et al., Adiposity measures as predictors of long-term physical disability, Ann. Epidemiol. 22 (10) (2012) 710–716.

[8] F.B. Ortega, C.J. Lavie, S.N. Blair, Obesity and cardiovascular disease, Circ. Res. 118 (11) (2016) 1752–1770.

[9] K. Lim, A. Haider, C. Adams, A. Sleigh, D.B. Savage, Lipodistrophy: a paradigm for understanding the consequences of "overloading" adipose tissue, Physiol. Rev. 101 (3) (2021) 907–993.

[10] L. de Koning, A.T. Merchant, J. Pogue, S.S. Anand, Waist circumference and waist-to-hip ratio as predictors of cardiovascular events: meta-regression analysis of prospective studies, Eur. Heart J. 28 (7) (2007) 850–856.

[11] E.Q. Khor, J.P. Lim, L. Tay, A. Yeo, S. Yew, Y.Y. Ding, et al., Obesity definitions in sarcopenic obesity: differences in prevalence, agreement and association with muscle function, J Frailty Aging 9 (1) (2020) 37–43.

[12] J.A. Kim, S.Y. Hwang, J.H. Yu, E. Roh, S.H. Hong, Y.B. Lee, et al., Association of the triglyceride and glucose index with low muscle mass: KNHANES 2008-2011, Sci. Rep. 11 (1) (2021) 450.

[13] L.K. Chen, J. Woo, P. Assantachai, T.W. Auyeung, M.Y. Chou, K. Iijima, et al., Asian working group for sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment, J Am. Med. Dir. Assoc. 21 (3) (2020) 300–307.e2.

[14] A.J. Cruz-Jentoft, G. Bahat, J. Bauer, Y. Boirie, O. Bruyère, T. Cederholm, et al., Sarcopenia: revised European consensus on definition and diagnosis, Age Ageing 48 (1) (2019) 16–31.

[15] S.A. Studenski, K.W. Peters, D.E. Alley, P.M. Cawthon, R.R. McLean, T.B. Harris, et al., The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates, J Gerontol. A Biol. Sci. Med. Sci. 69 (5) (2014) 547–558.

[16] P.M. Cawthon, K.W. Peters, M.D. Shardell, R.R. McLean, T.T. Dam, A.M. Kenny, et al., Cutpoints for low appendicular lean mass that identify older adults with clinically significant weakness, J Gerontol. A Biol. Sci. Med. Sci. 69 (5) (2014) 567–575.

[17] Y.S. Kim, Y. Lee, Y.S. Chung, D.J. Lee, N.S. Joo, D. Hong, et al., Prevalence of sarcopenia and sarcopenic obesity in the Korean population based on the Fourth Korean National Health and Nutritional Examination Surveys, J Gerontol. A Biol. Sci. Med. Sci. 67 (10) (2012) 1107–1113.

[18] P. Meng, Y.X. Hu, L. Fan, Y. Zhang, M.X. Zhang, J. Sun, et al., Sarcopenia and sarcopenic obesity among men aged 80 years and older in Beijing: prevalence and its association with functional performance, Geriatr. Gerontol. Int. 14 (Suppl 1) (2014) 29–35.

[19] K. Kinoshita, S. Satake, Y. Matsui, H. Arai, Quantifying muscle mass by adjusting for body mass index is the best for discriminating low strength and function in Japanese older outpatients, J Nutr. Health Aging. 25 (4) (2021) 501–506.

[20] L.A. Schaap, N.M. van Schoor, P. Lips, M. Visser, Associations of sarcopenia definitions, and their components, with the incidence of recurrent falling and fractures: the longitudinal aging study Amsterdam, J Gerontol. A Biol. Sci. Med. Sci. 73 (9) (2018) 1199–1204.

[21] C.A. Johnson Stoklossa, S.S. Ghosh, M. Forhan, A.M. Sharma, T. Terada, M. Siervo, et al., Poor physical function as a marker of sarcopenia in adults with class II/III obesity, Curr. Dev. Nutr. 2 (3) (2018) nzx008.

[22] S.B. Heymsfield, T.A. Wadden, Mechanisms, pathophysiology, and management of obesity, N Engl, J Med. 376 (3) (2017) 254–266.

[23] R.J. Dhillon, S. Hasni, Pathogenesis and management of sarcopenia, Clin. Geriatr. Med. 33 (1) (2017) 17–26.

[24] S. Kearney, N.C. Strang, B. Cagnolati, L.S. Gray, Change in body height, axial length and refractive status over a four-year period in Caucasian children and young adults, J Optom 13 (2) (2020) 128–136.

[25] K.Y. Chien, Y.J. Chen, K.J. Hsu, C.N. Chen, High-protein diet with immediate post-exercise protein drink: impact on appetite in middle-aged obesity, Physiol. Behav. 273 (2024) 114404.

[26] K.J. Hsu, K.Y. Chien, S.C. Tsai, Y.S. Tsai, Y.H. Liao, J.J. Chen, et al., Effects of exercise alone or in combination with high-protein diet on muscle function, aerobic capacity, and physical function in middle-aged obese adults: a randomized controlled trial, J Nutr. Health Aging. 25 (6) (2021) 727–734.

[27] K. James, A.W. Schwartz, A.R. Orkaby, Mobility assessment in older adults, N Engl. J Med. 385 (8) (2021) e22.

[28] J.M. Porto, A.P. Nakaishi, L.M. Cangussu-Oliveira, R.C. Freire Júnior, S.B. Spilla, D.C. Abreu, Relationship between grip strength and global muscle strength in community-dwelling older people, Arch. Gerontol. Geriatr. 82 (2019) 273–278.

[29] L.F. Tan, Y.H. Chan, A. Denishkrshna, R.A. Merchant, Association between different skeletal muscle mass indices, physical function, and inflammation in obese pre-frail older adults, Arch. Gerontol. Geriatr. 118 (2024) 105289.

[30] J.L. Nuzzo, Sex differences in skeletal muscle fiber types: a meta-analysis, Clin. Anat. 37 (1) (2024) 81–91.

[31] A. Stotz, D. Hamacher, A. Zech, Relationship between muscle strength and gait parameters in healthy older women and men, Int. J Environ. Res. Public Health 20 (7) (2023).

[32] A. Ziółkowska, E. Oleksy, P. Kasperska, W. Stemplowski, N. Sokołowska, R. Sokołowski, et al., Impact of the percentage of muscle and fat tissue and muscle strength on the quality of life of people over 60 years of age, Med. Res. J. 5 (3) (2020) 148–153.

[33] L.D. Sialino, L.A. Schaap, S.H. van Oostrom, H.S. Picavet, J.W. Twisk, W.M. Verschuren, et al., The sex difference in gait speed among older adults: how do sociodemographic, lifestyle, social and health determinants contribute? BMC Geriatr 21 (1) (2021) 340.

[34] A.C. Hwang, W.J. Lee, L.N. Peng, L.K. Liu, M.H. Lin, C.H. Loh, et al., Unfavorable body composition and quality of life among community-dwelling middle-aged and older adults: what really matters? Maturitas 140 (2020) 34–40.

[35] J. Fernandes de Souza Barbosa, C. Dos Santos Gomes, J. Vilton Costa, T. Ahmed, M.V. Zunzunegui, C.L. Curcio, et al., Abdominal obesity and mobility disability in older adults: a 4-year follow-up the International Mobility in Aging Study, J Nutr, Health Aging. 22 (10) (2018) 1228–1237.

[36] P. Guallar-Castillón, J. Sagardui-Villamor, J.R. Banegas, A. Graciani, N.S. Fornés, E. López García, et al., Waist circumference as a predictor of disability among older adults, Obesity (Silver Spring) 15 (1) (2007) 233–244.

[37] P. Song, P. Han, Y. Zhao, Y. Zhang, L. Wang, Z. Tao, et al., Muscle mass rather than muscle strength or physical performance is associated with metabolic syndrome in community-dwelling older Chinese adults, BMC Geriatr 21 (1) (2021) 191.

[38] A.S. Ryan, B.J. Nicklas, Age-related changes in fat deposition in mid-thigh muscle in women: relationships with metabolic cardiovascular disease risk factors, Int. J Obes. Relat. Metab. Disord. 23 (2) (1999) 126–132.

[39] G. Livshits, A. Kalinkovich, Inflammaging as a common ground for the development and maintenance of sarcopenia, obesity, cardiomyopathy and dysbiosis, Ageing Res. Rev. 56 (2019) 100980.

[40] E. Rolenz, J.C. Reneker, Validity of the 8-foot up and go, timed up and go, and activities-specific balance confidence scale in older adults with and without cognitive impairment, J Rehabil. Res. Dev. 53 (4) (2016) 511–518.