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The "Fat or Fit Paradox" in Postmenopausal Women: A Cross-Sectional Study on the Association Between Skeletal Muscle Mass, Adiposity, and Muscle Strength

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SUMMARY

Background. The "Fat or Fit Paradox" denotes an intriguing association between muscle mass and adiposity in older individuals, challenging conventional beliefs on health and fitness. This investigation seeks to elucidate this paradoxical relationship in a cohort of postmenopausal women.

Methods. In a cross-sectional study, we assessed the correlation between skeletal muscle mass and body fat percentage in 134 community-dwelling Malaysian postmenopausal women, aged 45-88 years. Body composition parameters, including skeletal muscle mass and fat indices, were measured utilizing a multi-segmental bioelectrical impedance analyzer (InBody 230), while muscle strength was indirectly determined by handgrip strength assessment using a JAMAR HAND dynamometer.

Results. Our analysis revealed a significant positive correlation between appendicular skeletal muscle mass index (ASMI) and body fat percentage ($r = 0.359$, $p < 0.001$), indicating that increased adiposity is linked to higher muscle mass in older women. Linear regression analyses further demonstrated a significant positive association between muscle strength and ASMI ($R2 = 0.195$, $p < 0.001$). Importantly, upon stratification by obesity status, muscle mass emerged as a significant predictor of muscle strength in low-obese participants; however, the predictive power decreased with escalating obesity levels.

Conclusions. Our findings confirm a positive association between skeletal muscle mass and body fat percentage in postmenopausal women, although muscle strength exhibits caveats contingent on obesity status. This study accentuates the importance of appraising both muscle mass and adiposity when evaluating overall health and fitness in an aging population.

KEY WORDS

Fat or Fit Paradox; skeletal muscle mass; muscle function; obesity; muscle strength.

INTRODUCTION

The complex relationship between muscle mass and body fat in the aging population has been a topic of ongoing interest in gerontological research (1, 2). As people age, they typically experience a decrease in skeletal muscle mass along with an increase in body fat percentage, which can lead to reduced physical function and increased vulnerability to various health problems (3). This seemingly contradictory association is referred to as the "Fat or Fit Paradox." Some studies have found negative correlations between skeletal muscle mass and body fat percentage (1), while others have reported positive correlations (4-6).

The negative correlation suggests that as body fat accumulates, skeletal muscle mass decreases, and *vice versa*. On the other hand, the positive correlation indicates that an increase in body fat is accompanied by a simultaneous gain in muscle mass (6). Unravelling this paradox has significant implications for the health and fitness of older individuals. Understanding the complex interplay between muscle mass and body fat is crucial for developing effective interventions to improve overall health and well-being in later life.

At present, the diagnosis of reduced muscle mass is hindered by a lack of standardized diagnostic approaches, leading to the variable use of body composition indices and cut-offs. Consequently, disparate terminologies have emerged across various fields to describe muscle mass depletion, including gerontology's sarcopenia, obesity research's sarcopenic obesity, and oncology's cachexia, all of which encompass a multifactorial pathophysiology (7). For example, the concurrent manifestation of sarcopenic obesity and cancer cachexia is frequently observed in obese cancer patients (8). Despite these distinct classifications, the shared pathophysiology underscores the necessity for a more cohesive strategy to diagnose and address muscle mass depletion (8). Moreover, the confluence of an aging population and the obesity epidemic has resulted in a heightened prevalence of sarcopenic obesity, where individuals exhibit both obesity and reduced muscle mass (9, 10). This intersection between age-related sarcopenia and sarcopenic obesity is anticipated to become increasingly prevalent, given current demographic trajectories. This overlap presents unique challenges for the clinical evaluation and management of muscle mass depletion, as the presence of surplus adipose tissue may obscure the detection of muscle loss, consequently delaying diagnosis and treatment.

Given the conflicting findings from previous research, it is essential to further explore the paradoxical relationship between muscle mass and body fat in older adults. The aim of this study was to examine the association between these variables in a group of community-dwelling postmenopausal women. Postmenopausal women represent a unique population where the standard BMI threshold for being overweight might not accurately reflect the health risks associated with excessive body fat. Specifically, recent evidence suggests that a significant number of postmenopausal women with "normal" BMI have high body fat percentages, indicating that they may actually be overweight or obese when considering body composition (11). The consequences of hidden overweight or obesity in postmenopausal women are significant, as undetected excess body fat can increase the risk of chronic diseases such as type 2 diabetes, cardiovascular disease, and certain cancers. It can also negatively affect physical function and quality of life. To better assess the health risks related to excess body fat in postmenopausal women, healthcare providers should consider using comprehensive body composition measurements, like bioelectrical impedance analysis, in addition to BMI. Adopting a multifaceted approach to evaluate obesity status in this population can help healthcare professionals more accurately identify those at risk, allowing for timely intervention and proper management of potential health issues. Our study aimed to address the limitations of previous research by using a sample of postmenopausal women, accurate measurements of both skeletal muscle mass and body fat percentage, and a rigorous statistical analysis method.

METHODS

Recruiting and selecting participants

The University of Nottingham Malaysia's Science and Engineering Research Ethics Committee (SEREC- NZA051016 – Date of approval: November 10, 2016) granted ethical approval for this investigation, adhering to the Declaration of Helsinki. Prior to enrolment, all participants provided written informed consent. A minimum of 91 participants was deemed necessary for the study based on the cross-sectional sample size calculation (12), factoring in an estimated attrition rate of 15%. Through tactics such as flyer distribution, phone calls, e-marketing initiatives, and establishing liaisons, 200 postmenopausal Malaysian women were enlisted from diverse locations in Semenyih and the Klang Valley regions of Kuala Lumpur, Malaysia. Recruitment transpired between April 2017 and June 2018, culminating in the inclusion of 136 women (n = 136, aged 45 to 88) who met the screening criteria in the analysis. Eligibility prerequisites for participation entailed being female, a Malaysian national, and postmenopausal, denoted by the absence of menstrual periods, bleeding, or spotting for 12 consecutive months prior to enrolment. Participants received detailed information about the study's aims, methodologies, potential advantages, risks, and possible discomforts pre-enrolment. Exclusion criteria included the incapacity to stand for height and weight measurements, inability to execute the handgrip test; presence of prosthetic limbs or metal implants, severe cardiac, pulmonary, or musculoskeletal disorders, significant cognitive impairment or communication disabilities, and terminal illness.

Height

Participant height was assessed using a portable stadiometer (SECA 217, Vogel & Halke GmbH & Co., Germany). Participants were instructed to stand erect with their shoulders, buttocks, and heels in contact with the stadiometer. Their toes were placed at a 45° angle, and the head was held in a neutral position with the neck aligned naturally. The stadiometer was adjusted to each participant's appropriate height, and measurements were recorded to the nearest 0.1 cm.

Waist circumference

Waist circumference (WC) was evaluated using a measuring tape (SECA 203, GmbH & Co. Kg., Hamburg, Germany). Participants were instructed to stand erect with arms by their sides and feet together. WC was gauged at the midpoint between the final rib and the anterior superior iliac spine, signifying the narrowest point between the lower rib margin and the iliac crest (12). The measuring tape was positioned horizontally around the waist, snug but without compressing the skin. Measurements were taken at the end of normal expiration and documented to the nearest 0.1 cm. WC is a widely utilized anthropometric indicator for assessing central obesity and functions as a reliable predictor of metabolic syndrome and cardiovascular disease (13).

Muscle strength

In this study, muscular strength was gauged by measuring handgrip strength using a JAMAR Hydraulic Hand Dynamometer® Model PC-5030 J1 (Fred Sammons, Inc., Burr Ridge, IL, USA). For accurate measurement, the American Society of Hand Therapists advocates a specific positioning: the participant should be seated, with shoulders adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral, and wrist between 0° and 30° of dorsiflexion (14). To obtain a dependable measure of handgrip strength, participants were instructed to grip the dynamometer with maximum effort twice using their dominant hand, with the highest value recorded for the analysis. Handgrip strength is extensively employed as a surrogate for overall muscular strength and has demonstrated reliability and validity in various populations (15).

Body composition, bioimpedance measurement

This study utilized a multi-frequency BIA device with eight-point tactile electrode system (Inbody 230, Biospace Corp., Seoul, Korea), to measure lean body mass (LBM), appendicular muscle mass (ALM), fat mass (FM), body mass index (BMI), skeletal muscle mass (SMM), fat-free mass (FFM) and body fat percent (BFP). The device uses two different frequencies to measure the five segments of the body (right leg, left leg, right arm, left arm, and trunk) and is suitable for individuals aged 3-99 years-old according to the manufacturer. Body composition estimates were calculated by the manufacturer's software (Lookin'Body 120, Biospace Corp., Seoul, Korea). While utilizing this device, the thumb needed to be placed on the electrode pad on the top surface of the handle. The reliability of this device was tested, and the test-retest reliability for whole body LBM and BFP estimates by this device were both ≥ 0.99 (n = 5) using ICC (16). Results obtained from the InBody 230 were then compared with the Gallagher's classification of body fat percentage for elderly (17). Gallagher's classification of body fat percentage for the elderly is a commonly used method for classifying body fat percentage in older adults. It is based on the idea that body fat percentage increases with age, and that the health risks associated with high body fat percentage also increase in older age. Gallagher's classification is useful for identifying older adults who may be at increased risk for obesity-related health conditions. Gallagher's classification for women is based on the following categories: low body fat percentage: < 33% for women; moderate body fat percentage: 33-38% for women; high body fat percentage: 39-45% for women; very high body fat percentage: > 45% for women. The formula is: *Body fat % = (1.46 × BMI) + (0.14 × Age) - (11.6 × gender) – 10* (18). The classification takes into account differences in body fat percentage between men and women, as well as the age-related increase in body fat percentage.

Statistical analysis

Descriptive statistics were presented as means ± SD. In **table I**, the measurements were divided into four groups based on BFP and further categorized according to muscle status into two groups. Obesity categories were defined using body fat percentage as follows: low body fat percentage: < 33% for women; moderate body fat percentage: 33-38% for women; high body fat percentage: 39-45% for women; very high body fat percentage: > 45% for women (17, 18). Muscle mass status was classified per AWGS (7) guidelines: normal muscle mass: ASMI > 5.7 kg/m^2; low muscle mass: ASMI ≤ 5.7 kg/m^2. Multiple linear regression analysis was employed to pinpoint body composition parameters that predict muscle strength. Adjusted r, standard error values, and multicollinearity statistics were utilized to ascertain the most appropriate equations, with all analyses conducted using IBM SPSS version 27 statistical software. A P-value less than 0.05 was deemed statistically significant.

RESULTS

The analyses included 134 participants (n = 134 postmenopausal women, mean ± SD = 60.4 yrs ± 7.5). **Table I** presents the descriptive statistics for the study population according to muscle mass status and body fat percentage (BFP) classification. Based on Gallagher's classification of body fat percentage for the elderly (17, 18) the majority of participants fell into the 'High' and 'Very High' categories (60%). A higher frequency of participants with normal muscle mass was observed within the elevated body fat

Table I. Participant characteristics by BFP classification and muscle mass status in postmenopausal Malaysian women.

Characteristics	Body Fat Percentage Classification*											
	Low < 33% for women (n = 23)			Moderate 33-38% for women (n = 26)			High 39-45% for women (n = 43)			Very high > 45% for women (n = 42)		
	Normal muscle mass ASMI > 5.7kg/m² (n = 10)	Low muscle mass ASMI ≤ 5.7kg/m² (n = 13)	P-value¹	Normal muscle mass ASMI > 5.7 kg/m² (n = 16)	Low muscle mass ASMI ≤ 5.7 kg/m² (n = 10)	P-value¹	Normal muscle mass ASMI > 5.7 kg/m² (n = 30)	Low muscle mass ASMI ≤ 5.7 kg/m² (n = 13)	P-value¹	Normal muscle mass ASMI > 5.7 kg/m² (n = 37)	Low muscle mass ASMI ≤ 5.7 kg/m² (n = 5)	P-value¹
Age (years)	60.0 (7.9)	64.15 (6.5)	.192	61.7 (7.5)	65.0 (8.0)	.292	59.0 (6.1)	61.4 (11.5)	.485	58.7 (6.4)	62.6 (8.9)	.225
Height (cm)	157.7 (4.9)	154.5 (6.6)	.223	157.2 (5.9)	152.4 (6.9)	.068	154.7 (5.4)	148.4 (5.0)	**.001**	151.9 (5.4)	149.9 (6.8)	.463
Weight (kg)	53.0 (2.9)	45.3 (5.6)	**.001**	63.2 (6.9)	49.2 (4.9)	**.000**	67.9 (6.1)	55.6 (5.2)	**.000**	76.4 (10.0)	60.8 (5.9)	**.002**
BMI (kg/m²)	21.3 (0.8)	18.9 (1.5)	**.000**	25.5 (2.3)	21.2 (1.2)	**.000**	28.4 (1.9)	25.2 (1.6)	**.000**	33.2 (4.2)	27.1 (3.0)	**.004**
WC (cm)	73.4 (3.4)	66.5 (7.4)	**.018**	82.4 (7.3)	71.2 (4.6)	**.000**	87.9 (6.8)	82.3 (7.4)	**.019**	96.5 (11.3)	79.6 (7.5)	**.003**
BFM (kg)	14.9 (2.5)	12.4 (2.7)	**.038**	22.6 (3.1)	17.5 (2.4)	**.000**	28.9 (3.1)	23.4 (3.0)	**.000**	37.8 (6.5)	29.0 (4.0)	**.006**
FFM (kg)	38.2 (2.6)	32.9 (3.9)	**.002**	40.6 (3.8)	31.7 (2.7)	**.000**	39.1 (3.3)	32.1 (2.4)	**.000**	38.6 (4.1)	31.8 (2.0)	**.001**
FFMI (kg/m²)	15.3 (0.9)	13.8 (0.9)	**.000**	16.4 (1.3)	13.7 (0.8)	**.000**	16.3 (1.0)	14.6 (0.6)	**.000**	16.7 (1.5)	14.2 (1.2)	**.001**
SMM (kg)	20.6 (1.6)	17.3 (2.3)	**.001**	22.0 (2.3)	16.5 (1.8)	**.000**	21.0 (2.0)	16.7 (1.3)	**.000**	20.8 (2.5)	16.6 (1.2)	**.001**
SMMI (kg/m²)	8.3 (0.5)	7.2 (0.6)	**.001**	8.9 (0.9)	7.1 (0.5)	**.000**	8.8 (0.6)	7.6 (0.3)	**.000**	9.0 (0.9)	7.4 (0.7)	**.000**
ALM (RA, kg)	1.8 (0.2)	1.4 (0.2)	**.000**	2.0 (0.3)	1.4 (0.2)	**.000**	2.0 (0.3)	1.5 (0.2)	**.000**	2.0 (0.3)	1.6 (0.2)	**.001**
ALM (LA, kg)	1.8 (0.2)	1.3 (0.2)	**.000**	1.9 (0.3)	1.3 (0.2)	**.000**	2.0 (0.3)	1.5 (0.2)	**.000**	2.0 (0.3)	1.6 (0.3)	**.002**
ALM (RL, kg)	5.8 (0.5)	4.9 (0.9)	**.011**	6.4 (1.4)	4.7 (0.8)	**.002**	5.7 (0.7)	4.3 (0.6)	**.000**	5.7 (0.8)	4.3 (0.5)	**.001**
ALM (LL, kg)	5.8 (0.5)	4.8 (0.9)	**.007**	6.2 (1.0)	4.7 (0.7)	**.000**	5.8 (0.7)	4.4 (0.6)	**.000**	5.6 (0.8)	4.3 (0.6)	**.001**
BMR	1194.2 (56.1)	1081.2 (84.5)	**.002**	1245.8 (82.5)	1055.2 (58.4)	**.000**	1214.0 (72.4)	1063.2 (50.7)	**.000**	1204.6 (89.0)	1057.8 (43.2)	**.001**
TRUNK MM (kg)	16.8 (1.1)	14.1 (1.5)	**.000**	17.8 (1.6)	14.1 (1.5)	**.000**	17.9 (1.7)	14.5 (1.3)	**.000**	18.1 (1.8)	15.3 (1.3)	**.001**
TRUNK FP (%)	28.4 (4.3)	26.9 (5.1)	.490	36.8 (2.5)	35.9 (1.6)	.339	43.4 (1.4)	43.3 (2.2)	.930	48.6 (2.0)	47.6 (1.9)	.328

ASMI: appendicular skeletal muscle mass index; BMI: body mass index; WC: waist circumference; BFM: body fat mass; FFM: fat-free mass; FFMI: fat-free mass index; SMM: skeletal mass index; SMMI: skeletal muscle mass index; ALM: appendicular lean mass; RA: right arm; LA: left arm; RL: right leg; LL: left leg; BMR: basal metabolic rate; MM: muscle mass; FP: fat percent. Data are expressed as mean (standard deviation) or frequency (n) and percent (%) based on Gallagher's classification of body fat percentage for elderly (16); ¹ analysed using Independent Sample t-test, significant at $p < 0.05$.

percentage categories (**table I**). A significant positive correlation between skeletal muscle mass and body fat percentage was found (**figure 1**, r = 0.36, $p < 0.001$), suggesting an increase in skeletal muscle mass as body fat percentage increased. Linear regression analyses revealed a significant positive association between muscle strength and appendicular skeletal muscle mass index (ASMI), with the inclusion of BFP slightly enhancing the model's predictive ability for muscle strength (R2 = 0.195, $p < 0.001$) (**table II**). Examining the relationship between muscle strength and muscle mass based on obesity classifications, muscle mass emerged as a significant predictor of muscle strength in low-obese participants, but the predictive power decreased with higher levels of obesity (R2 = 0.572, p = 0.000 > R2 = 0.207, p = 0.022 > R2 = 0.183, p = 0.006 > R2 = 0.129, p = 0.025) (**table III**).

DISCUSSION

This investigation explored the associations among muscle mass, muscle strength, and body fat percentage in postmenopausal women. Our sample comprised 134 community-dwelling postmenopausal women aged 45-88 years, enlisted from diverse locations in the Semenyih and Klang Valley regions of Kuala Lumpur, Malaysia. We employed a multi-segmental bio-electrical impedance analyzer to assess body composition, including body fat percentage (BFP) and appendicular skeletal muscle mass (ASM), while grip strength was evaluated using handgrip strength dynamometry. Our

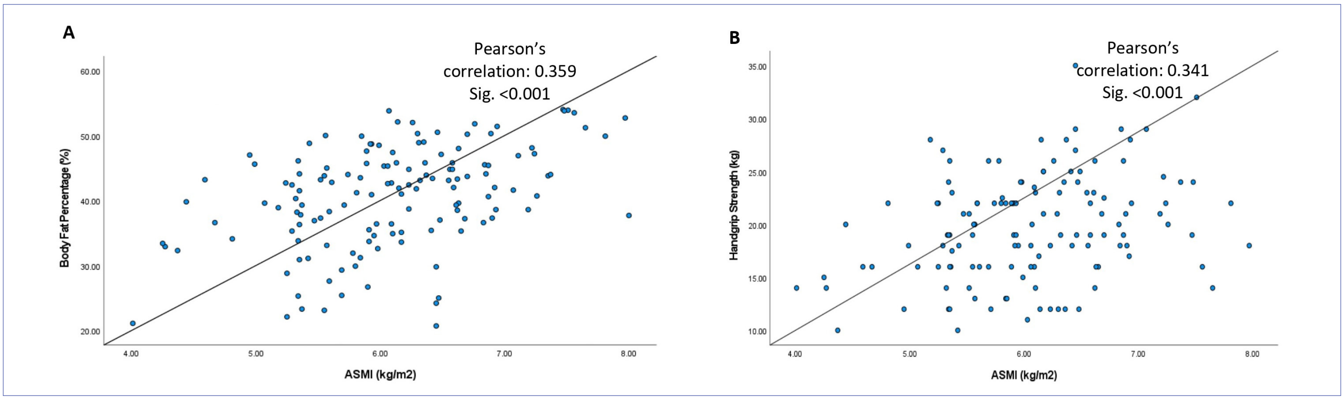

Figure 1. (A) Association between body fat percentage and muscle mass in postmenopausal Malaysian women; **(B)** Association between muscle strength and muscle mass in postmenopausal Malaysian women (n = 134).

Table II. Results of the multiple linear regression analysis examining the correlation between muscle mass, body fat percentage and muscle strength in postmenopausal women.

Model	Coefficient (B)	Standard error B	95%CI for B	Standardised β	R2	P-value*
Model 1					0.116	< 0.001
Constant	7.986	2.893	2.262, 13.710			
ASMI (kg/m^2)	1.951	0.471	1.020, 2.883	0.341		
Model 2					0.195	< 0.001
Constant	11.931	2.984	6.028, 17.833			
ASMI (kg/m^2)	2.569	0.483	1.614, 3.525	0.448		
BFP (%)	-0.191	0.053	-0.297, -0.085	-0.301		

ASMI: appendicular skeletal muscle mass index; BFP: body fat percentage; regression equation Model 1: muscle strength = 7.986 + 1.951 × (ASMI); regression equation Model 2: muscle strength = 11.931 + 2.569 × (ASMI) - 0.19 × (BFP). Dependent variable: muscle strength; *significant at $p < 0.001$.

Table III. Results of the multiple linear regression analysis investigating the impact of obesity on the correlation between muscle strength and muscle mass in older women.

Obesity categories	Model	Coefficient (B)	Standard error B	95% CI for B	Standardised β	R2	P-value*
Low	Constant	-17.458	7.506	-33.115, -1.801	0.756	0.572	0.000
	ASMI (kg/m^2)	6.928	1.341	4.130, 9.726			
Moderate	Constant	9.517	4.370	0.477, 18.556	0.455	0.207	0.022
	ASMI (kg/m^2)	1.745	0.713	0.270, 3.219			
High	Constant	2.609	5.998	-9.533, 14.752	0.428	0.183	0.006
	ASMI (kg/m^2)	2.875	0.985	0.880, 4.869			
Very high	Constant	4.908	5.985	-7.219, 17.035	0.359	0.129	0.025
	ASMI (kg/m^2)	2.157	0.922	0.290, 4.025			

ASMI: appendicular skeletal muscle mass index; dependent variable: muscle strength; *significant at $p < 0.01$.

results unveiled a positive correlation between ASMI and BFP (**table I** and **figure 1**), denoting that elevated body fat levels corresponded to increased muscle mass in older adults. Additionally, a positive correlation between muscle strength and ASMI was observed (t**able II**), signifying that greater muscle mass was linked to improved muscle strength in the study population. However, further analyses revealed that the relationship between muscle mass and muscle strength was impacted by participants' obesity levels. Specifically, muscle mass surfaced as a significant predictor of muscle strength in low-obese participants, but its predictive power waned with escalating obesity levels (**table III**). Therefore, body fat percentage should be factored in when scrutinizing the relationship between muscle mass and muscle strength in older adults. The intricate relationship between muscle mass and fat mass in older adults poses a paradox, necessitating additional research for a deeper comprehension of its implications on the health and well-being of this demographic.

Lean and mean: the paradox of muscle and fat in older adults

Muscle mass is a crucial determinant of physical strength and metabolic health, playing an essential role in fostering overall health and wellness (19). As body mass increases, the body may respond by augmenting muscle mass to counterbalance the added load (2). This compensatory process is often observed in individuals engaging in regular physical activity or resistance training, as the heightened mechanical stress on muscles can stimulate muscle hypertrophy and growth. Muscle mass is typically evaluated using two parameters: fat-free mass (FFM) and lean mass. FFM is calculated chemically by summing all non-lipid components of the body, encompassing non-fat elements of adipose tissue, such as essential and non-essential tissues like muscles, organs, bones, and other connective tissues. Conversely, lean mass is anatomically defined as the total of all non-adipose tissues, incorporating necessary lipids found in cell membranes or the central nervous system. In body composition assessment, lean mass is often employed to quantify the amount of skeletal muscle mass in the body (2). Some researchers utilize a more specific definition of lean mass known as fat-free soft tissue mass (2). It includes the entire body mass, excluding bone mineral mass and fat mass. Various techniques, such as DXA, are used to measure this, considered one of the most reliable and accurate methods of body composition assessment. Moreover, if fat-free soft tissue mass is derived from the arms and legs, it can provide a more precise estimate of skeletal muscle mass than FFM (2). To account for variations in body size, fat-free mass (FFM) is often normalized using different methods. One approach is to express FFM as a percentage of total body weight, known as %FFM. Alternatively, FFM can be divided by height squared to obtain the fat-free mass index (FFMI), expressed in kg/m^2 units. FFMI is calculated by dividing FFM in kilograms by the square of height in meters. This index enables comparison of FFM between individuals with differing body sizes, as it considers the impact of height on FFM (20). FFM is a complex compartment comprising various structures, such as skeletal muscle mass, organ mass, and portions of connective tissue. Nevertheless, in the context of sarcopenia, the primary focus is on skeletal muscle mass. Sarcopenia, a condition typified by loss of muscle mass and strength with aging, is of particular interest to researchers studying FFM (7). However, using the fat-free mass index (FFMI) as a measure of skeletal muscle mass has limitations warranting consideration. One such limitation is demonstrated by Swiss reference data, which reveal that FFM increases with advancing age, while FFMI remains relatively constant across age groups (21). This implies that using FFMI as a proxy for skeletal muscle mass may not accurately represent age-related changes in muscle mass. The decline in muscle mass with age may be counterbalanced by an increase in connective tissue, a component of FFM, leading to a false sense of stability in FFMI. In their study, Baumgartner *et al.* (22) employed dual-energy x-ray absorptiometry (DXA) to measure the lean or fat-free soft tissue mass of the four limbs, which was then summed to determine appendicular skeletal muscle mass (ASM). To provide a more precise measure of muscle mass, a skeletal muscle index (SMI) was defined as appendicular skeletal muscle mass divided by height squared (kg/m^2, ASMI). This is particularly crucial when considering that bone density can vary due to factors such as age, ethnicity, and medication use. However, it is essential to note that ASMI also has limitations, particularly with increasing age or advancing body fat mass. A comparison of regional lean mass measured by DXA with skeletal muscle mass assessed by magnetic resonance imaging (MRI) demonstrated that the contribution of skeletal muscle to appendicular lean soft tissue decreases as adiposity increases, especially in women who tend to store more adipose tissue at the extremities (limbs) compared to men who store more adipose tissue at the trunk with increasing fat-free mass index (FMI) (2, 23). Consequently, as adiposity rises, and potentially as age increases, the augmentation of connective tissue could obscure a reduction in skeletal muscle mass, despite no change in total lean soft tissue or FFM (2). It is important to note that when individuals experience weight gain, it typically consists of both fat and lean mass. Therefore, overweight and obese individuals are expected to have a higher fat-free mass index (FFMI) or skeletal muscle index (SMI) compared to individuals of normal weight (6). In fact, studies have shown that individuals with higher levels of body fat percentage may have higher levels of muscle mass due to the anabolic effects of adipose tissue on muscle tissue (5). Therefore, relying solely on normal values of lean mass as a basis for diagnosing lean mass deficiency may potentially result in an underestimation of sarcopenia in overweight and obese individuals.

Fat or Fit Paradox

Obesity is a critical global health issue and is linked to various health conditions such as diabetes, cardiovascular disease, and specific cancer types (10). While it is well-established that obese individuals tend to have higher body fat mass, it is also noteworthy that they have higher levels of muscle mass than non-obese individuals (5). This phenomenon is often referred to as the “fat or fit paradox”, in which higher muscle mass in obese individuals is paradoxical to the expected outcome. In this part of the discussion, we will explore the mechanisms underlying the relationship between obesity and muscle mass and why the amount of muscle mass in obese individuals may not be sufficient for their needs.

Several factors contribute to the higher muscle mass observed in obese individuals. Firstly, the increased mechanical load due to carrying excess body weight leads to an adaptive response in the muscles, resulting in hypertrophy (24). Additionally, insulin resistance in obesity (hyperinsulinemia) leads to anabolic stimuli that promote muscle protein synthesis, thereby increasing muscle mass (25). Furthermore, inflammation and oxidative stress (at appropriate concentrations of reactive oxygen species) associated with obesity may also stimulate muscle protein synthesis, leading to higher muscle mass (myogenesis) (26). Despite the increased muscle mass, obese individuals often suffer from functional limitations and reduced muscle performance (hence, the paradox). The higher body weight in obese individuals poses an extra burden on their muscles, which can lead to fatigue and reduced endurance. This phenomenon is known as the “muscle quality” concept, in which muscle mass does not necessarily reflect muscle function. It is essential to note that muscle size and strength are not always synonymous. Obese individuals may have intramuscular fat and connective tissue that may hinder efficient muscle contraction and, consequently, reduce muscle function and performance (27). Furthermore, the quality of the muscle in obese individuals may be compromised due to extreme chronic low-grade inflammation and oxidative stress, which may contribute to muscle dysfunction (26). The intramuscular fat deposition in obese individuals is also associated with muscle insulin resistance and impaired glucose metabolism, further reducing muscle function (27). This evidence supports the fact that high muscle mass in obese individuals does not necessarily translate to better muscle function and performance. The present study provides support for the notion that muscle strength is decreased in obese individuals (**table III**). The results indicate that in low-obese individuals, muscle mass was a significant predictor of muscle strength. However, as the degree of obesity increased, the predictive power of muscle mass on muscle strength decreased. The observed relative weakness may be attributed to a variety of factors, including reduced mobility, neural adaptations, and alterations in muscle morphology. Furthermore, excessive body fat percentage may also be related. Excessive body fat percentage has been implicated in the decline of muscle quality (28), as the presence of fat within the muscle fibers can hinder their contractile capacity. This can lead to a reduction in muscle strength, even in individuals with a high amount of muscle mass. Previous research by Goodpaster and colleagues (29) has shown that higher levels of intramuscular lipid content are associated with lower muscle strength, even after accounting for muscle mass. This suggests that intramuscular lipid content may play a role in the development of muscle weakness and even sarcopenia in individuals with obesity. This is also particularly relevant in the context of aging and obesity, as both conditions are associated with an increase in intramuscular fat content.

Dynapenic obesity: the hidden link between muscle weakness and excess weight

The term “dynapenic obesity” has been introduced to describe a subset of obese individuals who exhibit reduced muscle strength and increased adiposity (30). In this context, it has been hypothesized that the energy expenditure and muscle force required for performing the same physical tasks are higher in obese individuals, ultimately leading to a reduced capacity to perform physical activities and an increased risk of developing disability. This suggests that at higher levels of adiposity, a given amount of muscle mass may confer lower functional capacity compared to individuals with lower levels of body fat (2). The negative impact of excessive body fat on muscle quality is thought to be mediated by several factors, including the disruption of intracellular signaling pathways and mitochondrial dysfunction (31). Consequently, this can result in muscle fiber atrophy and reduced force production, which can contribute to the development of functional limitations and disability in affected individuals.

Implications for the health and well-being of older adults

The paradoxical relationship between skeletal muscle mass and body fat percentage in older adults has significant implications for their health and well-being. Low muscle strength is a prevalent risk factor for falls and falls are a leading cause of morbidity and mortality among older adults (32). In addition, decreased muscle strength and mass are associated with functional limitations, disability, and poor quality of life in older adults (32). Increased body fat percentage is also associated with a range of health problems, including metabolic disorders, cardiovascular disease, and some types of cancer (33). Therefore, it is essential to accurately assess both muscle mass and body fat percentage in older adults to identify individuals at risk of falls and functional limitations and to develop effective interventions to address these problems. The paradoxical connection between skeletal muscle mass and body fat percentage in older adults is a complex and multifaceted issue. While there is a growing body of research on this topic, more research is needed to fully understand the relationship between these two factors and their implications for the health and well-being of older adults. It is essential to accurately assess both muscle mass and body fat percentage in older adults to identify individuals at risk of falls and functional limitations and to develop effective interventions to address these problems.

CONCLUSIONS

The current study's findings add to the growing body of literature suggesting a positive association between skeletal muscle mass and body fat percentage in older adults. However, the observation of a positive correlation between skeletal muscle mass and body fat percentage warrants a contextual understanding of the functional implications, given that the augmentation of muscle mass may not necessarily translate into enhanced muscular strength. Due to the tendency for obese older adults to exhibit a decline in relative muscle mass rather than absolute muscle mass, the diagnosis of sarcopenia in this population should depends on alterations in muscle quality and/or relative levels of skeletal muscle mass, rather than absolute measurements. Further elucidation of this complex relationship may contribute to the development of targeted interventions aimed at improving both muscle mass and function. Moreover, there is a need for a more nuanced understanding of the relationship between these variables and their impact on health and fitness in later life. The positive relationship between skeletal muscle mass and body fat percentage suggests that gaining in body fat percentage may also lead to an increase in muscle mass. However, quantity does not equal quality. The presence of fat within the muscle fibers can impair the muscle's ability to contract effectively which may impair and negatively affect the muscle strength. In older adults, when examining the connections between muscle mass and muscle strength, it is important to take into account the body fat percentage. These results also highlight the importance of considering both skeletal muscle mass and body fat percentage when evaluating physical function and health outcomes in older adults. Additionally, future interventions aimed at improving physical function and health in older adults should consider both skeletal muscle mass and body fat percentage in their design and evaluation.

Limitations and strengths

There are some limitations to this study. Firstly, bioelectrical impedance analysis (BIA) was used to measure the body composition. While BIA is a convenient and non-invasive method, it may not be as accurate as the gold standard DXA. Therefore, the findings related to muscle mass and adiposity in this study should be interpreted with caution. The use of DXA would have been preferable to accurately measure muscle mass and body fat. It should also be mentioned that the study only involved postmenopausal women, which limits the generalizability of the findings to other populations. Since the study did not include men or premenopausal women, it is unclear if the same relationships between muscle mass, muscle strength, and adiposity would be observed in other groups. Therefore, caution should be exercised when attempting to apply these results to populations outside of postmenopausal women. Nevertheless, postmenopausal women are one subpopulation where the current classification based on BMI may not accurately reflect the health risks associated with excess adiposity (34). Therefore, they are the most in need for this type of study in order to accurately measure their health risk. Despite these limitations, this study boasts several strengths that bolster its contributions to gerontological research. Firstly, it addresses the intriguing Fat or Fit Paradox, delving into the complex relationship between muscle mass and adiposity in older adults, with a particular focus on postmenopausal women - a vulnerable population experiencing hormonal changes and increased health risks. The findings of this research offer valuable insights into the unique challenges faced by this demographic and enable the development of targeted interventions for maintaining and improving overall health and well-being. Furthermore, by identifying the factors that influence muscle mass and strength across different obesity levels, our study guides the design of tailored exercise, nutrition, and lifestyle programs, ultimately contributing to the enhancement of gerontological knowledge. Lastly, this investigation emphasizes the importance of appraising both muscle mass and adiposity in evaluating the health and fitness of older individuals, promoting the broader goal of healthy aging - an increasingly critical objective in the context of global population aging.

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DATA AVAILABILITY

The data are openly available in FigShare at https://doi.org/10.6084/m9.figshare.13786684.v1.

CONTRIBUTIONS

N.Z.A. entirely contributed to this work.

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CONFLICT OF INTERESTS

The author declares that she has no conflict of interests.

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