The Journal of Frailty & Aging

ORIGINAL RESEARCH

FAT MASS IS NEGATIVELY ASSOCIATED WITH MUSCLE STRENGTH AND JUMP TEST PERFORMANCE

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Abstract: *Background:* It is known that maintenance of muscle mass cannot prevent loss of muscle strength in older adults. Recent evidence suggests that fat mass can weaken the relationship between muscle mass and functional performance. No information exists if fat mass can independently affect muscle strength and jump test performance in middle-aged and older adults. *Objective:* To assess the independent relationships between fat mass, leg muscle mass, lower extremity muscle strength, and jump test performance in adults, 55-75 years of age. *Design:* Cross-sectional. *Setting:* University laboratory. *Participants:* Fifty-nine older adults (men, n = 27, age = 64.8 ± 6.5 years; women, n = 32, age = 62.5 ± 5.1 years) participated in this study. *Measurements:* Dual energy X-ray absorptiometry was used to measure fat mass and leg muscle mass. An average of 3 maximal countermovement jumps was used to calculate jump power and jump height. Two leg press and hip abduction strength were assessed by 1-repetition maximum testing. *Results:* Stepwise sequential regression analysis of fat mass and leg muscle mass versus jump test performance and measures of muscle strength after adjusting for age, height, and physical activity revealed that fat mass was negatively associated with jump height ($p = 0.047$, $r_{partial} = -0.410$) in men. In women, fat mass was negatively associated with jump height ($p = 0.003$, $r_{partial} = -0.538$), leg press ($p = 0.002$, $r_{partial} = -0.544$), and hip abduction strength ($p < 0.001$, $r_{partial} = -0.661$). Leg muscle mass was positively associated with jump power in women ($p = 0.047$, $r_{partial} = 0.372$) only. *Conclusions:* Fat mass has an independent negative relationship with jump test performance in middle-aged and older men and women. This has clinical implications for rehabilitating neuromuscular performance in middle-aged and older adults.

Key words: Body composition, muscle power, aging, muscle strength, neuromuscular performance.

J Frailty Aging 2020;in press
Published online March 16, 2020, http://dx.doi.org/10.14283/jfa.2020.11

Introduction

Aging is associated with changes in body composition such as reduced muscle mass and increased fat mass (1), which can ultimately have an adverse effect on muscle performance. For example, older adults with reduced muscle mass have lower muscle strength (2) and jump power (3). Typically, these deficits in muscle performance accelerate after the fifth decade at a rate of ~15% per decade (4). Evidence indicates that the deficits in muscle power may be greater than deficits in muscle strength (5), both of which can lead to clinically relevant implications such as decreased physical activity, functional declines, and lower quality of life. Notably, the degree of loss of muscle mass and muscle strength with aging is sex-specific with men showing greater rate of loss of muscle mass and muscle strength than women (6).

The interaction of fat mass with muscle mass and its effects on muscle performance is an area of active research interest. Previous data suggests that the maintenance of muscle mass cannot prevent loss of muscle strength in older adults (7). A recent meta-analysis article suggested that fat mass can weaken the relationship between muscle mass and functional performance, such as mobility in older adults (8). It is known that adiposity can lead to non-optimal muscle shortening (9) and attenuated calcium signaling (10) which can adversely affect muscle force generation. Accordingly, it can be postulated that fat mass could attenuate the relationship between muscle mass and muscle performance. This is supported by reports of lower muscle strength and power in obese individuals (11).

Jump test performance is a popular technique to assess muscle power in older individuals (3,12). Specifically, the use of a mobile contact mat to assess jump performance which is reliable (13), valid (14), user friendly, and easily administered in various settings such as the home, clinics, and community gymnasium settings provides an excellent low cost opportunity to assess muscle function. To our knowledge, relationships between fat mass, muscle mass, lower extremity muscle strength, and jump test performance independent of factors including age, body weight, height, and physical activity are unknown in older adults. Specifically, the effect of sex on these relationships is unknown. Understanding these relationships could provide insight into the relative role of fat mass on muscle performance in older men and women.

Thus, the aim of this investigation was to assess sex-based differences in the independent relationships between fat mass, leg muscle mass, lower extremity muscle strength, and jump test performance in adults, aged 55-75 years of age. We

Received November 15, 2019
Accepted for publication January 30, 2020

hypothesized that jump test performance and lower extremity muscle strength will be negatively related to fat mass in our study participants and that its degree would be greater from women versus men.

Methods

Participants

Participants aged 55 - 75 years of age were recruited from the Oklahoma City metro general community and were deemed medically cleared by their personal physician prior to enrolling in the study. An a priori power analysis was used to estimate the required sample size for the study. The statistical analysis was set for a linear regression: fixed model, single regression coefficient with an effect size (f2) of 0.35, alpha error probability at 0.05, and power at 0.8. The calculated sample size was found to be 25 participants per group.

Prior to participation, volunteers obtained medical clearance from their personal physician to ensure medical stability and capability of undergoing the strength and jump testing safely. Individuals were excluded from the study if they had any condition that did not allow them to fully perform the physical tests of the study. Participants were also excluded if they had any thyroid disorders, cardiovascular diagnoses, metal in their body, any recent surgery or fracture, used tobacco within the previous 10 years, body weight greater than 136kg (because of the equipment limit) or were on steroid or hormone therapy. The local institutional review board approved this study. All participants provided written informed consent for participation in this study.

Study Design

Participants made three visits to the laboratory. In the first visit, participants gave informed consent and completed a health status questionnaire to determine study eligibility. During the second visit, participants completed physical activity and menstrual history questionnaires (women only), a total body dual energy X-ray absorptiometry (DXA) scan and familiarization with strength and jump testing. At the third visit, participants underwent jump test and muscle strength testing. Detailed explanations of the methods used can be found in our previous studies (3, 12).

Anthropometric Measurements

A wall stadiometer (Novel Products Inc, Rockton, Illinois) was used to measure height in centimeters. A digital body weight scale (Tanita Corporation of America, Arlington Heights, Illinois) was used to measure body weight in kilograms. Body mass index (BMI) was calculated using the formula, weight divided by height squared (kg/m^2).

Questionnaires

All participants completed medical history and physical activity questionnaire. International Physical Activity Questionnaire, which is a valid and reliable measure of physical activity, was chosen to estimate the physical activity levels in METs/week (15). A customized menstrual history questionnaire was completed by all female participants to confirm their postmenopausal status and not taking any hormone replacement therapy.

Bone Densitometry and Body Composition

A single technician measured body composition using DXA (GE Lunar Prodigy, enCORE 2010 Software, Version 13.31.016, GE Medical Systems, Madison, Wisconsin). A quality assurance check of the DXA was performed before any data collection. Percent total body fat, fat mass, bone free lean body mass, leg muscle mass, and fat free mass were determined using a total body scan with the participant in supine, lying position. Universally acceptable cut-off values of BMI, recommended by bodies such as Center for Disease Control and Prevention/World Health Organization (16, 17) were used to categorize our participants into normal weight, overweight, and obesity. Per these cut-off values, a BMI between a) 18.5 and 24.9 is considered as normal weight, b) 25 and 29.9 is categorized as overweight, and c) greater than 30 is considered obese (16,17). The short-term in vivo precision coefficients of variation (CV%) were as follows: 1.24% for percent total body fat, 0.64% for bone free lean body mass, 1.16% for fat mass, and 0.83% for fat free mass.

Muscle Strength Testing

Muscle strength testing has been described in our previous studies (3, 12). In short, prior to muscle strength testing, participants were familiarized to the testing procedures. On the testing day, participants pedaled a Monark 828E stationary bicycle ergometer as warm-up prior to determining 1-repetition maximum (1RM) on Cybex weight machines (Cybex International, Medway, Massachusetts) for two-legged leg press (LP), right, and left hip abduction. 1RM was determined by increasing weight progressively in increments of 9.1 to 18.2kg for LP and 2.8 to 5.6kg for hip abduction until participants failed to lift weight through the full range of motion. Participants were provided 90 seconds of rest between each lift attempt.

Jump Test Measurement

Jump power (JPow) and jump height (JHt) were assessed by Tendo FiTRODYNE power and speed analyzer (Tendo Sports Machines, Trencin, Slovak Republic) and "Just Jump" contact mat (Probotics Inc, Huntsville, Alabama), respectively. In short, the Tendo unit measures jump velocity which is then used to estimate jump power (3, 12). The "Just Jump" contact mat and accompanied handheld equipment was used to measure JHt (Probotics Inc, Huntsville, Alabama). Moreover, use of the contact mat rather than force platforms has been shown to provide reliable vertical JPow results in older adults (13). Tendo FiTRODYNE power and speed analyzer is a reliable device for measuring movement velocity (18). It is a valid and

Table 1
Physical characteristics, muscle strength, and jump test performance of study participants

Variables	Participants (n = 59)		p	d
	Men (n = 27)	Women (n = 32)		
Age, years	64.8 ± 6.5	62.5 ± 5.1	0.147	0.39
Body mass, kg	81.3 ± 10.0	67.2 ± 11.7	< 0.001*	1.30
BMI, kg/m^2	26.65 ± 3.00	25.2 ± 3.89	0.112	0.42
Fat mass, kg	25.06 ± 10.51	26.76 ± 8.73	0.506	0.18
Leg muscle mass, kg	17.68 ± 2.55	11.81 ± 1.46	< 0.001*	2.83
PA, METs/week	5961.76 ± 5773.37	3716.17 ± 3831.91	0.08	0.46
JPow, W/kg BW^{-1}	11.71 ± 2.07	10.31 ± 1.13	0.003*	0.84
JHt, m	0.11 ± 0.03	0.08 ± 0.02	< 0.001*	1.18
HipAbd, kg/body mass	1.84 ± 0.45	1.59 ± 0.43	0.037	0.57
LP, kg/body mass	3.87 ± 0.94	3.07 ± 0.94	0.002*	0.85

Abbreviations: BMI, body mass index; PA, physical activity; MET, metabolic equivalent; JPow, jump power; JHt, jump height; HipAbd, hip abduction strength; LP, two-legged leg press strength; * Significant sex difference after Bonferroni correction with p < 0.0125.

reliable technique to assess muscle power in older adults (19). Our laboratory determined CV% for JPow and JHt are 4.0% and 3.3%, respectively (3, 12).

We have described jump test performance measurement in our previous studies (3, 12). Briefly, participants moved from a standing position, flexed their knees and hips, and were instructed to jump as high and as fast as possible without tucking the legs and instructed to land with both feet on the jump mat. Each participant performed 3 successful jumps, the average of which was used for data analyses. Participants rested for 60 seconds or longer if needed between each successive jump. All the testing was done by the same tester.

Statistical Analysis

Data from a previous study were used for secondary analysis for this investigation (3, 12). Statistical Package for Social Sciences SPSS 24.0 software (SPSS Inc., Chicago, IL) to perform data analysis. All descriptive statistics are reported as mean ± standard error (SE). Independent t-tests were computed to assess sex-based differences in physical characteristics, muscle strength, jump test performance, and physical activity. Bonferroni corrections were used for multiple comparisons. Data normality was checked using skewness, kurtosis, and Shapiro-Wilk test. The average of the right and left hip abduction (HipAbd) values were used for analysis. JPow, LP and HipAbd were normalized for body mass, meaning values of JPow, LP, and HipAbd of participants were divided by their respective body mass (kg), for all calculations. JHt was corrected prior to analysis in order to account for the overestimation of JHt by the Just Jump system.(20) We split our data based on sex and then stepwise sequential linear regression analyses were used to examine which independent variables (fat mass, leg muscle mass) correlated with the outcome measures (JPow, JHt, LP and HipAbd strength) after adjusting for age, height, and physical activity in men and women. Block one of the regression model contained the independent variables of age, height, and PA. Block two was set as stepwise and contained fat mass and leg muscle mass. The alpha level was set at $p < 0.05$ for all the significance tests. The magnitude of effects was measured by using Cohen's d, with values of 0.2, 0.5, and 0.8 demonstrating small, medium, and large effects respectively.

Results

Physical characteristics of participants based on sex are shown in Table 1. There were no differences in age, body mass index (BMI), and fat mass (all $p > 0.112$). Body weight and leg muscle mass were greater in men versus women (both $p < 0.001$). Measures of jump test performance and muscle strength were also greater in men versus women. Men had greater JPow ($p = 0.003$), JHt ($p < 0.001$), and LP ($p = 0.002$) versus women. There was a trend toward greater physical activity ($p = 0.08$) and hip abduction ($p = 0.037$) in men versus women. Based on the Center for Disease Control and Prevention/World Health Organization classification of BMI(16) 54% (32/59) of the study participants were overweight or obese. A greater percentage of men (20/27 = 74%) versus women (12/32 = 39%) were overweight or obese.

Results from the step-wise sequential regression analysis are displayed in Table 2. Fat mass was negatively associated with JHt ($p = 0.047$) in men (a) and JHt ($p = 0.003$), LP ($p = 0.002$), and HipAbd ($p < 0.001$) in women (b). Leg muscle mass was a significant predictor of JPow ($p = 0.047$) in women only.

Table 2
Stepwise sequential regression analyses of fat mass and leg muscle mass versus JPow, JHt, LP, and Hip Abd in men (A) and women (B). All the models were adjusted for age, height, and physical activity

A.

Dependent	Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	p
JHt	Fat mass	-0.381	-0.410	-0.219, -0.002	0.047*

B.

Dependent	Predictor	Standardized β-Coefficient	$r_{partial}$	95% Confidence Interval	p
JHt	Fat mass	-0.538	-0.538	-0.157, -037	0.003*
LP	Fat mass	-0.583	-0.544	-0.102, -0.025	0.002*
HipAbd	Fat mass	-0.671	-0.661	-0.048, -0.018	< 0.001*
JPow	Leg muscle mass	0.394	0.372	0.005, 0.604	0.047*

Abbreviations: JPow, jump power; JHt, jump height; LP, 2-leg press strength; HipAbd, hip abduction strength. Normalized values of JPow, LP, and HipAbd to body weight were used for all calculations. β-coefficients represent changes in SD in dependent variables per SD change in predictor variable; *Significant at $p < 0.05$; There were no significant predictors for JPow, LP, and HipAbd in men.

Discussion

To our knowledge, this is the first study to report negative relationships between fat mass and i) jump test performance and ii) muscle strength independent of age, height, physical activity, and leg muscle mass in men and women, 55-75 years of age. Positive association between leg muscle mass and jump power in women only was another main finding of this study.

Muscle activation capacity could be one of the critical factors that could explain negative relationships between fat mass and muscle performance in our population (21). There is some evidence that adiposity can adversely affect muscle activation capacity in young adults (22). Specifically, higher fat mass can markedly reduce agonist muscle activation (22). Thus, in addition to the typical aging-related loss in muscle activation capacity (23), a higher adiposity can further increase the degree of loss of muscle activation in older adults. A lower muscle activation capacity could result in lower muscle fiber recruitment and thus a lower net force generation. This is supported by our findings of negative relationships between fat mass and measures of muscle strength and power. These findings are in line with previous studies of lower muscle torques in individuals with obesity (11) even with greater fat free mass (11). Thus, fat mass versus leg muscle mass can play a critical role in dictating muscle performance in individuals with greater adiposity. Interestingly, visceral adiposity is associated with increased neural drive (24) but we did not collect any data on visceral adiposity in our population. Future studies should examine the interplay of visceral adiposity and muscle performance.

Muscle morphology is a critical factor which, in part, dictates muscle performance. Adiposity has been linked to a greater adipose tissue infiltration of skeletal muscles (ATSM) (25). ATSM is associated with reduced capacity for force and power generation by muscles leading to poor muscle quality (9,26). Moreover, there is some emerging evidence that ATSM can increase the stiffness of muscle and can adversely affect muscle shortening (9). This may explain the negative association of muscle strength with fat mass in our study. A negative relationship between muscle and neuromuscular performance, and fat mass in our study can also be explained by a synergistic effect of adiposity and aging which can result in greater degree of reduction in anabolic hormones such as insulin-like growth factor-1 (27) and chronic elevation of inflammatory cytokine such asinterleukin-6 (28) which could decrease voluntary muscle activation and thus, can decrease muscle performance in adults with greater fat mass. A positive relationship between JPow and leg muscle mass only in women was surprising. There is some evidence (28, 29) that women compared to men have greater muscle lengthening force production. A greater muscle lengthening force production mainly dictates jump power and may explain the positive relationship between JPow and leg muscle mass in women. Men and women display unique mechanisms for aging-associated muscle atrophy (31). The loss in total number of muscle fibers with aging is lower in women versus men (30) and the degree of loss of muscle mass and muscle strength is markedly greater in older men than women (6). This may be related to greater loss of muscle mass in men versus women seen with aging (7). Also, greater percent of men were obese than women in our study which may have conferred biomechanical disadvantage to men for jump test performance. However, we normalized JPow for body mass which may have attenuated, in part, effect of body mass on jump test performance. Thus, an interaction of various factors such as greater muscle lengthening force production, lower rate of loss of muscle mass, and lower rate of total number of muscle fiber loss in women versus men could explain the positive relationship between JPow and leg muscle mass in women only.

We did not use force plates for jump test performance in our study which may be considered a study limitation, however, we used a jump mat which has been shown to be a valid and reliable estimate for measures of jump test performance (13, 14). Jump mat is a user-friendly, cost-effective, and mobile piece of equipment which can be used to assess jump test performance in clinics or field settings. Thus, its translation to the rehabilitation community or field settings may be more feasible than using a force plate to assess jump test performance.

Taken together, the data from our current investigation provides earliest evidence of independent, negative relationships between fat mass and 1) jump test performance, and 2) muscle strength in both men and women between 55-75 years of age. For the same age group, leg muscle mass may dictate jump power in women but not in men. This knowledge is important for designing future intervention studies to inform evidence-based musculoskeletal rehabilitation in older adults with sarcopenia and increased adiposity, and in the decision-making process regarding weight loss in obese individuals.

Acknowledgements: We are thankful to all the participants without which this study would not have been possible.

Conflicts of interest: None declared by the Authors.

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