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Gender Differences in Anthropometric Predictors of Physical Performance in Older Adults

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Abstract

Background—Both high body fat and low muscle mass have been associated with physical disability in older adults. However, men and women differ markedly in body composition, where men generally have more absolute and relative lean muscle mass and less fat mass than women. It is not known how these anthropometric differences differentially impact physical ability in men and women.

Objectives—This study examines differences in anthropometric predictors of physical performance in older women and men.

Methods—Participants were 470 older women and men aged 72.9±7.9y. Body composition was measured using DXA. Maximum leg strength and power were measured using a leg press. Muscle quality (MQ) was calculated as relative strength (leg press strength per kg of leg muscle mass). Gait speed and chair rise were used to assess mobility performance and functional strength.

Results—BMI, age and muscle quality emerged as predictors ($p<0.05$) of functional strength and mobility in men and women somewhat differently. After accounting for age and sample, leg muscle quality was related to chair rise time and gait speed in men but not women. BMI was related to gait speed in both men and women, but BMI was related to chair rise time in only women and not men.

Discussion—Results implicate the prioritized importance of healthy weight and muscle maintenance in older women and men, respectively for maintained physical functioning with aging.

Keywords

Physical Function; Muscle Strength; Muscle Mass; Aging; Body Composition

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INTRODUCTION

Age-related declines in lean muscle mass have often been attributed to declining physical performance capacity, disability, mobility impairments, and frailty in older adults. However, contrary to this notion low skeletal muscle mass has been shown to be a surprisingly poor predictor of physical disability.¹ Instead, relative body fat has been associated with disability in older adults.¹ This disability may result from an insufficient ability to carry one's weight if lean muscle mass is low relative to body size, fat mass, and height.² However, this notion is complicated by gender differences in body composition measures.

Adult men and women differ markedly in body composition, where men generally have more absolute and relative lean muscle mass and less fat mass than women.³ Men, specifically have more appendicular muscle than women,⁴⁵ particularly in the upper body.⁵ However, with aging men lose lean muscle mass at a faster rate than women.³⁶ In fact, annual rates of appendicular skeletal muscle mass loss in men have been shown to be twice that in women.⁷ This loss is primarily due to a decrease in lower body skeletal muscle mass in both men and women.⁵⁷

Clinical definitions of the age-related decline in muscle mass, quality, and function, termed sarcopenia, have not yet been established.⁸ Thus, the prevalence rates of sarcopenia vary by definition.^{9–1112} When sarcopenia is defined as low fat free mass, prevalence has been shown to be 4% in men and 3% in women aged 70–75, increasing to 16% in men and 13% in women aged 85 and older.⁹ However, when sarcopenia, is defined as appendicular skeletal muscle mass scaled to height, the prevalence rates are higher, with a larger apparent gender difference, 22.6% in women and 26.8% in men aged 64–93 y and in 31.0% women and 52.9% in men over age 80 y.¹⁰ Nevertheless, sarcopenia increases risk of physical disability in both older men and women.¹² Moreover, the etiology of sarcopenia appears to develop differently in men and women¹²¹³ where sarcopenia is more prevalent in women at younger old ages (59–69y) and men at older old ages (over age 80y).¹³ Additionally, in men sarcopenia may mask an increase in body fat.⁷

Although being overweight is commonly associated with functional limitations and disability in both older men and women,¹⁴¹⁵¹⁶¹⁷¹⁸ gender differences in anthropometric characteristics impacting physical performance are apparent. For example, muscle area has previously been shown to be the strongest component of lower extremity performance in older men, while in women, total body fat was most strongly associated.¹⁹ Moreover, for men being classified as overweight (BMI 25.0–34.9) has been associated with a decreased risk of functional limitations compared to normal weight (BMI 18.5–24.9).¹⁴ In comparison to women who have an increased risk of functional limitations with a BMI over 35, men also do not see the functional limitation until BMI is over 40.¹⁴ Hence, anthropometric predictors of physical performance differ in older men and women, where it is hypothesized that lean mass becomes a critical limiting factor in least fit/most frail older women over time, while fat mass assumes this role in their male counterparts.²⁰ However, this hypothesis has not been tested in comparable samples of older men and women. To date, we do not know the relative benefit of muscle quality or burden of body load (BMI) on physical functioning ability between older men and women.

Given gender differences in body composition, sarcopenia, muscle mass and strength, we hypothesize that there may be contrasting anthropometric influences on physical function in older men and women. Thus, the purpose of this investigation was to determine whether older women and men differ in baseline anthropometric predictors of physical performance. Clarifying how older men and women differ in body composition predictors of functional performance will help in preventive and treatment interventions to maintain functional

muscle mass, mobility and performance in older adults. Moreover, clarifying this potential gender difference is important to determining whether clinically relevant definitions of sarcopenia need to be gender specific.

METHODS

Older adults residing in the community or assisted living facilities in Hartford County, CT were recruited and screened on the basis of age, bone mineral density, frailty, and hormonal status for potential participation in one of four interventional studies^{21–25} to assess the effects of exercise, dehydroepiandrosterone, testosterone, or estrogen on bone and physical function in women and men. Volunteers were recruited by newspaper advertisement, letter of invitation from existing databases, and community presentations to senior centers and residential retirement communities. Data for this study are pooled baseline assessments from the aforementioned studies prior to the initiation of any interventions. Baseline data were measured in 470 older adults (281 women and 193 men) aged 72.9 ± 7.9 yrs (Table 1). Since some participants did not complete all tests, regression models included those participants with complete data. All study participants provided written informed consent. The Institutional Review Board at the University of Connecticut Health Center approved all study procedures.

Body Composition—Total and regional skeletal muscle and fat mass were determined using a whole-body dual x-ray absorptiometry (DXA) using a DPX-IQ scanner (GE Medical Systems Lunar, Madison, WI). Total lean body mass (LBM (kg)), total fat mass (kg), and total-body bone density (BMD) (g/cm^2) were measured in the total body scan. Appendicular skeletal muscle mass (ASM) was determined by combining the lean tissue mass of the arm and leg regions, excluding all other regions from analysis. Leg skeletal muscle mass was used in the determination of muscle quality (MQ) of the lower body.

Physical Performance Descriptive Measures

Leg Press Strength & Power—Lower body voluntary isotonic strength and power^{26,27} were evaluated on the Keiser K400 pneumatic seated leg-press machine (Kaiser Corp., Fresno, CA) equipped with a force plate. Strength was determined by testing the maximum amount of weight each participant could lift for one repetition (1-RM). Participants sat in a semi-recumbent position on the leg-press machine. The starting position was set at a knee flexion angle of $\sim 90^\circ$, hip flexion of $\sim 45^\circ$ and ankle dorsiflexion of $\sim 5^\circ$. After a brief familiarization, participants warmed-up with three unilateral warm-up trials of five repetitions for each leg at 20% of body weight in Newtons, alternately. Resistance was then increased for the 1-RM attempts, based on the participants' perceived difficulty (rated 1–4 for easy to very hard), until he/she could not complete a lift (failure). Participants rested at least 1 minute between attempts, alternating each leg between trials. Standardized verbal encouragement was given to each participant before and during each attempt. The participant's 1RM was determined as the greatest resistance (N) that the participant was able to overcome (maximal extension) under this protocol. A trial was considered complete after each leg was unable to complete a leg press. MQ was calculated as relative strength (leg press strength per kg of leg muscle mass). Lower body power (W) was measured as the peak work rate (product of the instantaneous resistance (N) x instantaneous velocity). The leg press attempt that developed the maximal power was usually at between 50 and 70% of the 1-RM.

Single-leg stance—Balance was evaluated with the single-leg stance test.²⁸ This test evaluated the ability of volunteers to balance in a standing position on one leg with eyes open. Participants wore flat-heel, rubber-soled shoes. Participants shifted their weight to the

dominant foot and lifted and held the non-dominant lower extremity at 0° of extension at the hip and 80° to 90° of flexion at the knee. The time that participants balanced on the single-leg was recorded in seconds. The test was terminated after 30 seconds, since it was considered a successful outcome if participants were able to maintain balance for this duration. Time elapsed was measured with a stopwatch.

Outcome Measures

Gait Speed—Normal walking gait (mobility) was evaluated with the 8-foot walk test.²⁹ An 8-foot level course was marked by tape in an indoor corridor. Participants were instructed to walk at their ‘normal pace’ and were allowed to use any usual walking aids. Spotters walked along the side of the volunteer’s during the test to ensure safety. Time began when the volunteer initiated foot movement and stopped when one foot (completely) crossed the end line (8-foot mark). Time was measured with a stopwatch to the nearest one hundredth of a second. Two trials were completed. The best time of the two attempts was recorded.

Chair Rise—Functional lower body strength was evaluated with the chair rise test.²⁹ This test required participants to stand from a seated position in a 17-inch armless chair five times, consecutively. Participants were instructed to do so as rapidly as possible with the arms folded across the chest. If participants could not perform a single chair rise without the use of their arms the test was concluded. Otherwise, time to perform five consecutive chair rises was measured with a stopwatch in seconds.

Statistical Analysis

Anthropometric and performance measures are reported as means and standard deviations stratified by gender and age. Group differences were evaluated using analysis of variance stratified by age. For all analyses, the level of significance was $p < 0.05$. Total body fat, trunk fat, and appendicular fat mass were eliminated from the model, since all were highly correlated to BMI ($r > 0.8$) and did not provide any unique contributions when predicting physical performance. BMI was selected to represent a ‘load’ hypothesized to hinder mobility. MQ was selected to represent ‘functional tissue’ hypothesized to facilitate mobility. Simple slope regression models included sampling group as a fixed factor to account for potential variations between samples. Since samples were nested within gender (two samples included only women and two samples included only men), adjustments for samples were made only within each level of gender. Although a more common practice is to treat samples as a random factor in a hierarchical design, having only two samples within each level of gender would under power our analyses. Therefore, we included the samples as a fixed factor in each simple slope regression model.

Preliminary Analyses—To reduce threats to statistical conclusion validity³⁰, we tested several statistical assumptions for ordinary least squares regression and made some adjustments to our statistical models when these assumption were violated. For those violated assumptions that could not be corrected, we discuss the potential implications for validity in the limitations section of this paper.

The residual errors for a regression should be normally distributed—Results from the Shapiro-Wilk test indicated that the residual errors were not normally distributed when either chair rise time ($SW(448) = .919, p < .001$) or gait ($SW(451) = .819, p < .001$) was the dependent variable. To reduce the skewness and kurtosis of the residual errors, we used a square root transformation on each dependent variable. Although the transformation reduced both skewness ($g_{1raw} = 1.416, g_{1trans} = 0.588$) and kurtosis ($g_{2raw} = 4.915, g_{2trans} = 1.603$) of the residual errors when all of the significant predictor variables were regressed on

chair rise time, they were still not normally distributed ($SW(448) = .975, p < .001$). Similar results were obtained by transforming gait speed. Skewness ($g_{1raw} = 2.637, g_{1trans} = 1.334$) and kurtosis ($g_{2raw} = 14.356, g_{2trans} = 5.281$) of the residual errors were reduced, but not normally distributed ($SW = .907, p < .001$). Although transforming the dependent variables did not completely correct for this violation, hopefully it will reduce the impact that it had on our results.

Continuous predictor variables should be linearly related to the dependent variables—Curve fit estimates in SPSS were used to determine if age, BMI or muscle quality had curvilinear relationships with either dependent variable. We found that both age and BMI violated this statistical assumption. There was a significant quadratic trend between age and chair rise time, $\beta = 1.611, t(445) = 1.611, p = .025$; and age and gait speed, $\beta = 3.799, b = .003, t(448) = 5.573, p < .001$. There was also a quadratic relationship between BMI and gait speed, $\beta = -.430, b = -.334, t(448) = -2.603, p = .010$. Therefore, we included quadratic trends in each of our regression models.

There should be no outliers—Examining stem and leaf plots in SPSS, we found that there were outliers for all of the continuous predictor variables: 1 in age, 14 in BMI, and 11 in muscle quality. We tried transforming these variables to reduce the number of outliers, but this had little impact; therefore we used the raw scores for the predictor variables. Although dropping cases with outliers was another possibility, we chose to retain these cases to improve external validity. The impact of these outliers was considered when interpreting results that would likely be affected by them.

Inferential Analyses—Two sequential multiple regressions were used to test whether gender moderated the relationship between the anthropometric variables (age, BMI, and muscle quality) and physical performance, as measured by (a) chair rise time and (b) gait speed. Quadratic trends for age, BMI and muscle quality were also included in the models to account for the non-linear trends found in the preliminary analyses. To reduce multicollinearity, a stepwise procedure in SPSS version 19 was used to test each block of the non-linear and interaction terms. Statistics for all models are shown in Tables 3 and 4.

RESULTS

Anthropometric characteristics stratified by age group and gender are listed in Table 1. The mean age for each stratified age group were (57 – 70 y) women $65.2y \pm 3.0$ and men $66.1y \pm 3.8$, (71 – 77 y), (71 – 77 y) women 73.6 ± 1.9 and men $74.4y \pm 2.1$, (78y+) women $81.3y \pm 3.4$ and men $82.8y \pm 4.1$. As expected, men were taller and heavier than women ($p < 0.05$). Also, men had greater lean mass, bone mineral density (BMD), appendicular skeletal mass (ASM), and less relative body fat ($p < 0.05$). Interestingly, men had higher BMI than women and more trunk mass in the young-old age group (57–70 yr) only ($p < 0.05$). Neither BMI nor trunk mass differed between men and women in the older age groups (71–77 y or 78+ y). Muscle quality was higher in men in the younger age groups (57–70 y and 71–77 y) compared to women ($p < 0.05$). There were no differences in muscle quality in the oldest age group. Fat mass was only higher in women in the 71–77 y old age group ($p < 0.05$), but not the 57–70 y or 71–77 y age group.

Performance characteristics stratified by age group and gender are listed in Table 2. As expected, men were stronger in the leg press and were able to generate significantly higher leg power than women in all age groups ($p < 0.05$). Interestingly, women performed better in the timed single-leg stance balance test, chair rise, and gait speed than men in the younger age groups.

Chair Rise Time

Age and muscle quality did not have non-linear relationships with rise time; and after accounting for samples, neither did BMI. Since there was a non-linear relationship between BMI and rise time (Figure 1) before accounting for samples, gender was tested as a moderator between both the quadratic and linear terms for BMI and rise time. Before accounting for different samples, gender did not moderate any of the relationships between any of the predictor variables and chair rise time. However, after accounting for samples, it moderated the relationships between BMI and rise time and muscle quality and rise time. For both men and women, older age was associated with greater chair rise times – that is, slower chair rise (Table 3). After accounting for age and sample, BMI was not related to rise time among men, but leg muscle quality was. For men, as leg muscle quality decreased the time it took them to rise out of a chair increased. Among women, there was no relationship between leg muscle quality and rise time, but BMI was positively related to rise time. As BMI increased in women, so did the time it took them to rise from a chair.

Gait Speed

Although muscle quality was linearly related to gait speed, both age and BMI had quadratic relationships with gait speed. As in the previous analysis, gender was tested as a moderator between the *quadratic terms* for these two predictor variables and gait speed. Gender did not moderate the relationship between age and gait speed. However, it did moderate the relationships between BMI and gait speed and leg muscle quality and gait speed.

For both men and women, as participants got older it took them longer to walk eight feet – that is a greater gait time and slower gait speed. However, Figure 2 shows that gait time *exponentially* increases after 75 years of age. After accounting for age and sample, both BMI and leg muscle quality were related to gait speed among men. For all men, as BMI increased so did the time it took them to walk eight feet. However, as shown in Figure 3, this relationship is stronger for men whose BMI scores exceed 30. Leg muscle quality was negatively related to gait speed; the time it took men to walk eight feet increased as muscle quality decreased.

Among women, there was no relationship between leg muscle quality and gait speed. However, BMI was positively and linearly related to gait speed for females. Unlike the quadratic relationship that was found for men, women consistently took longer to walk eight feet as their BMI scores increased.

DISCUSSION

This study examined differences in anthropometric predictors of functional performance between older men and women. Primary results indicate that higher MQ and lower BMI were both associated with better performance, even after accounting for age and sampling group. However, this impact differed between older men and women and depended on the performance measure. MQ appeared to have a stronger influence on functional performance in men for both tasks, while that of BMI was greater in women. Although BMI was related to gait speed for both men and women; increasing BMI scores in women consistently decreased their gait speed, but BMI did not influence men's gait speed until their BMI scores exceeded 30. These findings support prior findings of differences in characteristics of sarcopenia between men and women and provide further insight on the anthropometric and functional impact of the age associated changes in body composition.

Gender interactions observed in our findings are likely due to physiological differences in muscle function and structure. Absolute lower body strength on the leg press was significantly lower in women compared to men. The magnitude of this discrepancy is

similar to prior data.³¹ Lower strength in women can likely be explained by differences in muscle mass between older men and women,³¹ since in the present study men had significantly higher muscle mass than women. The reduction of these gender differences when expressing strength per kilogram of muscle mass in the present study is also consistent with previous data,³¹ supporting the role of muscle mass in explaining gender differences in absolute lower extremity strength.

Interestingly, although men were both able to produce greater leg press strength and power and had favorable anthropometric characteristics for performance (greater absolute and relative lean muscle mass) than women in the present study, this did not translate to better functional performance. These findings would indicate that factors other than muscle mass, body composition, strength and power production are likely important to mobility, functional strength, and balance performance in older adults. These additional factors could include muscle quality, neural activation, motor recruitment patterns, or motivation, factors important in physical performance, but not measured in the present study. However, these contributions were likely small, since neural activation and motor unit recruitment were captured in the strength and power measures. Moreover, all participants received similar familiarization, instruction, and encouragement to reduce the potential impact of motivation. Hence, true physiologic gender differences in muscle, fat, and weight distributions between older men and women impact functional performance.

An alternative explanation may be that despite having favorable body composition and strength, men in the present study were generally more frail or fragile than the women. Reasons for the potential gender discrepancy due to level of fragility are unknown, but it has previously been proposed that lean mass becomes a critical limiting factor in least fit/most frail older women over time, while fat mass assumes this role in their male counterparts.²⁰³² Our data supports this concept and quantifies the relative burden of the load imposed by higher BMI on physical functioning in older women. Prior research has similarly reported associations between higher fat mass, BMI, and percent body fat and different measures of physical functioning (e.g. strength, 6-min walk, self-reported physical abilities), particularly in older women.³³³⁴ Prior data from our lab revealed that appendicular skeletal muscle mass relative to body mass is a better mobility predictor, than absolute sarcopenia.³⁵ Similarly, the importance of leg muscle mass for functional performance (timed walking test and a timed chair stand test) specifically in older men has previously been reported.³⁶ However, interestingly, in women in the present study, muscle quality, a relative measure accounting for muscle mass, was not an important predictor of physical performance in women. We do, however, report muscle quality as being important to function in men.

In the present study, muscle quality emerged as an important predictor of both chair rise time and gait speed, but only in men. Muscle quality, as measured in this study, indicates the relative muscle strength to regional muscle mass of the legs. Since, our data indicate that muscle quality impacts mobility in older men to a larger extent than older women, differences in muscle physiologic characteristics between older men and women may exist. Previous reports indicate that muscle quality is associated with lower extremity performance¹⁹ and is lower in less fit older adults.³²

Participants in the present study included a broad range of functional abilities, ranging from fully functional community dwelling²¹²⁴ individuals to individuals demonstrating some aspects of frailty.²²²³ It may be that there is a threshold of muscle mass, body weight and strength required to perform such functional tasks. These thresholds are likely relative to the demands of the functional tasks. Hence it may be that BMI and MQ have a greater impact on performance only at threshold levels. We found stronger associations between BMI and gait speed in men whose BMI exceeded 30. However, the few participants in our sample

with a high BMI restrict the generalizability of this trend. Similarly, a prior study by Friedmann and colleagues found that disability risk increases in men who have a BMI over 40 and at a BMI over 35 in women.¹⁴ Moreover, another study found that lower extremity muscle mass is an important determinant of physical performance among older adults with functional limitations.³⁷ Hence, further studies are needed to evaluate muscle mass, quality, and body mass thresholds that may be important for performance.

Although our analyses attempted to reduce threats to statistical conclusion validity by evaluating statistical assumptions for ordinary least squares regressions and making adjustments to our statistical models when assumptions were violated, our results should be interpreted with consideration of statistical assumptions that could not be corrected. First, although variable transformations were made to our dependent variables to improve the distribution of the residual errors from the predictor variables, the residual errors were still significantly skewed and kurtotic even after the optimal transformations. This could result in model misspecification either as Type I or Type II errors. Therefore, some of the relationships between variables in the older adult population may not have been detected in our sample or some of the non-linear trends that we did find (or failed to find) in our sample may not accurately represent the population. Second, the predictor variables had outliers that we retained in our analyses. The outliers may have been responsible for the significant relationships that we found. Therefore, the detected relationship between BMI and physical performance may be explained by the additional (and more extreme) outliers of BMI scores among women compared to men. Including outliers may allow us to generalize our results to older adults with exceptionally high or low BMI or MQ scores, but our results may not accurately reflect the relationships between these anthropometric characteristics and physical performance for the majority of older adults.

CONCLUSIONS

In summary, findings from the present study suggest that gender specific criteria may be needed in defining clinically relevant definitions of sarcopenia that translate to functional performance. Moreover, it is possible that BMI is a more important determinant of functional ability in these samples of women. However, in men, the muscle quality is more important to functional performance. These findings point to the need to maintain a healthy body composition and muscle functioning with aging. Particularly, these findings indicate the importance of maintaining a healthy body weight in older women, while maintaining high quality skeletal muscle is particularly important for older men. Both goals can be achieved with carefully designed physical activity and exercise targeted at weight maintenance and muscle quality improvements with aging and hence improving functional performance. Additionally, future research should examine the proper exercise intervention strategies to maintain favorable anthropometric characteristics related to performance with aging for men and women.

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References

1. Visser M, Harris TB, Langlois J, Hannan MT, Roubenoff R, Felson DT, et al. Body fat and skeletal muscle mass in relation to physical disability in very old men and women of the Framingham Heart Study. *J Gerontol A Biol Sci Med Sci*. 1998; 53(3):M214–221. [PubMed: 9597054]

2. Delmonico MJ, Harris TB, Lee JS, Visser M, Nevitt M, Kritchevsky SB, et al. Alternative definitions of sarcopenia, lower extremity performance, and functional impairment with aging in older men and women. *J Am Geriatr Soc.* 2007; 55(5):769–774. [PubMed: 17493199]
3. Silva AM, Shen W, Heo M, Gallagher D, Wang Z, Sardinha LB, et al. Ethnicity-related skeletal muscle differences across the lifespan. *Am J Hum Biol.* 22(1):76–82. [PubMed: 19533617]
4. Gallagher D, Visser M, De Meersman RE, Sepulveda D, Baumgartner RN, Pierson RN, et al. Appendicular skeletal muscle mass: effects of age, gender, and ethnicity. *J Appl Physiol.* 1997; 83(1):229–239. [PubMed: 9216968]
5. Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. *J Appl Physiol.* 2000; 89(1):81–88. [PubMed: 10904038]
6. Zamboni M, Zoico E, Scartezzini T, Mazzali G, Tosoni P, Zivelonghi A, et al. Body composition changes in stable-weight elderly subjects: the effect of sex. *Aging Clin Exp Res.* 2003; 15(4):321–327. [PubMed: 14661824]
7. Gallagher D, Ruts E, Visser M, Heshka S, Baumgartner RN, Wang J, et al. Weight stability masks sarcopenia in elderly men and women. *Am J Physiol Endocrinol Metab.* 2000; 279(2):E366–375. [PubMed: 10913037]
8. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol.* 2003; 95(5):1851–1860. [PubMed: 14555665]
9. Castillo EM, Goodman-Gruen D, Kritz-Silverstein D, Morton DJ, Wingard DL, Barrett-Connor E. Sarcopenia in elderly men and women: the Rancho Bernardo study. *Am J Prev Med.* 2003; 25(3):226–231. [PubMed: 14507529]
10. Iannuzzi-Sucich M, Prestwood KM, Kenny AM. Prevalence of sarcopenia and predictors of skeletal muscle mass in healthy, older men and women. *J Gerontol A Biol Sci Med Sci.* 2002; 57(12):M772–777. [PubMed: 12456735]
11. Melton LJ 3rd, Khosla S, Riggs BL. Epidemiology of sarcopenia. *Mayo Clin Proc.* 2000; 75(Suppl):S10–12. discussion S12–13. [PubMed: 10959209]
12. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc.* 2002; 50(5):889–896. [PubMed: 12028177]
13. Kirchengast S, Huber J. Gender and age differences in lean soft tissue mass and sarcopenia among healthy elderly. *Anthropol Anz.* 2009; 67(2):139–151. [PubMed: 19739465]
14. Friedmann JM, Elasy T, Jensen GL. The relationship between body mass index and self-reported functional limitation among older adults: a gender difference. *J Am Geriatr Soc.* 2001; 49(4):398–403. [PubMed: 11347782]
15. Visser M, Langlois J, Guralnik JM, Cauley JA, Kronmal RA, Robbins J, et al. High body fatness, but not low fat-free mass, predicts disability in older men and women: the Cardiovascular Health Study. *Am J Clin Nutr.* 1998; 68(3):584–590. [PubMed: 9734734]
16. Hubert HB, Bloch DA, Fries JF. Risk factors for physical disability in an aging cohort: the NHANES I Epidemiologic Followup Study. *J Rheumatol.* 1993; 20(3):480–488. [PubMed: 8478855]
17. Galanos AN, Pieper CF, Cornoni-Huntley JC, Bales CW, Fillenbaum GG. Nutrition and function: is there a relationship between body mass index and the functional capabilities of community-dwelling elderly? *J Am Geriatr Soc.* 1994; 42(4):368–373. [PubMed: 8144820]
18. Launer LJ, Harris T, Rumpel C, Madans J. Body mass index, weight change, and risk of mobility disability in middle-aged and older women. The epidemiologic follow-up study of NHANES I. *JAMA.* 1994; 271(14):1093–1098. [PubMed: 8151851]
19. Visser M, Kritchevsky SB, Goodpaster BH, Newman AB, Nevitt M, Stamm E, et al. Leg muscle mass and composition in relation to lower extremity performance in men and women aged 70 to 79: the health, aging and body composition study. *J Am Geriatr Soc.* 2002; 50(5):897–904. [PubMed: 12028178]
20. Duque G, Kuchel GA. Moving Beyond Static Body Composition Paradigms to Assessments of Change, Plasticity, and Function. *JAGS.* 2010 Feb.2(2)

21. Judge JO, Kleppinger A, Kenny A, Smith JA, Biskup B, Marcella G. Home-based resistance training improves femoral bone mineral density in women on hormone therapy. *Osteoporos Int*. 2005; 16(9):1096–1108. [PubMed: 15754082]
22. Kenny AM, Boxer RS, Kleppinger A, Brindisi J, Feinn R, Burleson JA. Dehydroepiandrosterone (DHEA) Combined with Exercise Improves Muscle Strength and Physical Function in Frail Older Women. *J Am Geriatr Soc*. In press.
23. Kenny AM, Kleppinger A, Annis K, Rathier M, Browner B, Judge JO, et al. Effects of transdermal testosterone on bone and muscle in older men with low bioavailable testosterone, low bone mass and physical frailty. *J Amer Geriatr Soc*. In press.
24. Kenny AM, Kleppinger A, Wang Y, Prestwood KM. Effects of ultra-low-dose estrogen therapy on muscle and physical function in older women. *J Am Geriatr Soc*. 2005; 53(11):1973–1977. [PubMed: 16274381]
25. Kenny AM, Smith J, Noteroglu E, Waynik IY, Ellis C, Kleppinger A, et al. Osteoporosis risk in frail older adults in assisted living. *J Am Geriatr Soc*. 2009; 57(1):76–81. [PubMed: 19054182]
26. Fiatarone MA, O'Neill EF, Ryan ND, Clements KM, Solares GR, Nelson ME, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N Engl J Med*. 1994; 330(25):1769–1775. [PubMed: 8190152]
27. Earles DR, Judge JO, Gunnarsson OT. Velocity training induces power-specific adaptations in highly functioning older adults. *Arch Phys Med Rehabil*. 2001; 82(7):872–878. [PubMed: 11441371]
28. Judge JO, Lindsey C, Underwood M, Winsemius D. Balance improvements in older women: effects of exercise training. *Phys Ther*. 1993; 73(4):254–262. discussion 263–255. [PubMed: 8456144]
29. Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol*. 1994; 49(2):M85–94. [PubMed: 8126356]
30. Shadish, WR.; Cook, TD.; Campbell, DT. *Experimental and Quasi-Experimental Designs for Casual Inference*. Boston, MA: Houghton Mifflin; 2002.
31. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol*. 1991; 71(2):644–650. [PubMed: 1938738]
32. Koster A, Visser M, Simonsick EM, Yu B, Allison DB, Newman AB, et al. Association between fitness and changes in body composition and muscle strength. *J Am Geriatr Soc*. 58(2):219–226. [PubMed: 20370856]
33. Lebrun CE, van der Schouw YT, de Jong FH, Grobbee DE, Lamberts SW. Fat mass rather than muscle strength is the major determinant of physical function and disability in postmenopausal women younger than 75 years of age. *Menopause*. 2006; 13(3):474–481. [PubMed: 16735945]
34. Zamboni M, Turcato E, Santana H, Maggi S, Harris TB, Pietrobelli A, et al. The relationship between body composition and physical performance in older women. *J Am Geriatr Soc*. 1999; 47(12):1403–1408. [PubMed: 10591232]
35. Estrada M, Kleppinger A, Judge JO, Walsh SJ, Kuchel GA. Functional impact of relative versus absolute sarcopenia in healthy older women. *J Am Geriatr Soc*. 2007; 55(11):1712–1719. [PubMed: 17979895]
36. Visser M, Deeg DJ, Lips P, Harris TB, Bouter LM. Skeletal muscle mass and muscle strength in relation to lower-extremity performance in older men and women. *J Am Geriatr Soc*. 2000; 48(4):381–386. [PubMed: 10798463]
37. Reid KF, Naumova EN, Carabello RJ, Phillips EM, Fielding RA. Lower extremity muscle mass predicts functional performance in mobility-limited elders. *J Nutr Health Aging*. 2008; 12(7):493–498. [PubMed: 18615232]

Figure 1.
Relationship between chair rise time and BMI for all participants.

Figure 2.
Relationship between gait speed (time to walk eight feet) and age for women and men.

Figure 3.
Relationship between gait speed (time to walk eight feet) and body mass index for women and men.

Table 1

Anthropometric characteristics of study participants

Age Group	Women				Men			
	57-70 y	71-77 y	78+ y		57-70 y	71-77 y	78+ y	
Age (y)	65.2 ± 3.0 (n=146)	73.6 ± 1.9 (n=84)	81.3 ± 3.4 (n=47)		66.1 ± 3.8 (n=31)	74.4 ± 2.1 (n=83)	82.8 ± 4.1 (n=79)	
BMI (kg/m ²)	25.5 ± 4.7 *	26.0 ± 5.1	26.0 ± 4.7		28.3 ± 5.0 *	26.7 ± 3.9	26.3 ± 3.3	
Height (cm)	160.9 ± 6.1 *	159.3 ± 6.5 *	157.6 ± 6.3 *		175.0 ± 5.9 *	172.8 ± 7.9 *	171.3 ± 6.7 *	
Weight (Kg)	66.1 ± 11.9 *	65.9 ± 12.6 *	64.7 ± 13.3 *		86.8 ± 16.6 *	80.1 ± 14.2 *	77.1 ± 11.2 *	
Fat %	37.1 ± 7.2 *	38.6 ± 6.6 *	37.1 ± 6.1 *		29.2 ± 8.3 *	27.2 ± 6.3 *	27.7 ± 7.0 *	
ASM (Kg)	15.8 ± 2.2 *	15.3 ± 2.7 *	15.1 ± 2.5 *		24.5 ± 4.0 *	23.2 ± 3.3 *	21.8 ± 2.8 *	
Muscle Quality	4.3 ± 0.9 *	3.9 ± 0.8 *	4.0 ± 0.9		4.8 ± 1.4 *	4.4 ± 1.1 *	4.0 ± 1.1	
BMD (g/cm ²)	1.111 ± 0.074 *	1.087 ± 0.100 *	1.042 ± 0.097 *		1.173 ± 0.094 *	1.198 ± 0.098 *	1.158 ± 0.103 *	
Lean mass (Kg)	37.9 ± 4.3 *	37.6 ± 5.2 *	37.8 ± 5.3 *		56.9 ± 8.0 *	54.1 ± 6.1 *	52.1 ± 5.6 *	
Fat mass (Kg)	23.8 ± 8.9	25.4 ± 9.2 *	24.5 ± 8.5		25.9 ± 10.7	22.2 ± 8.4 *	21.7 ± 7.9	
Trunk mass (Kg)	11.7 ± 4.0 *	12.4 ± 3.9	11.9 ± 4.1		13.9 ± 5.7 *	12.7 ± 4.6	12.1 ± 4.3	

* p < 0.05 based on analysis of variance comparing gender, stratified by age

ASM = Appendicular skeletal mass; BMD = Bone mineral density

Table 2

Performance Characteristics

Age	Women			Men		
	57–70 y (n=146)	71–77 y (n=84)	78+ y (n=47)	57–70 y (n=31)	71–77 y (n=83)	78+ y (n=79)
Single leg stance (s)	22.6 ± 10.7 *	13.1 ± 10.1	6.9 ± 6.9	15.2 ± 11.7 *	11.5 ± 10.5	6.7 ± 6.6
8-ft walk (s)	2.1 ± 0.4 *	2.4 ± 0.5	2.8 ± 0.8	2.6 ± 0.9 *	2.6 ± 0.9	3.1 ± 1.2
Chair rise time (s)	10.4 ± 3.9 *	11.6 ± 3.7 *	14.8 ± 6.3	13.0 ± 5.2 *	13.6 ± 6.0 *	15.8 ± 6.3
Leg press strength (N)	507.4 ± 139.1 *	435.2 ± 100.8 *	434.1 ± 132.9 *	834.7 ± 274.7 *	719.8 ± 209.7 *	632.4 ± 202.8 *
Leg press power (w)	236.9 ± 65.5 *	177.1 ± 60.7 *	145.1 ± 61.2 *	349.0 ± 158.0 *	321.7 ± 140.1 *	226.6 ± 100.6 *

* p < 0.05 based on analysis of variance comparing gender, stratified by age

Table 3

Statistics for Chair Rise Time

Model	Anthropometric Variable	β	df	t	p
All Participants					
Main Effects	Gender	.150	443	3.251	.001
	Age	.327	443	7.045	< .001
	BMI	.219	443	5.139	< .001
Non-linear	Muscle Quality	-.093	443	-2.130	.034
	Age ²	1.249	442	1.838	.067
	BMI ²	.789	442	2.895	.004
	Muscle Quality ²	.155	442	0.639	.523
	Gender*Age	.066	441	0.141	.888
	Gender*BMI	-.416	441	-1.524	.128
Interactions	Gender*MQ	-.301	441	-1.670	.096
	Gender*BMI ²	-.182	441	-1.304	.193
Men	Sample	.355	166	4.887	< .001
	Age	.220	163	2.964	.003
	BMI	.054	163	0.762	.447
	Muscle Quality	-.172	163	-2.368	.019
	Age ²	1.455	162	1.344	.181
	BMI ²	.885	162	1.462	.146
Women	Sample	.465	278	8.766	< .001
	Age	.140	275	1.985	.048
	BMI	.212	275	3.638	< .001
	Muscle Quality	-.028	275	-0.494	.621
	Age ²	-.163	276	-0.170	.865
	BMI ²	.387	276	1.183	.238

Table 4

Statistics for Gait Speed

Model	Anthropometric Variable	β	df	t	p
All Participants					
Main Effects	Gender	.128	446	2.954	.003
	Age	.368	446	8.466	< .001
	BMI	.305	446	7.623	< .001
Non-linear	Muscle Quality	-.175	446	-4.290	< .001
	Age ²	3.551	444	5.733	< .001
	BMI ²	.628	444	2.528	.012
	Muscle Quality ²	.143	444	0.650	.516
	Gender*Age ²	-.250	442	-0.992	.322
	Gender*BMI ²	.329	442	2.593	.010
Interactions	Gender*MQ	-.336	442	-2.028	.043
	Sample	.336	168	4.619	< .001
	Age	.297	165	4.373	< .001
Men	BMI	.287	165	4.394	< .001
	Muscle Quality	-.225	165	-3.383	.001
	Age ²	2.811	163	2.913	.004
Women	BMI ²	1.412	163	2.618	.010
	Sample	.534	279	10.546	< .001
	Age	.252	276	3.850	< .001
	Muscle Quality	-.051	276	-.985	.325
	Age ²	2.245	275	2.554	.011
	BMI ²	.182	275	0.600	.549