Preventive Medicine Reports 11 (2018) 15–22

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

# Body composition and physical function in the Women's Health Initiative Observational Study

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A R T I C L E I N F O

*Keywords:*
Adipose tissue
Muscle, striated
Body composition
Postmenopause

A B S T R A C T

Physical function is critical for mobility and quality of life. We hypothesized that higher total lean mass is associated with higher physical function, and body fat inversely associated, among postmenopausal women. Women's Health Initiative Observational Study participants at Pittsburgh, PA; Birmingham, AL; and Tucson-Phoenix, AZ (1993–1998) completed dual-energy X-ray absorptiometry scans and the Rand SF-36 questionnaire at baseline and 3 y (N = 4526). Associations between quartiles (Q1–4) of lean or fat mass and physical function were tested using linear regression, adjusted for demographics, lifestyle factors, medical history, and scanner serial number. At baseline, participants had a mean ± SD age of 63.4 ± 7.4 y and BMI of 27.4 ± 5.8 $kg/m^2$. Higher percent lean mass was positively associated with physical function at baseline (Q4, 83.6 ± 0.6 versus Q1, 74.6 ± 0.7; $p < 0.001$), while fat mass (kg and %) was inversely associated (e.g., Q4, 73.7 ± 0.7 versus Q1, 84.2 ± 0.7 kg; $p_{trend} < 0.001$). Physical function had declined across the cohort at 3 y; the highest relative lean mass quartile at baseline conferred a lesser decline in physical function than the lowest (Q4, −3.3 ± 0.6 versus Q1–7.0 ± 0.6; $p_{trend} < 0.001$), while the highest fat mass quartile (% and kg) conferred greater decline (ex. Kg Q4, −6.7 ± 0.7 versus Q1–2.8 ± 0.6; $p_{trend} < 0.001$). Increased fat mass (≥5%), but not lean mass, was associated with lower physical function at 3 y ($p < 0.001$). Adiposity, as well as lean mass, requires consideration in the prediction of physical function among postmenopausal women over time.

## 1. Introduction

The number of older adults (≥65 years) is rapidly increasing in the United States and expected to nearly double from 43.1 million in 2012 to 83.7 million by 2050 (Ortman et al., 2014). Maintaining physical function is important for independence and quality of life in older adults (Kuczmarski et al., 2010). Studies have found significant associations between body composition and physical function (Janssen et al., 2002; Newman et al., 2003; Sternfeld et al., 2002; Visser et al., 2000; Visser et al., 2002a), such that lower lean mass, termed sarcopenia, and higher fat mass are inversely related to physical performance measures. However, not all studies agree on the relationships between fat and lean mass and physical performance (Araujo et al., 2010; Visser et al., 2000).

Most studies of body composition and physical function have focused on adults over 65 years of age, which may inadvertently concentrate preventive efforts only to those in this age group. We found only one study among middle-aged adults, which included only males (Araujo et al., 2010). Since women begin with lower muscle mass (i.e. lean mass) than men and experience adverse changes in body composition with menopause (Kuczmarski et al., 2010; Sipila, 2003), it is important to investigate the association between body composition and physical function among postmenopausal women across a broader age range. Further, since these deleterious changes in body composition among postmenopausal women can be ameliorated through lifestyle interventions (Bea et al., 2010), it is important to understand the

*Abbreviations:* ASMI, appendicular skeletal muscle index; BMI, body mass index; Q, quartile

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https://doi.org/10.1016/j.pmedr.2018.05.007
Received 18 December 2017; Received in revised form 26 April 2018; Accepted 5 May 2018
Available online 09 May 2018

relationship between body composition and physical function from menopause onward.

Here, we assess the relationship between body composition and physical function at baseline and at three years' follow-up among postmenopausal women both older and younger than 65 y. We hypothesized that higher lean mass at baseline would be associated with higher physical function, while higher fat mass would be associated with poorer physical function, at baseline and over three years follow-up.

## 2. Methods

### 2.1. Study population

The Women's Health Initiative (WHI) Study enrolled postmenopausal women aged 50–79 y at 40 clinical centers across the United States between 1993 and 1998. Women were recruited to any of four Clinical Trials or an Observational Study, as previously published (Hays et al., 2003; The Women's Health Initiative Study Group, 1998). Only women enrolled in the observational study who completed body composition evaluations at both baseline and year 3 were included in this analysis [Pittsburgh, PA; Birmingham, AL; and Tucson-Phoenix, AZ sites (N = 4526)] (Chen et al., 2008). Each institutional review board approved the protocol, and all participants provided written informed consent.

### 2.2. Physical function

Physical function was evaluated by the Medical Outcomes Study Scale (Rand SF-36 questionnaire) (Ware and Sherbourne, 1992). The physical function scale included 10 items measuring whether health limits physical function in moderate/vigorous activity (2 items); strength to lift, carry, stoop, bend, stair climb (4 items); ability to walk various distances without difficulty (3 items); and self-care (1 item). The scale was scored from 0 to 100. Higher scores indicate better function.

### 2.3. Body composition

Body mass index (BMI) was calculated as weight (kg) / height (m)$^2$. Height was measured on a wall-mounted stadiometer to the nearest 0.1 cm, and weight was measured on a balance-beam scale to the nearest 0.1 kg. Waist circumference was measured at the narrowest part of the torso over non-binding undergarments to the nearest 0.5 cm using an anthropometric tape. All anthropometric measures were conducted by study staff according to standard anthropometric measurement training (The Women's Health Initiative Study Group, 1998). Body composition, including whole body and regional bone mineral density, lean mass, and fat mass, was measured by dual energy X-ray absorptiometry (DXA; QDR2000, 2000+, or 4500W; Hologic Inc., Bedford, MA). The DXA centers used a rigorous WHI quality assurance program that has been previously published (Chen et al., 2005). DXA measures of lean mass were validated against magnetic resonance imaging for the assessment of skeletal muscle mass in a subset (Chen et al., 2007). Appendicular skeletal muscle index (ASMI) was computed from lean mass in the arms and legs and height measurements [ASMI = appendicular lean mass (kg) / height (m)$^2$].

### 2.4. Assessment of covariates

Self-report questionnaires at baseline were used to obtain information on demographics, medical history (e.g. hypertension, arthritis, disabled/currently unable to work), smoking status, and prior hormone therapy use. Diet was assessed by a validated food frequency questionnaire (FFQ) (Block et al., 1990). Protein intake (g/kg body weight) from the FFQ was adjusted based on equations developed in the WHI Nutritional Biomarkers Study (N = 544) which used doubly labeled water for energy and urinary nitrogen for protein, as well as BMI, age, race/ethnicity, and smoking status to better reflect true intake (Neuhouser et al., 2008). The Healthy Eating Index (HEI-2005) was computed from the FFQ (Guenther et al., 2008). Physical activity was assessed by a validated questionnaire, including frequency, intensity, and duration of activity (Eaglehouse et al., 2016; Johnson-Kozlow et al., 2007; Langer et al., 2003; Manson et al., 2002; Meyer et al., 2009; Nguyen et al., 2013). Energy expenditure (MET-hr/wk) was computed, as previously published (Ainsworth et al., 2000; Sims et al., 2012). Neighborhood socioeconomic status (NSES) was computed from 2000 census tract data (Dubowitz et al., 2012; Shih et al., 2011).

### 2.5. Statistical analyses

Baseline characteristics of participants were compared across quartiles of ASMI using analysis of variance (ANOVA) for continuous variables and chi-squared tests for categorical variables. Associations between each body composition variable at baseline (quartiles) and SF-36 physical function score at baseline (continuous) were estimated using linear regression. Potential confounders previously identified in the literature were included in the models: age, NSES, race/ethnicity, smoking status, physical activity, HEI-2005, protein intake, hormone therapy use, disability, history of hypertension and arthritis, and scanner serial number (Beasley et al., 2013; Fried et al., 2001). Further adjustment for medical history of emphysema, diabetes, or cancer did not significantly affect the models, so they were not included in the final models. Similar linear regression models, with further adjustment for baseline SF-36, were used to test associations between each body composition variable at baseline and change in SF-36 between baseline and year 3. Tests for trend were conducted by treating each body composition as a continuous variable. In additional models, change in each body composition measure between baseline and year 3 was categorized into three groups: decreased $\geq$5%, no change (change < 5% in either direction), and increased $\geq$5%. These categories were regressed on change in physical function scores over 3 years, with “no change” as the reference group. Potential interactions between each body composition measure and age (< versus $\geq$65 y) on SF-36 were tested using likelihood ratio tests. Due to significant interactions between age and body composition on physical function change for several of the measures tested, these models were subsequently stratified by age. Similar tests for potential interactions with race/ethnicity in the groups with sufficient power (non-Hispanic white versus black) were also explored, but no significant results were found (data not shown). Likewise, no significant interactions with physical activity were detected (data not shown). All statistical analyses were conducted using Stata 15.1 (StataCorp, College Station, TX).

## 3. Results

Of the 4526 postmenopausal women included in the WHI Observational Study that completed body composition assessments twice, the women were on average 63.4 ± 7.4 years of age, primarily non-Hispanic white (81.5%), and non-smokers (92.7%), with a mean BMI of 27.4 ± 5.8 kg/m$^2$, waist circumference of 83.7 ± 13.3 cm, and physical activity of 12.9 ± 14.6 MET-hr/wk. Hormone therapy was currently used in 42.1% of participants. Physical function scores were wide ranging, encompassing the full scale of 0–100, and strongly left-skewed at baseline; the mean score was 80 ± 20 (median = 85). Total lean mass averaged 54.2 ± 7.2% of body weight, while total fat mass averaged 42.8 ± 7.4% of body weight overall. ASMI was relatively normally distributed; the mean was 5.5 ± 1.0 kg/m$^2$ (median 5.4 kg/m$^2$). ASMI ranged from 3.29 to 10.7 kg/m$^2$. Table 1 shows baseline characteristics of the WHI subset by quartiles of ASMI. Women in the highest quartile of ASMI were younger, with lower NSES and diet (HEI-2005) scores. Women in the highest quartile of ASMI were also more

**Table 1**
Baseline characteristics by quartiles of appendicular skeletal muscle index (kg/m$^2$): mean ± SD or *n* (%) in Women's Health Initiative Observational Study in Pittsburgh, PA; Birmingham, AL; and Tucson-Phoenix, AZ, 1993–1998.

| Characteristic | Total (*n* = 4526) | Quartile 1 < 4.9 (*n* = 1132) | Quartile 2 4.9–5.3 (*n* = 1131) | Quartile 3 5.4–5.9 (*n* = 1132) | Quartile 4 ≥6.0 (*n* = 1131) | p |
|---|---|---|---|---|---|---|
| Age (y) | 63.4 ± 7.4 | 64.1 ± 7.1 | 64.0 ± 7.5 | 63.4 ± 7.3 | 62.2 ± 7.3 | < 0.001 |
| NSES | 72.6 ± 9.0 | 73.9 ± 7.7 | 74.0 ± 8.0 | 72.6 ± 9.0 | 69.7 ± 10.4 | < 0.001 |
| Race/ethnicity | | | | | | < 0.001 |
| Non-Hispanic white | 3687 (81.5) | 1016 (89.8) | 979 (86.6) | 943 (83.3) | 749 (66.2) | |
| Black | 506 (11.2) | 38 (3.4) | 63 (5.6) | 106 (9.4) | 299 (26.4) | |
| Other or unknown | 333 (7.4) | 78 (6.9) | 89 (7.9) | 83 (7.3) | 83 (7.3) | |
| Smoking status | | | | | | 0.038 |
| Never | 2447 (54.7) | 653 (58.1) | 610 (54.9) | 595 (53.1) | 589 (52.5) | |
| Former | 1703 (38.1) | 387 (34.4) | 411 (37.0) | 447 (39.9) | 458 (40.9) | |
| Current | 326 (7.3) | 84 (7.5) | 90 (8.1) | 78 (7.0) | 74 (6.6) | |
| Physical activity (MET-hr/wk) | 12.9 ± 14.6 | 12.3 ± 13.0 | 14.1 ± 14.7 | 14.4 ± 16.3 | 11.0 ± 14.0 | < 0.001 |
| Body size | | | | | | |
| Weight (kg) | 71.6 ± 15.5 | 61.2 ± 9.5 | 66.2 ± 9.8 | 71.5 ± 11.0 | 87.4 ± 16.3 | < 0.001 |
| Height (cm) | 162 ± 6.3 | 162 ± 6.2 | 162 ± 6.2 | 162 ± 6.0 | 161 ± 6.8 | 0.164 |
| Waist (cm) | 83.7 ± 13.3 | 75.0 ± 8.3 | 79.3 ± 9.4 | 83.8 ± 10.5 | 87.4 ± 16.3 | < 0.001 |
| BMI (kg/m$^2$) | 27.4 ± 5.8 | 23.4 ± 3.5 | 25.3 ± 3.4 | 27.2 ± 3.9 | 33.6 ± 6.1 | < 0.001 |
| Body composition | | | | | | |
| Appendicular lean mass (kg) | 14.5 ± 2.7 | 11.8 ± 1.1 | 13.4 ± 1.1 | 14.9 ± 1.2 | 17.8 ± 2.2 | < 0.001 |
| Lean mass (kg) | 37.3 ± 5.2 | 32.6 ± 2.8 | 35.4 ± 2.9 | 38.0 ± 3.1 | 43.1 ± 4.6 | < 0.001 |
| Fat mass (kg) | 30.9 ± 11.2 | 25.3 ± 7.0 | 27.5 ± 8.4 | 30.1 ± 9.3 | 40.6 ± 12.6 | < 0.001 |
| Hormone therapy use | | | | | | < 0.001 |
| Never | 1939 (42.9) | 398 (35.2) | 443 (39.2) | 493 (43.6) | 605 (53.5) | |
| Former | 679 (15.0) | 157 (13.9) | 168 (14.9) | 192 (17.0) | 162 (14.3) | |
| Current | 1906 (42.1) | 576 (50.9) | 520 (46.0) | 446 (39.4) | 364 (32.2) | |
| Calibrated protein (g/kg body weight) | 1.07 ± 0.2 | 1.15 ± 0.2 | 1.11 ± 0.2 | 1.07 ± 0.2 | 0.93 ± 0.2 | < 0.001 |
| HEI-2005 | 68.5 ± 10.8 | 69.3 ± 10.4 | 69.7 ± 10.4 | 68.7 ± 10.6 | 66.4 ± 11.5 | 0.002 |
| Diabetes | 209 (4.62) | 12 (1.06) | 21 (1.86) | 47 (4.16) | 129 (11.4) | < 0.001 |
| Disability | 123 (3.20) | 21 (2.13) | 23 (2.35) | 21 (2.22) | 58 (6.18) | < 0.001 |
| Arthritis | 2297 (51.1) | 530 (47.3) | 547 (48.7) | 588 (52.4) | 632 (56.1) | < 0.001 |
| Hypertension | | | | | | < 0.001 |
| Never | 2899 (66.1) | 815 (73.8) | 790 (72.0) | 731 (66.7) | 563 (51.8) | |
| Untreated | 340 (7.75) | 84 (7.60) | 73 (6.65) | 70 (6.39) | 113 (10.4) | |
| Treated | 1147 (26.2) | 206 (18.6) | 235 (21.4) | 295 (26.9) | 411 (37.8) | |

NSES, neighborhood socioeconomic status; HEI, Healthy Eating Index.
Missing data: NSES, 81 (2%); smoking, 50 (1%); physical activity, 45 (1%); waist circumference, 6 (< 1%); HRT 2, (< 1%); calibrated protein, 357 (8%); HEI-2005, 181 (4%); diabetes, 4 (< 1%); disability, 679 (15%); arthritis, 34 (< 1%); hypertension, 140 (3%).

likely to be Black, less physically active, and never-users of hormone therapy. BMI and waist circumference were approximately 10 kg/m$^2$ and 10 cm greater, respectively, among those in the highest quartile of ASMI compared to the lowest quartile. Lean and fat masses (kg) also increased across quartiles of ASMI.

At baseline, higher relative total lean mass and appendicular lean mass (%) were generally associated with higher physical function scores ($p < 0.05$) across models (approximately 9 points). However, higher absolute total and appendicular lean mass (kg and kg/m$^2$) were associated with slightly lower physical function scores (Model 3; all $p_{trend} < 0.01$). Conversely, higher fat (% and kg) and higher BMI were associated with lower physical function scores by SF-36 ($p_{trend} < 0.001$; Table 2). Physical function scores were 9–17 points lower across models, for women in the highest quartile of fat (kg or %) compared to the lowest quartile ($p < 0.05$). Similarly, women in the overweight, obese class I, and ≥obese class II categories (BMI 25–29.9, 30–34.9, ≥35 kg/m$^2$, respectively) demonstrated lower physical function scores compared to normal-weight women (BMI < 25 kg/m$^2$; $p < 0.05$). For example, in the fully adjusted model, participants in the obese class II category had an average physical function score of 69.4 ± 1.1 versus 83.4 ± 0.5 among those in the normal weight group (< 25 kg/m$^2$). When measures of lean and fat mass were included in the same model (mutual adjustment), higher fat (kg) remained significantly associated with lower physical function scores (Model 4 $p_{trend} < 0.001$); however, total and appendicular lean mass (kg and kg/m$^2$) were no longer associated with function.

Physical function decreased across the cohort over the three year period. Those with the lowest relative lean mass (% appendicular and total) and highest fat mass (% and kg) at baseline lost the most physical function over 3 years ($p_{trend} < 0.001$; Table 3). For example, total lean mass (%) quartile 1 at baseline lost 7.0 ± 0.6 points over three years, while quartile 4 lost only 3.3 ± 0.6 points. High baseline BMI was also associated with greater loss in reported physical function; the difference in function between normal weight and ≥obese class II was approximately 8 points ($p_{trend} < 0.001$). There were no significant interactions between any composition measure and race/ethnicity (NHW versus black), nor physical activity, on SF-36 at baseline or year 3 (data not presented).

An increase in lean mass (≥5%) from baseline to year 3 was not associated with better preservation of physical function (increased lean compared to no change: $p > 0.05$; $p_{trend} = 0.979$). Conversely, an increase in total body fat mass (≥5%) from baseline to year 3 was significantly associated with greater decline in physical function scores over 3 years (Table 4, increased fat compared to no change: $p < 0.05$; $p_{trend} < 0.001$). Of note, many more women increased fat mass (N = 1827; 40.4%) than increased lean mass (N = 379; 8.4%) over the 3 years.

There were no significant interactions between any body composition measure and age (< versus ≥65 y) on physical function at baseline (all $p > 0.1$), but several interactions were significant for change in physical function between baseline and year 3. When these models were stratified by age (Table 5), associations between body composition and change in physical function score were limited to the younger group, except for fat mass (kg). Higher fat (kg) was associated with

**Table 2**
Mean (SE) predicted baseline SF-36 Physical Functioning Score by quartile of each baseline body composition measure using multivariate linear regression in Women's Health Initiative Observational Study in Pittsburgh, PA; Birmingham, AL; and Tucson-Phoenix, AZ, 1993–1998.

| Body composition measure | Category | Model 1[a] | Model 2[b] | Model 3[c] | Model 4[d] |
|---|---|---|---|---|---|
| Appendicular skeletal muscle index (kg/m$^2$) | Q1 (3.2–4.8) | 82.4 (0.6) | 83.0 (0.6) | 80.2 (0.6) | 79.4 (0.6) |
| | Q2 (4.9–5.3) | 82.9 (0.6) | 82.8 (0.6) | 81.4 (0.6) | 80.9 (0.6) |
| | Q3 (5.4–6.0) | 80.4 (0.6)* | 80.4 (0.6)* | 80.2 (0.6) | 79.9 (0.6) |
| | Q4 (6.1–10.7) | 73.5 (0.6)* | 74.6 (0.6)* | 77.6 (0.6)* | 79.3 (0.7) |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | 0.083 |
| Appendicular lean mass (kg) | Q1 (7.8–12.5) | 82.2 (0.6) | 82.6 (0.6) | 79.8 (0.6) | 79.2 (0.6) |
| | Q2 (12.6–14.1) | 82.2 (0.6) | 82.2 (0.6) | 80.3 (0.6) | 79.8 (0.6) |
| | Q3 (14.2–15.9) | 81.0 (0.6) | 81.2 (0.6) | 81.1 (0.6) | 80.8 (0.6) |
| | Q4 (16.0–28.6) | 73.9 (0.6)* | 74.8 (0.6)* | 78.2 (0.7) | 79.8 (0.7) |
| | Test for trend | < 0.001 | < 0.001 | 0.004 | 0.996 |
| Appendicular lean mass (%) | Q1 (27.7–42.0) | 72.1 (0.6) | 73.7 (0.6) | 75.6 (0.6) | |
| | Q2 (41.1–46.6) | 79.0 (0.6)* | 79.5 (0.6)* | 79.9 (0.6)* | |
| | Q3 (46.7–51.1) | 82.7 (0.6)* | 82.9 (0.6)* | 81.3 (0.6)* | |
| | Q4 (51.2–87.8) | 85.5 (0.6)* | 84.8 (0.6)* | 82.5 (0.6)* | |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | |
| Lean mass (kg) | Q1 (23.0–33.5) | 82.3 (0.6) | 82.6 (0.6) | 79.9 (0.6) | 79.0 (0.6) |
| | Q2 (33.6–36.6) | 81.9 (0.6) | 82.3 (0.6) | 80.8 (0.6) | 80.4 (0.6) |
| | Q3 (36.7–40.3) | 81.4 (0.6) | 81.2 (0.6) | 80.7 (0.6) | 80.8 (0.6)* |
| | Q4 (40.4–59.9) | 73.7 (0.6)* | 74.7 (0.6)* | 77.8 (0.7)* | 79.2 (0.7) |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | 0.971 |
| Lean mass (%) | Q1 (34.9–49.2) | 70.3 (0.6) | 72.1 (0.6) | 74.6 (0.7) | |
| | Q2 (49.3–53.8) | 78.6 (0.6)* | 79.3 (0.6)* | 79.3 (0.6)* | |
| | Q3 (53.9–58.5) | 83.3 (0.6)* | 83.3 (0.6)* | 81.8 (0.6)* | |
| | Q4 (58.6–89.2) | 87.1 (0.6)* | 86.3 (0.6)* | 83.6 (0.6)* | |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | |
| Fat mass (kg) | Q1 (25.1–22.9) | 87.3 (0.6) | 86.2 (0.6) | 84.1 (0.7) | 84.2 (0.7) |
| | Q2 (23.0–29.1) | 83.4 (0.6)* | 83.3 (0.6)* | 82.0 (0.6)* | 82.0 (0.6)* |
| | Q3 (29.2–36.8) | 79.0 (0.6)* | 79.9 (0.6)* | 79.5 (0.6)* | 79.4 (0.6)* |
| | Q4 (36.9–81.1) | 69.5 (0.6)* | 71.1 (0.6)* | 73.6 (0.7)* | 73.7 (0.7)* |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Fat mass (%) | Q1 (7.2–38.2) | 87.1 (0.6) | 86.3 (0.6) | 83.7 (0.6) | |
| | Q2 (38.3–43.1) | 83.4 (0.6)* | 83.3 (0.6)* | 81.9 (0.6)* | |
| | Q3 (43.2–47.9) | 78.4 (0.6)* | 79.2 (0.6)* | 79.2 (0.6)* | |
| | Q4 (48.0–63.0) | 70.4 (0.6)* | 72.1 (0.6)* | 74.5 (0.7)* | |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | |
| BMI (kg/m$^2$) | < 25 | 85.9 (0.4) | 85.4 (0.4) | 83.4 (0.5) | |
| | 25–29.9 | 80.0 (0.5)* | 80.6 (0.5)* | 80.2 (0.5)* | |
| | 30–34.9 | 74.1 (0.7)* | 74.9 (0.7)* | 76.5 (0.8)* | |
| | ≥35 | 63.5 (0.9)* | 65.8 (0.9)* | 69.4 (1.1)* | |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | |

Abbreviations: Q, quartile; BMI, body mass index.
[a] Adjusted for age, race/ethnicity, and scanner serial number.
[b] Further adjusted for NSES, smoking, physical activity, hormone therapy use, and HEI-2005.
[c] Further adjusted for calibrated protein intake (g/kg body weight), disability, history of hypertension, and history of arthritis.
[d] For appendicular lean mass (kg and kg/m$^2$), Model 4 is further adjusted for appendicular fat mass (kg). For lean mass (kg) and fat mass (kg), Model 4 is mutually adjusted (i.e. same model).
* Significantly different from quartile 1 or, for BMI, < 25 kg/m$^2$ ($p < 0.05$).

lower physical function scores in both age groups (both $p_{trend} < 0.05$), though the difference between quartiles 1 and 4 was larger for the younger group. The aforementioned trend between higher BMI and lower physical function score remained only among women < 65 y, though the difference between normal weight and ≥obese class II for those ≥65 y was significant ($p < 0.05$), with lower physical function score among those ≥obese class II.

## 4. Discussion

In our cross-sectional analysis in postmenopausal women, we confirmed our hypothesis that lean mass (total and appendicular % lean mass) was positively associated with self-reported physical function and that fat mass (kg or %) was inversely associated with physical function. Given that a five-point difference on the SF-36 is considered to be clinically and socially relevant (Angst et al., 2001; Ware et al., 1993), the differences in physical function scores between the highest and lowest quartiles of both lean and fat in our sample were clinically meaningful, as well as statistically significant.

Overall, the cohort reported loss in physical function over three years, as expected for this age group. The measured decline in physical function was clinically meaningful for those with the lowest relative baseline lean mass and highest fat mass (%). Women with high relative lean mass and low fat mass at baseline experienced a lesser decline in physical function which was not yet clinically meaningful at three years. These results indicate a slower rate of decline in physical function for women beginning with more optimal body composition. The importance of this finding is underscored by prior WHI analysis indicating that change in SF-36-derived physical function is associated with future pre-clinical mobility disability (Laddu et al., 2017).

Based on the importance of lean mass to mobility and physical function, one might hypothesize that it (i.e. lean mass) would be the more important component of body composition related to physical function as we age. However, absolute lean mass models did not follow the same pattern noted for relative lean; i.e. higher lean (%) was associated with higher physical function score, but higher lean (kg) was not. The examination of change in body composition (≥5%) over 3 years to predict change in function further emphasized the need to

**Table 3**
Mean (SE) predicted change in SF-36 Physical Functioning Score between baseline and year 3 by quartile of each baseline body composition measure using multivariate linear regression in Women's Health Initiative Observational Study in Pittsburgh, PA; Birmingham, AL; and Tucson-Phoenix, AZ, 1993–1998.

| Body composition measure | Category | Model 1[a] | Model 2[b] | Model 3[c] | Model 4[d] |
|---|---|---|---|---|---|
| Appendicular skeletal muscle index (kg/m$^2$) | Q1 (3.2–4.8) | −3.1 (0.5) | −3.2 (0.5) | −4.2 (0.6) | −4.5 (0.6) |
| | Q2 (4.9–5.3) | −3.0 (0.5) | −3.1 (0.5) | −3.2 (0.5) | −3.3 (0.5) |
| | Q3 (5.4–6.0) | −3.6 (0.5) | −3.7 (0.5) | −3.3 (0.5) | −3.4 (0.5) |
| | Q4 (6.1–10.7) | −7.9 (0.5)* | −7.7 (0.5)* | −6.7 (0.6)* | −6.2 (0.6) |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | 0.002 |
| Appendicular lean mass (kg) | Q1 (7.8–12.5) | −3.5 (0.5) | −3.5 (0.5) | −4.8 (0.6) | −5.1 (0.6) |
| | Q2 (12.6–14.1) | −2.8 (0.5) | −2.9 (0.5) | −2.8 (0.5)* | −3.0 (0.5)* |
| | Q3 (14.2–15.9) | −4.2 (0.5) | −4.3 (0.5) | −4.2 (0.5) | −4.3 (0.5) |
| | Q4 (16.0–28.6) | −7.0 (0.5)* | −7.0 (0.5)* | −5.4 (0.6) | −4.8 (0.6) |
| | Test for trend | < 0.001 | < 0.001 | 0.001 | 0.039 |
| Appendicular lean mass (%) | Q1 (27.7–42.0) | −7.0 (0.5) | −6.5 (0.5) | −5.9 (0.6) | |
| | Q2 (41.1–46.6) | −3.9 (0.5)* | −3.8 (0.5)* | −3.8 (0.5)* | |
| | Q3 (46.7–51.1) | −3.9 (0.5)* | −4.1 (0.5)* | −4.0 (0.5)* | |
| | Q4 (51.2–87.8) | −2.7 (0.5)* | −3.1 (0.5)* | −3.5 (0.6)* | |
| | Test for trend | < 0.001 | < 0.001 | 0.040 | |
| Lean mass (kg) | Q1 (23.0–33.5) | −3.5 (0.5) | −3.3 (0.5) | −4.2 (0.6) | −4.5 (0.6) |
| | Q2 (33.6–36.6) | −2.9 (0.5) | −3.1 (0.5) | −3.2 (0.5) | −3.4 (0.5) |
| | Q3 (36.7–40.3) | −4.4 (0.5) | −4.4 (0.5) | −4.5 (0.5) | −4.5 (0.5) |
| | Q4 (40.4–59.9) | −6.8 (0.5)* | −6.9 (0.5)* | −5.4 (0.6) | −4.9 (0.6) |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | 0.058 |
| Lean mass (%) | Q1 (34.9–49.2) | −8.2 (0.5) | −7.8 (0.5) | −7.0 (0.6) | |
| | Q2 (49.3–53.8) | −4.2 (0.5)* | −4.1 (0.5)* | −4.0 (0.5)* | |
| | Q3 (53.9–58.5) | −3.0 (0.5)* | −3.2 (0.5)* | −3.1 (0.5)* | |
| | Q4 (58.6–89.2) | −2.1 (0.5)* | −2.6 (0.5)* | −3.3 (0.6)* | |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | |
| Fat mass (kg) | Q1 (25.1–22.9) | −1.6 (0.5) | −2.1 (0.5) | −2.7 (0.6) | −2.8 (0.6) |
| | Q2 (23.0–29.1) | −3.1 (0.5)* | −3.2 (0.5) | −3.4 (0.5) | −3.5 (0.5) |
| | Q3 (29.2–36.8) | −4.4 (0.5)* | −4.3 (0.5)* | −4.3 (0.5) | −4.4 (0.5) |
| | Q4 (36.9–81.1) | −8.4 (0.5)* | −8.1 (0.5)* | −3.9 (0.7)* | −6.7 (0.7)* |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Fat mass (%) | Q1 (7.2–38.2) | −1.9 (0.5) | −2.5 (0.5) | −3.1 (0.6) | |
| | Q2 (38.3–43.1) | −3.1 (0.5) | −3.2 (0.5) | −3.1 (0.5) | |
| | Q3 (43.2–47.9) | −4.5 (0.5)* | −4.4 (0.5)* | −4.4 (0.5) | |
| | Q4 (48.0–63.0) | −8.0 (0.5)* | −7.5 (0.5)* | −6.7 (0.6)* | |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | |
| BMI (kg/m$^2$) | < 25 | −2.0 (0.4) | −2.1 (0.4) | −2.4 (0.5) | |
| | 25–29.9 | −4.3 (0.4)* | −4.5 (0.4)* | −4.5 (0.5)* | |
| | 30–34.9 | −5.7 (0.6)* | −5.6 (0.6)* | −4.8 (0.7)* | |
| | ≥35 | −12.3 (0.8)* | −11.6 (0.8)* | −10.9 (1.0)* | |
| | Test for trend | < 0.001 | < 0.001 | < 0.001 | |

Abbreviations: Q, quartile; BMI, body mass index.
[a] Adjusted for baseline physical function score, age, race/ethnicity, and scanner serial number.
[b] Further adjusted for NSES, smoking, physical activity, hormone therapy use, and HEI-2005.
[c] Further adjusted for calibrated protein intake (g/kg body weight), disability, history of hypertension, and history of arthritis.
[d] For appendicular lean mass (kg and kg/m$^2$), Model 4 is further adjusted for appendicular fat mass (kg). For lean mass (kg) and fat mass (kg), Model 4 is mutually adjusted (i.e. same model).
* Significantly different from quartile 1 or, for BMI, < 25 kg/m$^2$ ($p < 0.05$).

consider adiposity when predicting physical function decline, as increased body fat was significantly associated with decreased physical function over 3 years, while lean mass change was not.

These findings align with the Health ABC study, for women aged 70–79 at baseline, in which lean mass alone (ASMI, kg/ht$^2$) was not associated with reduced physical function, measured by a Short Physical Performance Battery protocol. In contrast, the residual method for quantifying sarcopenia, which accounts for fat, was significantly associated with lower physical performance scores in Health ABC (Delmonico et al., 2007; Newman et al., 2003). The tighter range of lean mass, compared to fat mass, in the present study may partially explain the lack of consistent association between physical function and lean mass. Nevertheless, at a minimum, the data suggest that fat is an important consideration when assessing physical function among postmenopausal women, especially when evaluating mass alone (and not quality of the tissue) in body composition analyses. Longer follow-up may improve our ability to detect larger changes in lean mass and associated changes in physical function.

Much work has been done in recent years to suggest that lean mass measurements alone are not sufficient and that a measure of muscle quality is needed (typically strength) in combination with lean mass to determine muscle health (Chen et al., 2014; Cruz-Jentoft et al., 2010; Fielding et al., 2011). The impetus for concensus around international standards for defining and tracking muscle health (i.e. sarcopenia) has been its association with functional decline and sequelae, including morbidity, mortality, quality of life, and health care costs (Cruz-Jentoft et al., 2010; Fielding et al., 2011). Indeed, the International Working Group on Sarcopenia (IWGS) and the European Working Group on Sarcopenia included lean mass and quality measures in their definitions of sarcopenia (Cruz-Jentoft et al., 2010; Fielding et al., 2011), while the Foundation for the National Institutes Sarcopenia Project included both fat and muscle quality in their definition (Studenski et al., 2014). Interestingly, the association between functional outcomes, such as falls and fractures, and the current standardized definitions of sarcopenia have varied (Clynes et al., 2015). Therefore, a better understanding of how body composition, mass and quality, contributes to functional decline is still needed.

It is possible that excess adiposity-associated inflammatory factors

**Table 4**
Mean (SE) predicted change in SF-36 Physical Functioning Score between baseline and year 3 by change between baseline and year 3 in each body composition, using multivariate linear regression in Women's Health Initiative Observational Study in Pittsburgh, PA; Birmingham, AL; and Tucson-Phoenix, AZ, 1993–1998.

| Body composition measure | Category | Predicted change[a] |
|---|---|---|
| Lean mass (kg) | Decrease ≥5% | −5.1 (0.3) |
| | No change (ref.) | −4.0 (0.7) |
| | Increase ≥5% | −5.5 (0.9) |
| | Test for trend | 0.979 |
| Fat mass (kg) | Decrease ≥5% | −2.6 (0.6) |
| | No change (ref.) | −3.5 (0.4) |
| | Increase ≥5% | −5.9 (0.4)* |
| | Test for trend | < 0.001 |

[a] Adjusted for baseline physical function score, age, race/ethnicity, scanner serial number, baseline body composition measure, NSES, smoking, physical activity, hormone therapy use, HEI-2005, adjusted for calibrated protein intake (g/kg body weight), disability, history of hypertension, and history of arthritis; additionally, lean mass (kg) and fat mass (kg) were mutually adjusted (i.e. same model).
* Significantly different from no change ($p < 0.05$).

may be contributing to deleterious effects on skeletal muscle quality (Cesari et al., 2005; Murton, 2015; Visser et al., 2002b), such that including fat mass in models may be partially accounting for muscle quality differences that would otherwise be reflected in measures such as strength or performance. Few women within the WHI DXA cohort underwent the SPPB tests to be able to analyze lean mass and muscle quality simultaneously. One must carefully consider, however, whether it is valid to include function in the definition of sarcopenia when predicting risk of functional decline (Dawson-Hughes and Bischoff-Ferrari, 2016); though, when predicting other outcomes, such as falls and fractures, inclusion of both muscle mass and function measures may be more robust. Detailed muscle characteristics, such as fatty infiltration, that may impact muscle quality and strength could be informative in future studies but were not possible here with DXA alone.

Of note, weight status, based on BMI, was negatively associated with physical function in the present analysis, such that those with a BMI ≥35 had significantly lower physical function scores at baseline and greater losses in physical function after three years. These findings align with that of Kuczmarski et al. where older overweight and obese adults demonstrated poorer physical function (Kuczmarski et al., 2010). One may posit that larger individuals self-limit activity, potentially due to the difficulty of movement with excess weight, which may influence the perception of physical function, though relevant data to confirm this assertion were not available.

Upon stratification, the relationships between body composition and BMI were stronger among those < 65 y of age, though the older age group demonstrated lower scores overall. A previous WHI study similarly showed that frailty, which includes the physical function score used herein, was associated with weight status (Woods et al., 2005), though body composition was not investigated in that analysis. Due to inclusion criteria for the SPPB substudy of age ≥65 y, we were unable to compare age-stratified results. However, others have shown that validity of the SF-36 is non-inferior to objective measures of physical performance in older adults (Latham et al., 2008).

Several other factors, besides body composition and BMI, have been associated with physical function measured by either the SPPB or questionnaire in the WHI. Chronic conditions (Gray et al., 2016; Stefanick et al., 2016; Weaver et al., 2016), multimorbidity (Rillamas-Sun et al., 2016), and pain (Patel et al., 2016) have been negatively correlated with physical function. Calcium/vitamin D (Brunner et al., 2008) and hormone therapy (Michael et al., 2010) were not. Importantly, modifiable risk factors such as sedentary time (inverse) (Seguin et al., 2012), physical activity (Laddu et al., 2017), and protein

**Table 5**
Mean (SE)[a] predicted change in SF-36 Physical Functioning Score between baseline and year 3 by quartile of each baseline body composition measure, stratified by baseline age in Women's Health Initiative Observational Study in Pittsburgh, PA; Birmingham, AL; and Tucson-Phoenix, AZ, 1993–1998.

| Body composition measure | Category | Age < 65 y (N = 1723) | Age ≥ 65 y (N = 1554) | $P_{interaction}$ |
|---|---|---|---|---|
| Appendicular skeletal muscle index (kg/m$^2$) | | | | 0.040 |
| | Q1 (3.2–4.8) | −3.8 (0.8) | −5.5 (0.8) | |
| | Q2 (4.9–5.3) | −2.0 (0.7) | −4.7 (0.8) | |
| | Q3 (5.4–6.0) | −2.1 (0.7) | −4.7 (0.8) | |
| | Q4 (6.1–10.7) | −6.0 (0.8) | −5.9 (1.0) | |
| | Test for trend | 0.002 | 0.492 | |
| Appendicular lean mass (kg) | | | | 0.001 |
| | Q1 (7.8–12.5) | −3.9 (0.9) | −6.3 (0.8) | |
| | Q2 (12.6–14.1) | −1.9 (0.8) | −4.3 (0.8) | |
| | Q3 (14.2–15.9) | −2.7 (0.7) | −6.0 (0.8) | |
| | Q4 (16.0–28.6) | −5.4 (0.8) | −3.4 (1.1)* | |
| | Test for trend | 0.005 | 0.800 | |
| Appendicular lean mass (%) | | | | 0.290 |
| | Q1 (27.7–42.0) | −5.3 (0.8) | −6.9 (0.8) | |
| | Q2 (41.1–46.6) | −3.8 (0.7) | −3.6 (0.8)* | |
| | Q3 (46.7–51.1) | −3.1 (0.7)* | −5.2 (0.8) | |
| | Q4 (51.2–87.8) | −2.0 (0.8)* | −5.1 (0.8) | |
| | Test for trend | 0.024 | 0.361 | |
| Lean mass (kg) | | | | 0.017 |
| | Q1 (23.0–33.5) | −3.6 (0.9) | −5.5 (0.8) | |
| | Q2 (33.6–36.6) | −1.9 (0.8) | −4.8 (0.8) | |
| | Q3 (36.7–40.3) | −3.3 (0.7) | −5.8 (0.8) | |
| | Q4 (40.4–59.9) | −5.0 (0.8) | −4.3 (1.0) | |
| | Test for trend | 0.004 | 0.632 | |
| Lean mass (%) | | | | 0.510 |
| | Q1 (34.9–49.2) | −7.1 (0.8) | −7.1 (0.9) | |
| | Q2 (49.3–53.8) | −3.2 (0.7)* | −4.7 (0.8)* | |
| | Q3 (53.9–58.5) | −2.3 (0.7)* | −4.0 (0.8)* | |
| | Q4 (58.6–89.2) | −1.7 (0.8)* | −5.0 (0.9) | |
| | Test for trend | < 0.001 | 0.125 | |
| Fat mass (kg) | | | | 0.021 |
| | Q1 (25.1–22.9) | −1.4 (0.9) | −4.2 (0.9) | |
| | Q2 (23.0–29.1) | −2.8 (0.7) | −4.3 (0.8) | |
| | Q3 (29.2–36.8) | −2.5 (0.7) | −6.1 (0.8) | |
| | Q4 (36.9–81.1) | −7.0 (0.9)* | −6.3 (1.1) | |
| | Test for trend | 0.001 | 0.030 | |
| Fat mass (%) | | | | 0.377 |
| | Q1 (7.2–38.2) | −1.5 (0.8) | −4.9 (0.9) | |
| | Q2 (38.3–43.1) | −2.6 (0.7) | −3.7 (0.8) | |
| | Q3 (43.2–47.9) | −3.4 (0.7) | −5.2 (0.8) | |
| | Q4 (48.0–63.0) | −6.9 (0.8)* | −6.9 (0.9) | |
| | Test for trend | < 0.001 | 0.090 | |
| BMI (kg/m$^2$) | | | | 0.044 |
| | < 25 | −1.0 (0.7) | −4.1 (0.7) | |
| | 25–29.9 | −3.4 (0.6)* | −5.7 (0.7) | |
| | 30–34.9 | −4.0 (1.0)* | −5.8 (1.1) | |
| | ≥35 | −12.4 (1.2)* | −7.9 (1.6)* | |
| | Test for trend | < 0.001 | 0.075 | |

Abbreviations: Q, quartile; BMI, body mass index.
[a] Adjusted for baseline physical function score, age, race/ethnicity, scanner serial number, NSES, smoking, physical activity, hormone therapy use, HEI-2005, calibrated protein intake (g/kg body weight), disability, history of hypertension, and history of arthritis. For appendicular lean mass (kg and kg/m$^2$), models are further adjusted for appendicular fat mass (kg). For lean mass (kg) and fat mass (kg), measures are mutually adjusted (i.e. same model).
* Significantly different from quartile 1 or, for BMI, < 25 kg/m$^2$ ($p < 0.05$).

intake (Beasley et al., 2013) have been associated with physical function in this cohort, including over the long-term. Therefore, decreased sedentary time and increased physical activity, including adequate fall-prevention measures (Bea et al., 2017), should be promoted among postmenopausal women regardless of body habitus measures, as well as sufficient protein intake.

### 4.1. Strengths and limitations

Whether the results of these analyses can be generalized beyond postmenopausal women is unknown. Though this study relies on the subjective assessment of self-reported physical function from the SF-36 subscale, the subscale is widely used and clinically meaningful. The large sample size in this study is a strength, as is the detailed characterization of the population allowing for statistical adjustment for several factors considered to be associated with physical function in the literature. However, statistical adjustment cannot fully overcome the limitation of observational study in terms of understanding causal relations. The field will be advanced by randomized controlled trials of functional interventions. Detailed body composition and functional measurements, as well as sufficient follow-up to assess meaningful long-term changes in physical function across the menopausal years, are needed to fully characterize the contributions of tissue type and quality in future interventions.

### 4.2. Conclusion

Body composition is associated with self-reported physical function both cross-sectionally and longitudinally. Though lean mass (%) was associated with higher physical function, the consistent associations between fat mass and BMI with poorer physical function among postmenopausal women indicate the need to evaluate overall body habitus when predicting risk, especially in the absence of measures of muscle quality.

## Conflicts of interest

None.

## Acknowledgments

The WHI programs is funded by the National Heart, Lung, and Blood Institute, National Institutes of Health, U.S. Department of Health and Human Services through contracts, HHSN268201600018C, HHSN268201600001C, HHSN268201600002C, HHSN268201600003C, and HHSN268201600004C.

We are thankful for the contribution of the WHI Investigators and staff at the clinical centers, clinical coordinating center, and project office.

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