Sarcopenia Is Related to Physical Functioning and Leg Strength in Middle-Aged Women

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Background. In the aging process, loss of muscle is relatively continuous, but the initiation, timing, and amount of muscle loss that relate to functional compromise are poorly described. Also poorly understood is whether strength and functioning in aging are related to the amount of lean mass and its change as well as to the amount of fat mass and its change.

Methods. The purpose of the study was to ascertain whether 3-year lean and fat mass change predicted functional status in 712 African American and Caucasian women, aged 34–58 years. Fat and lean mass were assessed with bioelectrical impedance. Lower leg strength (torque) was measured with a portable isometric chair, and two indices of physical functioning, walking velocity and double support (both feet touching the surface while walking), were measured with an instrumented gait mat.

Results. Almost 9% of middle-aged women had at least a 6% loss (>2.5 kg) of lean mass over the 3-year observation period. Women who lost at least 2.5 kg of lean mass had slower walking velocity and less leg strength, although women who simultaneously gained more than 2.5 kg of fat mass (at least 7.5%) did not have less leg strength. Age was significantly associated with less velocity, less leg strength, and more time in double support.

Conclusions. Even in middle-aged women, there is loss of lean mass among almost 1 woman in 10, and this loss of lean mass (sarcopenia) is associated with greater compromise in physical functioning.

NORMAL aging is associated with a 2%–3% decline in muscle mass among older men and women, loss of muscle protein stores, and relative increases in body fat (1,2), even among those who continue to actively engage in training (3). However, at midlife, patterns of muscle mass loss can be masked by continued weight gain. Women experience an increase in weight until their mid 50s, with an earlier loss of muscle mass, followed by a subsequent loss of fat mass (4).

The loss of muscle mass in ill health or severe undernutrition is widely described as sarcopenia; however, this term is increasingly associated with the decline in muscle protein stores during aging (5–7). Sarcopenia is important because a loss of more than 40% of muscle mass is associated with death, and muscle loss can contribute to diminished strength, functional limitation, and disability in either the elderly (8) or in those with chronic inflammatory conditions (9,10). As a consequence of muscle loss and accompanying weakness, there can be a reduction in physical activity and aerobic capacity. This inactivity can then reduce the anabolic input into muscle, leading to diminished fitness and more inactivity, reduction in physical functioning, and, in some, disability.

It is anticipated that, during the aging process, muscle loss is relatively continuous, but the initiation, timing, and amount of muscle loss that lead to functional decline are poorly described. Further, whether the compromise in strength and functioning is related only to the amount of muscle mass and its change or also to the amount of fat mass and its change is unclear. Of note, two studies (11,12) have indicated that a greater relative proportion of fat and a greater fat infiltration into muscle mass have attenuated knee extensor strength and walking speed, and some definitions of sarcopenia are linked to a current obese state labeled sarcopenic obesity (13).

This report identified the body composition (lean and fat mass) profile and its 3-year change among middle-aged women in a community-based setting, and related these profiles to measures of their leg strength and physical functioning.

METHODS

Study Population

Pre- and perimenopausal women from two longitudinal studies used a common protocol for the ascertainment of body composition and physical functioning (14). Measures of leg strength and gait were evaluated in 478 women from the Michigan Bone Health Study (MBHS) and 234 women from the Study of Women’s Health Across the Nation (SWAN) participating in the first 40 weeks of their 1999/2000 annual examinations. Participants provided written informed consent to procedures and interviews which had been approved by the University of Michigan Institutional Review Board.

The Michigan SWAN is a population-based longitudinal study, begun in 1996, of African-American and Caucasian women transitioning the midlife. Enrollees were identified from a household census of two suburban communities located within 35 miles of Detroit, Michigan. From household interviews, 2621 age-eligible women (40–55 years) were identified. From these, study personnel enrolled 325 African-American and 218 Caucasian women, aged...
42–52 years, who were still menstruating and not using hormone therapy for the longitudinal study. Loss to follow-up has been less than 20% after seven annual examinations. In 1996/1997, a study of body composition and physical functioning was implemented, and measures from computerized gait mats and kinematics were added in 1999.

The MBHS is a population-based longitudinal study of musculoskeletal disease development in pre- and perimenopausal Caucasian women (15). The 664-woman sample was identified from two sampling frames, the family records of the historical Tecumseh Community Health Study and a 1992 Tecumseh community census. More than 80% of age-eligible female offspring (aged 24–44 years) were recruited from the Tecumseh Community Health Study, and 90% of the age-eligible women were recruited from the community census. Loss to follow-up has been less than 15% after 10 annual examinations. Measures were simultaneously implemented in both the MBHS and the Michigan SWAN.

Measurements

Lower leg strength was measured with a portable isometric chair, which replicates the chair designed for the Dynamics of Health, Aging and Body Composition Study (11). Strength was measured as torque, the product of force and the torque arm length. Torque arm length is equal to the length measured between the lateral joint line of the knee and the transducer axis. Torque (Nm) was averaged following subtracting the fourth data value from the initial value. Analyses, body composition change was calculated by time or the body composition value of interest. In these regression analyses incorporated an exponential term for intervals (95% CI) for the partial correlation coefficients (19). To evaluate potential linear or curvilinear associations, regression analyses incorporated an exponential term for time or the body composition value of interest. In these analyses, body composition change was calculated by subtracting the fourth data value from the initial value.

Longitudinal analyses.—A regression calibration approach related the four consecutive annual measures of body composition to the single subsequent measures of physical functioning (20). SAS PROC MIXED with a REPEATED statement was used to fit regression models for each woman’s annual measures of body composition, yielding two new variables per woman, an intercept beta coefficient and a beta coefficient for the slope, which reflected the per-woman deviation from the population average change and accounted for the within-woman correlation of the body composition measures. These two variables, along with age, race, and interaction terms, were incorporated into multiple variable regression models to relate change in body composition to velocity or double support time. The probability of significant associations occurring by chance alone was expressed with $p$ values, based on two-sided tests, as well as 95% CI. Data management and data analyses were undertaken using SAS version 8.0 (SAS Institute, Cary, NC).

RESULTS

In this sample of 712 community-based women, of which 24% were African American, the mean baseline age was 44.4 years (standard deviation (SD) = 4.8). The mean BMI was 29.9 kg/m², and the mean percent body fat was 38.9% (see Table 1). The mean leg strength was 84.9 Nm (SD = 23.5), as compared to 81.5 Nm (SD = 22.0) for the 1319 African-American and Caucasian female Dynamics of Health, Aging and Body Composition Study enrollees, aged 70–79 years (7). As shown in Figure 1, more than 25% of

\[
\text{BMI} = \frac{\text{weight (kg)}}{\text{height (m)}^2}
\]

\[
\text{Waist-to-hip ratio} = \frac{\text{waist circumference (cm)}}{\text{hip circumference (cm)}}
\]

\[
\text{Waist circumference} = 22.0 	ext{ cm (} \pm 4.8\text{ cm)}
\]

\[
\text{Hip circumference} = 36.5 	ext{ cm (} \pm 7.8\text{ cm)}
\]

\[
\text{Waist-to-hip ratio} = 0.61 	ext{ (} \pm 0.07\text{)}
\]

\[
\text{Mean Nm} = 84.9 	ext{ Nm (} \pm 23.5\text{ Nm)}
\]

\[
\text{Mean percent body fat} = 38.9\%
\]
women had leg strength values less than 70 Nm, the cutpoint used by Ploutz-Snyder and colleagues (21) to define persons as functionally compromised. Women with less leg strength were, on average, 1 year older and 2 BMI units heavier than women with more leg strength. As shown in Figure 1, almost 9% of women lost more than 2.5 kg of lean mass (∼6% decrease) over the 3-year observation period, whereas 30% of women gained more than 2.5 kg of fat mass (∼7.5%).

Lean mass was positively and better correlated with leg strength (partial \( r = 0.33, 95\% \text{ CI: 0.27, 0.42} \)) than was fat mass (partial \( r = 0.17, 95\% \text{ CI: 0.10, 0.25} \)), cross-sectionally, after adjustment for age and race (Table 2). Fat mass, but not lean mass, was highly positively associated with double support time (partial \( r = 0.45, 95\% \text{ CI: 0.35, 0.54} \)) and with velocity (\( r = -0.25, 95\% \text{ CI: } -0.34, -0.15 \)), indicating slower walking speed among women with more fat mass.

Longitudinally, with each 1 kg higher lean mass at baseline, women had 1.1 Nm higher leg strength 3 years later (\( p < .0001, 95\% \text{ CI: 0.8, 1.3} \)), whereas women with an average 1 kg increase in lean mass over 3 years had 9.2 Nm higher leg strength (\( p = .0002, 95\% \text{ CI: 4.3, 14.1} \)). However, an interaction term indicated a more complex picture. Women who gained at least 2.5 kg of lean mass had higher levels of leg strength, irrespective of the amount of fat mass change, and women who lost more than 2.5 kg of lean mass had markedly lower leg strength levels (see Figure 2). Women who had lost at least 2.5 kg of lean mass were slightly older, had higher baseline weight, lost weight during the 3-year period, and compared to their peers, were less likely to report physical activity and more likely to report a disease diagnosis (see Table 3). Incongruously, the subgroup of women \(( n = 26) \) who lost at least 2.5 kg of lean mass but gained more than 2.5 kg of fat mass over the 3-year period did not have lower leg strength.

Longitudinally, with a 1 kg higher average lean mass level at baseline, women walked with 0.5 cm/s less speed (\( p < .004, 95\% \text{ CI: } -0.9, -0.2 \)) 3 years later, but if they experienced a 1 kg increase in lean mass, they walked with an 11 cm/s greater speed (\( p < .0002, 95\% \text{ CI: 4.2, 17.8} \)). In contrast, women with a 1 kg higher fat mass at baseline had a 0.5 cm/s slower velocity 3 years later (\( p < .0001, 95\% \text{ CI: } -0.7, -0.4 \)), whereas women with a 1 kg increase in fat mass over 3 years had a 2.4 cm/s lower velocity (\( p < .02, 95\% \text{ CI: } -4.3, -0.5 \)).

Women with a 1 kg higher fat mass at baseline had 0.13 cm/s greater speed in double support 3 years later (\( p < .0001, 95\% \text{ CI: 0.11, 0.15} \)). Women with a 1 kg increase in fat mass over 3 years had, on average, a 0.78 s increase in double support time (\( p < .0001, 95\% \text{ CI: 0.5, 1.0} \)).
Table 2. Partial Spearman Correlations of Concurrently-Measured Body Composition and Physical Functioning Measures at the Close of a 3-Year Observation Period, Adjusted for Age and Race

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Leg Strength, Nm (95% CI, p Value)</th>
<th>Velocity, cm/s (95% CI, p Value)</th>
<th>Double Support, s (95% CI, p Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight, kg</td>
<td>0.26 (0.18, 0.33), &lt;.0001</td>
<td>0.00 (0.00, 0.10), 0.0001</td>
<td>0.00 (0.00, 0.00), 0.0001</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>0.19 (0.12, 0.27), &lt;.0001</td>
<td>0.00 (0.00, 0.10), 0.0001</td>
<td>0.00 (0.00, 0.00), 0.0001</td>
</tr>
<tr>
<td>Lean body mass, excluding bone, kg</td>
<td>0.33 (0.27, 0.42), &lt;.0001</td>
<td>0.00 (0.00, 0.10), 0.0001</td>
<td>0.00 (0.00, 0.00), 0.0001</td>
</tr>
<tr>
<td>Fat body mass, kg</td>
<td>0.17 (0.10, 0.25), &lt;.0001</td>
<td>0.00 (0.00, 0.10), 0.0001</td>
<td>0.00 (0.00, 0.00), 0.0001</td>
</tr>
</tbody>
</table>

**DISCUSSION**

We identified three important relationships between physical functioning and body composition among women at midlife. First, a substantial number of women (almost 1 in 10) had lean mass loss, despite an average increase in weight. Second, lean mass and its change were strongly related to leg strength and less strongly related to gait speed. Third, the associations of lean and fat mass with measures of physical function were important after adjusting for age.

Studies of older men and women with low lean mass, estimated by dual energy X-ray densitometry, had more disability and use of assistive devices (22), and older well-functioning men (although not older women) with low muscle area had more compromised lower extremity performance (22). We have extended this work by demonstrating that: 1) the association of low lean mass and compromised physical functioning occurs in women; 2) associations are observable in middle-aged as well as in elderly persons; and 3) although lower lean mass was more likely to be associated with less leg strength, a loss of lean mass, measured over four time periods, affected both strength and speed of task performance. Similar patterns were seen in both African-American and Caucasian women.

Sarcopenia is a construct still being operationally defined. Two population-based studies (5,6) measured lean mass to characterize the frequency of sarcopenia in men and women. However, these studies did not identify whether muscle mass had been lost and, assuming that lean mass reduction is synonymous with muscle mass reduction, they did not provide an indication of the rate of change in muscle mass. We have shown that the rate of change is an important element in relation to both strength and task performance speed.

Earlier studies (7,23) have identified that high fat mass is associated with poor physical performance, and in some definitions of sarcopenia, the relative contribution of percent body fat is labeled sarcopenic-obesity (13). It remains to be determined whether fat in and around muscle may directly affect muscle contractility (cellular function), muscle fiber recruitment (nerve function), or muscle metabolism (energy utilization), thereby affecting muscle strength and physical functioning. It has been argued that higher fat mass is associated with lower physical functioning among elderly women because of its relationship with chronic diseases, including diabetes, or because women with greater impaired functioning are more likely to get fatter (23). We identified that women at midlife who lost more than 2.5 kg of lean mass were more likely to report concurrent illness as well as to have lower levels of functioning, but the interaction of lean loss and fat gain with respect to leg strength among women at midlife suggests that the relation of lean and fat (and their changes) is neither parallel nor linear. It will be important to determine whether this is just a function of middle age or if this interaction is also present in older women.

Although strength training in elderly women may decrease muscle strength attenuation (24,25), middle-aged women have not been the target of such intervention programs. Given the apparent impact in a relatively brief 3-year period, and an expected life expectancy of more than 80 years, it appears that a focus on retaining lean mass with strength training in middle-aged women may be more relevant than the current national focus on weight loss or a focus on nutritional interventions (26).

We did not directly characterize muscle mass, muscle fiber histology, or degree of fat infiltration within muscle (8,27,28). Our lean mass measure reflects the total body and is not limited to lean mass in the legs. Further, leg strength may not approximate strength in other muscle groups throughout the body. We do not yet have changes in the leg strength and gait over time which would be useful in determining whether change in body composition is a strong indicator of physical functioning at follow-up.

**Summary**

We have demonstrated the importance of both level and amount of change in lean mass relative to multiple measures of physical functioning. Further, the strong association with age and less physical functioning in these women suggest that targeting women in this age group for activities to maintain or increase lean mass might lead to a more positive health impact than just promoting weight loss alone.

**ACKNOWLEDGMENTS**

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Table 3. Characteristics at Baseline According to Amount of 3-Year Lean Mass Change

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Lost Lean Mass*</th>
<th>No Change</th>
<th>Gained Lean Mass\footnote{\textsuperscript{1}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>46.2 ± 0.63\textsuperscript{3}</td>
<td>44.4 ± 0.24</td>
<td>44.4 ± 0.33 \textsuperscript{\textit{.02}}</td>
</tr>
<tr>
<td>Height, cm</td>
<td>161.9 ± 0.82</td>
<td>163.1 ± 0.31</td>
<td>162.3 ± 0.43 \textsuperscript{.23}</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>88.2 ± 2.7\textsuperscript{4}</td>
<td>73.3 ± 0.87</td>
<td>81.4 ± 1.3\textsuperscript{\textit{.0001}}</td>
</tr>
<tr>
<td>Weight change, 4-year, kg</td>
<td>−3.6 ± 0.82\textsuperscript{5}</td>
<td>1.3 ± 0.32</td>
<td>4.1 ± 0.43 \textsuperscript{&lt;.0001}</td>
</tr>
<tr>
<td>Lean mass, kg</td>
<td>48.5 ± 1.0\textsuperscript{6}</td>
<td>42.9 ± 0.36</td>
<td>42.8 ± 0.49 \textsuperscript{.0001}</td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>34.8 ± 1.9\textsuperscript{\textit{.01}}</td>
<td>26.4 ± 0.56</td>
<td>33.8 ± 0.98 \textsuperscript{.0001}</td>
</tr>
<tr>
<td>Waist-to-hip ratio</td>
<td>0.84 ± 0.01\textsuperscript{\textit{.01}}</td>
<td>0.80 ± 0.004</td>
<td>0.81 ± 0.005 \textsuperscript{.0001}</td>
</tr>
<tr>
<td>Comorbidity present, % (3 years after baseline)</td>
<td>45</td>
<td>29</td>
<td>38 \textsuperscript{.01}</td>
</tr>
<tr>
<td>Physical activity level, %</td>
<td>More than peers</td>
<td>15</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Same as peers</td>
<td>45</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Less than peers</td>
<td>40</td>
<td>26</td>
</tr>
</tbody>
</table>

Notes: \*Lost at least 2.5 kg over the time period.
\textsuperscript{1}Gained at least 2.5 kg over the time period.
\textsuperscript{2}The difference between those with a loss of lean mass and those with no change is significant at the \textit{.01} level.
\textsuperscript{3}The difference between those with a loss of lean mass and those with no change is significant at the \textit{.001} level.

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