Original Contribution

Performance-based Physical Functioning in African-American and Caucasian Women at Midlife: Considering Body Composition, Quadriceps Strength, and Knee Osteoarthritis

MaryFran Sowers1, Mary L. Jannausch1, Melissa Gross2, Carrie A. Karvonen-Gutierrez1, Riann M. Palmieri2, Mary Crutchfield1, and Kerry Richards-McCullough1

1 Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, MI.
2 Division of Kinesiology, University of Michigan, Ann Arbor, MI.

Received for publication September 2, 2005; accepted for publication December 15, 2005.

In 2000, body composition, x-ray–defined knee osteoarthritis, and self-reported knee pain information from a cross-sectional, community-based study of 211 African-American and 669 Caucasian women in southeast Michigan (mean age, 47 years) was related to performance-based physical functioning measures to characterize development of functional limitations. Body composition was assessed with bioelectrical impedance. Functioning measures were gait assessment, timed walk, timed stair climb with and without videography, and isometric quadriceps strength. Knee osteoarthritis was determined by Kellgren-Lawrence score from radiography, whereas knee pain was self-reported. Almost 31% of mid-aged women walked at functionally inadequate speeds, and over 12% walked at speeds considered typical of frailty in older women. Ten percent of women had skeletal muscle mass levels less than a proposed cutpoint for increased physical disability risk in older adults. Gait measures correlates included increasing age, increasing fat mass (in kilograms), knee joint pain, and reduced quadriceps strength. Stair climbing correlates included skeletal muscle mass (in kilograms) and its change, painful knee osteoarthritis, and reduced quadriceps strength. Race differences in walking measures and stair climbing time diminished when the authors accounted for other factors. Compromised physical functioning began earlier than expected, with indications that approximately 12–31% of women might benefit from interventions to forestall future decline.

arthritis; body composition; gait

Abbreviations: MBHS, Michigan Bone Health Study; SWAN, Study of Women’s Health Across the Nation.

The substantial body of theoretical and applied literature about the disability process (1–7) reflects limited consideration of a population at mid-age, when functional limitations may begin and initiation of prevention efforts may be the most viable. Understanding the natural history and correlates that give rise to functional limitations may identify high-risk individuals in whom the disability process occurs earlier or progresses more rapidly. For example, the Buchner-de Lateur (8) thesis postulated that associations between measures of skeletal muscle strength and physical functioning are curvilinear and that there are events or characteristics that accelerate the loss of muscle strength and its impact on physical functioning. An efficacious approach is to determine characteristics associated with the more steep elements of the curve. While the association of strength with physical functioning has been characterized, these studies have typically been conducted among the elderly (4) and do not identify whether the divergence between strength and
physical functioning begins in midlife or whether any events observed in midlife will have a linear progression with chronological aging.

It may be particularly important to address the issue of racial/ethnic disparities in the development of functional limitations (9, 10). Investigators have yet to well explain racial/ethnic differences in functioning, although more compromised maximum oxygen uptake (VO2max) (11) and fear of falling (9) have been evoked as explanations in elderly populations. Other explanations may include cultural differences in diet and physical activity, nonspecified socioeconomic factors, or differential interpretation of interview questions or performance expectation. If these disparities are evident in mid-aged populations, their role in the natural history becomes critical because race/ethnicity may represent a different set point for the risk of developing disabilities.

Important contributors to physical functioning include arthritis and pain. Although limitations in physical functioning are linked to osteoarthritis in the elderly (12, 13), there are few studies of initiation or progression of osteoarthritis in the fifth and sixth decades of life (14). Knee osteoarthritis in the elderly is highly prevalent, the most commonly reported chronic disability in older persons, and the risk of further disability associated with knee osteoarthritis is greater than any other medical disorder in the elderly (15–17). However, data suggest that only about half of those persons reporting knee pain have osteoarthritis (18), suggesting that a large segment of the population may experience functional limitations for reasons apart from osteoarthritis. We have reported that not all women at midlife who report knee pain have x-ray–defined knee osteoarthritis (14). There is a relative dearth of information about osteoarthritis and pain with disability and functioning in mid-aged adults, although mid-age is the juncture at which osteoarthritis becomes increasingly prevalent and the likelihood of a negative impact on quality of life and productivity commences (19).

Assessing initial events during midlife associated with decline in physical functioning is important for providing the context for appropriate preventive, clinical, and supportive practice, particularly for women who experience more limitations and have, on average, a 30-year lifespan remaining after midlife (20–22). We evaluated performance-based measures of physical functioning in African-American and Caucasian mid-aged women to consider the association with x-ray–defined knee osteoarthritis, self-reported knee pain, body composition, measured quadriceps strength, age, and smoking status.

**MATERIALS AND METHODS**

**Study population**

This study was conducted among pre- and perimenopausal women participating in two longitudinal studies assessed with the same protocol. The aggregate of the two longitudinal studies, called the Southeast Michigan cohort, includes data from 514 women from the Michigan Bone Health Study (MBHS) and 366 women from the Study of Women’s Health Across the Nation (SWAN)—Michigan site. Written informed consent was obtained from all participants, and approval for conducting the study was obtained from the University of Michigan Institutional Review Board.

SWAN is a multisite, multiracial/ethnic longitudinal study of women at midlife designed to characterize reproductive hormone patterns and health status as women approach and traverse menopause. The study design and recruitment to SWAN have been described elsewhere (23). In 1995, enrollees were identified from a household census of two suburban communities located near Detroit, Michigan. From 24,283 households, 2,621 eligible women, aged 40–55 years, were identified by using telephone (25 percent) or in-person (75 percent) interviews. From this sample, a longitudinal cohort of 543 eligible women (325 African American, 218 Caucasian) was enrolled at the Michigan SWAN site. The eligible criteria were age 42–52 years, menstrual bleeding within the previous 3 months, and no use of hormone replacement therapy. The Michigan site includes a biracial sample with known sampling probabilities to reference the underlying population. In 1996–1997, a site-specific substudy of physical functioning was implemented in the SWAN population to characterize x-ray–defined osteoarthritis and interview-based measures of physical functioning. In 1999–2000, the scope of the functioning substudy was expanded to incorporate performance-based measures of physical functioning. There is an 85 percent participation rate in the Michigan SWAN study; however, 13 percent of women are unwilling or unable to provide more than a 15-minute interview and are not described in this report. There have been 18 deaths (2.5 percent) in the cohort.

MBHS is a population-based longitudinal study of musculoskeletal disease development in pre- and perimenopausal Caucasian women, organized to describe the natural history of peak bone mass (24). The 664-woman sample was identified from two sampling frames: the family records from the historical Tecumseh Community Health Study and a 1992 Tecumseh community census. From the Tecumseh Community Health Study, 80 percent of the female offspring aged 24–44 years were recruited in 1992. Additionally, more than 90 percent of age-eligible women from the community census were recruited to include those who had become community residents after the Tecumseh Community Health Study family census in 1959–1960. Loss to follow-up has been less than 15 percent over the 10-year period; more than 80 percent of the cohort members have contributed to at least eight of the 10 available annual data collection efforts. There have been eight deaths in the sample.

Measures of osteoarthritis and physical functioning were administered concurrently in the MBHS and SWAN enroll- ees, using the same protocol, to facilitate pooling in data analyses.

**Measurements**

*Walk and gait analysis.* Each participant was timed during a purposeful walk down a 12.3-m carpeted (commercial nap)
Biomechanical measures of gait were obtained from an instrumented mat (Gaitrite; CIR Systems, Clifton, New Jersey) placed midway in the corridor. The gait mat measured 4.57 m × 0.90 m × 0.60 m with an active sensor area slightly smaller than the mat (3.66 m × 0.61 m (0.0127 m between sensor centers)) and an 80-Hz sampling frequency. Individual footsteps recorded during the walk were displayed on a computer screen, and incomplete footsteps were removed manually. Data from both walking trials were combined to yield one set of gait data for each participant.

**Stair climb and videography.** Participants were timed and videotaped as they ascended and descended three standardized stairs fitted with rubber traction strips. The time began with the toe-off of the leading leg at the start of ascent and ended with the final foot contact of the trailing leg after descent. Interviewers recorded whether one or both handrails were used. Participants repeated stair climbing while being videotaped. They wore visual markers affixed to the acromion process, greater trochanter, lateral epicondyly, and lateral malleolus. A video camera was placed perpendicular to the staircase, so that a lateral view of a participant’s leg markers was captured on videotape (30 frames/second). The second of two videotaped trials was selected for analysis unless that video image was inadequate. Variables from the videotapes included the following: ascent cycle (the interval between first foot off the floor to the subsequent second foot off the second stair) and double support (the amount of time both feet are on the floor or a stair surface). Percent double support refers to the percentage of time that both feet are on the floor or a stair surface in a cycle. Descent cycle time is decomposed similar to ascent cycle time.

Two reviewers defined each stair cycle independently, and any differences were resolved by a third methodologist.

**Quadriceps strength.** A portable isometric chair that replicates the chair designed for the Dynamics of Health, Aging and Body Composition Study (25) was used to measure quadriceps strength as torque (Nm), the product of force and torque arm length. Torque arm length is equal to the length between the lateral knee joint line and the bottom surface of the heel plus 0.0251 m, the distance from the top surface of the foot trolley platform and the transducer axis. Torque for three successful trials was averaged. The left leg was tested unless participants reported knee surgery, knee replacement, or pain, conditions under which the right leg was tested. Four participants with knee pain in both legs were not tested.

**Knee osteoarthritis.** Weight-bearing anteroposterior radiographs were taken of both knees in 1998–1999, a year prior to the performance-based physical functioning assessment. This procedure and its calibration have been extensively described in previous work (26–28). Technicians used x-ray equipment (model X-GE MPX-80; General Electric Co. Medical Systems Division, Milwaukee, Wisconsin) and X-DA film with Kodak rare earth intensifying screens (Eastman Kodak, Rochester, New York). The source film distance was 1 m, and standard radiographic techniques were used. Films were read independently by two reviewers using the Kellgren-Lawrence system (29). The Kellgren-Lawrence scores assigned by the two readers were compared. The radiographs of those joints without perfect correspondence were reread and, if necessary, subjected to consensus reading. A more detailed account of the methods for standardization and reading of the x-ray films has been described previously (30). Joints were classified with a five-level scale of severity: 0, normal; 1, doubtful osteoarthritis; 2, minimal osteoarthritis; 3, moderate osteoarthritis; or 4, severe osteoarthritis. Women who had a Kellgren-Lawrence score of 2 or higher for either knee were defined as having knee osteoarthritis, whereas women with Kellgren-Lawrence scores of 0 or 1 were considered free of knee osteoarthritis. This classification was used to calculate the point prevalence of knee osteoarthritis.

**Knee joint pain.** Answers to the question, “Have you had any joint pain in your knees in the last month lasting most of the month?” were dichotomized (yes/no) to indicate whether or not pain was present.

**Other measures.** Height (in meters) and weight (in kilograms) measures were used to calculate body mass index as weight in kilograms divided by height in meters squared (kg/m²). Body composition was assessed with bioelectrical impedance. Because fat-free mass comprises water, proteins, and electrolytes, conductivity is greater in fat-free mass than in fat (31), and resistance and reactance are used to estimate total body water and, by extension, fat mass and lean mass (32). To approximate a three-compartment body composition model, the absolute level of lean tissue was reduced by 7% to exclude the contribution of bone to lean mass (33). Lean mass includes muscle, visceral proteins, and intracellular and extracellular water. Skeletal muscle mass was calculated by using the method of Janssen (34), who subsequently indexed skeletal muscle mass to height for a skeletal muscle index and developed cutpoints relating to the risk of disability associated with skeletal muscle index (35). Furthermore, using available data from 1996 and 2000 examinations, we calculated the 4-year change in skeletal muscle index. The tertiles of distribution change had the following cutpoints: ≤0.022 kg/m², 0.023–0.3659 kg/m², and ≥0.366 kg/m².

**Timing of measurements.** In 1996–1997, and annually thereafter, interviews about physical functioning and timed physical functioning measures were collected in SWAN and MBHS. In 1999–2000, gait analysis, stair climb videography, and quadriceps strength measurements were added to the protocols for both studies. Physical functioning data in the present analyses are from the 1999–2000 data collection time point. To determine the status of knee osteoarthritis, knee radiographs were collected for SWAN and MBHS study participants in 1998–1999.

**Statistical analyses**

The Shrout-Fleiss (36) intraclass correlation coefficient was calculated to estimate reliability. These correlations were as follows: stair climb time (0.94), quadriceps strength (0.92), and timed 12.3-m walk (0.87). Correlations of more than 0.75, 0.75–0.40, or less than 0.40 were interpreted as excellent, good, and poor reliability, respectively (36).

Measures of stair climbing, gait, body composition, and quadriceps strength were evaluated for their distributions, and, when necessary, transformations were used. Following
RESULTS

The mean age of this 880-woman sample was 46.9 years, and the mean body mass index was 30.6 kg/m². African Americans constituted 24 percent of the sample (n = 211); population characteristics and physical functioning performance measures are summarized by race in table 1. The prevalence of knee osteoarthritis, based on a Kellgren-Lawrence score of 2 or greater, was 20 percent. Almost one third of the population (29 percent) reported knee pain. Overall, 11 percent of the women had painful knee osteoarthritis, 9 percent had knee osteoarthritis without pain, 18 percent had knee pain but without knee osteoarthritis, and 62 percent had neither knee osteoarthritis nor knee pain. Ten percent of the women had skeletal muscle mass levels of 6.75 kg/m² or less, a proposed cutpoint identified with increased risk of physical disability in older adults (35).

Correlates of gait measures

Gait velocity, normalized to leg length, tripled over the performance range, from 0.76 m/second to more than 2.30 m/second. Thirty-one percent of the women walked at velocities of less than 1.16 m/second, a value markedly less than 1.22 m/second, the federal standard speed for crossing an intersection (37). Moreover, 12 percent of these mid-aged women walked at velocities of less than 1.00 m/second, a cutpoint that has been used to characterize frailty in the elderly (38).

The combination of age, knee osteoarthritis, pain, body composition, quadriceps strength, race, and smoking explained between 22 percent and 33 percent of the variation in gait measures and 19 percent of the variation in the timed 12.3-m walk (table 2). Even in this mid-aged sample, each year of age was associated with increasing total gait cycle time and time in gait double support, with accompanying shortened stride length and lower velocity.

Self-reported knee pain was consistently correlated with more limited gait performance. Women with knee pain had approximately 0.4-second longer cycle times (p = 0.004), had stride lengths that were 0.046 m shorter (p = 0.02), had less velocity (p < 0.001), and spent more time in double support (p = 0.005) than women with neither knee pain nor knee osteoarthritis, after we adjusted for fat and skeletal muscle mass, quadriceps strength, race, age, and cigarette smoking.

Total fat mass (in kilograms) was more consistently associated with gait measures than skeletal muscle mass (in kilograms). Increasing fat mass was associated with longer cycle time, shorter stride length, lower velocity, and greater time in double support. A measure of quadriceps strength was significantly associated with all measures of gait contributing substantially to stride length (p < 0.001), even following adjustment for amount of skeletal muscle mass.

Smoking status, self-identified race, and race by body composition interaction terms were not related to these gait composite measures.

Correlates of timed 12.3-m walk

Compared with that for composite gait measures, the pattern of explanatory factors was somewhat different in the timed 12.3-m walk (table 2). This walk was associated with fat mass (in kilograms), quadriceps strength, and the presence of painful knee osteoarthritis. Women with painful knee osteoarthritis required approximately 13 percent more time for the 12.3-m walk (p < 0.001) than women without knee pain or knee osteoarthritis, after adjusting for age and race; however, women with only knee pain did not have a longer 12.3-m walk time. Unlike other gait measures, the 12.3-m walk was not correlated with age but was correlated with cigarette smoking. Compared with nonsmokers, current smokers took 6 percent longer (p < 0.001) in the 12.3-m walk, after adjusting for age and race.

Correlates of stair climbing

Most of the variation in stair climbing performance could be attributed to three factors: the presence of painful knee osteoarthritis, skeletal muscle mass (in kilograms) and its change, and quadriceps strength (table 3). Women with painful knee osteoarthritis were most compromised in the stair climb, with significantly longer ascent (p = 0.002) and descent (p < 0.001) cycle times, and more time spent in double support on ascent (p = 0.004) and descent (p = 0.005) and overall (p < 0.001) than women with neither knee osteoarthritis nor pain. Although the regression analyses suggest that African-American women fared worse in the timed stair climb, further investigation revealed that this finding was true for only those women in the highest fat mass tertile (>36 kg).

Handrail use as an assistive device

Most of this population did not use handrails during the stair test. On ascent, 28 (4 percent) of the women used both stair handrails, while 239 (35 percent) used one handrail and 414 (61 percent) did not use either handrail. Proportions were similar for descent. As shown in figure 1, the amount of time spent in double support by women with knee pain only (no knee osteoarthritis) and by women with both knee
TABLE 1. Characteristics* of the population of mid-aged women, southeast Michigan, 2000, Study of Women’s Health Across the Nation and Michigan Bone Health Study

<table>
<thead>
<tr>
<th>Overall</th>
<th>African American (n = 211)</th>
<th>Caucasian (n = 669)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prevalence (%) 95% CI†</td>
<td>Prevalence (%) 95% CI</td>
</tr>
<tr>
<td>Prevalence of risk for not crossing an intersection safely‡</td>
<td>31 28, 34</td>
<td>73 67, 80</td>
</tr>
<tr>
<td>Prevalence of frailty-defined velocity§</td>
<td>12 10, 15</td>
<td>30 24, 27</td>
</tr>
<tr>
<td>Prevalence of risk for disability (skeletal muscle index ≤ 6.75 (34))</td>
<td>10 8, 12</td>
<td>9 5, 13</td>
</tr>
<tr>
<td>Prevalence of knee osteoarthritis</td>
<td>20 17, 23</td>
<td>33 26, 41</td>
</tr>
<tr>
<td>Prevalence of knee joint pain</td>
<td>29 25, 32</td>
<td>45 36, 52</td>
</tr>
<tr>
<td>Timed performance measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timed 12.3-m walk (seconds)</td>
<td>8.0 1.7</td>
<td>8.9 2.5</td>
</tr>
<tr>
<td>Timed three-stair climb (seconds)</td>
<td>16.2 4.7</td>
<td>18.2 6.1</td>
</tr>
<tr>
<td>Gait test measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cycle time (seconds)</td>
<td>3.55 1.89</td>
<td>4.93 1.64</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>1.356 0.296</td>
<td>1.160 0.172</td>
</tr>
<tr>
<td>Average double support time (seconds)</td>
<td>0.67 0.59</td>
<td>1.18 0.59</td>
</tr>
<tr>
<td>Percentage of cycle in double support</td>
<td>19.6 6.5</td>
<td>23.9 5.8</td>
</tr>
<tr>
<td>Velocity (m/second)</td>
<td>1.45 0.36</td>
<td>1.11 0.20</td>
</tr>
<tr>
<td>Normalized velocity¶</td>
<td>1.69 0.69</td>
<td>1.26 0.25</td>
</tr>
<tr>
<td>Stair test measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ascent: cycle time (seconds)</td>
<td>1.23 0.40</td>
<td>1.43 0.37</td>
</tr>
<tr>
<td>Double support (seconds)</td>
<td>0.40 0.20</td>
<td>0.47 0.23</td>
</tr>
<tr>
<td>Percentage of time in double support</td>
<td>32.6 6.6</td>
<td>34.0 6.3</td>
</tr>
<tr>
<td>Descent: cycle time (seconds)</td>
<td>1.20 0.40</td>
<td>1.40 0.57</td>
</tr>
<tr>
<td>Double support (seconds)</td>
<td>0.43 0.17</td>
<td>0.50 0.17</td>
</tr>
<tr>
<td>Percentage of time in double support</td>
<td>35.7 6.11</td>
<td>36.4 6.1</td>
</tr>
<tr>
<td>Quadriceps strength (Nm)</td>
<td>82.2 32.0</td>
<td>81.63 31.0</td>
</tr>
<tr>
<td>Body size measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>46.9 4.6</td>
<td>49.1 2.9</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.629 0.060</td>
<td>1.632 0.062</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>80.5 19.2</td>
<td>87.1 19.8</td>
</tr>
<tr>
<td>Fat mass (kg)#</td>
<td>32.8 15.1</td>
<td>38.7 16.0</td>
</tr>
<tr>
<td>Lean mass (kg)**</td>
<td>48.5 8.0</td>
<td>50.5 8.8</td>
</tr>
<tr>
<td>Skeletal muscle mass (kg)††</td>
<td>21.3 3.2</td>
<td>21.9 3.5</td>
</tr>
<tr>
<td>Skeletal muscle index (kg/m²)</td>
<td>8.04 1.17</td>
<td>8.22 1.27</td>
</tr>
<tr>
<td>Skeletal muscle index, 4-year difference (kg/m²)</td>
<td>0.22 0.53</td>
<td>0.20 0.66</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>30.6 7.5</td>
<td>33.1 8.1</td>
</tr>
</tbody>
</table>

* Prevalence of knee osteoarthritis, knee joint pain, and normative risk; performance-based assessment of gait and stair climbing capacity; and age, height, and body composition.
† CI, confidence interval; IQR, interquartile range (i.e., 75th–25th percentile); SD, standard deviation.
‡ Walked at velocities of <1.22 m/second, the federal standard speed for crossing an intersection (37).
§ Walked at velocities of <1.00 m/second, a cutpoint used to characterize frailty in the elderly (38).
¶ Velocity (m/second)/leg length (m).
# Fat mass as determined by bioelectrical impedance.
** Lean mass as determined by bioelectrical impedance.
†† Skeletal muscle mass calculated by the method of Jannsen et al. (34).
### TABLE 2. Statistically significant beta coefficients from regression analyses using partial correlations to relate gait composite measures and timed 12.3-m walk in mid-aged African-American and Caucasian women to knee osteoarthritis, knee joint pain, body composition, and quadriceps strength, southeast Michigan, 2000, Study of Women’s Health Across the Nation and Michigan Bone Health Study

<table>
<thead>
<tr>
<th></th>
<th>Knee osteoarthritis without pain report</th>
<th>Pain report without knee osteoarthritis</th>
<th>Knee osteoarthritis with pain report</th>
<th>logFat (kg)</th>
<th>logSkeletal muscle index (34) (kg/m²)</th>
<th>Stone muscle index change (tertiles)</th>
<th>logQuadriceps strength</th>
<th>Age</th>
<th>Cigarette smoking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cycle time (seconds) ($R^2 = 22%$)</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
</tr>
<tr>
<td>Stride length (m) ($R^2 = 33%$)</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
</tr>
<tr>
<td>Normalized velocity</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
</tr>
<tr>
<td>12.3-m walk time (seconds) ($R^2 = 19%$)</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
</tr>
</tbody>
</table>

* $R^2$, explained variation; $r_p$, partial correlation; NS, not statistically significant in most parsimonious models.
† Reference category is women with no knee osteoarthritis or pain report.
§ Reference category is women in the middle tertile (0.023–0.3659 kg/m²).

### TABLE 3. Statistically significant beta coefficients from regression analyses using partial correlations to relate stair climbing composite measures and timed stair climb in mid-aged African-American and Caucasian women to knee osteoarthritis, knee joint pain, body composition, and quadriceps strength, southeast Michigan, 2000, Study of Women’s Health Across the Nation and Michigan Bone Health Study

<table>
<thead>
<tr>
<th></th>
<th>Ascent</th>
<th>Descent</th>
<th>12.3-m walk time (seconds) ($R^2 = 19%$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cycle time (seconds) ($R^2 = 15%$)</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
</tr>
<tr>
<td>Stride length (m) ($R^2 = 12%$)</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
</tr>
<tr>
<td>Normalized velocity</td>
<td>β</td>
<td>p value</td>
<td>$r_p$</td>
</tr>
</tbody>
</table>

* $R^2$, explained variation; $r_p$, partial correlation; NS, not statistically significant in most parsimonious models.
† Reference category is women with no knee osteoarthritis or pain report.
§ Reference category is women in the middle tertile (0.023–0.3659 kg/m²).
osteoarthritis and knee pain was greater if handrails were used for either ascent or descent. However, this relation was not observed for women with knee osteoarthritis only or for those without either knee osteoarthritis or knee pain.

DISCUSSION

A substantial proportion of mid-aged women had evidence of diminished physical functioning performance. The current federal standard for pedestrian clearance at intersections is based on a walking velocity of 1.22 m/second, a value not achieved by 31 percent of those evaluated (37). Moreover, women in the lowest 12 percent of our population walked at velocities of less than 1.00 m/second, which may compromise their ability to safely negotiate their physical environment and, if they were older, could result in their being classified as frail (38). To our knowledge, there are no similar reference points with which to index our measures of stair climbing with respect to functional impairment. Furthermore, we applied skeletal muscle mass cutpoints for risk of disability in the elderly (35) and found that 10 percent of the women would be classified as at risk for disability.

There were subtle but important differences in factors associated with stair climbing and walking behaviors, in both summary measures of functioning, and the composite measures associated with stair climbing or gait. For example, knee pain was an important element associated with walking; however, our assessment of stair climbing suggests that painful knee osteoarthritis was the more important element. Regarding body composition, amount of fat mass was the dominant element in walking composite measures, but skeletal muscle mass and quadriceps strength were the dominant elements in stair climbing.

An important, consistently reported difference between the gait patterns of young and old walkers is decreased velocity and stride length and increased double support time among old walkers (39). Decreased stride time has been associated with an increased risk of falls in the elderly (40). Stride length is decreased in fit and healthy elderly walkers even when their cadence is matched with that of the young (39). Women with knee pain exhibited a different pattern of movement that was reflected in the gait data. While mid-aged women with knee pain fared less well in the more sensitive composite measures of gait, their overall 12.3-m walk time and stair climbing performances were not compromised when compared with those for women without either knee pain or knee osteoarthritis. These women may have adapted their movement in a way that does not compromise the amount of time required to walk 12.3 m or climb stairs; additional research is needed to address the nature of this potential adaptation.

The time needed to climb up and down stairs has been used as a performance-based measure of functional status in older adults (38), and the diminished ability of older adults to climb stairs has been associated with loss of functional ability (41). Stair climbing requires strength, and the large joint torque required at weight-bearing joints is considerably higher with stair climbing than during walking (42). This requirement was quite recognizable in these mid-aged women because quadriceps strength was consistently correlated with both composite and summary measures of stair climbing capacity. In other studies, persons with knee pain (42) and knee osteoarthritis (43) or increased body mass index (43), compared with controls, climbed stairs with less knee extensor movement, a strategy consistent with minimizing the loading on the knee joint. Stair ascent and descent also requires dynamic balance control since the body weight is controlled from a single support limb during swing. Stair descent may be particularly risky, as joint torques are larger than those during ascent (42). As
a person descends a step, quadriceps musculature is necessary to absorb forces and decelerate the increasing load as the weight-bearing limb is stabilized beneath the load.

On the basis of these data, some women with more compromised quadriceps strength may not be able to sufficiently absorb the load encountered during stair descent and thus their ability to dissipate the forces is compromised, exposing other musculoskeletal tissues (e.g., bone and cartilage) to substantial forces. Himan et al. (44) reported that those with knee osteoarthritis differed from controls during stair descent; persons with knee osteoarthritis had less knee flexion during early stance. These authors suggested that the observed reduction in knee flexion may be a compensatory strategy to minimize the need for eccentric quadriceps activation and reduce compressive forces across the knee joint complex.

Interestingly, fat and skeletal muscle mass had differential effects on the physical functioning of mid-aged women. Whereas increasing fat mass was one of the most important correlates of the walking composite measures, both fat and skeletal muscle mass were major predictors of stair climbing performance. Our findings are consistent with those of Sternfeld et al. (45) in that increased fat mass was associated with decreased walking speed. While Sternfeld et al. found that increased lean mass was associated with increased strength, this factor was measured by grip strength only. Because stair climbing requires strength, our findings corroborate the important association of skeletal muscle mass with climbing performance.

Chronologic age was significantly associated with the composite measures of gait but not with any of the stair climbing measures. Although age is a known risk factor for knee osteoarthritis, these data suggest that age-related changes in body composition, especially skeletal muscle mass and quadriceps strength, explained the variation in the age component of functioning.

Smoking status was associated with summary timed 12.3-m walk, timed stair climb, and amount of time spent in double support during the stair climb exercise. Knowing the effect that smoking can have on cardiovascular and respiratory health, these results are not surprising. Forced expiratory volume at 1 second was associated with walking velocity in a sample of Mexican Americans and Caucasians (10); thus, smoking may be a proxy measure of this physiologic compromise.

We identified no walking measures that were independently associated with race and no consistent difference in stair climbing time between groups when we accounted for other factors. A number of intermediate measures could explain unadjusted associations of race with physical functioning, including an increased frequency of knee osteoarthritis among African-American women and a greater prevalence of knee pain among African-American women.

These data suggest that approximately 12–31 percent of the population of mid-age women might benefit from activities to forestall any additional decline in functional status. The research indicates that onset of compromised physical functioning begins earlier than expected and is associated more with knee pain as well as the physical joint deformities that mark the first stages of development of knee osteoarthritis visualized by radiography. These data suggest that treating knee osteoarthritis, managing pain, optimizing quadriceps strength and skeletal muscle mass, and minimizing fat mass may be effective targets for intervention. However, it is yet to be determined whether mid-aged women with knee osteoarthritis and knee joint pain in this study will have similar disability trajectories as elderly persons.

ACKNOWLEDGMENTS

Grants from the National Institutes of Health (NIH), Department of Health and Human Services (DHHS), through the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS-40888; Dr. Sowers, Principal Investigator), National Institute on Aging (AG17104; Dr. Sowers, Principal Investigator), and National Institute of Nursing Research (NR004061; Dr. Sowers, Principal Investigator) funded the MBHS, the Michigan site of SWAN, and the SWAN Michigan site-specific study of functioning.

SWAN has grant support from NIH, DHHS, through the National Institute on Aging, the National Institute of Nursing Research, and the NIH Office of Research on Women’s Health (grants NR004061 (University of Michigan), AG012505, AG012535, AG012531, AG012539, AG012546, AG012553, AG012554, and AG012495).

Conflict of interest: none declared.

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