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# Skeletal Muscle Health, Physical Performance, and Lower Urinary Tract Symptoms in Older Adults: The Study of Muscle, Mobility, and Aging

**Scott R. Bauer, MD, ScM,[1,2,*] Candace Parker-Autry, MD,[3] Kaiwei Lu, MS,[3] Steven R. Cummings, MD,[4,5] Russell T. Hepple, PhD,[6] Rebecca Scherzer, PhD,[1] Kenneth Covinsky, MD,[1,7] and Peggy M. Cawthon, PhD, MPH,[4,5]**

[1]Department of Medicine, University of California and the San Francisco Veterans Affairs Medical Center, San Francisco, California, USA.
[2]Department of Urology, University of California, San Francisco, California, USA.
[3]Department of Urology, Section on Female Pelvic Health, Wake Forest Baptist Health, Winston-Salem, North Carolina, USA.
[4]San Francisco Coordinating Center, California Pacific Medical Center Research Institute, San Francisco, California, USA.
[5]Department of Epidemiology and Biostatistics, University of California, San Francisco, California, USA.
[6]Department of Physical Therapy, College of Public Health and Health Professions, University of Florida, Gainesville, Florida, USA.
[7]Division of Geriatrics, Department of Medicine, University of California, San Francisco, California, USA.

*Corresponding Author: Scott R. Bauer, MD, ScM. E-mail: Scott.Bauer@ucsf.edu

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## Abstract

**Background:** Lower urinary tract symptoms (LUTS) and mobility limitations are bidirectionally associated among older adults, but the role of skeletal muscle remains unknown. We evaluated cross-sectional associations of muscle health and physical performance with LUTS.

**Methods:** We used data from 377 women and 264 men aged >70 years in the Study of Muscle, Mobility and Aging (SOMMA). LUTS and urinary bother were assessed using the LURN Symptom Index-10 (SI-10; higher = worse symptoms). Muscle mass and volume were assessed using $D_3$-creatine dilution (D3Cr) and magnetic resonance imaging. Grip strength and peak leg power assessed upper/lower extremity physical performance. 400-m walk, Short Physical Performance Battery (SPPB), and Four Square Step Test (FSST) assessed global physical performance. Mobility Assessment Tool-short form (MAT-sf) assessed self-reported mobility. We calculated Spearman correlation coefficients adjusted for age, body mass index, multimorbidity, and polypharmacy, chi-square tests, and Fisher's *Z*-test to compare correlations.

**Results:** Among women, LURN SI-10 total scores were inversely correlated with FSST ($r_s$ = 0.11, $p$ = .045), grip strength ($r_s$ = −0.15, $p$ = .006), and MAT-sf ($r_s$ = −0.18, $p$ = .001), but not other muscle and physical performance measures in multivariable models. LURN SI-10 was not associated with any of these measures among men. Forty-four percent of women in the lowest tertile of 400-m walk speed versus 24% in the highest tertile reported they were at least "somewhat bothered" by urinary symptoms ($p$ < .001), whereas differences among men were not significant.

**Conclusions:** Balance and grip strength were associated with LUTS severity in older women but not men. Associations with other muscle and physical performance measures varied by LUTS subtype but remained strongest among women.

**Keywords:** Mobility limitation, Urinary bladder diseases, Urinary incontinence, Prostatic diseases, Sarcopenia

More than 1 in 3 older adults experience bothersome lower urinary tract symptoms (LUTS), including urinary *incontinence* (UI; involuntary urine leakage), other problems with urine *storage* (urinary urgency, frequency, nocturia), or problems with urine *voiding* (weak/slow stream, hesitancy, straining) (1,2). Older adults with LUTS are more likely to exhibit phenotypic frailty (3–5) and have mobility limitations (6,7). Longitudinal studies suggest a possible bidirectional association between LUTS and mobility limitations (8); the presence of either LUTS or mobility limitations alone significantly increases the risk of developing the other condition. A yet unexplored explanation for these associations is that both LUTS and mobility limitations are caused by age-related declines in skeletal muscle health, such as loss of muscle mass, volume, and strength/power, and related physical performance.

The importance of skeletal muscles in the pelvic floor for maintaining normal urinary function and preventing LUTS is well established. Pelvic floor muscle strength before and after childbirth (9) or prostatectomy for prostate cancer (10) is associated with several LUTS subtypes. Small preliminary studies have also described differences in the volume, shape, and strength of pelvic floor muscles between older and

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younger women (11,12) and men (11) and between older women with and without UI (13). The paradigm cited in these studies contends that age-related LUTS can be explained entirely by changes in skeletal muscle within or immediately proximal to the urinary tract, leading to interventions that specifically target the pelvic floor (14,15). However, several systemic age-related changes in skeletal muscle, such as global loss of muscle mass, fatty infiltration, neurovascular, metabolic, and immune response changes, may represent currently untargeted LUTS mechanisms that require novel systemic interventions. Despite a well-established bidirectional association between LUTS and mobility limitations, the relationship between LUTS and more objective muscle health and physical performance measures is less well understood. The limited prior studies have been restricted to one sex, preventing comparisons between sexes and the identification of shared versus sex-specific mechanisms, and focus on individual LUTS symptoms or subtypes, such as UI, preventing the discovery of novel muscle-related LUTS phenotypes.

In order to address this gap in knowledge, we evaluated sex-specific, cross-sectional associations of muscle mass/volume, upper and lower extremity muscle function (grip strength and peak leg power), and global physical performance measures with LUTS severity and urinary bother. We hypothesized that both older women and men with lower muscle mass and volume, worse muscle function, and worse physical performance would have greater LUTS severity and urinary bother.

## Method

### Participants

The Study of Muscle, Mobility and Aging (SOMMA) is a prospective cohort of community-dwelling older adults designed to investigate the mechanisms of age-related loss of mobility, as previously described (16). Participants were recruited from the University of Pittsburgh and Wake Forest University School of Medicine and were eligible to enroll if they met the following criteria: age ≥70 years, body mass index (BMI) of 18–40 kg/m$^2$, and willing and able to complete a muscle tissue biopsy and magnetic resonance (MR) imaging. Individuals who reported active cancer, advanced heart failure, severe kidney disease on dialysis, dementia, Parkinson's disease, or inability to walk ¼ mile or climb a flight of stairs, and those who were unable to complete a usual-pace 400-m walk within 15 minutes on the first day of testing were excluded. Of 879 participants enrolled in SOMMA, we further excluded 238 who completed their SOMMA baseline visit before the LUTS assessments were implemented and are therefore missing the lower urinary tract dysfunction research network symptom index-10 (LURN SI-10), leaving 641 participants for this analysis. All study participants provided informed written consent and the study protocol was approved by the Western Institutional Review Board (WCG IRB; study number 20180764).

### Muscle Health, Physical Performance, and Mobility Assessments

Whole-body $D_3$-creatine (D3Cr) muscle mass was assessed using a $D_3$-creatine dilution protocol (17,18). Thigh fat-free muscle volume was calculated from MR images of both thighs. Participants completed full-body MR imaging and images were analyzed using AMRA Researcher (AMRA Medical AB, Linköping, Sweden) (19). Grip strength was assessed using Jamar dynamometers (Sammons Preston Rolyan, Bolingbrook, IL), and the maximum of 2 trials on both the right and left sides was used. Peak leg power with knee extension was assessed at 40%, 50%, 60%, and 70% of the participants' maximum using a Keiser Air 420 exercise machine (20); the highest power measured across these assessments was analyzed. Four hundred-meter usual pace walk speed was measured by trained staff. The Short Physical Performance Battery (SPPB) was administered to assess global lower extremity functioning (range: 0–12; higher score = better functioning) (21). The Four Square Step Test was administered to assess standing balance and is recorded as the fastest time of 3 trials (lower time = better functioning) (22). Self-reported mobility was assessed using the Mobility Assessment Tool-short form (MAT-sf) (23), a video-animated tool for assessing self-perception of mobility (range: 30–80; higher score = better mobility).

### LUTS Severity and Urinary Bother Assessment

LUTS were assessed using the Lower Urinary Tract Dysfunction Research Network Symptom Index-10 (LURN SI-10) (24), a 10-item self-administered patient-reported outcome measure developed by the NIDDK-funded LURN Study Group to assess urinary symptoms in adult women and men in clinical practice. The LURN SI-10 was created to replace existing legacy measures that were developed in a sex-specific way, did not cover the full spectrum of LUTS, or were too burdensome for population-based studies. The LURN SI-10 recall period is 7 days and each item includes response options with a numerical score ranging from 0 to 4 for urinary urgency, urgency incontinence, stress incontinence, bladder pain, delayed voiding, weak urine stream, and postvoid dribbling, with 0 representing no symptoms and 4 representing the highest symptom burden (eg, response to "how often did you leak urine or wet a pad after feeling a sudden to urinate" as "Every time"). For the item assessing the number of urinations "during waking hours," numerical scores range from 0 ("3 or fewer times a day") to 3 ("11 or more times a day"). For the item assessing nocturia, numerical scores range from 0 ("none") to 3 ("more than 3 times"). Total scores range from 0 (least severe) to 38 (most severe). If data are missing for <5 items, a prorated total score is calculated by computing the proportion of observed scores to the possible maximum score for items completed and then multiplying by 38 (a prorated total score was calculated for 1 participant for this analysis). LURN SI-10 subscores include 4 UI questions (urgency UI, stress UI, activity UI, and postvoid dribbling), 2 urine voiding questions (delayed voiding and weak urine stream), and 3 urine storage questions excluding UI (urgency, daytime frequency, and nocturia). A separate unscored question of urinary bother is assessed by asking "In the past 7 days, how bothered were you by urinary symptoms?" and 4 response options range from "Not at all bothered" to "Extremely bothered."

### Other Measurements

Additional measures included self-reported gender, race, ethnicity, education, and health-related behaviors. Height, weight, and waist circumference were measured by study staff. The Community Healthy Activities Model Program for Seniors (CHAMPS) questionnaire was used to assess self-reported frequency and duration of engagement in various physical activities (eg, walking, sports, gardening, housework) (25). We used caloric expenditure per week in all physical activities as a measure of total energy expenditure. Participants reported whether they were ever diagnosed with the following conditions and the responses were summed to produce a total multimorbidity count: diabetes, stroke, myocardial infarction, heart failure, lung disease (eg, chronic obstructive pulmonary disease, chronic bronchitis, asthma), nonskin cancer, peripheral vascular disease, chronic kidney disease or renal failure, osteoporosis, and arthritis. Participants were asked to bring all prescription medications they had taken in the past 30 days to the clinic visit and the total number of medications was counted. Global cognition was measured using the Montreal Cognitive Assessment (MoCA; range: 0–30) (26), with a score <26 indicating potential cognitive impairment, and the Trail-Making Test, part B, with higher scores indicating worse visual attention and task switching abilities (27). Depressive symptoms were measured using the 10-item Centers for Epidemiologic Studies Depression scale (CESD-10), with higher scores indicating greater depressive symptoms (range: 0–30; higher scores = more depressive symptoms) (28). The 5-level EuroQol (EQ-5D) was used to assess quality of life across 5 dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression (range: 0–100; higher score = better health state) (29).

### Data Analysis

In this analytic cohort, the primary independent variables were muscle mass, thigh muscle volume, upper and lower extremity muscle function, global physical performance, or self-reported mobility, and the 2 dependent variables were LUTS severity and urinary bother. To evaluate associations with LUTS severity, we calculated sex-specific, age-adjusted, and multivariable-adjusted Spearman correlation coefficients. Multivariable models were adjusted for age, BMI, comorbidity count, and total number of medications. We tested for differences between Spearman correlation coefficients by sex using the Fisher *Z*-test (30). To evaluate associations with the presence of urinary bother, we calculated chi-square tests across categories or tertiles of the primary independent variables. In sensitivity analyses, we calculated unadjusted Spearman correlation coefficients between the primary independent variables and LURN SI-10 subscores (UI, voiding, and storage) as well as individual urinary symptoms. We also created a correlation matrix of unadjusted Spearman correlation coefficients between individual urinary symptoms to visualize relationships between LURN SI-10 components. A $p$ value < .05 was considered statistically significant. All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies.

## Results

Baseline demographic and health-related characteristics of the 377 women and 264 men in the analytic sample are reported in Table 1. Women with more severe LUTS were on average older, had less education, exercised less, had higher BMI and waist circumference, took longer to complete the Trails Making Test, reported more depressive symptoms and worse quality of life, had more comorbidities, took more medications, reported a greater number of pregnancies and live births, and were more likely to have received hormone replacement therapy. Similarly, men with more severe LUTS were older, had higher BMI, took longer to complete the Trails Making Test, reported more depressive symptoms, had more comorbidities, and took more medications. We depict the pattern of associations of muscle health, physical performance, and self-reported mobility with LURN SI-10 total score, subscores (UI, storage, voiding), and urinary bother in Figure 1.

Associations of muscle health, physical performance, and self-reported mobility with overall LUTS severity among women and men are compared in Table 2. Among older women, grip strength and MAT-sf were inversely correlated, and Four Square Step Test (higher time = worse balance) was positively correlated with LURN SI-10 total score after multivariable adjustment. Four hundred-meter walk speed, SPPB, and peak leg power were inversely correlated with LURN SI-10 total score in age-adjusted models, but associations were attenuated and no longer statistically significant after further adjustment for BMI, comorbidity count, and number of medications. Among older men, both 400-m walk speed and MAT-sf were inversely correlated with LURN SI-10 total score after adjustment for age alone, although the inverse correlation between MAT-sf and LURN SI-10 score did not reach statistical significance and associations were no longer present after multivariable adjustment.

Associations of selected physical performance and self-reported mobility measures with urinary bother are shown in Table 3. Among older women in the lowest tertile of 400-m walk speed, 44% reported that they were at least "somewhat bothered" by urinary symptoms compared to 24% of women in the highest tertile of 400-m walk speed ($p$ < .001). Older women in the lowest tertile of MAT-sf were also more likely to report being bothered by urinary symptoms compared to women in the highest tertile of MAT-sf. Four Square Step Test appeared to be inversely associated with urinary bother but did not reach statistical significance. Among older men, associations of 400 m and MAT-sf with urinary bother appeared similar, although did not reach statistical significance. Grip strength was not significantly associated with urinary bother in women or men.

Associations of muscle health, physical performance, and self-reported mobility with LURN SI-10 subscores are shown in Supplementary Table 1. Among older women, MAT-sf was the only measure that was significantly associated with all 3 LURN SI-10 subscores (UI, storage, and voiding). Four hundred-meter walk speed was also inversely correlated with all 3 subscores, although only UI subscore was statistically significant. Short Physical Performance Battery was inversely correlated with UI and voiding subscores, Four Square Step Test was positively correlated with UI and voiding subscores (only voiding was statistically significant), grip strength was inversely correlated storage and voiding subscores, peak leg power/body mass was inversely associated with UI and storage subscores, and D3Cr muscle mass/body mass were inversely correlated with only UI subscore. Among older men, 400-m walk speed, SPPB, and D3Cr muscle mass were inversely correlated with UI subscore (only 400-m walk speed was statistically significant), and 400-m walk speed was also inversely correlated with storage subscore. Additional characteristics of the analytic study population are reported in Supplementary Table 2.

In Supplementary Figure 1, we show the scatterplot of 400-m walk speed and LURN SI-10 total score in women

**Table 1.** Characteristics of Older Women and Men Enrolled in SOMMA, by Lower Urinary Tract Symptom Severity

| Variable | Categories of Lower Urinary Tract Symptom Severity (LURN SI-10 Total Score) | | |
|---|---|---|---|
| | None/Mild (0–4) | Moderate (5–7) | Severe (8–21) |
| Women (*n* = 377) | | | |
| Sample size, *n* (%) | 189 (50) | 113 (30) | 75 (20) |
| Demographics | | | |
| Age, years, mean (*SD*) | 74.9 (4.1) | 76.9 (4.7) | 76.6 (4.3) |
| High school education or less, *n* (%) | 64 (34) | 48 (42) | 36 (49) |
| Self-reported race, *n* (%) | | | |
| White | 154 (81) | 102 (90) | 65 (87) |
| Black or African American | 30 (16) | 10 (9) | 10 (13) |
| Other, unknown, or not reported | 5 (3) | 1 (1) | 0 (0) |
| Health metrics and behaviors | | | |
| Total energy expenditure*, kcal/week, mean (*SD*) | 3 328 (2297) | 3 104 (1963) | 3 027 (2132) |
| BMI, kg/m$^2$, mean (*SD*) | 26.8 (4.7) | 27.5 (4.8) | 28.0 (4.6) |
| Waist circumference, cm, mean (*SD*) | 87.6 (12.5) | 90.4 (12.5) | 91.0 (13.1) |
| Cognition, Mood, and Quality of Life Questionnaires, mean (*SD*) | | | |
| MoCA Test | 25.2 (2.8) | 25.0 (2.9) | 24.9 (3.0) |
| Trail-Making Test, Part B | 102.1 (50.0) | 109.8 (59.2) | 120.5 (63.7) |
| CESD-10 | 3.8 (3.3) | 5.1 (3.2) | 5.5 (3.7) |
| EuroQol-5D (EQ-5D) | 86.8 (11.1) | 84.4 (9.8) | 82.6 (12.1) |
| Multimorbidity and polypharmacy | | | |
| Multimorbidity†, *n* (%) | | | |
| 0 chronic conditions | 25 (13) | 12 (11) | 7 (9) |
| 1 chronic condition | 71 (38) | 39 (35) | 20 (27) |
| 2 chronic conditions | 61 (32) | 43 (38) | 28 (37) |
| ≥3 chronic conditions | 32 (17) | 19 (17) | 20 (27) |
| Number of medications, mean (*SD*) | 4.3 (3.1) | 5.0 (3.5) | 5.0 (3.6) |
| Reproductive and gynecologic history | | | |
| Number of pregnancies, mean (*SD*) | 2.6 (1.4) | 2.8 (1.6) | 3.2 (1.7) |
| Number of live births, mean (*SD*) | 2.0 (1.2) | 2.4 (1.4) | 2.6 (1.3) |
| Hormone replacement therapy, *n* (%) | 94 (51) | 60 (55) | 47 (63) |
| History of hysterectomy, *n* (%) | 75 (40) | 44 (39) | 30 (40) |
| Men (*n* = 264) | | | |
| Sample size, *n* (%) | 96 (36) | 106 (40) | 62 (23) |
| Demographics | | | |
| Age, years, mean (*SD*) | 75.4 (4.5) | 76.1 (4.7) | 76.1 (4.3) |
| High school education or less, *n* (%) | 21 (22) | 30 (28) | 15 (24) |
| Self-reported race, *n* (%) | | | |
| White | 83 (86) | 91 (86) | 55 (89) |
| Black or African American | 11 (11) | 8 (8) | 5 (8) |
| Other, unknown, or not reported | 2 (3) | 6 (6) | 2 (3) |
| Health metrics and behaviors | | | |
| Total energy expenditure*, kcal/week, mean (*SD*) | 4 802 (4 400) | 4 329 (3 258) | 4 951 (4 027) |
| BMI, kg/m$^2$, mean (*SD*) | 27.4 (3.9) | 27.8 (4.5) | 28.2 (4.3) |
| Waist circumference, cm, mean (*SD*) | 99.3 (10.1) | 101.2 (13.1) | 100.8 (12.1) |
| EQ-5D | 85.8 (11.8) | 85.5 (9.1) | 84.2 (10.0) |
| Cognition, Mood, and Quality of Life Questionnaires, mean (*SD*) | | | |
| MoCA Test | 24.7 (2.8) | 24.8 (2.6) | 24.2 (2.8) |
| Trail-Making Test, Part B | 105.6 (55.9) | 114.9 (60.9) | 116.2 (53.0) |
| CESD-10 | 2.6 (2.8) | 3.4 (2.7) | 5.1 (4.8) |
| EQ-5D | 85.8 (11.8) | 85.5 (9.1) | 84.2 (10.0) |
| Multimorbidity and polypharmacy | | | |
| Multimorbidity†, *n* (%) | | | |

**Table 1.** Continued

| Variable | Categories of Lower Urinary Tract Symptom Severity (LURN SI-10 Total Score) | | |
|---|---|---|---|
| | None/Mild (0–4) | Moderate (5–7) | Severe (8–21) |
| 0 chronic conditions | 21 (22) | 26 (25) | 11 (18) |
| 1 chronic condition | 44 (46) | 40 (38) | 21 (34) |
| 2 chronic conditions | 22 (23) | 23 (22) | 21 (34) |
| ≥3 chronic conditions | 9 (9) | 17 (16) | 9 (15) |
| Number of medications, mean (*SD*) | 4.2 (2.3) | 4.8 (2.6) | 4.9 (4.4) |

*Notes*: BMI = body mass index, CESD-10 = Center for Epidemiologic Studies Depression scale, 10-item version, LURN SI-10 = Lower Urinary Tract Dysfunction Research Network Symptom Index-10, MoCA = Montreal Cognitive Assessment, *n* = sample size; *SD* = standard deviation.
[*]Calculated using the Community Health Activities Model Program for Seniors (CHAMPS) Physical Activity questionnaire.
[†]Cumulative number of the following chronic medical conditions: diabetes, stroke, myocardial infarction, heart failure, lung disease (eg, chronic obstructive pulmonary disease, chronic bronchitis, asthma), nonskin cancer, peripheral vascular disease, chronic kidney disease or renal failure, osteoporosis, and arthritis.

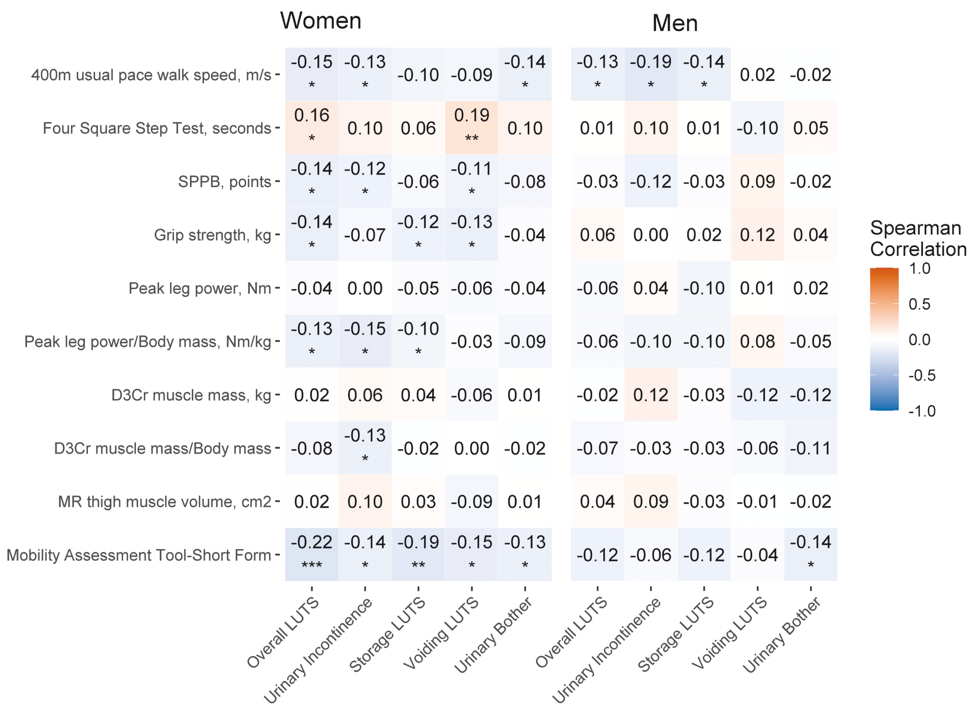


**Figure 1.** Associations of muscle health, physical performance, and self-reported mobility with lower urinary tract symptoms, overall and by subtype, and urinary bother among older women and men. Overall LUTS based on Lower Urinary Tract Dysfunction Research Network Symptom Index-10 (LURN SI-10) total score. Urinary incontinence, storage LUTS, and voiding LUTS based on LURN SI-10 subscores. Urinary bother based on LURN SI-10 global urinary bother question. Higher Short Physical Performance Battery (SPPB) score indicates better functioning. Lower Four Square Step Test time indicates better balance. Mobility Assessment Tool-short form score indicates better mobility. Correlation coefficient and *p* value calculated using Spearman's rank correlation adjusted for age. *$p < .05$; **$p < .01$; ***$p < .001$. m = meters; s = seconds; SPPB = Short Physical Performance Battery; kg = kilograms; Nm = Newton-meters; D3Cr = D3-creatine; cm = centimeters; MR = magnetic resonance; LUTS = lower urinary tract symptoms; UI = urinary incontinence.

and men. We visualized the pattern of associations between muscle health, physical performance, and self-reported mobility with individual LUTS among women in Supplementary Figure 2 and among men in Supplementary Figure 3. In Supplementary Figures 4 and 5, we visualized the pattern of correlations between individual urinary symptoms and urinary bother as assessed by the LURN SI-10.

## Discussion

In this cross-sectional analysis using data from a multicenter cohort study, we found that worse balance (assessed by Four Square Step Test) and decreased upper extremity strength (assessed by grip strength) were associated with greater overall LUTS severity in older women but not men. Lower SPPB was also weakly correlated with worse LUTS in women, although the association no longer reached statistical significance after multivariable adjustment. We also found that faster 400-m walking speed was significantly correlated with greater overall LUTS severity in both women and men after adjusting for age alone, although this association was largely attenuated in multivariable models. Peak leg power, D3Cr muscle mass, and MR thigh muscle volume were not correlated with LURN SI-10 total scores in either sex, although

**Table 2.** Associations of Muscle Health, Physical Performance, and Self-Reported Mobility With Overall Lower Urinary Tract Symptom Severity, Stratified by Sex

| | Missing | Spearman Correlation Coefficient with LURN SI-10 Total Score | | | | | | Sex Difference *p* Value† |
|---|---|---|---|---|---|---|---|---|
| | | Women | | | Men | | | |
| | | Age-adjusted rho ($r_s$) | MV-adjusted rho ($r_s$) | *p* Value* | Age-adjusted rho ($r_s$) | MV-adjusted rho ($r_s$) | *p* Value* | |
| 400-m usual pace walk speed, m/s | 0.0% | −0.15 | −0.05 | .33 | −0.13 | −0.07 | .29 | .58 |
| SPPB‡, points | 0.1% | −0.14 | −0.09 | .08 | −0.03 | 0.01 | .92 | .07 |
| Four Square Step Test‡, s | 8.5% | 0.16 | 0.11 | .045 | 0.01 | −0.01 | .91 | .05 |
| Grip strength, kg | 0.7% | −0.14 | −0.15 | .006 | 0.06 | 0.09 | .19 | .01 |
| Peak leg power, Nm | 6.6% | −0.04 | −0.06 | .30 | −0.06 | −0.10 | .15 | .99 |
| Peak leg power/body mass, Nm/kg | 6.6% | −0.13 | −0.05 | .34 | −0.06 | 0.00 | .97 | .29 |
| D3Cr muscle mass, kg | 5.6% | 0.02 | −0.03 | .54 | −0.02 | −0.03 | .64 | .72 |
| D3Cr muscle mass/body mass | 5.6% | −0.08 | −0.01 | .86 | −0.07 | 0.00 | 1.00 | .94 |
| MR thigh muscle volume, cm$^2$ | 5.8% | 0.02 | −0.05 | .41 | 0.04 | 0.06 | .40 | .83 |
| MAT-sf‡ | 3.9% | −0.22 | −0.18 | .001 | −0.12 | −0.08 | .24 | .15 |

*Notes*: D3Cr = $D_3$-creatine, cm = centimeters, kg = kilograms, LURN SI-10 = Lower Urinary Tract Dysfunction Research Network Symptom Index-10, m = meters, MAT-sf = Mobility Assessment tool-short form, MV = multivariable, MR = magnetic resonance, Nm = Newton-meters, s = seconds, SPPB = Short Physical Performance Battery.
*Multivariable-adjusted correlation coefficient and *p* value calculated using Spearman's rank correlation adjusted for age, BMI, comorbidity count, and total number of medications.
†Calculated using Fischer's *Z*-test to compare age-adjusted correlation coefficients.
‡Higher Short Physical Performance Battery score indicates better functioning. Lower Four Square Step Test time indicates better balance. Higher Mobility Assessment Tool-Short Form score indicates better mobility.

peak leg power indexed to body mass and D3Cr muscle mass were both inversely correlated with the UI subscore in women. The results of this study provide evidence that several skeletal muscle health and physical performance measures are correlated with LUTS severity and urinary bother in older adults and that the relationships vary by sex and LUTS subtype, with strongest associations generally observed among older women and with UI subscores.

Our results are consistent with prior literature consistently demonstrating that LUTS, as a syndrome and individual urinary symptoms, and/or urinary bother are associated with self-reported mobility limitations among older women (8), and more recently, older men (31). Furthermore, we demonstrated that self-reported mobility limitations are associated with several LUTS subtypes and individual urinary symptoms in women, suggesting that the association might be best captured using a comprehensive LUTS assessment tool. Prior studies focusing only on UI in women or on LUTS severity (but not urinary bother) in men may have underestimated the relationship with mobility limitations by failing to assess other important dimensions of urinary symptom severity and burden. Future cohort studies using repeated measures of self-reported mobility and LUTS to determine the temporality and potential mediators of this relationship should consider using instruments that capture a wider range of both mobility (eg, MAT-sf) and LUTS (eg, LURN SI-29).

Similarly, numerous prior studies have demonstrated that objective measures of physical performance, such as the SPPB and components of phenotypic frailty (gait speed and grip strength), are associated with the presence and severity of LUTS in older adults (5,32–40). For example, we previously demonstrated in the Health, Aging, and Body Composition Study that lower gait speed in older women and lower grip strength and quadriceps torque in older men are associated with prevalent UI and that decreasing grip strength is associated with increased risk of new or worsening incontinence in both older men (41) and older women (42). The current study builds upon the prior literature by confirming associations between LUTS severity and grip strength in older women and by demonstrating novel associations between LUTS overall, subtypes, and individual symptoms with important neuromuscular tests and muscle function measures, such as the Four Square Step Test and peak leg power. In terms of strength of association, most muscle health and physical performance measures were most strongly associated with the LURN SI-10 total score in women, although there were exceptions (eg, FSST was most strongly associated with voiding LUTS subscore). Our study findings suggest that both composite measures of overall LUTS as well as more focused UI measures are more consistently associated with muscle health and physical performance measures in older women compared to older men, although associations did vary by muscle and LUTS measure.

To our knowledge, this is the first study to examine the relationship between direct measures of skeletal muscle mass/volume, such as D3Cr muscle mass or MR thigh muscle volume, and LUTS outcomes. Prior studies have instead relied on weaker surrogates of muscle mass/volume, such as dual-energy x-ray absorptiometry to estimate appendicular lean (or fat-free) mass, bioimpedance analysis to estimate overall fat-free mass, or computed tomography to estimate psoas muscle area or density (35,41–44), which are less consistently associated with adverse health outcomes in community-dwelling older adults (45,46). Unlike self-reported mobility and physical performance, these skeletal muscle measures were not correlated with overall LUTS severity in women or men. Instead, we observed stronger correlations with LUTS subtypes or individual urinary

**Table 3.** Associations of Selected Physical Performance and Self-Reported Mobility Measures With Urinary Bother, Stratified by Sex

| | Women | | | Men | | |
|---|---|---|---|---|---|---|
| | Range | Not at All Bothered* | At Least Somewhat Bothered* | Range | Not at All Bothered* | At Least Somewhat Bothered* |
| 400-m usual pace walk speed, m/s, *n* (%) | | | | | | |
| Tertile 1 | 0.46–<0.95 | 57 (56) | 45 (44) | 0.55–<1.02 | 41 (58) | 30 (42) |
| Tertile 2 | 0.95–<1.09 | 69 (57) | 52 (43) | 1.02–<1.16 | 62 (71) | 25 (29) |
| Tertile 3 | 1.09–1.59 | 117 (76) | 37 (24) | 1.16–1.49 | 69 (65) | 37 (35) |
| *p* Value† | | <.001 | | | .21 | |
| Short Physical Performance Battery‡, *n* (%) | | | | | | |
| Low | 3–9 | 53 (58) | 39 (42) | 3–9 | 29 (67) | 14 (33) |
| High | 10–12 | 189 (67) | 95 (33) | 10–12 | 143 (65) | 78 (35) |
| *p* Value† | | .12 | | | .72 | |
| Four Square Step Test‡, s, *n* (%) | | | | | | |
| Tertile 1 | 4.9–<8.9 | 83 (71) | 34 (29) | 4.5–<9.0 | 54 (65) | 29 (35) |
| Tertile 2 | 8.9–10.6 | 79 (69) | 35 (31) | 9.0–<10.9 | 57 (69) | 26 (31) |
| Tertile 3 | 10.6–32.6 | 67 (58) | 49 (42) | 10.9–21.4 | 52 (63) | 31 (37) |
| *p* Value† | | .07 | | | .71 | |
| Grip strength, kg, *n* (%) | | | | | | |
| Tertile 1 | 6–19 | 76 (61) | 49 (39) | 14–33 | 63 (66) | 33 (34) |
| Tertile 2 | 20–25 | 97 (66) | 50 (34) | 34–39 | 55 (65) | 30 (35) |
| Tertile 3 | 26–40 | 69 (68) | 33 (32) | 40–62 | 52 (64) | 29 (36) |
| *p* Value† | | .52 | | | .98 | |
| Mobility Assessment Tool-short form‡, *n* (%) | | | | | | |
| Tertile 1 | 39.5–<64.2 | 64 (55) | 53 (45) | 38.8–<69.0 | 51 (58) | 37 (42) |
| Tertile 2 | 64.2–<70.3 | 111 (68) | 52 (32) | 69.0–<70.3 | 40 (61) | 26 (39) |
| Tertile 3 | 70.3–73.1 | 58 (68) | 27 (32) | 70.3–73.1 | 68 (73) | 25 (27) |
| *p* Value† | | .04 | | | .08 | |

*Notes*: D3Cr = $D_3$-creatine, kg = kilograms, m = meters, *n* = sample size, Nm = Newton-meters, s = seconds.
*Assessed by asking "In the past 7 days, how bothered were you by urinary symptoms?" and 4 response options range from "Not at all bothered" to "Extremely bothered."
†*p* Value calculated using chi-square test.
‡Higher Short Physical Performance Battery (SPPB) score indicates better functioning. Lower Four Square Step Test time indicates better balance. Higher Mobility Assessment Tool-Short Form score indicates better mobility.

symptoms, particularly UI, suggesting that the phenotype of sarcopenia-related LUTS likely involves a more specific subset of symptoms compared to LUTS related to declining mobility or physical performance. Additional work is needed to determine which urinary symptom clusters are most strongly correlated with and potentially caused by age-related decline in skeletal muscle health and whether measures of pelvic floor or abdominal muscles (which were not included in this study) are more strongly correlated with specific clusters. In particular, these future studies should assess direct measures of skeletal muscle mass and volume as well as the full spectrum of LUTS in both sexes.

The mechanisms underlying the relationship between LUTS and mobility limitations, including muscle health and global physical performance as potential mediators, remain hypothetical but several overlapping frameworks have been proposed (35,47,48). Collectively, these frameworks include the following possible interpretations of observed associations: (1) LUTS cause older adults to limit their physical activity, which causes declines in muscle health and physical performance and eventually lead to mobility limitations; (2) age-related declines in muscle health, physical performance, and physical activity directly cause LUTS or indirectly cause functional LUTS via mobility limitations (eg, normal lower urinary tract function and ability to sense bladder fullness but strong urges to urinate or urine leakage prior to reaching the toilet due to mobility deficits); (3) LUTS and age-related declines in muscle health and physical performance share common pathophysiology, such as geroscience mechanisms affecting multiple organs (eg, mitochondrial dysfunction (49)) or organ-specific pathology (eg, prefrontal cortex dysfunction (50)) affecting both genitourinary and lower extremity function; (4) LUTS and mobility limitations are both geriatric syndromes with multifactorial causes (eg, sarcopenia, cognitive decline, hormone dysregulation, chronic inflammation, etc.) that cumulatively lead to reduced compensatory ability, and; (5) LUTS is on the disablement pathway and an indicator of declining physical function that will eventually result in major mobility disability. Longitudinal studies with repeated measures of muscle health, physical performance, mobility limitations, and LUTS are needed to begin disentangling this complex relationship and to test core assumptions of these potential explanations.

In addition to potentially shared mechanistic pathways, there are also sex-specific differences in LUTS pathophysiology that may explain some of our findings. For example, menopause may contribute to both genitourinary syndrome of menopause and sarcopenia in older women, and metabolic syndrome may contribute to both prostatic hypertrophy and sarcopenia in older men. Age-related declines in muscle health could also disproportionately affect individual LUTS that drive the LURN SI-10 total score that are more common in older women, such as urgency with and without UI, explaining why fewer associations were observed in men. Straining, hesitancy, and intermittent urinary stream are common voiding LUTS in older men but were not assessed in this study. The results of this study suggest that muscle health and physical performance do not appear to be correlated with the same individual LUTS assessed by the LURN SI-10 in women and men, except for possibly urinary urgency with and without incontinence. Future investigations of sex-specific mechanistic pathways connecting LUTS and mobility limitations would be strengthened by including comprehensive LUTS assessments and genitourinary assessments.

Strengths of this multicenter cohort study include state-of-the-art skeletal muscle mass/volume, upper and lower extremity muscle function, global physical performance, mobility measures, and a comprehensive LUTS questionnaire that was developed in both women and men. We also recognize several limitations in our study. First, study participants were community-dwelling older adults, predominantly (86%) non-Hispanic White, and did not have Parkinson's disease, major mobility disability, or severe obesity, which limits generalizability to older adults who are institutionalized, more racially diverse, or who meet any of the SOMMA exclusion criteria. We also had a smaller sample, and therefore less power, to test for associations in men. Second, this cross-sectional analysis was limited to data collected during the baseline SOMMA visit; therefore, the temporality of observed associations remains unexplored. Third, a minimally important difference in the LURN SI-10 has not been published by the LURN team, a 7-day recall period may underestimate the burden of more mild-to-moderate LUTS severity in this study population (particularly among men), and there is only one item per individual urinary symptom. The limited dimensionality of the LURN SI-10 limits our ability to investigate associations with LUTS subtypes and may also bias our analyses towards the null. Additional studies are needed to validate these findings using legacy measures or LUTS tools with multiple items per symptom or cluster of symptoms and qualitative data or new instruments may be required to capture muscle-related LUTS not captured in the validated LUTS questionnaires currently available. Fourth, we did not have specific measures of pelvic floor skeletal muscle mass, volume, strength, or power. Lastly, observed associations could be due to multiple comparisons and/or residual confounding and must be validated.

In conclusion, overall LUTS severity was inversely associated with balance and upper extremity strength in older women, although correlations were generally weak. Associations with LUTS subtype or individual urinary symptoms were also consistently stronger among older women but the strength of association varied by muscle health or physical performance measure. Among women, age-related changes in skeletal muscle could partially explain the relationship between LUTS, particularly UI, and mobility limitations and should therefore be evaluated in longitudinal studies. Skeletal muscle measures are less strongly associated with LUTS severity in men and, therefore, nonmuscle factors may play a larger role in explaining the relationship between male LUTS and mobility limitations.

## Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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## Conflict of Interest

None.

## Data Availability

Publicly available data: https://sommaonline.ucsf.edu

## Author Contributions

S.R.B.: Conception and design, acquisition of data, analysis and interpretation of data, drafting and revising the article, final approval of the version to be published. C. P.-A.: Conception and design, analysis and interpretation of data, revising the article for important intellectual content, final approval of the version to be published. K.L.: Conception and design, acquisition of data, analysis and interpretation of data, revising the article for important intellectual content, final approval of the version to be published. S.R.C.: Analysis and interpretation of data, revising the article for important intellectual content, final approval of the version to be published. R.T.H.: Analysis and interpretation of data, revising the article for important intellectual content, final approval of the version to be published. R.S.: Conception and design, analysis and interpretation of data, revising the article for important intellectual content, final approval of the version to be published. K.C.: Conception and design, analysis and interpretation of data, revising the article for important intellectual content, final approval of the version to be published. P.M.C.: Conception and design, acquisition of data, analysis and interpretation of data, revising the article for important intellectual content, final approval of the version to be published. Sponsor's role: The study funders had no role in the design, methods, subject recruitment, data collections, analysis, or preparation of this paper.

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