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Research Article

Associations of Computed Tomography-Based Trunk Muscle Size and Density With Balance and Falls in Older Adults

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Abstract

Background. Deficits in balance and muscle function are important risk factors for falls in older adults. Aging is associated with significant declines in muscle size and density, but associations of trunk muscle size and density with balance and falls in older adults have not been previously examined.

Methods. Trunk muscle size (cross-sectional area) and attenuation (a measure of tissue density) were measured in computed tomography scans (at the L2 lumbar level) in a cohort of older adults (mean ± *SD* age of 81.9 ± 6.4) residing in independent living communities. Outcome measures were postural sway measured during quiet standing and Short Physical Performance Battery (SPPB) at baseline, and falls reported by participants for up to 3 years after baseline measurements.

Results. Higher muscle density was associated with reduced postural sway, particularly sway velocities, in both men and women, and better Short Physical Performance Battery score in women, but was not associated with falls. Larger muscle size was associated with increased postural sway in men and women and with increased likelihood of falling in men.

Conclusions. The results suggest that balance depends more on muscle quality than on the size of the muscle. The unexpected finding that larger muscle size was associated with increased postural sway and increased fall risk requires further investigation, but highlights the importance of factors besides muscle size in muscle function in older adults.

Keywords: Balance-biomechanics—Sarcopenia—Incident falls—Muscle composition—Postural sway

Every year 30%–40% of adults aged 65 and older fall, and falls are a common cause of injury and death in older adults (1–3). Deficits in balance and muscle function are among the most important risk factors for falls (1,3), although studies measure balance in a wide variety of ways. A common approach to measuring balance is quantifying postural sway while standing on a force platform. Prospective studies indicate that postural sway increases with age (4,5), and that increased postural sway, particularly in mediolateral motion, is predictive of falls in older adults (6,7).

Muscles in the lumbar and abdominal region are thought to play an important role in trunk stability (8,9). Aging is associated with significant declines of muscle size and strength (10,11), and muscle size and tissue density can be measured on computed tomography (CT) scans. Low CT-based density indicates fat accumulation within the muscle tissue (12), and CT-based density is lower in older adults than younger adults (13). Low trunk muscle density is associated with lower functional capacity (14), faster declines in functional capacity (15), more low back pain (14), greater hyperkyphosis (16), and lower trunk extension strength (17) in older adults. In addition, a recent cross-sectional study found lower gluteal muscle density in fallers than nonfallers (18), and low thigh muscle density is predictive of fractures in older adults (19,20). However, despite the potential importance of trunk muscles to trunk stability, the associations of trunk muscle size and density with balance and falls in older adults have not been previously examined.

The aims of this study were to determine if CT-based trunk muscle size and density are cross-sectionally associated with postural sway and physical function, and predictive of incident falls in older adults. We hypothesized that higher trunk muscle size and density would be associated with lower postural sway and higher Short Physical Performance Battery (SPPB) score, and that higher trunk muscle size and density would be associated with reduced likelihood of falling.

Methods

Participants

This was a secondary analysis of data from a clinical trial testing low intensity whole body vibration to improve bone density (21). Detailed inclusion and exclusion criteria have been described previously (22). Briefly, participants were cognitively intact men (n = 57) and women (n = 117) over the age of 60 with osteopenia (sex-specific bone mineral density T-score < −1 and > −2.5) residing in independent living communities in the Boston metropolitan area. Exclusion criteria included known terminal disease, weight ≥ 250 pounds, nonambulatory, hip or total knee replacement, and history of recent fragility fracture. The initial trial period was 2 years, but 55 participants took part in an extension of the trial for a third year. For the primary study (21), participants were randomized to daily exposure to a vibrating platform (active), or to a nonvibrating platform (placebo), but groups were combined for this analysis. Protocols were approved by the Institutional Review Board of Hebrew SeniorLife and Beth Israel Deaconess Medical Center and participants supplied written informed consent.

CT-Based Muscle Measurements

The independent variables were muscle cross-sectional area (CSA, cm^2) and density (x-ray attenuation in Hounsfield Units, HU) as measured on CT scans for four muscle groups (all muscles, paraspinal, posterior abdominal, anterior abdominal), as shown in Figure 1. All participants underwent CT scanning of the lumbar spine (L1 and L2) at baseline on the same helical CT scanner operating at 120 kVp, 150 mAs, 48 mm field of view, and 1 mm slice thickness. Individual muscles were traced in the mid-vertebral slice at the L2 level, or the L1 level if L2 was not available (n = 4), using an image processing program (Analyze, Biomedical Imaging Resource, Mayo Clinic, Rochester, MN (23)). Muscle CSA was calculated as CSA within the muscle contour, and density as the mean of voxel attenuation within the muscle contour, averaging the right and left sides. Attenuation values were zeroed based on the attenuation of a nominally 0 HU chamber in a hydroxyapatite phantom (Image Analysis, Inc., Columbia, KY), and voxels outside the range of −50 to 150 HU were excluded to exclude pure fat or bone. This approach provides good inter- and intra-reader reliability (most intraclass correlation coefficients > .90) for muscle CSA and attenuation measurements (13), and all measurements in this study were performed by a single trained reader with similar reliability.

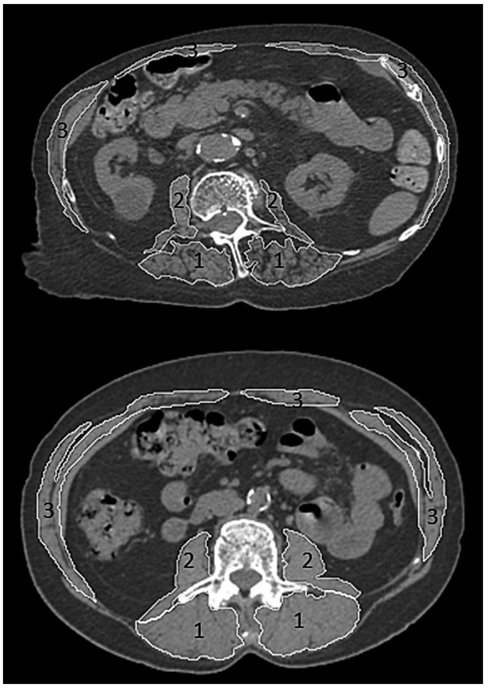

Figure 1. Examples of muscle groups measured in computed tomography scans at the L2 level of the spine in a participant with low muscle density (top) and high muscle density (bottom). Muscle grouping examined included: 1) paraspinal muscles (erector spinae and transversospinalis), 2) posterior abdominal muscles (psoas major and quadratus lumborum), and 3) anterior abdominal muscles (rectus abdominis, external oblique, and internal oblique).

Postural Sway and Physical Function

Postural sway was measured at baseline with an eight-channel force plate (Kistler, Winterthur, Switzerland). As described previously (22,24), participants stood as still as possible with hands at sides, eyes open, and feet at shoulder width for 4 minutes while center of pressure (CoP) position data were sampled at 1000 Hz. Data were low-pass filtered at 50 Hz, and postural sway variables were calculated as previously described (24). Variables analyzed in this study were the root mean square of the anteroposterior (AP) CoP motion (mm), root mean square of the mediolateral (ML) CoP motion (mm), root mean square of the AP velocity of CoP motion (mm/s), and root mean square of the ML velocity of CoP motion (mm/s). Physical function was measured using the SPPB (25,26), which includes gait speed, sit to stand, and standing balance components.

Self-reported Falls

Falls history at baseline was self-reported as a fall within the previous 6 months. The primary falls outcome was the number of falls during the follow-up period of up to 3 years. Falls were self-reported every other month by a mail-in questionnaire asking participants if they had fallen to the ground or lower surface (22). If no questionnaire was received, study staff contacted participants by phone to ascertain fall status.

Statistical Analysis

Linear regression models were constructed to estimate the associations of muscle measurements with postural sway and with SPPB score. Associations between muscle measurements and incident fall rates were examined using Poisson regression, adjusting for the number of successfully completed fall questionnaires during follow-up.

For each outcome measure, we conducted two analyses: unadjusted, including muscle CSA and density, and fully adjusted, which additionally controlled for age, weight, baseline fall history, and score on the Physical Activity Scale for the Elderly (27). Due to sex-specific differences in both postural sway and muscle, analyses were stratified by sex. Additional adjustment for treatment group (active vs placebo) was also examined but did not markedly alter the results. Similarly, baseline fall history was removed from adjusted models to check for potential bias, but results were similar and fall history was included in the reported analyses. Beta estimates and incidence rate ratios per 1-*SD* increase in muscle measurement are reported. A p value < .05 was considered to be statistically significant. All analyses were performed using SAS version 9.3 (SAS Institute, Inc., Cary, NC).

Results

Descriptive statistics for participant characteristics, postural sway, SPPB, and muscle measurements are reported in Table 1. At baseline, 17.9% of men and 13.7% of women reported having a fall during the previous 6 months. Follow-up time ranged from 0 to 36 months, with a median of 24 months, and mean ± *SD* of 21.4 ± 11.4 months. During follow-up, a total of 57 falls were recorded in 19 men (33.3%), and a total of 119 falls were recorded in 57 women (48.7%).

Muscle CSA and density were associated with the outcome measures in fully adjusted models as reported in Table 2 (unadjusted model results are available in Supplementary Table 1). Larger CSA of paraspinal and posterior abdominal muscles in men and larger CSA of anterior abdominal muscles in women were associated with increased AP motion. Larger CSA of anterior abdominal and posterior abdominal muscles was associated with increased AP velocity in women, but not men. Muscle CSA was not associated with ML motion, whereas larger CSA of anterior abdominal muscles was associated with increased ML velocity in women only. Higher density of the paraspinal and posterior abdominal muscles was associated with reduced AP motion in men (unadjusted and adjusted models) and women (unadjusted models only), with reduced ML motion in men (unadjusted models only) and women (unadjusted and fully adjusted models), and with reduced AP velocity and ML velocity in men and women (unadjusted and adjusted models). Higher density of the anterior abdominal muscles was associated with reduced AP velocity in women (unadjusted model only). Higher muscle density was associated with better SPPB performance in women, but this association was only significant for the posterior abdominal muscles in men (unadjusted model only).

Larger muscle CSA was associated with increased incidence of falls in men for all muscle groups in adjusted models (Table 3). In women, higher posterior abdominal muscle density was associated with reduced incidence of falls (unadjusted model only, see Supplementary Table 2).

Table 1. Participant Characteristics, Postural Sway Measures, and Muscle Measurements at Baseline

	Men	Women
N	57	117
Age at baseline (y)	83.7 (5.9)	81.1 (6.5)
Body weight (kg)	79.7 (11.9)	67.4 (12.2)
Physical Activity Scale for the Elderly	72.4 (43.2)	88.6 (51.7)
Fall in past 6 mo (%)	17.9	13.7
Postural sway and physical function		
RMS of AP motion (mm)	4.92 (1.60)	4.00 (1.30)
RMS of AP velocity (mm/s)	21.8 (11.2)	14.9 (9.2)
RMS of ML motion (mm)	3.28 (1.58)	2.50 (1.27)
RMS of ML velocity (mm/s)	10.1 (4.2)	8.9 (2.8)
Short Physical Performance Battery	8.9 (2.9)	9.2 (2.6)
Muscle measurements		
All muscles		
CSA (cm^2)	53.9 (9.5)	38.1 (6.1)
Density (HU)	23.3 (8.6)	17.4 (10.1)
Paraspinal		
CSA (cm^2)	21.8 (4.3)	15.7 (2.9)
Density (HU)	27.2 (9.8)	21.2 (12.1)
Posterior abdominal		
CSA (cm^2)	8.2 (2.0)	5.7 (1.3)
Density (HU)	30.7 (7.2)	29.7 (8.4)
Anterior abdominal		
CSA (cm^2)	20.2 (4.7)	14.4 (3.0)
Density (HU)	18.4 (11.7)	11.0 (12.0)

Notes: AP = anteroposterior; CSA = cross-sectional area; ML = mediolateral; RMS = root mean square; HU = Hounsfield Units.

Discussion

The results support the hypothesis that high trunk muscle density is indicative of better balance, but this did not translate into reduced likelihood of falling. However, larger trunk muscle size was indicative of worse balance and increased risk for falls. The finding that larger muscle size indicates more postural sway suggests that muscular strength alone is not sufficient for good balance. Strength is likely important, as strength training programs generally improve measures of balance in older adults (28). However, current evidence does not indicate that strength training alone reduces falls in older adults, although exercise interventions that include multiple types of exercise can reduce falls, as can Tai Chi movement training (29). Balance likely depends on other components of muscular function such as neuromuscular control and fatigue resistance. Muscle fatigue reduces postural stability (30), as does prolonged standing (31), and the 4-minute testing period in this study might have induced fatigue and increased postural sway in some older participants. The finding that lower muscle density was associated with more postural sway suggests that low density may be a marker of declines in these other areas of muscle function.

The most consistent result was a negative association between muscle density and postural sway, particularly sway velocity. For example, 1 *SD* (about 10–12 HU) higher paraspinal muscle density translated to about 10%–20% lower sway velocity. This is the first study to directly associate muscle density with a quantitative measure like postural sway, providing novel evidence that low trunk muscle density is associated with poor balance in older adults. Similarly, positive associations were found between muscle density and SPPB score in women, consistent with reported associations with the Health ABC Physical Performance Battery, which also incorporates tests that challenge balance (14,15). The lack of such associations in men may be due to limited statistical power and/or smaller effects. However, no consistent association was found between muscle density and fall incidence. Thus, although low density muscle may indicate impaired balance control, it is not a strong predictor of fall risk.

Unexpectedly, the results indicate that larger trunk muscle size is associated with worse balance and more falls. For example, 1 *SD*

Table 2. Associations of Postural Sway With Muscle Size and Density in Men and Women

	Men	Women
RMS of AP motion		
All muscles		
CSA	**0.78 (0.16, 1.39)**	0.24 (−0.03, 0.52)
Density	**−0.70(−1.19, −0.22)**	−0.11 (−0.40, 0.19)
Paraspinal		
CSA	**0.67 (0.10, 1.23)**	0.03 (−0.24, 0.30)
Density	**−0.79 (−1.26, −0.31)**	−0.23 (−0.51, 0.04)
Posterior abdominal		
CSA	**0.49 (0.06, 0.91)**	0.06 (−0.19, 0.32)
Density	**−0.91 (−1.36, −0.45)**	−0.14 (−0.42, 0.14)
Anterior abdominal		
CSA	0.56 (−0.04, 1.16)	**0.39 (0.14, 0.64)**
Density	−0.39 (−0.91, 0.12)	0.05 (−0.22, 0.32)
RMS of AP velocity		
All muscles		
CSA	−1.63 (−5.76, 2.51)	**2.84 (1.10, 4.58)**
Density	**−4.62 (−7.89, −1.35)**	**−2.49 (−4.21, −0.63)**
Paraspinal		
CSA	−1.36 (−5.27, 2.55)	1.52 (−0.24, 3.27)
Density	**−4.23 (−7.49, −0.97)**	**−2.20 (−3.99, −0.41)**
Posterior abdominal		
CSA	0.52 (−2.23, 3.27)	**2.24 (0.59, 3.89)**
Density	**−6.76 (−9.72, −3.81)**	**−2.22 (−4.04, −0.40)**
Anterior abdominal		
CSA	−0.26 (−4.41, 3.88)	**2.69 (1.01, 4.36)**
Density	−2.89 (−6.41, 0.64)	−1.57 (−3.33, 0.19)
RMS of ML motion		
All muscles		
CSA	0.25 (−0.41, 0.90)	0.04 (−0.23, 0.30)
Density	−0.38 (−0.90, 0.14)	−0.19 (−0.47, 0.09)
Paraspinal		
CSA	0.15 (−0.44, 0.75)	−0.13 (−0.39, 0.12)
Density	−0.42 (−0.92, 0.02)	**−0.36 (−0.63, −0.10)**
Posterior abdominal		
CSA	0.35 (−0.11, 0.80)	0.06 (−0.18, 0.31)
Density	−0.47 (−0.96, 0.02)	**−0.30 (−0.57, −0.02)**
Anterior abdominal		
CSA	0.15 (−0.47, 0.77)	0.21 (−0.04, 0.46)
Density	−0.16 (−0.68, 0.37)	−0.01 (−0.27, 0.26)
RMS of ML velocity		
All muscles		
CSA	0.26 (−1.33, 1.85)	**0.67 (0.12, 1.21)**
Density	**−2.14 (−3.40, −0.50)**	−0.56 (−1.15, 0.02)
Paraspinal		
CSA	−0.17 (−1.65, 1.30)	0.09 (−0.45, 0.63)
Density	**−2.00 (−3.23, −0.77)**	**−0.80 (−1.35, −0.25)**
Posterior abdominal		
CSA	0.61 (−0.47, 1.68)	0.48 (−0.03, 1.00)
Density	**−2.60 (−3.76, −1.44)**	**−0.68 (−1.24, −0.11)**
Anterior abdominal		
CSA	0.73 (−0.88, 2.33)	**0.92 (0.41, 1.43)**
Density	−1.35 (−2.71, 0.01)	−0.15 (−0.69, 0.39)
SPPB		
All muscles		
CSA	0.47 (−0.54, 1.48)	0.14 (−0.33, 0.62)
Density	0.34 (−0.45, 1.14)	**0.75 (0.24, 1.26)**
Paraspinal		
CSA	0.31 (−0.60, 1.22)	0.22 (−0.25, 0.68)
Density	0.48 (−0.27, 1.22)	**0.50 (0.01, 0.98)**
Posterior abdominal		
CSA	0.08 (−0.64, 0.80)	−0.22 (−0.65, 0.21)
Density	0.67 (−0.09, 1.44)	**1.03 (0.56, 1.50)**
Anterior abdominal		
CSA	0.10 (−0.86, 1.07)	−0.08 (−0.53, 0.37)
Density	0.15 (−0.66, 0.97)	**0.72 (0.24, 1.19)**

Notes: Beta coefficients per *SD* increase in muscle measure (95% confidence interval) for fully adjusted models. Fully adjusted models include age, weight, Physical Activity Scale for the Elderly, and baseline falls history as covariates. Associations in bold are significant ($p < .05$). AP = anteroposterior; CSA = cross-sectional area; ML = mediolateral; RMS = root mean square; SPPB = Short Physical Performance Battery.

Table 3. Incidence Rate Ratios (IRRs) per *SD* Increase in Muscle Measure (95% confidence interval) for Falls During Follow-up in Men and Women, Fully Adjusted Models

	Men	Women
All muscles		
CSA	**2.35 (1.24, 4.45)**	1.14 (0.84, 1.55)
Density	1.44 (0.69, 2.97)	1.05 (0.74, 1.48)
Paraspinal		
CSA	**2.04 (1.12, 3.70)**	0.86 (0.63, 1.17)
Density	2.11 (0.91, 4.89)	1.05 (0.77, 1.44)
Posterior abdominal		
CSA	**2.12 (1.13, 3.97)**	1.21 (0.94, 1.56)
Density	0.81 (0.41, 1.60)	0.83 (0.61, 1.12)
Anterior abdominal		
CSA	**2.20 (1.12, 4.34)**	1.23 (0.92, 1.64)
Density	0.87 (0.43, 1.80)	1.16 (0.84, 1.60)

Notes: Models adjust for follow-up time and include age, weight, Physical Activity Scale for the Elderly, and baseline falls history as covariates. IRRs in bold are significant ($p < .05$). CSA = cross-sectional area.

larger muscle CSA indicates about 15% larger AP motion in men, and about 19% larger AP velocity in women. Similarly, men (but not women) with 1 *SD* larger muscle CSA were more than twice as likely to fall during follow-up. These findings are counter to our hypotheses, necessitating considerations of possible explanations. First, we questioned whether larger muscle might be of lower quality, although in post hoc analysis, CSA was positively correlated with muscle density ($r = .275$, $p < .001$ for all muscles), which does not support this idea. Second, one might speculate that greater strength without proper neuromuscular control could impair balance. Antagonistic co-contraction is increased in older adults at the ankle, possibly in an attempt to increase stability and counteract declines in postural control, but this co-contraction is associated with increased postural sway (32). Increased age-related co-contraction in the trunk muscles might negatively affect postural sway more in individuals with larger or stronger muscles. Third, muscle CSA may not be representative of muscle strength and function as it relates to balance and fall risk in older adults. The association of trunk strength with muscle CSA in older adults is moderate (eg, $r = .61$ with total L4-level muscle CSA (17)), leaving a large amount of variance unexplained by muscle size. Furthermore, muscle strength declines more rapidly with age than muscle mass or CSA (10,11), suggesting that other factors besides size are important for strength in older adults. Fourth, greater weight is associated with increased postural sway (33), as well as greater muscle CSA (34), although including weight as a covariate did not change the association of CSA with balance or falls. Fifth, individuals with larger muscles may be more confident or allow greater postural sway, as strength training and agility training both decrease fear of falling in older adults while having little effect on postural stability or fall risk score (35). Finally, individuals with larger muscles may be more physically active, and very active older adults are more likely to fall (36,37), although we adjusted for self-reported physical activity. Overall, the results suggest that larger muscle size in older adults worsens balance and likelihood of falls, a finding that should be confirmed and explained in future research.

This study has several important limitations. The study cohort of osteopenic older adults from independent living communities may limit the applicability of the findings in other populations, and the sample size, particularly in men, limited statistical power. Falls were self-reported, raising the possibility for omissions or reporting errors. Only four commonly reported measures of postural sway were analyzed, although other measures may be calculated from force platform data, and such measures do not fully represent "balance," which is multifactorial in nature. Similarly, falls have numerous risk factors besides musculoskeletal or postural measures, including cognitive, visual, vestibular, and environmental factors. Finally, CT-based measures of muscle size and density remain primarily of investigative interest and their clinical utility remains uncertain.

The unique aspects of this study include the comparison of trunk muscle size and density with quantitative measures of balance and with incident falls. Higher muscle density, reflecting lower fat content in the muscle, is indicative of less postural sway in older men and women, whereas larger muscle size is indicative of increased postural sway in men and women and of increased likelihood of falling in men. These apparently opposite effects are the most intriguing result, and future research should clarify how muscle size and density are related to muscle strength and function, and how age-related changes might affect these relationships. This could help explain our findings and would have implications for assessing muscle properties when predicting functional outcomes.

Supplementary Material

Please visit the article online at http://gerontologist.oxfordjournals.org/ to view supplementary material.

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Conflict of Interest

Dr. Kiel has received grant funding from Eli Lilly, received royalty payments from Wolters Kluwer for authoring an UpToDate chapter on falls, and served on scientific advisory boards for Novartis. Dr. Rubin is a founder of Marodyne Medical. All other authors state they have no disclosures.

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