THE GERONTOLOGICAL SOCIETY OF AMERICA®

Journals of Gerontology: Medical Sciences
cite as: *J Gerontol A Biol Sci Med Sci*, 2016, Vol. 71, No. 3, 385–390
doi:10.1093/gerona/glv136
Advance Access publication August 21, 2015

OXFORD

Research Article

Leg Muscle Mass and Foot Symptoms, Structure, and Function: The Johnston County Osteoarthritis Project

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Received October 31 2014; Accepted July 20 2015

Decision Editor: Stephen Kritchevsky, PhD

Abstract

Background. Loss of muscle mass occurs with aging and in lower limbs it may be accelerated by foot problems. In this cross-sectional analysis, we evaluated the relationship of leg muscle mass to foot symptoms (presence or absence of pain, aching, or stiffness), structure while standing (high arch or low arch), and function while walking (pronated or supinated) in a community-based study of Caucasian and African American men and women who were 50–95 years old.

Methods. In the Johnston County Osteoarthritis Project, leg muscle mass was measured with whole body dual-energy x-ray absorptiometry, and plantar foot pressure data, using predetermined values, were used to classify foot structure and function. Sex-specific crude and adjusted (age, body mass index, and race) linear regression models examined associations of leg muscle mass index (Leg muscle mass [kg] / Height [m]^2) with foot symptoms, structure, and function.

Results. Complete data were available for 1,037 participants (mean age 68 years, mean body mass index 31 kg/m^2, 68% women, 29% African American). In women, pronated foot function was associated with lower leg muscle mass in crude (p = .02), but not adjusted (p = .22), models. A low arch was associated with a higher leg muscle mass in adjusted models for both men and women ($p < .01$).

Conclusions. Leg muscle mass was associated with foot structure in our biracial sample, whereas relations between leg muscle mass and foot function were attenuated by age, body mass index, and race. Future longitudinal analyses are needed to explain the temporal relationship between these conditions and how they relate to other aspects of impairment and physical function.

Key Words: Foot—Pain—Muscle—Gait—Cohort study

Poor physical function, disability, and falls have been linked to foot pain (1–5), high toe pressures of the foot during walking (6), and decreased plantar flexor strength (4,5). Theoretically, a pathway to disability and falls may begin with foot problems. Structural or functional disorders of the foot or pain in the foot may contribute to weakness or loss of the musculature of the foot and lower leg. Over time, particularly in combination with age-related muscle loss, the resulting muscle weakness attributed to these foot problems may lead to functional limitations and overall physical decline. Leg muscle mass is a marker of mechanical loading and has been shown to be associated with physical function (ie, higher lean mass is associated with better function) (7,8), but little is known about how foot pain or the structure and dynamic function of the foot might affect leg muscle mass.

In clinical populations, poorer muscle function of the lower extremity has been linked with flatfoot deformity (9), and among runners, overpronation of the foot is seen among individuals with lower extremity muscle weakness (10). Recently, McLean and colleagues (11) examined the cross-sectional associations between leg muscle mass and foot pain, posture, and function in the first large community-based study. In the Framingham Foot Study cohort (average age 67 years, 43% men, all Caucasian), reduced leg muscle mass was associated with foot pain and pronation, with some results suggesting potential differences by sex. However, the time difference between assessment of leg muscle mass and foot exam (on average 6.7 years) was a limitation that may have underestimated the associations between the two measures; the authors adjusted for potential age-related loss in their analyses by assuming a constant rate across all participants, but leg muscle mass loss over time likely varied.

Our prior work has shown differences in foot type and disorders between African Americans and Caucasians (12,13), and no prior population-based study has reported associations of leg muscle mass and the foot among African Americans. The purpose of this cross-sectional analysis was to examine the association of foot symptoms, foot structure, and foot function with leg muscle mass in a community-based study of Caucasian and African American men and women 50 years of age or older. Along with the inclusion of African Americans, this investigation benefited from the acquisition of leg muscle mass and foot exam data during the same study visit. We hypothesized that foot symptoms and more extreme foot structures (eg, high arch or low arch foot types) and poorer foot function (eg, supination or pronation, correspondingly described as excessive outward or inward rolling of the foot while walking) would be linked to lower leg muscle mass, even after controlling for other potential confounders of sex, race, age, and obesity.

Methods

Study Participants

Participants were from the community-based Johnston County Osteoarthritis Project, an ongoing, prospective study of osteoarthritis in African Americans and Caucasians living in a rural county in North Carolina. Civilian, noninstitutionalized residents aged 45 and older from six townships in Johnston County were enrolled between 1991 and 1997 (14), and additional Johnston County residents were enrolled during 2003–2004. Clinical examinations were completed by 1,695 participants during a follow-up visit conducted from 2006 to 2010, and participants were at least 50 years of age at this visit. Cross-sectional analyses for the present study were based on data collected during this follow-up visit. Participants completed an examination that included dual-energy x-ray absorptiometry, a walking plantar pressure assessment, and collection of demographic and clinical variables.

Leg Muscle Mass

Whole body dual-energy x-ray absorptiometry (Hologic QDR Delphi A, New Rochelle, NY) scans were obtained for eligible participants. These scans provide reliable measures of body composition, including lean body mass, total body fat mass, and leg lean mass (7,15–18). Individuals were considered ineligible to complete this scan if they had metal anywhere in their body. Participants were asked to lie supine and remain still during the exam, which took approximately 5 minutes while the scanner completed three passes over the body. Lean muscle mass of the leg (includes whole lower extremity below the pelvis) was measured in kilograms.

Foot Symptoms

Participants were asked to respond “yes” or “no” to the questions: “On most days, do you have pain, aching or stiffness in your [right/left] foot?”

Foot Structure and Foot Function

Plantar pressure data were collected at a sampling frequency of 40 Hz using a Tekscan Matscan System (Tekscan Inc, Boston, MA). This system has a 5-mm-thick floor mat (432 × 368 mm) with 2,288 resistive sensors (1.4/cm^2), and reliability for the MatScan system has been shown to be moderate to good (19). Scans were completed during standing (bipedal relaxed stance) and walking. For the walking scans, participants walked at a self-selected pace and scans were collected using the two-step method (ie, striking the foot mat on the second step) (20). Two trials were collected for each foot.

Foot structure was assessed using the Modified Arch Index (21). Using the maximum peak pressure image from the standing scan, the Modified Arch Index was calculated as the ratio of the area of the middle third of the foot to the whole foot area, excluding the toes. Modified Arch Index cutoff values were set a priori based on data from the Framingham Foot Study (3,100 participants with data available for 6,153 feet) (11) in which values in the lowest 20% for that cohort were considered to represent a high arch foot structure and those in the highest 20% represented a flat arch foot structure (22,23). Based on these values, we created a three-category foot structure variable in the present study in which high arch was defined as values ≤0.030, low arch as values ≥0.164, and values >0.030 to <0.164 were considered the referent category.

Foot function was determined by calculating the Center of Pressure Excursion Index (CPEI) from the walking trials data. The CPEI measures dynamic foot pronation and supination and is sensitive to changes in foot structure (24). To determine the CPEI, a line was drawn to connect the first and last center of pressure data points of the foot and the distance between this line and the center of pressure in the anterior third of the foot was measured. The CPEI was calculated as the distance between the lines and the center of pressure divided by the forefoot width. A lower CPEI suggested a more pronated foot, whereas a higher CPEI designated a more supinated foot during gait (24). The mean CPEI value for the two walking trials was used in the present study. CPEI cutoff values were set a priori based on values from the Framingham Foot Study (22,23). In the Framingham Cohort, values in the lowest 20% were considered to represent a pronated foot function (inward rolling of the foot during walking) and those in the highest 20% represented a supinated foot function (outward rolling). A three-category foot function variable was created for the present study based on these cutpoints, with CPEI values ≤7.3% for pronated foot function, values ≥21.0% for supinated foot function, and values >7.3% to <21.0% were considered the referent category.

Demographic and Clinical Characteristics

Age in years, female/male sex, body mass index (BMI; calculated as Weight in kilograms / Height in meters squared [kg/m^2]), and race (African American and Caucasian) were collected at the time of the exam. Weight was measured in pounds using a balance beam scale and converted to kilograms, and height without shoes was measured using a calibrated stadiometer in inches and converted to meters.

Analysis

Because leg muscle mass, foot symptoms, foot structure, and foot function may vary by sex, sex-specific analyses were conducted. Distributions of age, BMI, race, sex, leg muscle mass, foot symptoms, foot structure, and foot function were calculated. Sex-specific crude and adjusted (controlling first for age and BMI, then adding race (with Caucasian as referent) linear regression models were used to determine the association between leg muscle mass (response variable) and foot symptoms, structure, and function (explanatory variables). BMI was included as a covariate to account for adiposity, which is related to foot pain (25,26), foot function (13), and leg lean mass (27). For these models, a leg muscle mass index was created by dividing leg muscle mass (kg) by height (m) squared to create a measure of relative muscle mass compared with body size to account for the high correlation between absolute body mass and body height (28). Analyses were foot based rather than person based to examine associations within a given limb, and generalized estimating equations were used to adjust for correlations between right and left feet. Interactions of foot symptoms, foot structure, or foot function by age, BMI, or race were examined, and a $p < .10$ for interaction was considered statistically significant.

Results

Characteristics of Participants

Of the 1,695 Johnston County Osteoarthritis Project participants who attended the follow-up clinical exam visit, 643 participants were removed from analyses because of missing leg muscle mass data, followed by 12 for missing foot pain data, and 3 participants missing foot structure data on both feet, leaving 1,037 participants with complete data for this study. Additionally, 2 feet were deleted for missing foot structure data, and 29 feet for missing foot function data (Figure 1). Thirty-one of the 1,037 participants contributed only one foot to the analysis because values for the other foot were missing or improbable, and a total of 2,043 feet were analyzed (1,006 participants contributing both feet for a total of 2,012 feet and 31 participants contributing one foot).

Table 1 shows characteristics for the study sample and by men and women. Participants were 68% women and 29% African American with a mean age of 68 years (SD 8.7, range 50–95) and mean BMI of 30.5 kg/m^2 (SD 6.0). Eighteen percent of feet had symptoms. Seventeen percent of feet had a high arch foot structure, 27% had a low arch foot, 14% had a pronated foot function, and 19% had a supinated function. Leg muscle mass index was greater on average for men's than for women's legs (3.4 vs 2.9 kg/ m^2). Foot symptoms (20% vs 14%) and pronated foot function (16% vs 10%) were more common in women's than in men's feet.

Associations Among Men

Results of linear regression models are summarized in Table 2. In men, a high arch foot structure was associated with a lower leg muscle mass ($p < .001$) and a flat arch foot structure was associated with a higher leg muscle mass ($p < .001$) in crude models. After adjusting for age, BMI, and race, the association between a high arch foot structure and leg muscle mass was no longer statistically significant

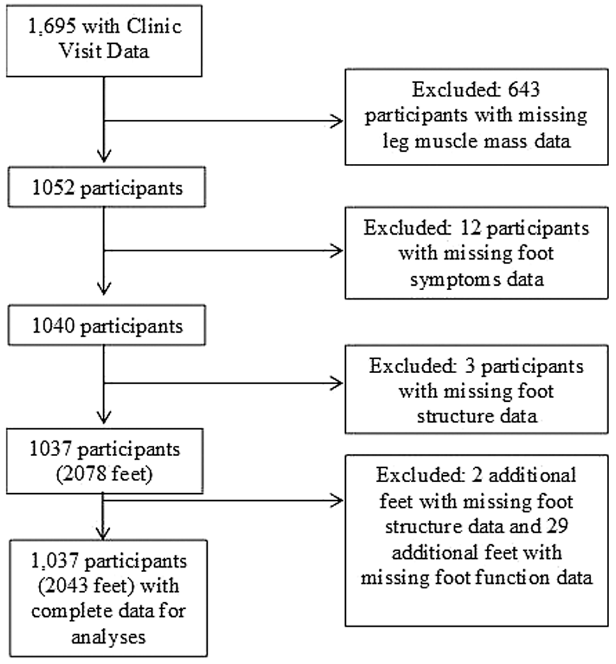

Figure 1. Johnston County Osteoarthritis Project participants included in analyses.

($p = .63$) whereas the relationship between a flat arch foot structure and higher leg muscle mass maintained significance ($p < .04$). Foot function and foot symptoms were not associated with leg muscle mass in men.

Associations Among Women

Among women, a high arch foot structure was associated with lower leg muscle mass ($p < .001$) and a flat arch foot structure with higher leg muscle mass ($p < .001$), but after adjustment, relationships for the high arch foot structure were not statistically significant whereas the linkage between flat arch foot structure and leg muscle mass maintained significance ($p = .02$). A pronated foot function was associated with lower leg muscle mass ($p = .02$), but these associations were attenuated in adjusted models. Foot symptoms were not associated with leg muscle mass in women.

Assessment of Statistical Interactions

Interactions were statistically significant for foot symptoms and race ($p = .02$) and foot function and BMI (BMI < 30 vs BMI ≥ 30 kg/m^2, $p = .09$), but no other interactions were significant. When associations between foot symptoms and leg muscle mass were stratified by race, foot symptoms were associated with lower leg mass among Caucasians (men: beta = −0.0502, $p = .30$; women: beta = −0.0264, $p = .24$) and with higher leg mass among African Americans (men: beta = 0.1042, $p = .21$; women: beta = 0.0888, $p = .13$), but these results were not statistically significant. When associations between foot function and leg muscle mass were stratified by BMI, a supinated foot function was associated with lower leg mass among those with BMI <30 kg/m^2 (men: beta = −0.0978, $p = .04$; women: beta = −0.0600, $p = .04$), whereas a pronated foot function was associated with lower leg mass among those with BMI ≥30 kg/m^2 (men: beta = −0.1210, $p = .02$; women: beta = −0.1075, $p = .02$).

Table 1. Characteristics of Sample, by Sex

	Study Sample	Men	Women
	N = 1037	*n* = 329 (31.7%)	*n* = 708 (68.3%)
Mean age, y (*SD*)	68 (8.7)	67 (8.7)	68 (8.8)
Mean BMI, kg/m^2 (*SD*)	30.5 (6.0)	30.2 (4.8)	30.6 (6.5)
Mean height, m (*SD*)	1.64 (0.09)	1.73 (0.07)	1.59 (0.06)
African American, *n* (%)	306 (30)	86 (26)	220 (31)
	N (feet) = 2043	*n* (feet) = 652 (31.9%)	*n* (feet) = 1391 (68.1%)
Mean leg muscle mass, kg (*SD*)	8.31 (2.01)	10.25 (1.66)	7.40 (1.44)
Mean leg muscle mass/height^2, kg/m^2 (*SD*)	3.08 (0.56)	3.41 (0.47)	2.92 (0.53)
Foot symptoms, *n* (%)	365 (18)	92 (14)	273 (20)
High arch foot structure, *n* (%)	353 (17)	115 (18)	238 (17)
Flat arch foot structure, *n* (%)	548 (27)	160 (25)	388 (28)
Pronated foot function, *n* (%)	284 (14)	68 (10)	216 (16)
Supinated foot function, *n* (%)	398 (19)	139 (21)	259 (19)

Note: BMI = body mass index.

Table 2. Associations of Foot Symptoms, Foot Structure, and Foot Function with Leg Muscle Mass / Height^2

			Men		Women	
	Model	Category	Beta (*SE*)	*p* Value	Beta (*SE*)	*p* Value
Foot symptoms	Crude	Symptoms present	0.056 (0.075)	.45	0.091 (0.048)	.06
	+ Age, BMI	Symptoms present	−0.010 (0.054)	.85	−0.038 (0.024)	.11
	+ Race	Symptoms present	−0.012 (0.044)	.79	−0.001 (0.022)	.98
Foot structure	Crude	High arch	−0.184 (0.047)	<.001	−0.336 (0.031)	<.001
		Flat arch	0.383 (0.056)	<.001	0.449 (0.037)	<.001
	+ Age, BMI	High arch	−0.038 (0.030)	.20	−0.071 (0.020)	.001
		Flat arch	0.211 (0.041)	<.001	0.116 (0.021)	<.001
	+ Race	High arch	0.014 (0.030)	.63	−0.030 (0.020)	.12
		Flat arch	0.079 (0.038)	.04	0.044 (0.019)	.02
Foot function	Crude	Pronated	−0.042 (0.066)	.52	−0.099 (0.042)	.02
		Supinated	−0.025 (0.055)	.65	−0.030 (0.042)	.47
	+ Age, BMI	Pronated	−0.042 (0.054)	.44	−0.001 (0.024)	.98
		Supinated	−0.061 (0.033)	.07	0.017 (0.020)	.38
	+ Race	Pronated	−0.058 (0.046)	.20	−0.025 (0.021)	.22
		Supinated	−0.052 (0.030)	.08	−0.001 (0.018)	.98

Note: BMI = body mass index.

Discussion

In women, foot structure and foot function were associated with leg muscle mass in this biracial sample, but age, BMI, and race attenuated relationships for foot function. In men and women, foot structure was associated with leg muscle mass, even after adjustment, suggesting a link between a low arch foot structure and a higher leg muscle mass. Estimates of associations for foot symptoms, foot structure, and foot function with leg muscle mass for men and women were generally similar in direction and magnitude. Our findings for associations between leg muscle mass and foot structure are consistent with those reported in the Framingham Foot Study (11), providing confirmation of their results in a different population that included African Americans and with simultaneous attainment of leg muscle mass and foot data.

The key result of a relationship between low arch foot structure and higher leg muscle mass countered our hypothesis of poorer foot structure with lower muscle mass, which we based on an assumption that foot problems may lead to less muscle mass in the legs, particularly with a loss of muscle function with aging. In our cross-sectional analyses, however, we could not account for temporality, and perhaps our results demonstrate either a nonsequential pairing of these two factors or that higher leg muscle mass may occur in response to a low arch foot structure in an attempt to provide greater muscular control to a dysfunctional medial longitudinal arch. Compared with individuals with normal-arched feet, Murley and colleagues (29) reported greater tibialis posterior and peroneus longus activation on electromyography during ambulation (ie, mid- and late-stance) in adults with low arch feet, suggesting that a low arch foot structure places "a greater demand" on the lower leg musculature that controls arch movement. Furthermore, Angin and colleagues (30) recently reported that greater cross-sectional area and extrinsic (ie, leg) muscle thickness were observed among 49 people with flat feet compared with 49 with normal foot posture. The authors suggest that the function of the intrinsic foot muscles may be limited by the flat foot structure, and the extrinsic muscles compensate for this deficiency.

Another interesting result of this study was the difference in foot function and leg muscle mass by obesity where a supinated foot function was associated with lower muscle mass among nonobese participants and a pronated foot function was associated with lower muscle mass among obese individuals. Interpretation of these results is challenging because of the cross-sectional nature of this study and the lack of knowledge about the sequence of events for obesity, foot function, and leg muscle mass either over the short term or over trajectories in an adult life span. Future longitudinal studies may clarify these findings.

Strengths of the present study are that it is community based, consists of African American and Caucasian men and women, includes a reliable measure of leg muscle mass, and comprises quantitative, biomechanical measures of foot structure and foot function. These foot pressure measures were captured twice and averaged to approximate representative foot structure and foot function measures for each participant. An additional strength is that the analyses were foot based and included left and right feet for an individual (when data were available), and statistical methods were used to account for correlated data within a participant.

A limitation of the present study is that a temporal relationship between foot symptoms, foot structure, foot function, and leg muscle mass cannot be inferred due to the cross-sectional study design. Potentially, associations were attenuated in the present study because of the cross-sectional nature, and a longitudinal analysis would assist in determining how they may be linked and whether there is an order of these components on the pathway to functional decline. The current study is a starting point. Repeat measures comparable with those used in the present analysis currently are being collected during a new follow-up visit for the Johnston County Osteoarthritis Project, and these data will allow for assessment of associations over time. Another limitation is that leg muscle mass may not be directly associated with muscle strength, and leg strength (31) or muscle quality (32) may have been more suitable measures when examining foot symptoms, structure, and function. However, muscle strength and quality variables for the lower extremity were not available for this secondary analysis.

Overall, the results of this study suggest that foot symptoms and foot function may not be associated with leg muscle mass when examined at a single time point and when controlling for individual characteristics. However, a flat arch foot structure may be associated with higher leg muscle mass, and longitudinal analyses may help elucidate this relationship. Given the lack of publications concerning foot symptoms, structure, and function in the community, these data are provocative and open the door for future work, especially research focusing on longitudinal changes. An essential aspect of future research will be how these conditions relate to other aspects of impairment and physical function.

Funding

This work was supported by the National Center for Advancing Translational Sciences, the National Institutes of Health(KL2TR000084 / UL1 TR000083); the Arthritis Foundation (Postdoctoral Fellowship), the National Institute of Arthritis and Musculoskeletal and Skin Diseases (R01 AR047853); and the Centers for Disease and Prevention Control / Association of Schools of Public Health (S043, S3486). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health, the CDC, or the Arthritis Foundation.

Conflict of Interest

None

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