Published in final edited form as:
Arthritis Care Res (Hoboken). 2012 January ; 64(1): 15–21. doi:10.1002/acr.20588.

Muscle Strength, Mass and Quality in Older Men and Women with Knee Osteoarthritis: Findings from Health, Aging and Body Composition Study

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Abstract

Objective—To examine the relationships between knee osteoarthritis (OA) and muscle parameters in a biracial cohort of older adults.

Methods—858 participants in the Health, Aging and Body Composition Study were included in this cross-sectional analysis. Computed tomography (CT) was used to measure muscle area and quadriceps strength was measured isokinetically. Muscle quality (specific torque) was defined as strength per unit of muscle area for both total thigh and quadriceps. Knee OA was assessed based on radiographic features and knee pain. We compared muscle parameters between those with and without radiographic knee OA (+RKOA, −RKOA) and among four groups defined by +/− RKOA with and without pain.

Results—The mean age was 73.5 (2.9) years and mean BMI was 27.9 (4.8) kg/m^2. 58% of participants were women and 44% were Black. Compared to − RKOA, +RKOA participants had a higher BMI (30.2 vs. 26.8 kg/m^2), larger thigh muscles (117.9 vs. 108.9 cm^2), and a greater amount of intermuscular fat (12.5 vs. 9.9 cm^2) (all p<0.0001). In adjusted models, +RKOA subjects had significantly lower specific torque (p<0.001), indicating poorer muscle quality, than −RKOA subjects, but there was no difference between groups in quadriceps specific torque. +RKOA/−pain (p<0.05) and +RKOA/+pain (p<0.001) subjects had lower specific torque compared to −RKOA/−pain group. There were no significant differences in quadriceps specific torque among RKOA/pain groups.

Conclusions—Muscle quality was significantly poorer in participants with RKOA regardless of pain status. Future studies should address how lifestyle interventions might affect muscle quality and progression of knee OA.

Osteoarthritis (OA) of the knee is a major cause of disability among the elderly (1–3), and its prevalence is projected to grow substantially with the aging of the U.S. population (2,4). Despite the high prevalence of this condition and the high personal and economic impact of osteoarthritis-related disability, there are currently no specific therapies that can prevent the onset or progression of joint damage caused by OA. Medical therapies designed to control pain and swelling can be associated with side effects, and the withdrawal of certain COX-2 inhibitors from the market due to safety concerns has further limited therapeutic options (5). With limited therapeutic modalities and concerns about long-term safety of existing

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The authors have financial conflicts of interest. There is no financial support or other benefits from commercial sources for the work reported in this manuscript.

modalities, it is imperative to better understand the physiological and biological relationships underlying knee OA in order to devise and promote better preventive and therapeutic options.

Muscle weakness, and in particular quadriceps weakness, has been implicated in knee OA and quadriceps strengthening exercises are a therapeutic approach recommended by some experts (6–9). However, reports on the relationship between muscle strength and knee OA have presented conflicting data, due in part, perhaps, to an emphasis on gross measurements of strength that do not adequately control for other intrinsic muscle properties. A generalized loss of skeletal muscle mass with aging, known as sarcopenia, contributes to muscle weakness. In OA patients as well as in aging, the decrement in strength is greater than would be expected for reduction in size of the muscle (10). This suggests that alterations in the intrinsic characteristics of muscle, reflecting a diminished muscle quality, may also contribute to impaired muscle function of the elderly and of those with knee OA. However, there is little information concerning the association of skeletal muscle composition with the prevalence of OA.

Lower limb muscle composition and quality is likely related to overall body composition, and obesity has also been implicated as a risk factor for OA, particularly in women (10,11). Many patients with knee OA are obese, and will be stronger than those who are less obese because they have a higher muscle mass as part of a higher total mass. Strength is highly correlated with lean or muscle mass (12). Thus, strength differences in those with and without OA cannot be adequately examined without adjusting for lean mass. One of the most intruiging reports relating body composition and muscle strength to knee OA was that of Slemenda and colleagues (10), who showed that reduced quadriceps strength relative to body weight and lean muscle mass (measured by Dual Energy X-ray Absorptiometry (DXA)) was a risk factor for development of knee OA in women. These results suggest that the quality of muscle is impaired; however, there has been little recent literature to follow-up or confirm these provocative findings.

A more recent report by Sharma and colleagues (14) suggested that in some cases greater quadriceps strength may be associated with higher risk of progressive knee OA in patients with greater laxity in their knee. Unfortunately, this study did not include any measures of muscle mass or composition and controlled for body composition only through BMI. However, these results emphasize that the relationship of muscle strength and knee OA may be modified by other factors.

Advanced imaging techniques such as computed tomography (CT) can be used to give accurate estimates of lower extremity muscle mass. Lower extremity strength per unit muscle mass, or *specific torque*, is a measure of muscle quality. In addition, CT can be used to measure muscle attenuation, suggestive of an increased muscle fat content (15), is a marker of muscle quality that contributes to muscle weakness independent of the age-associated loss in muscle mass (16).

In the current study, we examined the association of radiographic and symptomatic knee OA with muscle strength, muscle area, intermuscular fat infiltration, and muscle quality using CT in a large, biracial cohort of elderly participants. We hypothesized that both radiographic and symptomatic knee OA would be associated with poorer muscle quality and higher muscle fat content.

Materials and Methods

Study population

The Health, Aging and Body Composition (Health ABC) Study is a longitudinal cohort study of factors that contribute to disability in the elderly, with special focus on body composition and weight-related health conditions. Health ABC was approved by the Institutional Review Boards at The University of Tennessee and The University of Pittsburgh, which are the two clinical sites for the study. Participants were recruited to Health ABC from a random sample of Medicare beneficiaries aged 70–79 years residing in zip codes from the metropolitan areas surrounding Pittsburgh and Memphis. All participants signed an informed consent document. To be eligible, participants had to report that they had no difficulty walking at least one-quarter mile and climbing 10 stairs without resting. A total of 3,075 male and female participants were enrolled in Memphis, Tennessee (n=1,548) and Pittsburgh, Pennsylvania (n=1,527).

In a knee OA substudy of Health ABC, individuals with and without knee pain had knee radiographs obtained during the second and third annual visits. A qualifying case of knee pain was defined as having at least one of the following: 1) knee pain on most days of the last month; 2) knee pain lasting ≥1 month in past 12 months; or 3) moderate or severe pain with any of the activities in the Western Ontario and McMaster Universities Osteoarthritis (WOMAC) pain scale (i.e., walking on a flat surface, going up or down stairs, at night while in bed, standing upright, getting in or out of a chair, and getting in or out of a car) in past 30 days. Individuals with qualifying knee pain and a random sample of those without qualifying knee pain were invited to be a part of the knee OA substudy and undergo knee imaging. Knee radiographs were obtained on 864 knee pain cases and 273 controls.

Measurement of body composition, including muscle mass and adiposity

All subjects in the Health ABC cohort underwent a total body Dual Energy X-ray Absorptiometry (DXA) scan and a computed tomography (CT) scan. Total body DXA scan was performed using the pencil beam technology (QDR 1500, Hologic, Waltham, MA, USA; enhanced whole body, software version 5.71). A standard soft tissue examination includes total body and regional measurements of trunk, arms and legs to analyze body composition according to a three-compartment model (fat mass, lean tissue and bone mineral content).

The CT scan of the thigh was acquired in Memphis using a Somatom Plus 4 (Siemens, Erlangen, Germany) or a Picker PQ 2000S (Marconi Medical Systems, Cleveland, OH, USA), and in Pittsburgh using a 9800 Advantage (General Electric, Milwaukee, WI, USA). Slice thickness was set at 10 mm. Muscle and fat areas were calculated by multiplying the number of pixels of a given tissue type by the pixel area. Density values were determined by averaging the CT number (pixel density) values of the regions outlined on the images. CT numbers were defined on a Hounsfield Unit (HU) scale where 0 equals the HU of water and −1000 equals the HU of air. The HU scale was used to define tissue types as well as a measure of muscle density. For each participant the determination of soft tissue type was made using the bimodal image distribution histogram resulting from the distribution numbers in adipose tissue and non-adipose soft tissue. (17) Using this method we were able to quantify the proportion of intermuscular fat in the total thigh muscle as well as the area of the total thigh and quadriceps muscles.

Measurement of lower extremity muscle strength

The strength of the participant’s dominant leg was evaluated with an isokinetic dynamometer (Kin-Com dynamometer, 125 AP; Chattanooga, TN). All subjects were given

the same instructions before testing and the same prompting during testing. Concentric peak torque of knee extensors was assessed; the participant's limb was weighed for gravity correction, and start-stop angles were set at 90° and 30°. Subjects were allowed several submaximal practice efforts, followed by the recording of the best of three maximal efforts. Strength testing was performed by research technicians trained and certified in the Kin-Com protocol and primarily measured quadriceps. Full details of the strength testing protocol have been described in detail elsewhere (18).

Calculation of specific torque and quadriceps specific torque

Specific torque was calculated as the peak strength divided by the total thigh muscle area of the same leg for which strength testing was performed. Quadriceps (quad) specific torque was calculated as the peak strength divided by the quadriceps muscle area of the same leg for which strength testing was performed. Intermuscular fat was not included in the muscle cross sectional area used to define specific torque or quadriceps specific torque.

Radiographic measurement of knee osteoarthritis

Bilateral, standing, semi-flexed views of the tibiofemoral compartment of the knee joint were obtained using the Fixed-Flexion technique. For the tibiofemoral compartment, both knees were assessed radiographically with a posteroanterior projection using a positioning frame (SynaFlexer; Synarc, San Francisco, CA) in order to fix knee flexion (between 20° and 30°) and external rotation of the feet at 10° for each subject. For our analyses, we defined a case of radiographic knee OA as any knee having a Kellgren Lawrence (KL) score of ≥ 2.

Measurement of covariates

Physical activity level was determined using a standardized questionnaire designed specifically for the Health ABC study, modeled from commonly used physical activity assessments including the leisure-time physical activity questionnaire (19). Physical activity level was calculated as kcal/wk by multiplying the appropriate kcal score for each of the activities by the amount of time spent during the week doing the activity (20). Anti-inflammatory drug use was self-reported and included non-steroidal anti-inflammatory drugs (NSAIDs), salicylates, and oral steroids.

Statistical Analysis

We conducted two primary sets of analyses to address our research questions. In the first, we used t-tests to examine the differences in body composition, muscle mass, strength and quality between participants who did and did not have radiographic knee OA as defined by KL score ≥ 2. In the second, we used ANOVA to test the differences in the same outcome measures between 4 groups: 1) no radiographic knee OA and no knee pain (− RKOA/ −pain); 2) no radiographic knee OA and knee pain (−RKOA/+ pain); 3) radiographic knee OA and no knee pain (+RKOA/− pain); and 4) both radiographic knee OA and knee pain (+ RKOA/+ pain). We stratified our unadjusted results by both gender and race to determine whether the effects differed between either men and women or blacks and whites.

Univariate analyses were followed by multivariable linear regression models that controlled for: 1) age, sex, race, physical activity, arthritis medication use (any non-steroidal anti-inflammatory drug (NSAID), anti-inflammatory or steroid); and 2) all of the above plus body mass index (BMI). In each of the multivariable analyses the body composition, muscle mass, strength and quality variables were the outcome (dependent) variables while the RKOA and RKOA/pain groups were the main predictor (independent) variables. In the

RKOA/pain group models, separate models were run to test for a trend across the four categories of the predictor variable for each outcome variable.

Since lower extremity strength data was only collected in one leg for each participant, for the primary analyses we considered the muscle mass, knee radiograph, and knee pain data *for the same leg in which strength data was collected*. A secondary set of analyses considered evidence of radiographic knee OA or knee pain in either leg. For each set of primary analyses, we also conducted analyses stratified by sex, given prior reports showing sex-related differences in the relationships among body composition, muscle mass and strength, and knee OA.

Results

Characteristics of cohort

A total of 858 Health ABC participants with complete knee pain, radiographic knee OA, CT and leg strength data were included in the present analyses; the characteristics of this group are similar to those of the overall Health ABC cohort. At baseline, the mean age was 73.5 (2.9) years. 58% of participants were women; 56% were white and 44% were Black. The mean BMI was 27.9 (4.8) kg/ m^2; 52% were fairly sedentary with physical activity levels of <500 kcal/week. 57% were taking an anti-inflammatory drug, including non-steroidal anti-inflammatory drugs (NSAIDs).

Radiographic knee OA and body composition, muscle strength, mass, and quality

Participants with radiographic knee OA (+ RKOA) were heavier (83.2 vs. 73.6 kg; $p<0.0001$) and had greater amounts of both total body lean (51.5 vs. 47.4 kg; $p<0.0001$) and fat (31.9 vs. 26.3 kg; $p<0.0001$) tissue, as measured by DXA, than those without radiographic knee OA (−RKOA). They also had larger thigh muscles (117.9 vs. 108.9 cm^2; $p<0.0001$) and a greater amount of intermuscular fat (12.5 vs. 9.9 cm^2; $p<0.0001$), as measured by CT. There were no significant differences in either quadriceps muscle size ($p=0.11$) or strength ($p=0.61$) between the two groups. However, both specific torque (strength per unit of muscle area) (0.86 vs. 0.94; $p<0.0001$) and quad specific torque (1.92 vs. 2.02; $p=0.002$) were significantly lower in +RKOA group, indicating poorer muscle quality than the −RKOA group. The differences between OA groups were similar both in men and women and in blacks and whites (data not shown), and similar results were seen when radiographic OA in either knee was considered (data not shown).

Knee pain, radiographic OA and muscle strength, mass, and quality

We also examined differences in measures of body composition, and muscle strength, mass, and quality when accounting for knee pain in addition to radiographic knee OA. Table 1 shows how these measurements varied across 4 distinct groups, those with: 1) no radiographic knee OA or knee pain (− RKOA/−pain); 2) no radiographic knee OA and knee pain (−RKOA/+ pain); 3) radiographic knee OA and no knee pain (+RKOA/− pain); and 4) both radiographic knee OA and knee pain (+ RKOA/+ pain). The participants in the +RKOA groups (with or without knee pain) were slightly older and more likely to be black than those in the −RKOA groups. When compared to those with no radiographic knee OA and no knee pain (− RKOA/−pain), those with both radiographic knee OA and pain (+ RKOA/+ pain) were heavier and had larger thigh muscles with a greater amount of intermuscular fat. However, quadriceps muscle size did not vary by group. Absolute strength also did not differ by group. Similar to the findings above, participants with both radiographic knee OA and knee pain (+RKOA/+ pain) has poorer muscle quality, reflected in both lower muscle attenuation and lower specific torque than those with no knee pain and no radiographic knee OA.

As with the radiographic knee OA analyses, differences between groups were not significantly different in women and men (data not shown), and similar results were seen when knee pain or radiographic OA in either knee was considered (data not shown). We also performed analyses using an alternate definition of knee pain as WOMAC score > 0 and also found similar results (data not shown).

Multivariable analyses

Table 2 shows the results of multivariable linear regression models of body composition, and muscle mass, strength, and muscle quality in participants without (−RKOA) and with (+RKOA) radiographic knee OA, where the −RKOA serves as the referent group. After adjusting for gender, age, race, physical activity, and anti-inflammatory medication use (model 2), those with radiographic knee OA remain heavier, with more lean and fat tissue, and larger thigh and quadriceps muscle area, whereas muscle attenuation, specific torque, and quad specific torque remain significantly lower. After adding BMI to the model (model 3), significant differences remain between groups in more lean body tissue, greater strength, and lower specific torque; however, there is no longer a significant difference in quad specific torque between groups after adjusting for BMI.

Table 3 shows similar multivariable results for the analyses body composition, and muscle strength, mass, and quality when accounting for knee pain in addition to radiographic knee OA. Here, the −RKOA/−pain group is the referent group and model is adjusted for gender, age, race, physical activity, and anti-inflammatory medication use, and BMI. When compared to the referent group, those with RKOA have lower specific torque (indicating poorer muscle quality) regardless of their pain symptom status. There was no significant difference among the groups in quad specific torque. Participants with RKOA and pain also have more fat mass and lower muscle attenuation and strength than those in the referent group.

Discussion

We examined the relationships between knee OA measured by both radiographic findings and knee pain and muscle mass, strength, and muscle quality in a relatively large, biracial cohort of older men and women. The key finding from these analyses is that while absolute strength did not differ by knee OA group, measures of muscle quality, i.e., muscle attenuation and specific torque (strength/muscle area) were significantly poorer in participants with knee OA. However, there were no differences in quad specific torque in fully adjusted models.

Our findings are consistent with those of Slemenda and colleagues (10) in showing that reduced leg strength relative to thigh muscle mass may be associated with knee OA. In our population, we found similar relationships in men as well. There are a few important differences in our population and measures that should be considered when comparing our results. The age of the Slemenda cohort was similar to Health ABC, but predominantly white, whereas ours was biracial. Also, while similar measures of strength (i.e., extensor strength measured via KIN-COM) were employed, we used CT, a more precise means of measuring thigh and quadriceps muscle area that can also measure and account for factors such as intermuscular fat. Lastly, the Slemenda study examined incident knee OA, whereas our current study is cross-sectional. Our finding that the “lower quality” muscle of participants with knee OA could be related to higher amounts of intermuscular fat infiltration extends this previous report on biomechanical mechanisms linking reduced lower extremity strength relative to body mass and knee OA.

It is somewhat more challenging to compare our results to those of other recent studies due to somewhat limited data in these reports about lower extremity muscle mass. Sharma and colleagues (14) found in a slightly younger cohort (mean age 64 years) that greater lower extremity strength may be associated with an increased risk of knee OA in those with lax or malaligned knees. While this study controlled for subject BMI, no other data on body composition or muscle mass were collected. Another study in a notably younger cohort (mean age 45 years) (21) found that decreased lower extremity strength and poorer functional performance predicted development of knee OA. Again, BMI was the only measure reported to put this into the context of body and/or muscle composition. Segal and colleagues (22) examined the relationship between incident knee OA and thigh strength and found thigh strength predicted incident symptomatic knee OA but not radiographic OA. Our findings seemed to be more robust with relation to radiographic knee OA findings. However, we believe that a consistent message from these other studies and our current study is that other host factors, be they biomechanical, body composition, or functionality variables, should be considered when looking at the relationship between lower extremity strength and knee OA.

The results of our study should be interpreted within the context of its limitations. Because we consider only baseline results from the Health ABC knee OA study, we cannot make any comment about the causal or directional nature of the relationships among muscle strength, mass and quality and knee OA. Poorer muscle quality could be an intermediary variable between obesity and knee OA. We chose to control for BMI in our fully adjusted multivariable models as we wished to see whether knee OA groups and muscle quality parameters were related independent of BMI, as higher BMI is already a well-known risk factor for knee OA. However, these final models could be overadjusted as specific torque and quad specific torque by definition already contain an estimate of body size. Although we did not see a difference in physical activity levels between the RKOA groups in our study, physical activity levels may play in important role in muscle quality for those with knee OA. We were limited by a self-reported measure and future studies may be enhanced by inclusion of an objective physical activity assessment, such as accelerometry.

Another potential concern is the stability of our measure of knee pain, a subjective measure that may vary greatly depending on the timing of the survey and numerous other individual factors. Unfortunately, we do not have any test-retest data of this particular pain variable within our cohort. We attempted to control for any possible misclassification by examining the WOMAC pain variable as well, and found that results were similar a definition of knee pain as a WOMAC > 0, and also that there was a linear trend in increased WOMAC scores through the four groups 4 groups ((− RKOA/− pain); (−RKOA/+ pain); (+RKOA/− pain); and (+ RKOA/+ pain)) (data not shown). We do not hypothesize that there would be any directionality to misclassification of pain symptoms, i.e., participants would probably be equally likely underreport as overreport.

A limitation of our measurement of muscle strength and quality is that we cannot distinguish neuromuscular recruitment limitations versus intrinsic muscle tissue or cellular limitations. Future studies could include testing modalities such as EMG to better discriminate these potential defects. Lastly, we do not account for other individual characteristics such as knee alignment and gait speed that might help to account for some of the variability in the relationships among muscle strength, mass and quality and knee OA.

Despite these limitations, our current study adds to the literature on the role of lower extremity weakness in knee OA and has several strengths. We study a fairly large population that includes more Black subjects than most previous reports. We also had the opportunity to look at specific, high quality muscle mass and composition data that has been for the most

part missing from prior reports in this area. CT is a particularly useful modality for examining lower extremity muscle in detail and has been validated against muscle biopsy (15) as a tool for measuring intermuscular fat. Using CT longitudinal CT data or looking at CT measures in a younger cohort would be two areas for future study that could help to further illuminate the causal among muscle strength, mass and quality and knee OA.

Lastly, our findings of the relationship between measures of lower extremity muscle quality and knee OA may have important treatment implications. Apart from medical therapy, practitioners tend to focus on weight loss and quadriceps strengthening as methods to either prevent or treat knee OA. While these may be sound recommendations, it is unknown how they would impact muscle quality and are often given in a “blanket” fashion without full consideration of the patient characteristics that may also influence knee OA. Future intervention studies should address how various weight loss and strengthening programs might affect muscle quality and the progression of OA.

Significance and Innovations

- Study of the relationships between muscle strength, mass, and quality conducted in a large, biracial population
- Study uses detailed and sophisticated computed tomography (CT) measures to assess muscle area and fat infiltration which are lacking in most other studies in this area
- Study supports that knee osteoarthritis is associated with lower specific torque, indicating poorer muscle quality

Acknowledgments

Grant Support: This research was supported by National Institute on Aging (NIA) Contracts N01-AG-6-2101; N01-AG-6-2103; N01-AG-6-2106; NIA grant R01-AG028050, NINR grant R01-NR012459 and in part by the Intramural Research program of the National Institutes of Health, National Institute on Aging. Dr. Conroy is supported by a career development award from the NIH K23-HL-085405.

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Table 1

Body composition, and muscle mass, strength, and muscle quality in Health ABC participants without and with radiographic knee OA and knee pain (n=858)

	− RKOA, − pain (n=334)	−RKOA, + pain (n=263)	+ RKOA, − pain (n=91)	+ RKOA, + pain (n=170)	p-value
Age (years)	73.3 (2.7)	73.3 (2.9)	73.7 (2.9)	74.1 (3.1)	0.008
Gender (n (%) male)	140 (42)	110 (42)	38 (42)	69 (41)	0.99
Race (n (%) Black)	145 (43)	100 (38)	52 (57)	84 (49)	0.007
NSAID use (n (%), yes)	181 (55)	143 (54)	56 (62)	105 (62)	0.22
Physical activity, kcal/week (n(%)) <500 500–999 1000–1499 ≥1500	159 (48) 58 (17) 35 (10) 82 (25)	151 (57) 47 (18) 23 (9) 42 (16)	49 (54) 10 (11) 10 (11) 22 (24)	91 (54) 27 (16) 22 (13) 30 (18)	0.15
BMI (kg/m^2)	26.4 (4.3)	27.3 (4.4)	30.5 (5.0)	30.1 (4.8)	<0.0001
Total mass (kg)	72.2 (13.3)	75.4 (14.9)	83.8 (13.0)	83.0 (15.5)	<0.0001
Total body lean (kg)	47.1 (10.4)	47.8 (10.6)	52.1 (9.4)	51.2 (9.7)	<0.0001
Total body fat (kg)	25.2 (7.6)	27.6 (8.3)	31.7 (9.3)	32.0 (10.0)	<0.0001
Thigh muscle area (cm^2)	108.8 (27.7)	108.9 (27.7)	120.5 (27.3)	116.5 (26.1)	<0.0001
Quadriceps muscle area (cm^2)	51.0 (13.3)	50.7 (13.0)	53.6 (13.2)	51.8 (12.7)	0.29
Muscle attenuation (HU)	36.3 (6.9)	35.0 (6.6)	33.9 (8.2)	32.3 (7.1)	<0.0001
Intermuscular fat (cm^2)	9.5 (6.2)	10.5 (5.8)	12.4 (6.7)	12.5 (7.4)	<0.0001
Absolute strength/peak torque (Newton•meters)	103.2 (34.6)	102.6 (35.9)	104.6 (38.3)	100.0 (35.4)	0.74
Specific torque (strength/thigh area)	0.94 (0.20)	0.94 (0.20)	0.87 (0.24)	0.85 (0.19)	<0.0001
Quadriceps specific torque (strength/quad area)	2.02 (0.41)	2.01 (0.43)	1.94 (0.47)	1.91 (0.41)	0.02

Note: Data are n (%) or means (standard deviations). P-value reflects chi-square test or ANOVA for the difference in means. Radiographic knee OA is defined as KL score ≥ 2 in the same knee for which we have strength (KinCom) and CT data. Knee pain is also for the same knee for which we have strength and CT data.

Table 2

Multivariable analysis of body composition, and muscle mass, strength, and muscle quality in Health ABC participants without (−RKOA) and with (+RKOA) radiographic knee OA (n=858)

Variable	1	2	3
BMI, kg/m2	0.33***	0.32***	n/a
Total body lean, kg	0.18***	0.18***	0.04*
Total body fat, kg	0.29***	0.29***	0.002
Thigh muscle area, cm^2	0.15***	0.15***	0.022
Quadriceps muscle area, cm^2	0.05	0.05*	−0.06**
Muscle attenuation, HU	−0.19***	−0.17***	−0.03
Strength, N·m	−0.017	−0.009	−0.066*
Specific torque (strength/thigh area)	−0.19***	−0.17***	−0.13***
Quad specific torque (strength/quad area)	−0.10**	−0.08*	−0.05

Values in columns represent standardized beta coefficients from linear regression models. 1: unadjusted; 2: age, gender, race, medications, physical activity (PA); 3: age, gender, race, medications, PA, BMI

* p<0.05;

** p<0.01;

*** p<0.001;

Note: −RKOA is referent group.

Table 3

Multivariable analysis of body composition, and muscle mass, strength, and muscle quality in Health ABC participants without (−RKOA) and with (+RKOA) radiographic knee OA and pain (n=858)

Variable	− RKOA , − pain (referent)	−RKOA, +pain	+ RKOA, −pain	+ RKOA, + pain	p-value (trend)
Total body lean, kg	n/a	−0.001	0.032	0.033	0.03
Total body fat, kg	n/a	0.05**	−0.004	0.034*	0.07
Thigh muscle area, cm2	n/a	−0.023	0.019	0.002	0.73
Quadriceps muscle area, cm^2	n/a	−0.031	−0.035	−0.069**	0.002
Muscle attenuation, HU	n/a	−0.053	0.009	−0.077*	0.05
Strength, N•m	n/a	−0.020	−0.039	−0.074**	0.007
Specific torque (strength/thigh area)	n/a	−0.016	−0.071*	−0.13***	0.0004
Quad specific torque (strength/quad area)	n/a	−0.009	−0.03	−0.06	0.12

Values in columns represent standardized beta coefficients from linear regression models. Adjusted for age, gender, race, medications, physical activity, BMI. Note: −RKOA, −pain is referent group.

* p<0.05;

** p<0.01;

*** p<0.001