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Isometric Quadriceps Strength in Women with Mild, Moderate, and Severe Knee Osteoarthritis

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Abstract

Objective—Quadriceps weakness is a common clinical sign in persons with moderate-to-severe osteoarthritis and results in physical disability; however, minimal data exist to establish whether quadriceps weakness is present in early stages of the disease. Therefore, our purpose was to determine whether quadriceps weakness was present in persons with early radiographic and cartilaginous evidence of osteoarthritis. Further, we sought to determine whether quadriceps strength decreases as osteoarthritis severity increases.

Design—Three hundred forty-eight women completed radiologic and magnetic resonance imaging evaluation, in addition to strength testing. Anterior-posterior radiographs were graded for tibiofemoral osteoarthritis severity using the Kellgren-Lawrence scale. Scans from magnetic resonance imaging were used to assess medial tibiofemoral and patellar cartilage based on a modification of the Noyes scale. The peak knee extension torque recorded was used to represent strength.

Results—Quadriceps strength (Nm/kg) was 22% greater in women without radiographic osteoarthritis than in women with osteoarthritis ($P < 0.05$). Quadriceps strength was also greater in women with Noyes' medial tibial and femoral cartilage scores of 0 when compared in women with Noyes' grades 2 and 3–5 ($P = 0.05$).

Conclusions—Women with early evidence of osteoarthritis had less quadriceps strength than women without osteoarthritis as defined by imaging.

Keywords

Knee Extensors; Muscle; Joint Disease

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Tibiofemoral osteoarthritis (OA) is the most common cause of chronic disability in the United States. Approximately 37% of Americans have radiographic evidence of OA, with 12% of American adults suffering OA-related pain and complaining of functional difficulties.¹ It has been projected that over the next 25 yrs, the number of individuals affected by arthritis will increase from ~47.8 million to 67 million, substantially increasing the cost of this chronic disability.²

Quadriceps muscle weakness is a common clinical sign associated with tibiofemoral OA³⁻⁵ and is considered to be a critical determinant of disability.⁶ Adequate quadriceps strength in persons with knee OA seems necessary to perform activities of daily living,^{7,8} and quadriceps muscle strengthening has been shown to be capable of improving physical function in those suffering from the disease.^{9,10} Quadriceps weakness not only leads to pain and disability in those with knee OA but has also been recently linked with incident symptomatic knee OA¹¹ (although not all research supports this tenet¹²). Because quadriceps strength seems critical in promoting physical function and may be related to symptomatic knee OA, interventions aimed at improving quadriceps strength may best be introduced early in the OA disease process; however, few data are available to ascertain whether quadriceps weakness is present in the early stages of OA. The purpose of this study was to determine whether isometric quadriceps strength differs based on the presence and severity of OA (characterized by radiographs and magnetic resonance imaging [MRI]). We hypothesized that quadriceps strength would be higher in women without radiographic evidence of OA or cartilaginous defects visible on MRI compared with women displaying radiographic and cartilaginous evidence of the disease. Furthermore, we hypothesized that quadriceps weakness would be present in persons with early OA (Kellgren-Lawrence 2 and Noyes 2) and that a decline in strength would be noted as OA severity increased.

PARTICIPANTS AND METHODS

Participants

The study sample included women who participated in the Michigan site-specific Strength and Functioning study of the Study of Women's Health Across the Nation (SWAN). SWAN is a multisite and multiethnic longitudinal study designed to study women during the menopausal transition. Details of the SWAN study and population have been published previously.¹³ Of the seven SWAN sites, studies of OA and physical functioning were unique to the Michigan site. At baseline in 1996/1997, 543 premenopausal women were enrolled in Michigan SWAN. Of those, 348 women had quadriceps strength and Kellgren-Lawrence (K-L) summary scores of knee radiographs available from the 2007–2008 collection period and were considered for this study. From the group of 348 women, 327 also had cartilage scores from MRI scans available and were also considered. Demographic information for the included participants can be found in Tables 1 and 2. Only women were considered for entry into this study because only they were available from the SWAN population. Ethical approval was obtained from The University of Michigan Health Sciences Institutional Review Board and written informed consent form was provided by all volunteers.

Radiographic Assessment

Anterior-posterior knee radiographs were taken (AXIOM Aristos, Erlangen, Germany) in a semiflexed weight-bearing position for all participants between January 2007 and July 2008. Evidence of OA was undertaken by two investigators (M.F. Sowers and a musculoskeletal radiologist) using the K-L scoring system, with values assigned between 0 and 4 and higher scores indicating greater OA severity.¹⁴ Both readers were blinded to the other's assessment for the radiologic score. Women were placed into three groups a priori based on the K-L scores in their left knee (0–1, no OA; 2, mild OA; and 3–4, moderate-to-severe OA).

Women with K-L scores of 0 and 1 were combined into a single group based on standard convention that these scores are representative of no or doubtful OA.¹⁴

Radiographs of knee joints where agreement between readers was not achieved on the K-L score were re-read and, if required, subjected to consensus reading. The x-ray procedures and the methods for reading and standardizing the radiographs have been described in detail in previous work.^{15–17}

MRI Assessment

The left knee was imaged using a 3.0 T (Phillips Achieva 3T Quasar Dual, Phillips) or 1.5 T (GE Signa) MRI scanner equipped with a knee coil. Sagittal, coronal, and axial fast spin-echo proton density with fat saturation sequences (repetition time (TR) 4000 ms, echo time (TE) 15 msec, 4 mm thickness), sagittal spin-echo proton density (TR 1000 msec, TE 14 ms, 3 mm thickness), and sagittal 3D spoiled gradient echo with fat saturation sequences (TR 38 ms, TE 6.9 ms, flip angle 45 degrees, 2 mm thickness) were acquired.^{18–20} The MRI scans were then evaluated for cartilage defects over three specific surfaces (medial tibia, medial femur, and medial patellar facet). Only medial surfaces were evaluated because the medial compartment is where OA is most prevalent. Cartilage on each surface was graded for severity using the Noyes' arthroscopic system (grade 0: normal; grade 1: internal signal alteration only; grade 2: defect <50%; grade 3: defect 50%–99%; grade 4: 100% defect, no bone ulceration; grade 5: 100% defect, with bone ulceration) modified for MRI.²¹ Women were then placed into three groups based on their Noyes' severity scores (Noyes 0–1, Noyes 2, Noyes 3–5).

MRI scans of the knee were interpreted independently by two musculoskeletal radiologists. Sixty percent of MRI scans were double-read with agreement in excess of 90%, and when agreement was not achieved scans were subjected to consensus reading.

Quadriceps Strength Assessment

Women were positioned in a portable isometric strength chair (BioLogic Engineering, Dexter, MI) with their knees at 90 degrees and their hips at ~85 degrees. The left leg was strapped to the chair at the level of the ankle, and the waist was secured to the chair with restraint. Volunteers leaned against the backrest and were allowed to grip the side of the chair when being tested. Subjects were asked to perform three maximal voluntary isometric contractions with their left leg. Practice trials were allowed to familiarize the participants with the setup. The peak torque (Nm) from each of the three trials was recorded, and the largest peak torque value was normalized to body mass (Nm/kg) and used in data analyses.

Pain and Functioning

Knee pain was described by asking the women if they experienced persistent left knee pain in the past year, and they answered either yes or no. Knee functioning was characterized using the 17-item Western Ontario McMaster Universities Osteoarthritis Index disability index.²² Women completed pain and functioning, strength, radiographic, and MRI assessments on the same day.

Statistical Analyses

Nonparametric analyses were used to compare group means because preliminary examination indicated that there were unequal variances for quadriceps strength (Levene's test; $P = 0.01$). Kruskal-Wallis tests were used to examine the effects of the independent variables (K-L score: 0–1, 2, 3–4 and Noyes' cartilage score: 0–1, 2, 3–5) on the dependent variable (quadriceps strength). Mann-Whitney U tests were used to make pairwise comparisons post hoc when appropriate. The experiment-wise type I error rate for all tests

was set at $P = 0.05$. Descriptive statistics were calculated for pain data (%) and the Western Ontario McMaster Universities Osteoarthritis Index disability index (mean $\pm$ SD).

RESULTS

Quadriceps Strength and Kellgren-Lawrence Scores

The mean ranks of normalized quadriceps strength (Nm/kg) were significantly different among the three groups classified according to the K-L scores (0–1, 204; 2, 154; 3–4, 138) ($P = 0.0001$). Women with K-L scores of 0–1 were stronger than women with K-L scores of 2 and K-L scores of 3–4 ($P = 0.0001$). However, there was no difference in quadriceps strength between women with K-L scores of 2 and women with K-L scores of 3–4 ($P = 0.333$). Figure 1 provides a parametric presentation of the quadriceps strength data for each K-L group (mean $\pm$ SD).

Quadriceps Strength and Noyes' Cartilage Scores

The mean ranks of normalized quadriceps strength were significantly different among the three groups classified according to medial tibial cartilage score (Noyes 0–1 = 181; Noyes 2 = 160; Noyes 3–5 = 124; $P = 0.001$), medial femoral cartilage score (Noyes 0–1 = 186; Noyes 2 = 177; Noyes 3–5 = 133; $P = 0.0001$), and medial patellar cartilage score (Noyes 0–1 = 200; Noyes 2 = 163; Noyes 3–5 = 144; $P = 0.0001$). For the medial tibial cartilage, women with Noyes' scores of 0–1 were stronger than women with scores of 2 ($P = 0.05$) and scores of 3–5 ($P = 0.0001$). Furthermore, women with medial tibial cartilage scores of 2 were stronger than women with cartilage scores of 3–5 ($P = 0.02$). For the medial femoral cartilage, women with Noyes' scores of 0–1 were stronger than women with scores of 3–5 ($P = 0.0001$). Quadriceps strength was also greater in women with Noyes' scores of 2 in the medial femoral cartilage when compared with women with Noyes' scores of 3–5 ($P = 0.0001$). No difference in mean ranks was noted between groups for participants with medial femoral cartilage scores of 0–1 and 2 ($P = 0.49$). Participants with medial patellar cartilage Noyes' scores of 0–1 were stronger than participants with scores of 2 ($P = 0.01$) and 3–5 ($P = 0.0001$). Quadriceps strength was not different in women with Noyes' scores of 2 when compared with women with Noyes' scores of 3–5 ($P = 0.10$). Figures 2–4 provide a parametric presentation (with mean $\pm$ SD) of the quadriceps strength data for each surface (medial tibial, medial femoral, and medial patellar) by cartilage score grouping.

Pain and Physical Functioning

Descriptive statistics for pain and physical functioning data by radiographic and MRI groupings are listed in Tables 1 and 2, respectively.

DISCUSSION

Quadriceps weakness contributes to pain and physical disability^{6,23} in patients with knee OA and has recently been implicated as a risk factor for the onset of symptoms in persons with radiographic evidence of the disease.¹¹ Therefore, improving quadriceps strength is warranted in persons with OA. Whether persons in the early stages of the disease, when symptoms are nonexistent or mild, suffer from quadriceps weakness is unknown and requires future study, so that rehabilitation professionals can introduce strengthening interventions at an appropriate stage. Using a cross-sectional study design, we ascertained whether quadriceps strength differed among women with and without radiographic evidence of OA and with and without cartilaginous defects characteristic of OA as seen on MRI scans. Furthermore, we examined whether quadriceps strength varied based on radiographic and MRI OA severity.

Consistent with our hypothesis, women in our study classified as not having radiographic (K-L 0–1) and cartilaginous evidence (Noyes 0–1) of OA were stronger than women with clinical indications of the disease. Our findings are in agreement with those of others who have found osteoarthritic patients to have lower isometric quadriceps strength than healthy adults.^{24,25} The osteoarthritic women in our population were ~22% weaker than women with healthy knees, similar to previously reported isometric and isokinetic knee extension torque deficits, which have ranged from 20% to 40%.^{4,5,24,26}

In general, women with early signs of OA (K-L 2 and Noyes 2) did display quadriceps weakness when compared with healthy controls (K-L 0–1) from the same population. Women with radiographic evidence of mild OA were ~18% weaker than the women without OA, whereas women with mild cartilage defects were ~15% weaker than women without cartilage defects. These data support our hypothesis that women with early radiographic and cartilaginous evidence of OA do indeed suffer from quadriceps weakness. Our findings illustrate that quadriceps weakness is not only present in the later or more advanced stages of OA, but also it does indeed seem to be present earlier in the disease process when radiographic and cartilaginous disease is classified as “mild.” On the basis of our results, we can infer that exercises and interventions aimed at improving quadriceps strength may prove beneficial in persons with evidence of early OA. Strengthening exercises introduced early on in the disease process may prove useful in promoting continued physical function and possibly may aid in preventing the onset of symptoms¹¹ and thus seem to be warranted.

The lack of difference between mild (K-L 2) and moderate-to-severe radiographic OA (K-L 3–4) in our work is in agreement with the findings of Liikavainio et al.,²⁴ who failed to identify any distinction in the quadriceps strength of men with K-L scores of 2, 3, and 4. These radiographic findings, however, seem to contradict our MRI data, which revealed differences in quadriceps strength between women with mild (Noyes 2) and moderate-to-severe (Noyes 3–5) cartilage defects in the medial tibia and femur. If the radiographic data were to be considered alone, one might surmise that OA severity does not impact quadriceps strength. However, when taking into consideration our MRI findings, it seems that quadriceps strength may indeed be affected by cartilaginous disease severity, with women displaying more severe cartilaginous defects and also having greater magnitudes of weakness. The inability of radiographs to directly quantify cartilage loss²⁷ may limit its usefulness when establishing the overall health of knee joint tissues considered critical in OA and could help to explain the apparent disagreement in findings. The contradiction between our radiographic and MRI findings could also reflect that cartilage is more sensitive to deficits in quadriceps strength when compared with bone. The relationship between lower limb strength and MRI measures of cartilage loss (e.g., cartilage volume) has been previously examined by Ding et al.²⁸ Their results showed that greater quadriceps/hip flexor weakness was associated with greater loss of medial and lateral femoral cartilage volume. Their findings when considered along with ours suggest that quadriceps strength may affect cartilage loss or vice versa.

It is of interest to note that less than half of the women with OA in our sample were symptomatic (i.e., complained of persistent knee pain) (Tables 1 and 2); however, these women were still weaker than women without evidence of OA. This suggests that the quadriceps strength deficits noted in the women with OA may be unrelated to pain. Quadriceps weakness associated with injury^{29,30} and arthritis^{23,31} is often attributed to pain, which, in turn, causes arthrogenic muscle inhibition (an inability to fully activate the quadriceps musculature due to a failure to recruit alpha motoneurons). Despite these claims, several others have reported no relationship^{32,33} or only a small-effect relationship^{34,35} between pain and quadriceps weakness, suggesting that factors other than pain are primarily responsible for the quadriceps strength deficits associated with OA. Hurley et al.³² have

suggested that degenerative changes to knee joint structures alter sensory signals arising from joint mechano-receptors, diminishing alpha motoneuron output, thereby causing arthrogenic muscle inhibition, which, in turn, leads to quadriceps weakness. The quadriceps weakness present in the women in our study may also be explained by atrophy that results from aging or disuse.³⁶

Although women were classified into groups based on left leg K-L and Noyes scores for the purposes of this study, it should be mentioned that many of our women (~83%) presented with bilateral radiographic and cartilaginous evidence of OA. The presence of bilateral OA may have influenced our findings, because women with bilateral knee OA could have strength deficits of a greater magnitude than those with unilateral OA. Along similar lines, there were some women who were grouped as not having OA based on their left leg K-L scores but did in fact present with OA in the right limb (15% of the K-L 0–1 group). The presence of OA in the contralateral limb may have influenced the magnitude of quadriceps strength in these women, making them weaker than those without OA bilaterally. Because the strength data were collected as part of a longitudinal data set, not primarily focused on muscle strength and OA, only strength for the left limb was available and this is the reason why women were classified based on data recorded from the left limb only.

Although the use of a cross-sectional study design was reasonable to answer the questions proposed for this study, it does have limitations. Our data cannot speak to when in time (i.e., before or after the onset of radiographic evidence of OA) the muscle weakness occurred and also does not provide information as to why muscle weakness presented in our patients. To answer these questions, longitudinal research studies should be conducted. Another limitation to our study is that data were only collected on women, and thus we cannot confirm whether similar findings would be observed in men. On the basis of available research,²⁴ however, we contend that the results noted in women would be comparable in men.

CONCLUSION

Women with early radiographic and cartilaginous evidence of OA suffer from quadriceps weakness. Introducing exercises and interventions aimed at improving quadriceps strength in women with early OA may minimize existing symptoms or prevent the onset of symptoms, in cases in whom symptoms are not already present, although future longitudinal research studies are needed to confirm this premise.

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FIGURE 1.
Average ($\pm$ SD) knee extension torque (Nm/kg) for each Kellgren-Lawrence score grouping.

FIGURE 2. Average ($\pm$ SD) knee extension torque (Nm/kg) for each Noyes' cartilage score grouping, medial tibial cartilage.

FIGURE 3.

Average ($\pm$ SD) knee extension torque (Nm/kg) for each Noyes' cartilage score grouping, medial femoral cartilage.

FIGURE 4.

Average ($\pm$ SD) knee extension torque (Nm/kg) for each Noyes' cartilage score grouping, medial patellar cartilage.

TABLE 1

Characteristics of participants according to K-L score from radiographs

	K-L Scores		
	0–1 (<i>n</i> = 160)	2 (<i>n</i> = 120)	3–4 (<i>n</i> = 68)
Age (yrs)	56.8 ± 2.7	57.3 ± 2.7	56.3 ± 2.8
Height (cm)	162.6 ± 6.1	162.9 ± 5.7	163.1 ± 6.8
Body mass (kg)	78.2 ± 16.6	94.0 ± 19.2	105.1 ± 20.1
Body mass index (kg/m ²)	29.6 ± 6.3	35.4 ± 7.3	39.6 ± 7.6
Number with persistent knee pain (% of group) ^a	36 (22.5%)	37 (30.8%)	46 (67.6%)
WOMAC disability score	22.5 ± 8.8	27.2 ± 12.8	33.6 ± 12.1

Values represent mean ± SD.

^aPain was reported to be in either the left knee or both knees in the past year.

WOMAC, Western Ontario McMaster Universities Osteoarthritis Index.

TABLE 2

Characteristics of study participants according to magnetic resonance imaging-based classification of cartilage defects on three medial surfaces (medial tibial, medial femoral, and medial patellar)

	Medial Tibial Cartilage			Medial Femoral Cartilage			Medial Patellar Cartilage		
	0-1	2	3-5	0-1	2	3-5	0-1	2	3-5
Number	141	135	51	66	147	114	67	122	138
Age (yrs)	56.7 ± 2.8	57.0 ± 2.8	56.9 ± 2.7	56.3 ± 2.6	57.1 ± 2.9	56.9 ± 2.7	57.3 ± 2.9	56.1 ± 2.9	56.8 ± 2.7
Height (cm)	163.4 ± 5.8	162.5 ± 6.4	163.3 ± 5.8	162.8 ± 5.5	163.0 ± 6.4	163.1 ± 6.0	162.4 ± 5.5	163.0 ± 5.9	163.3 ± 6.5
Body mass (kg)	89.1 ± 21.1	89.6 ± 22.1	85.6 ± 18.8	90.5 ± 18.6	89.1 ± 23.0	87.2 ± 20.0	90.1 ± 19.6	88.4 ± 22.2	88.2 ± 21.1
Body mass index (kg/m ²)	33.4 ± 7.7	34.0 ± 8.3	32.2 ± 7.3	34.1 ± 6.9	33.5 ± 8.3	32.9 ± 7.9	34.3 ± 7.8	33.3 ± 8.1	33.1 ± 7.9
Number with persistent knee pain ^a	51 (36.2%)	44 (32.6%)	15 (29.4%)	24 (36.3%)	54 (36.7%)	32 (28.1%)	20 (29.9%)	46 (37.7%)	42 (30.4%)
WOMAC disability score	25.6 ± 11.6	26.6 ± 11.9	25.4 ± 12.1	26.2 ± 13.1	26.1 ± 11.5	25.7 ± 11.4	25.5 ± 11.0	27.1 ± 12.8	25.0 ± 11.1

Values represent mean ± SD.

^aPain was reported to be in either the left knee or both knees in the past year.

WOMAC, Western Ontario McMaster Universities Osteoarthritis Index.