Effect of a Home Program of Hip Abductor Exercises on Knee Joint Loading, Strength, Function, and Pain in People With Knee Osteoarthritis: A Clinical Trial

Elizabeth A. Sled, Latif Khoja, Kevin J. Deluzio, Sandra J. Olney, Elsie G. Culham

Background. Hip abductor muscle weakness may result in impaired frontal-plane pelvic control during gait, leading to greater medial compartment loading in people with knee osteoarthritis (OA).

Objective. This study investigated the effect of an 8-week home strengthening program for the hip abductor muscles on knee joint loading (measured by the external knee adduction moment during gait), strength (force-generating capacity), and function and pain in individuals with medial knee OA.

Design. The study design was a nonequivalent, pretest-posttest, control group design.

Setting. Testing was conducted in a motor performance laboratory.

Patients. An *a priori* sample size calculation was performed. Forty participants with knee OA were matched for age and sex with a control group of participants without knee OA.

Intervention. Participants with knee OA completed a home hip abductor strengthening program.

Measurements. Three-dimensional gait analysis was performed to obtain peak knee adduction moments in the first 50% of the stance phase. Isokinetic concentric strength of the hip abductor muscles was measured using an isokinetic dynamometer. The Five-Times-Sit-to-Stand Test was used to evaluate functional performance. Knee pain was assessed with the Western Ontario and McMaster Universities Osteoarthritis Index questionnaire.

Results. Following the intervention, the OA group demonstrated significant improvement in hip abductor strength, but not in the knee adduction moment. Functional performance on the sit-to-stand test improved in the OA group compared with the control group. The OA group reported decreased knee pain after the intervention.

Limitations. Gait strategies that may have affected the knee adduction moment, including lateral trunk lean, were not evaluated in this study.

Conclusions. Hip abductor strengthening did not reduce knee joint loading but did improve function and reduce pain in a group with medial knee OA.

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Excessive knee joint loading has been shown to contribute to progression of knee osteoarthritis (OA).[1] Knee joint loading during walking may be estimated by the external knee adduction moment,[2–4] which provides a valid, indirect measure of the magnitude of dynamic load on the medial compartment.[3,5–7] Higher knee adduction moments have been reported in people with medial knee OA compared with participants without knee OA matched for age, sex, height, and weight.[8–11] The knee adduction moment has been shown to relate to radiographic disease severity,[4,6,10–12] varus alignment,[1,6,8,13] and knee pain.[1,8,14,15]

It has been suggested that gait strategies and interventions focused on decreasing the knee adduction moment during gait may be effective for reducing load through the medial compartment.[16] Increased toe-out angle[8,17–19] and trunk lean toward the stance limb[20] are 2 gait strategies adopted by individuals with knee OA that have been shown to reduce the knee adduction moment.

The hip abductor muscles also may influence knee joint loading through their control of the pelvis in the frontal plane.[11,21] Researchers have proposed that during the single-limb stance phase of gait, weakness of the stance-limb hip abductor muscles may lead to drop of the pelvis toward the contralateral limb, shifting the body's center of mass away from the stance limb toward the swing side.[11,21] These adjustments, theoretically, could lead to higher knee adduction moments and greater medial knee joint loading. Thus, increasing the strength (force-generating capacity) of the hip abductor muscles and controlling the pelvis in the frontal plane might reduce joint loading and have a disease-modifying effect.[11,21]

To our knowledge, an investigation of strengthening exercises targeting the hip abductor muscles as an intervention to reduce knee joint loading in people with knee OA has not been performed. Thus, the purpose of our study was to examine the influence of an 8-week home strengthening program for the hip abductor muscles on hip strength and the knee adduction moment in people with medial compartment knee OA. Given the functional importance of the hip abductor muscles, secondary objectives were to determine whether hip abductor strengthening would improve physical function and knee symptoms in this sample of people with knee OA. We hypothesized that, following the exercise program, participants with medial knee OA would demonstrate greater strength of the hip abductor muscles, a reduction in the knee adduction moment during gait, and improved physical functioning and decreased knee pain compared with a matched group of asymptomatic participants.

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Method

Design Overview

The design of the study was a nonequivalent, pretest-posttest, control group design. A design incorporating participants with knee OA and a control group of individuals who were healthy was selected because few studies have compared the strength of the hip abductor muscles between these groups.

Setting and Participants

All testing was conducted in the Motor Performance Laboratory at Queen's University, Kingston, Ontario, Canada, with the exception of knee radiographs, which were completed in the Radiology Department at Kingston General Hospital. Testing sessions lasted approximately 2 to 2.5 hours. All individuals gave informed consent before participating.

Forty individuals with medial knee OA were recruited through newspaper advertisements and from the practices of orthopedic surgeons in Kingston, Ontario. Potential participants were included in the study if they met all of the following criteria[22,23]: age greater than 40 years, self-reported knee pain for most days of the month, physician diagnosis of knee OA, and radiographic evidence of medial compartment knee OA or evidence of cartilage loss in the medial compartment by arthroscopy or magnetic resonance imaging. For those participants with bilateral medial compartment OA, the more affected side (as identified by radiographic OA grade and symptoms) was selected as the test leg.

Participants were excluded if they had any of the following: intra-articular corticosteroid or viscosupplementation injection into either knee within the previous 3 months, significant comorbidities, or a history of other medical conditions affecting the knee joint.[24] Individuals with known hip OA, previous trauma affecting one or both hips, or previous replacement of any joint in the lower extremities also were excluded from the study. Finally, those who were receiving rehabilitation services for knee OA or performing a hip strengthening program at the time of testing were not eligible to participate.

Participants with knee OA were matched by age (±5 years) and sex with a control group of individuals with no clinical diagnosis of knee OA, hip OA, or rheumatoid arthritis and no reports of hip or knee pain or previous trauma. Participants in the control group were recruited through newspaper advertisements and posters displayed in senior centers in the Kingston area.

An estimate of sample size was obtained from 2 calculations (2-tailed test, power=80%, and significance level=.05) and 10% loss to attrition. All of the following values are mean (±SD). A within-group calculation used data from tests of isometric hip abductor strength before and after an exercise program (mean difference=16.42%±22.82%) in individuals with OA and lower-extremity functional impairment.[25] A between-group calculation also was computed using knee adduction moment data from a group of older adults with knee OA (0.25±0.06 N·m/kg) and a matched, asymptomatic group (0.33±0.06 N·m/kg).[26] Based on these 2 power calculations, at least 35 participants per group were needed for the study.

Intervention

All participants with knee OA were taught a home strengthening program for the hip abductor muscles by a physical therapist (E.A.S.). An exercise instruction booklet and graded resistance elastic bands were supplied to the participants. Individuals were instructed in the following program: side-lying resistive exercises for the hip abductor muscles, progressing to using resistance bands positioned around the distal thighs; standing single-leg stabilization exercises, progressing to standing hip abduction using resistance bands placed just proximal to the ankles; and single-leg standing exercise off the side of a 10-cm step (beginning with the free limb lower than the level of the step, participants contracted the stance-limb hip abductor muscles and raised the free leg to step level while keeping the stance knee extended). Participants were instructed to perform the exercise program 3 to 4 times per week for 8 weeks, completing one set of each exercise to fatigue. All exercises were performed for both legs. Progression to greater resistance levels occurred when participants could perform the exercise without fatigue for 20 repetitions.

Participants completed weekly exercise calendars in which they recorded the frequency and resistance levels of the exercises. Over the 8-week period, the physical therapist arranged 2 follow-up visits with each participant in the laboratory or the participant's home to ensure that he or she was performing the exercises correctly and to progress resistance levels. The therapist provided telephone follow-up support every 2 weeks, and participants were encouraged to call with any questions or concerns. Participants in the control group were instructed to continue their daily activities and refrain from beginning any new exercise program over the 8-week period.

Outcomes and Follow-up

Knee alignment and OA grading. In situations where participants had recent weight-bearing knee radiographs (within 6 months of the testing date), permission was requested to obtain digital images of these radiographs. For all other participants, bilateral knee radiographs in weight-bearing anterior-posterior views were obtained on the initial visit, according to the hospital's standardized protocol. Digital images of the radiographs were received from the Radiology Department on anonymous compact discs with only the subject code to identify the participant.

Frontal-plane knee alignment was measured from the digital images by means of a computer software program (Horizon Image Viewer, version 1.5*), which incorporates electronic tools to define femoral and tibial bone landmarks on the digital images.[27,28] An investigator (E.A.S.) trained in application of the software program completed all alignment

* OAISYS Medical Inc, 797 Princess St, Suite 404, Kingston, Ontario, Canada K7L 1G1.

The Bottom Line

What do we already know about this topic?

Higher external knee adduction moments during gait have been shown to contribute to the progression of knee osteoarthritis. Different interventions have been tested for their potential to decrease the knee adduction moment.

What new information does this study offer?

Hip abductor muscle strengthening did not influence the knee adduction moment in 40 participants with knee osteoarthritis. However, participants demonstrated improvements in function and knee symptoms.

If you're a patient, what might these findings mean for you?

Hip abductor muscle strengthening may be beneficial for increasing function and decreasing pain in individuals with knee osteoarthritis.

measurements. As the images were of the knee joint only and not full-limb radiographs, an estimate of mechanical axis alignment (depicted as the hip-knee-ankle [HKA] angle) was obtained from the angle formed by the intersection of femoral and tibial anatomic (shaft) axes.[29,30] The femoral mechanical axis was shown to be offset from the femoral anatomic axis by 4 to 5 degrees.[29,31,32] Thus, an estimate of mechanical axis alignment was derived by subtracting 5 degrees from the anatomic axis angle. Offset-corrected anatomic axis measurement from knee radiographs is considered a valid, cost-effective alternative to alignment measures from full-limb radiography.[31–33]

Radiographs were graded for disease severity using the Kellgren-Lawrence scale[34,35] by investigators (E.A.S. and T.D.V.C) who were experienced in reading knee radiographs. Disease severity was graded as follows: 0=no radiographic OA findings, 1=questionable (doubtful joint space narrowing, possible osteophyte lipping), 2=mild (definite osteophytes, possible joint space narrowing), 3=moderate (multiple moderate osteophytes, definite joint space narrowing, some bony sclerosis, possible deformity of bone ends), and 4=severe (large osteophytes, marked joint space narrowing, severe bony sclerosis, definite deformity of bone ends).[35,36]

Gait analysis. Testing in the Motor Performance Laboratory began with an evaluation of the participants' level walking on an 8-m-long walkway (E.A.S. and L.K.). Three-dimensional kinematic data (sampled at 100 Hz) were collected using 2 Optotrak 3020 optoelectronic motion tracking cameras[†] placed on either side of the walkway. Two AMTI forceplates[‡] embedded in the center of the walkway collected ground reaction force data at a sampling frequency of 200 Hz.

Participants dressed in shorts and a loose-fitting shirt and the same pair of walking shoes was worn at both sessions. Rigid clusters containing infrared light-emitting diodes (IREDs) were positioned on the dorsum of the foot (over the metatarsal area), lateral shank, lateral thigh, and sacrum to track movements of the limbs.[37] The clusters were secured with Velcro straps[§] to avoid movement of the IRED markers during the walking trials. Participants walked at their self-selected normal gait speed, and 5 good walking trials were obtained. Trials were considered successful if participants landed with one foot on each forceplate and all IREDs were visible by the cameras. Raw motion and forceplate data were filtered with a dual-pass Butterworth low-pass filter at a cutoff frequency of 6 Hz.

Following the gait trials, participants stood in view of the cameras, and a series of reference trials were captured using a pointed probe fitted with 4 IRED markers. The tip of the probe was placed on specific bone landmarks to identify the location of the landmarks in relation to the clusters and to approximate joint centers. Ankle and knee joint centers were calculated as midpoints between the malleoli and femoral epicondyles, respectively. The hip joint center was calculated as a point located at 25% of the distance between the 2 greater trochanter landmarks to the left or right, depending on the test limb.[38] Using an inverse dynamics approach, a visual 3-dimensional (3-D) motion analysis software program[‖] incorporated forceplate and Optotrak motion data, landmarking reference trials, and anthropometric parameters in order to calculate knee moments during the stance phase.

Net external knee adduction moment data from the 5 walking trials were exported from the visual 3-D motion analysis software program to a Microsoft Excel (Microsoft Office 3000[#]) worksheet. The stance phase of the test leg was divided into 100 points representing 100% of stance, and an average moment waveform was obtained for each participant. Peak knee adduction moment values in the first 50% of the stance phase were selected as the highest peak that was preceded by at least 5 continuously ascending values and followed by at least 5 continuously descending values.[20] Peak moments were normalized to body weight and height (expressed as %BW×Ht) to allow for comparison between participants.

During the 2 testing sessions, gait speed was controlled by verifying that each participant's gait speed on final testing was within ±15% of their initial (baseline) gait speed. This step was to control for gait speed as a potential confounding factor that could influence the knee adduction moment[10] in addition to the intervention. For 2 participants only, it was necessary to repeat final walking trials at a faster or slower speed to match their initial gait speed.

Measurement of hip muscle strength. Isokinetic concentric strength of the hip abductor muscles was measured in a standing position using the Biodex System 3 isoki-

[†] Northern Digital Inc, 103 Randall Dr, Waterloo, Ontario, Canada N2V 1C5.

[‡] Advanced Mechanical Technology Inc, 176 Waltham St, Watertown, MA 02472-4800.

[§] Velcro USA Inc, PO Box 5218, 406 Brown Ave, Manchester, NH 03103.

[‖] C-Motion Inc, 20030 Century Blvd, Suite 104A, Germantown, MD 20874-1111.

[#] Microsoft Corp, One Microsoft Way, Redmond, WA 98052-7329.

netic dynamometer,** following hip strength testing protocols in the literature.[39,40] High test-retest intraclass correlation coefficients of .96 have been reported for standing isokinetic concentric tests of hip abduction.[39] Participants stood with their posterior trunk supported by a pillow placed against the back of the dynamometer chair. The trunk and pelvis were stabilized using Velcro straps. The axis of rotation of the dynamometer was aligned with the participant's anterior superior iliac spine, and the dynamometer pad was secured snugly with a Velcro strap around the lower thigh just proximal to the knee. Hip abduction range of motion was set from 0 degrees to approximately 30 degrees, and concentric hip abductor muscle strength was measured at an angular velocity of 60°/s.

Participants completed a practice set of 3 submaximal concentric hip abduction repetitions prior to each test to ensure familiarization with the test procedures. This practice set was followed by 5 consecutive repetitions of maximal concentric hip abduction, with verbal encouragement provided to facilitate maximum effort. Data were sampled at 100 Hz. The data from the first repetitions were omitted, and the last 4 of 5 peak torque values from each test were averaged to obtain mean peak hip abductor torques.[41] Data processing was performed using a MATLAB software program,†† which filtered the torque data with a 6-Hz low-pass filter (Butterworth, sixth order). Mean peak torque values were normalized to body weight (expressed as newton-meters per kilogram) for comparisons between groups.

** Biodex Medical Systems Inc, 20 Ramsay Rd, Shirley, NY 11967-4704.

†† The MathWorks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.

Assessment of knee symptoms, physical function, and activity level. Knee symptoms and perceived disability experienced due to OA were assessed with the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), a disease-specific, self-administered questionnaire given in a Likert scale format.[42] The reliability, validity, and responsiveness of WOMAC scores have been well established in individuals with knee OA.[42,43] The WOMAC consists of 24 questions, probing the dimensions of pain (5 questions), joint stiffness (2 questions), and physical functioning (17 questions). A standard scoring system was used in which responses for each subscale were rated from 0 to 4, with 4 representing extreme pain, stiffness, or difficulty functioning. Scores then were summed to produce a total score for each of the 3 subscales.[42]

The Five-Times-Sit-to-Stand Test (FTSST) was used as a clinical measure of lower-extremity physical function.[44] This test measures the time required to rise from a chair and sit down for 5 repetitions. Test-retest reliability of FTSST measurements has been established in community-dwelling older adults,[45–47] and the correlation of FTSST scores with walking performance, lower-extremity muscle strength, and self-reported physical functioning provides evidence for the validity of the test.[45,48] Participants sat on an armless chair (43-cm height, 47.5-cm depth) with their arms across their chest and their back resting against the chair initially. They were instructed to stand up fully on each repetition and not to touch the back of the chair during the sitting phase of the repetitions.[49] The test was finished when participants returned to sitting after the fifth stand.

Participants also completed the Physical Activity Scale for the Elderly (PASE), a self-report measure designed to assess occupational, household, and leisure activities performed by older adults.[50] Construct and convergent validity of the PASE have been established in community-dwelling older adults with knee pain and physical disability.[51] Physical Activity Scale for the Elderly scores have demonstrated good test-retest reliability (r=.75) in 254 community-dwelling older adults.[50] Respondents were asked to record the frequency for 12 types of activities over the previous week. A total PASE score for each participant was computed by multiplying weighted values for each activity with the activity frequency per week and then summing the products for all 12 activities.[52] Higher PASE scores indicate greater levels of physical activity.[52] At the end of the 8 weeks, both groups returned to the laboratory for a repeat of the gait and strength measures and questionnaire completion.

Data Analysis

Independent t tests were used to assess for significant baseline differences in demographic and clinical characteristics between the OA and control groups. Repeated-measures analysis of variance calculations determined the main effects and interactions of group and time for all outcome measures. Statistical analysis was performed using SPSS software (version 15.0.1),‡‡ and the significance level was set at $P<.05$.

Role of the Funding Source

This study was supported by a Bickell Foundation of Canada Medical Research grant. The funding source had no involvement in study design or reporting.

Results

Forty participants with knee OA (mean age=62.98±9.73 years; 23

‡‡ SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606-6306.

Table 1.
Baseline Demographic and Clinical Characteristics of Participants Who Completed the Study

Variable	Osteoarthritis Group (n=40) Mean (SD) [Range]	Control Group (n=40) Mean (SD) [Range]	*P*
Age (y)	62.98 (9.73) [46–90]	64.13 (9.04) [47–84]	.59
Weight (kg)	82.31 (20.0)	69.71 (11.03)	.001[a]
Height (m)	1.73 (0.11)	1.70 (0.86)	.23
Body mass index (kg/m^2)	27.38 (5.47)	24.04 (3.24)	.001[a]
Knee alignment (°)[b]	−4.1 (4.3)	−2.2 (1.9)	.014[a]
Grading of osteoarthritis severity[c]	2.5 (0.91)	0.28 (0.55)	.000[a]
Temporal-distance gait parameters			
Gait speed (m/s)	1.00 (0.20)	1.12 (0.19)	.006[a]
Stride length (m)	1.19 (0.16)	1.26 (0.15)	.08
Stance time (s)	0.84 (0.11)	0.75 (0.07)	.000[a]
Double-limb support time (s)	0.39 (0.08)	0.33 (0.05)	.001[a]
Cadence (steps/min)	97.36 (10.48)	104.60 (9.29)	.003[a]

[a] Significant differences between groups ($P<.05$).
[b] Negative alignment values represent varus.
[c] Kellgren-Lawrence radiographic grading scale (0–4).[34,35]

women and 17 men) and 40 matched control participants (mean age=64.13±9.04 years; 23 women and 17 men) completed the study. An additional 5 participants with knee OA completed the initial testing only, 3 participants had to discontinue their participation because of death or illness in the family, and 2 participants did not want to continue after the initial testing session. Thirty-three of the OA group participants had bilateral medial compartment knee OA.

Baseline demographic and clinical characteristics for the 40 participants in each group who completed the study are displayed in Table 1. The OA group had higher values for weight and body mass index (BMI), demonstrated greater varus alignment, and walked at a slower gait speed compared to the control group ($P<.05$). The median Kellgren-Lawrence grade of disease severity for the OA group was 2, indicating an overall mild level of severity. Paired t tests confirmed that gait speed within subjects had been controlled for, as there were no significant differences in gait speed between initial and final testing in either group ($P>.05$).

At baseline, the OA group demonstrated weakness of the hip abductor muscles compared with the control group ($P=.03$). Improvement in hip abductor strength occurred over time in both groups, but the significant interaction effect indicated a

Table 2.
Initial and Final Means and 95% Confidence Intervals (CIs) for the Outcomes of Hip Muscle Strength, Peak Knee Adduction Moments, Chair Rise Time, and Physical Activity Scale for the Elderly (PASE) Scores in the Osteoarthritis and Control Groups

Variable	Group[a]	Initial Testing Mean (95% CI), *P* Value[b]	Final Testing Mean (95% CI), *P* Value[c]	*P*[d]
Isokinetic hip abductor muscle strength (N·m/kg)	Osteoarthritis Control	0.75 (0.62–0.88) 0.96 (0.83–1.09) $P=.03$[e]	1.00 (0.87–1.13) 1.06 (0.93–1.19) $P=.56$	.036[e]
Peak knee adduction moment (%BW×Ht)[f]	Osteoarthritis Control	2.97 (2.70–3.24) 2.47 (2.28–2.66) $P=.004$[e]	2.96 (2.68–3.24) 2.52 (2.31–2.73) $P=.02$[e]	.52
FTSST[g] (s)	Osteoarthritis Control	15.2 (12.6–17.9) 10.1 (9.2–11.0) $P<.001$[e]	12.5 (10.6–14.4) 9.3 (8.4–10.2) $P=.004$[e]	.021[e]
PASE score	Osteoarthritis Control	196.2 (175.7–216.7) 165.0 (144.9–185.2) $P=.037$[e]	200.9 (176.0–225.9) 147.3 (128.7–166.0) $P=.001$[e]	.065

[a] n=40 participants in each group.
[b] *P* values for between-group differences on initial testing.
[c] *P* values for between-group differences on final testing.
[d] *P* values for between-group differences in change over time (interaction effect).
[e] Significant differences ($P<.05$).
[f] %BW×Ht=percentage of body weight × height.
[g] FTSST=Five-Times-Sit-to-Stand Test.

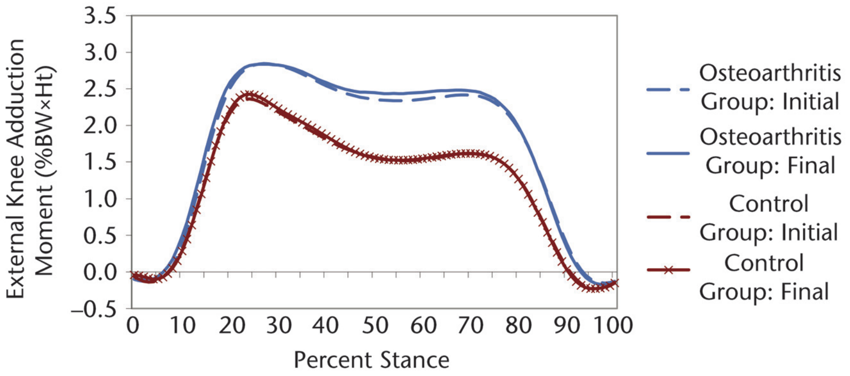

Figure.
Average knee adduction moment waveforms for the osteoarthritis and control groups across the stance phase of the gait cycle on both initial and final testing. The waveforms were obtained by averaging across participants at each percent of stance, such that data were normalized across time to 100% of the stance phase. %BW×Ht = percentage of body weight × height. Both initial and final mean peak moments were higher for the osteoarthritis group than for the control group.

greater change in the OA group following the exercise intervention (F=4.56, *P*=.036) (Tab. 2).

The OA group had higher peak knee adduction moments than the control group (main effect of group; F=8.02, *P*=.006), but there was no significant change in the peak knee adduction moment over time and no interaction effect (Tab. 2, Fig. 1).

Analysis of physical function measures revealed that the OA group performed the FTSST more slowly than the control group (main effect of group; F=12.34, *P*=.001). Although an improvement in sit-to-stand time was observed for both groups over time, the improvement in the OA group was significantly greater (F=5.55, *P*=.021) (Tab. 2). From the evaluation of the PASE scores, the OA group demonstrated higher total scores for physical activity compared with the control group (main effect of group; F=9.06, *P*=.004). There were no significant changes in physical activity level over time for either group (Tab. 2).

All WOMAC measures were significantly higher in the OA group compared with the control group (*P*<.05). Neither group demonstrated any change in WOMAC stiffness or physical function scores over time. The WOMAC pain scores showed a significant interaction effect, with the OA group reporting decreased knee pain over time compared with the control group (*P*=.03) (Tab. 3).

Adherence to the exercise program was assessed by means of the self-completed, weekly calendars. Participants were considered adherent if they performed at least 75% of the prescribed exercises over the 8-week period. According to this criterion, 31 of the 40 participants with OA (78%) were adherent. When only the 31 adherent participants and their matched controls were included in the statistical analyses, the same results were obtained as with 40 participants. Therefore, the results are presented for all participants.

Discussion

The primary findings of the current study were that an 8-week, home strengthening program targeting the hip abductor muscles resulted in increased hip abductor strength but had no effect on reducing the knee adduction moment during gait in people with medial knee OA. Hip abductor strengthening led to an improvement in functional performance on the sit-to-stand test and reduced knee pain in the sample with knee OA.

Table 3.
Initial and Final Means and 95% Confidence Intervals (CIs) for the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Subscale Scores[a] in the Osteoarthritis and Control Groups

Test	Group[b]	Initial Testing Mean (95% CI)	Final Testing Mean (95% CI)	*P*
WOMAC pain subscale (total score: 0–20)	Osteoarthritis Control	5.55 (4.66–6.44) 0.175 (0.03–0.32)	4.78 (3.72–5.84) 0.32 (0.00–0.69)	.03[c]
WOMAC stiffness subscale (total score: 0–8)	Osteoarthritis Control	3.08 (2.52–3.64) 0.43 (0.16–0.70)	2.95 (2.40–3.50) 0.34 (0.13–0.57)	.83
WOMAC physical function subscale (total score: 0–68)	Osteoarthritis Control	19.60 (15.95–23.25) 1.2 (0.25–2.15)	18.15 (14.19–22.11) 1.24 (0.00–2.46)	.22

[a] Higher scores on the WOMAC subscales indicate greater severity of pain, stiffness, and difficulty in physical function.
[b] n=40 participants in each group.
[c] Significant interaction effect (*P*<.05).

Baseline isokinetic hip abductor strength measurements revealed that the OA group was weaker compared with the control group. This hip muscle weakness was present despite the fact that the OA group was more physically active than the control group, as indicated by the PASE scores. Only one other study was identified that compared isometric hip abductor strength in women with and without knee OA, and there were no differences between the 2 groups.[53] Following the exercise intervention, our sample of participants with knee OA demonstrated significant improvement in hip abductor strength. Few other studies have incorporated hip strengthening as part of exercise programs for people with knee OA or included hip muscle strength as an outcome measure in this population. McGibbon et al[25] measured seated isometric hip abductor strength using a handheld dynamometer in 15 older individuals with lower-extremity impairment (not isolated to knee OA) who had been randomly assigned to receive either a 6-week lower-extremity strengthening or functional training intervention. Both groups demonstrated significant improvements in hip abductor strength following the interventions.

Gait analysis revealed that peak knee adduction moments in the first 50% of the stance phase were higher in our sample of participants with knee OA compared with the control group. These results are consistent with other reported findings.[1,2,4,6,10] Higher BMI and greater varus alignment could have contributed to the higher knee adduction moments in the OA group. However, there were no changes in peak knee adduction moment in either group over time. Thus, strengthening the hip abductor muscles did not influence the knee adduction moment in our participants with medial knee OA, indicating that hip abductor strengthening may not be an effective strategy for decreasing medial compartment forces and progression of joint disease.

Other studies have failed to demonstrate a change in the knee adduction moment during gait following lower-extremity strengthening.[54–56] In an 8-week pilot study[56] of 13 people with early knee OA who participated in a lower-extremity strengthening and functional exercise program, peak knee adduction moments during gait were not significantly reduced at the completion of the program but were significantly lower during single-leg raise. The authors suggested that peak knee adduction moments during the more demanding task of single-leg raise may be more sensitive to change than peak moments during gait.[56] Similarly, a 12-week, high-intensity, isokinetic resistance training program for the knee extensor and flexor muscles had no effect on the peak knee adduction moment during gait in 14 people with medial knee OA.[54] Lim et al[55] performed a 12-week randomized controlled trial of 107 people with medial knee OA in which participants were stratified into 2 groups according to varus malalignment or neutral alignment. The participants in each group then were randomly assigned to receive a supervised, home-based quadriceps muscle strengthening program or to receive no intervention. The results of the study showed no significant change in the knee adduction moment in the groups with more varus malalignment or neutral alignment following the exercise program.[55]

The WOMAC pain scores revealed reduced knee pain over time in the OA group compared with the control group. However, the change of 0.77 for the WOMAC pain scores may not be clinically meaningful. The lack of a more definite reduction in symptoms over the 8-week intervention period may have been related to the relatively low scores for knee pain, stiffness, and function that characterized our sample at baseline.

Although functional performance on the FTSST was decreased in our participants with knee OA compared with the control group, the OA group demonstrated significant improvement (18%) in time to complete the test following the exercise intervention. The FTSST has been shown to relate to lower-extremity muscle strength, particularly quadriceps muscle strength, and balance control.[45,57] One limitation of our study was that strength of the knee muscles was not assessed before and after the intervention. The weight-bearing exercises performed as part of the hip strengthening program likely produced co-contraction of other lower-extremity and trunk muscles. Thus, it is possible that improvements in functional performance on the sit-to-stand test and the decrease in knee pain may have been more closely correlated with knee muscle strength gains than improvements in hip abductor strength.

The design of the study was another limitation. The inclusion of a control group of individuals with knee OA in a randomized controlled trial would have strengthened the study. However, a control group of older adults who were healthy was selected due to the lack of available literature comparing hip abductor strength between those with and without knee OA. In addition, gait strategies that may have affected the knee adduction moment, including lateral trunk lean, were not evaluated for change over time in this study. Hip abductor strengthening may have increased trunk stability, thus decreasing lateral trunk lean toward the stance limb, increasing the lever arm magnitude at the knee, and potentially nullifying a reduction in the knee adduction moment that might have occurred as a result of the exercise program. Recruitment of participants through newspaper advertising also may have introduced bias toward those individuals in the population who were wealthier and more highly educated. Finally, our participants with knee OA were highly active in recreational, household, and occupational activities, as shown by the PASE scores. Therefore, the results from this study may not be generalized to the average population of people with OA.

Our results suggest the need for further studies to investigate the effects of hip abductor strengthening on lower-extremity function and knee symptoms in people with medial knee OA. Randomized controlled trials with larger cohorts are recommended. Furthermore, accumulating evidence suggests that the local mechanical environment, including OA disease severity, lower-limb alignment, and varus-valgus knee laxity, may influence response to exercise interventions in people with knee OA.[55,58,59] Stratification according to biomechanical factors would provide insight as to whether hip abductor strengthening is more effective in subgroups of people with knee OA. Future studies of hip abductor strengthening in those with knee OA also should incorporate measures of knee muscle strength and lateral trunk lean during gait to better elucidate relationships between factors and to clarify the biomechanical and functional benefits of this intervention.

In summary, an 8-week strengthening program for the hip abductor muscles resulted in increased hip muscle strength, reduced knee pain, and improved functional performance on a sit-to-stand task in 40 participants with medial knee OA compared with a control group without knee OA. There was no change in the knee adduction moment with the exercise program. Further research is needed to investigate whether hip abductor strengthening would be an effective intervention for slowing disease progression and protecting against functional decline in people with medial knee OA.

Dr Sled, Dr Deluzio, and Dr Culham provided concept/idea/research design and writing. Dr Sled and Mr Khoja provided data collection and participants. Dr Sled, Mr Khoja, Dr Deluzio, and Dr Culham provided data analysis. Dr Sled, Mr Khoja, and Dr Culham provided project management. Dr Sled and Dr Deluzio provided fund procurement. Dr Deluzio provided facilities/equipment. Dr Sled provided clerical support. Dr Sled, Mr Khoja, Dr Deluzio, and Dr Olney provided consultation (including review of manuscript before submission).

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