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Hip Range of Motion and Strength Predict 12-Month Physical Function Outcomes in Older Adults With Chronic Low Back Pain: The Delaware Spine Studies

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Objective. The objective of this study was to investigate whether poor hip range of motion (ROM) and strength predict 12-month physical function decline among older adults with chronic low back pain (LBP) and whether hip osteoarthritis modifies those relationships.

Methods. At baseline, passive ROM and strength measurements were taken for hip flexion, extension, abduction, adduction, internal rotation, and external rotation; ultrasound images and self-reported symptoms were used to evaluate hip osteoarthritis presence (eg, osteophytes and hip pain). At baseline and 12 months, performance-based (repeated chair rise, self-selected gait speed, 6-minute walk test [6MWT]) and self-reported (Quebec LBP Disability Questionnaire, Late-Life Function & Disability Instrument [LLFDI] basic and advanced lower extremity scales) physical function outcomes were assessed. Regression models were constructed for each outcome predicted by baseline hip ROM and strength measures, with adjustment for potential covariates. To avoid collinearity, hip ROM and strength measures with the strongest unadjusted correlations were included in final models. The hip osteoarthritis presence by hip ROM/strength interaction was also explored.

Results. Hip abduction strength predicted repeated chair rise ($\beta = -0.297$, $P < 0.001$), gait speed ($\beta = 0.160$, $P = 0.003$), 6MWT ($\beta = 0.159$, $P \leq 0.001$), Quebec LBP Disability Questionnaire ($\beta = -0.152$, $P = 0.003$), and LLFDI basic lower extremity scale ($\beta = 0.171$, $P = 0.005$) outcomes. Regarding hip ROM, extension predicted repeated chair rise ($\beta = -0.110$, $P = 0.043$) and LLFDI advanced lower extremity scale ($\beta = 0.090$, $P = 0.007$) outcomes, external rotation predicted gait speed ($\beta = 0.122$, $P = 0.004$) outcomes, and abduction predicted LLFDI basic lower extremity scale ($\beta = 0.114$, $P = 0.026$) outcomes. The hip osteoarthritis interaction was not significant for any model.

Conclusion. Reduced hip strength and ROM predict physical function decline; hip osteoarthritis presence may not modify these relationships.

INTRODUCTION

Chronic low back pain (LBP) commonly affects older adults (1), and hip osteoarthritis (OA) often accompanies it (2–4). Chronic LBP and hip OA share similar underlying impairments, such as reduced hip range of motion (ROM) and reduced lower extremity muscle strength (5–8). Hip impairments commonly associated with OA may contribute to the disablement process in older adults with chronic LBP (2,9,10). Functional activities (eg, walking and sit-to-stand transitions) require adequate hip ROM and muscle strength (11,12); deficits in these areas may contribute to the declines in physical function associated with these conditions (5–7).

Emerging cross-sectional evidence suggests hip ROM and strength impairments are linked to worse physical function among older adults (13–15); limited longitudinal evidence indicates these impairments predict functional limitations in older adults with lower extremity OA (16). However, no studies have prospectively examined whether OA-related hip impairments affect physical function

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in older adults with a primary complaint of chronic LBP. From a rehabilitation perspective, identifying any modifiable hip impairments that contribute to poor physical function and disability is crucial. If limitations in hip ROM and strength predict poor physical function in older adults with chronic LBP, then these hip impairments may be viable targets for rehabilitative intervention.

The primary objective of this investigation was to assess how hip impairments classically associated with OA, namely hip ROM and muscle strength deficits, impact prospective performance-based and self-reported physical function outcomes in older adults with chronic LBP. We hypothesized that poor hip ROM and strength at baseline would predict larger deficits in performance-based and self-reported physical function outcomes at 12 months, independent of potential covariates. In addition, we sought to explore whether these relationships differed on the basis of the presence of OA signs on ultrasound imaging plus hip pain (ie, symptomatic hip OA).

PATIENTS AND METHODS

Participants and study design. Study details of this prospective cohort have been outlined (Hicks GE, et al: submitted for publication). Participants aged 60 to 85 years were recruited from the greater Delaware area from 2013 to 2016. Participants were included if they met specific LBP criteria: pain intensity score of greater than or equal to 3 of 10 occurring 4 or more days per week for 3 or more months. Participants were excluded if they had nonmechanical LBP symptoms, severely limited mobility (eg, used an assistive device for household ambulation), a progressive neurological disorder, or a terminal illness. All participants were recruited from newspaper advertisements, mailing lists, fliers, health fairs, and retirement communities. Of the 432 individuals screened, 250 participants were enrolled (mean age 69.7 ± 6.8 years); reasons for exclusion are outlined in Figure 1.

The baseline and 12-month assessments consisted of three parts: 1) a standardized evaluation of hip clinical characteristics (ROM and strength), 2) a comprehensive measurement of physical function (performance-based and self-report outcomes), and 3) ultrasound imaging of hip joint morphology. All test and measurement protocols contained standard instructions and an exemplary script.
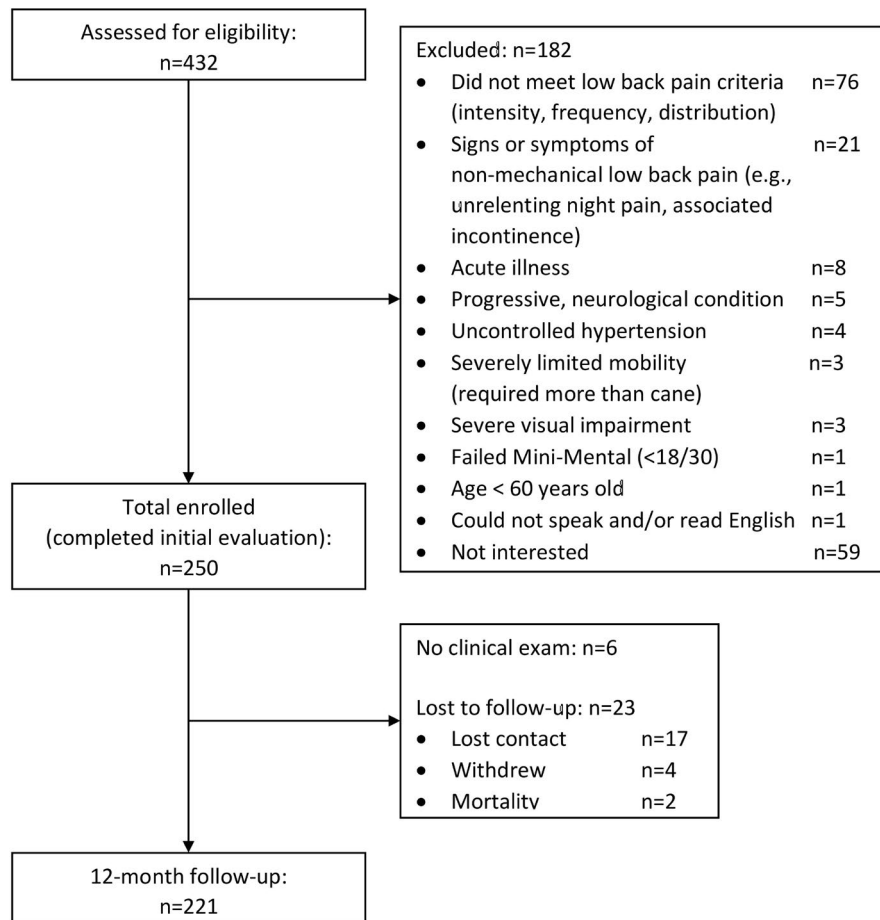
The assessment team was composed of four licensed physical therapists. Those who collected hip data were masked to physical function data and vice versa. All assessors underwent a day of training in clinical study procedures (hip ROM, hip strength, and physical function), practiced study procedures for 1 to 2 weeks, and completed two practical examinations before conducting any research evaluations; two senior study staff members administered the practical examinations, one of whom completed advanced clinical training and was a board-certified orthopedic clinical specialist. Two of the assessors had specialized training in ultrasound imaging and conducted all ultrasound measures.

The University of Delaware Institutional Review Board approved this study, and the protocol was developed in accordance with the principles outlined in the Helsinki Declaration. Each participant provided written informed consent.

Demographics and self-ratings. Participants' age and sex were recorded. Body mass index (BMI) was calculated from height and weight measurements taken with a digital scale. Comorbidity burden was quantified by using the Cumulative Illness Rating Scale (CIRS) (17), a 13-item tool that assesses the presence and severity of impairments in different bodily regions (eg, cardiac, respiratory, gastrointestinal); higher scores indicated greater comorbid disease burden. Pain intensity was measured by using the Pain Thermometer (18); participants were asked to rate their current pain intensity as well as their lowest and highest pain intensity in the last 24 hours (0 = no pain; 10 = worst possible pain). These ratings were averaged, forming a composite pain intensity rating.

Hip ROM and strength. Hip ROM and strength measures were taken by using a standard goniometer or inclinometer and a hand-held dynamometer (Lafayette Instrument Company), respectively, for various motions: hip flexion, extension, abduction, adduction, internal rotation, and external rotation. Specific hip ROM and strength measurement protocols can be found in Supplement 1. For hip strength measurements, the examiner described the motion and instructed the participant to perform a maximal 3-second isometric contraction against the dynamometer. Three trials were performed per limb, with 30-seconds rest in between, and the best trial (ie, highest value) was recorded for each side. The reliability of these measures has been established (19–23). The more restricted of the two sides was used to arrive at a single ROM measurement, whereas the weaker of the two sides was used to arrive at a single hip strength measurement.

Performance-based functional outcomes. The repeated chair rise test, self-selected gait speed measurement, and the 6-minute walk test (6MWT) were used to assess performance-based function; detailed verbal instructions for participants can be found in Supplement 1. For the repeated chair rise test, participants started in the seated position and were instructed to safely complete

Assessed for eligibility: n=432

Excluded: n=182
- Did not meet low back pain criteria (intensity, frequency, distribution) — n=76
- Signs or symptoms of non-mechanical low back pain (e.g., unrelenting night pain, associated incontinence) — n=21
- Acute illness — n=8
- Progressive, neurological condition — n=5
- Uncontrolled hypertension — n=4
- Severely limited mobility (required more than cane) — n=3
- Severe visual impairment — n=3
- Failed Mini-Mental (<18/30) — n=1
- Age < 60 years old — n=1
- Could not speak and/or read English — n=1
- Not interested — n=59

Total enrolled (completed initial evaluation): n=250

No clinical exam: n=6

Lost to follow-up: n=23
- Lost contact — n=17
- Withdrew — n=4
- Mortality — n=2

12-month follow-up: n=221

Figure 1. Study flow diagram.

five sit-to-stand transitions as fast as possible while keeping their arms folded across their chest; this test is reliable and valid (24).

Self-selected gait speed was measured by the GaitMat II system (EQ Inc), a 4-m-long electronic walkway. Participants were instructed to walk at their usual comfortable speed for six trials, using their assistive device if needed. The last three walks were recorded; the average gait speed of the three recorded trials was used for analyses. The GaitMat II has excellent reliability for measuring gait speed (25). Self-selected gait speed is a strong predictor of mortality among older adults (26).

The 6MWT was performed on a rectangular track. Participants were instructed to cover as much ground as possible in 6 minutes, using their assistive device if needed. The assessor trailed behind the participant to prevent pacing and measured the distance walked using a rolling measurement tool. Standard encouragement was provided every 30 seconds. The 6MWT is a reliable and valid measure of physical function among older adults (27).

Self-reported functional outcomes. The Quebec LBP Disability Questionnaire was used to measure LBP-related physical function. Participants were asked how difficult it was to perform certain activities of daily living (eg, prolonged standing) owing to LBP. For each of the 20 items, scores range from 0 to 100, with

higher scores suggesting greater dysfunction. The reliability and the validity of this questionnaire have been established among older adults (28).

The Late-Life Function & Disability Instrument (LLFDI) lower extremity functioning scales were used to measure self-reported physical function more broadly, without the consideration of the presence of pain. The LLFDI contains two scales for lower extremity functioning: basic and advanced. The former contains 14 items that include lower extremity tasks that are less challenging (eg, stepping down from a curb). The latter contains 11 items that include more challenging lower extremity tasks (eg, walking several blocks). The scales are scored from 0 to 100, with higher scores suggesting better physical function. The reliability and the validity of the LLFDI lower extremity functioning scales have been established among older adults (29).

Hip ultrasound imaging. We adopted imaging procedures from prior work (30). First, participants reported if and where they had hip pain (neither, right, left, or bilateral). Then participants were put in a supine position, and their lower extremities were held in a resting position via an apparatus around the ankles. A MyLab 25 ultrasound system (Biosound Esaote, Inc) on brightness mode at 5.0 MHz with a 3.5 to 7.0-MHz curvilinear

transducer at 75% power was used to image the anterior hip joint, including the femoral head, neck, capsule, and synovium; insonation depth and gain were adjusted on an individual basis to optimize image quality. Image acquisition was randomized between right and left sides to avoid an order effect. In between trials, the ultrasound probe was completely removed from the skin to maintain independence of observations. The examiner visually inspected each set of images and scored four morphological features: effusion (0 = none, 1 = perhaps present, 2 = present), synovial profile (0 = concave, 1 = flat, 2 = convex), femoral head shape (0 = round, 1 = slightly flattened, 2 = very flattened, 3 = no obvious contour), and osteophytes (0 = no occurrence, 1 = slight degree, 2 = medium degree, 3 = severe degree). These measures have been found to be reliable and reproducible (31). If participants had previous hip surgery (eg, repair, arthroplasty), ultrasound imaging was not completed, given joint morphological changes and hardware artifact. For descriptive purposes, the worst score of the two hips was reported for each feature.

Participants who reported having hip pain and who had an osteophyte score of 1 or higher (ie, at least a slight degree of osteophytes) from the ultrasound imaging examination were classified as having symptomatic hip OA. We adapted this definition from the American College of Rheumatology's various criteria and decision trees for classifying hip OA; Altman et al (32) found that hip pain plus radiographically identified osteophytes accurately classified those with hip OA, with a sensitivity of 89% and specificity of 90%.

Statistical analysis. Statistical analyses were performed by using SPSS 26 (IBM Corporation). Descriptive analyses included means and SDs for continuous variables and frequencies for categorical variables. Additionally, we examined bivariate correlations for hip ROM and strength measures from the baseline evaluation (predictors) and functional measures from the 12-month follow-up (outcomes).

Multiple linear regression models ($\alpha = 0.05$) were constructed for each functional outcome predicted by baseline measures of hip ROM and strength. To avoid collinearity, the hip ROM and strength measure (eg, abduction, extension) that had the strongest correlation with a given functional outcome was included in the regression model for that outcome. We adjusted for sex, age, BMI, comorbidity burden, (CIRS score), composite LBP intensity, and baseline outcome score (33–36). The adjusted R^2 value was examined for overall model fit. Standardized slopes (β) were examined to estimate relative importance of each predictor variable. All assumptions were checked, and residuals were screened for outliers. Outlier removal was performed if models did not meet parametric test assumptions.

As an exploratory aim, we investigated the impact of hip OA presence on these relationships. First, we explored the unadjusted relationships between baseline and 12-month outcome scores to ensure they were similar between those with and without hip OA;

when relationships differed between groups, we controlled for hip OA presence by baseline outcome score interaction as well as for the covariates previously described. Then we entered the main effect for hip OA presence, as well as the hip OA by hip ROM/strength interaction, into the model.

RESULTS

Baseline descriptive characteristics of the cohort are displayed in Table 1. Hip joint profile characteristics are described in Table 2. Because of surgical history, 16 and 9 participants did not have their right and left hips imaged, respectively. Other reasons for lack of imaging included an inability to find anatomical landmarks (n = 3 for both hips) and shortened clinical examinations due to participant time constraints or refusal (n = 12 for both hips). Ultimately, 229 participants were able to have at least one hip assessed for the presence/absence of symptomatic hip OA at baseline, and 152 participants were found to have symptomatic hip OA.

Table 3 displays the results of the bivariate correlations between baseline hip measures and 12-month functional outcomes. Overall, hip abduction ROM and strength shared the strongest and most consistent relationships with physical function outcomes. Hip extension ROM and strength showed the next strongest relationships.

Table 1. Baseline descriptive characteristics

Variable	n	Mean ± SD or %
Age (y)	250	69.7 ± 6.8
Women	250	51
BMI	248	29.3 ± 5.7
CIRS (0-52)	250	9.4 ± 3.8
Composite LBP intensity (0-10)	250	3.1 ± 1.5
Repeated chair rise (s)	239	14.7 ± 9.7
Gait speed (m/s)	249	1.01 ± 0.23
Quebec LBP Disability Questionnaire (0%-100%)	248	28.3 ± 16.6
6MWT (m)	247	487.7 ± 132.9
LLFDI basic LE scale (0%-100%)	247	66.0 ± 12.1
LLFDI advanced LE scale (0%-100%)	248	49.9 ± 14.0
Hip ROM (degrees)		
Flexion	250	92.4 ± 7.9
Extension	249	4.3 ± 5.7
Abduction	250	23.4 ± 6.7
Adduction	250	12.7 ± 6.6
Internal rotation	249	23.5 ± 10.5
External rotation	249	29.9 ± 10.1
Hip strength (kg)		
Flexion	242	12.9 ± 5.7
Extension	243	6.3 ± 3.5
Abduction	246	7.1 ± 2.7
Adduction	246	7.6 ± 3.3
Internal rotation	242	6.1 ± 2.8
External rotation	243	7.8 ± 3.5

Abbreviations: BMI, body mass index; CIRS, Cumulative Illness Rating Scale; LBP, low back pain; LE, lower extremity; LLFDI, Late-Life Function & Disability Instrument; ROM, range of motion; 6MWT, 6-minute walk test.

Table 2. Baseline hip joint profile characteristics

Variable	n	%
Effusion	229	–
None	60	26
Perhaps present	134	59
Present	35	15
Synovial profile	229	–
Concave	33	14
Flat	128	56
Convex	68	30
Femoral head shape	229	–
Round	69	30
Slightly flattened	122	53
Very flattened	35	15
No obvious contour	3	1
Osteophytes	229	–
No occurrence	8	4
Slight degree	167	73
Medium degree	46	20
Severe degree	8	4
Pain	231	–
Neither	72	31
Right only	44	19
Left only	43	19
Bilateral	72	31
Symptomatic hip OA[a]	229	–
Present	152	66
Absent	77	34

OA, osteoarthritis.
[a] Osteophytes greater than or equal to slight degree and hip pain on same side.

Regarding multiple linear regression models, the assumption of residual normality was violated for models predicting repeated chair rise performance, 6MWT performance, and LLFDI advanced lower extremity scale scores. Outlying cases were removed if they had a residual value 1.5 times greater than the interquartile range of residual distribution for each model. For the repeated chair rise model, nine outliers had residual values greater than 6.5 and three outliers had residual values less than –6.5, resulting in a somewhat positive skew. For the 6MWT model, all 12 outliers had a residual value of less than –109.8, resulting in a negative skew. For the LLFDI advanced lower extremity model, although residuals were generally symmetrical, four outliers had residual values greater than 21.5 and six outliers had residual values less than –21.5. Outlier removal resulted in satisfying the assumption of normality of residuals for all three of these outcomes.

Table 4 displays the results from the regression analyses for the performance-based function outcomes, after outlier removal. Each model had good overall fit ($P \leq 0.001$). After we adjusted for potential covariates, baseline hip abduction strength was a significant predictor of repeated chair rise test performance, self-selected gait speed, and 6MWT performance at the 12-month follow-up; baseline hip extension and external rotation ROM were significant predictors of 12-month repeated chair rise test performance and self-selected gait speed, respectively. The standardized β coefficients illustrate the relative importance that each independent variable has on the effect of the dependent variable. Aside from baseline performance, baseline hip abduction strength was the strongest predictor for repeated chair rise test performance ($\beta = -0.297$, $P < 0.001$), self-selected gait speed ($\beta = 0.160$, $P = 0.003$), and 6MWT performance ($\beta = 0.159$, $P < 0.001$), which underscores its importance in predicting future performance. Of note, baseline hip extension and external rotation ROM not only appeared to be significant predictors of repeated chair rise test performance and self-selected gait speed, respectively, but also had higher standardized β coefficients compared with several other predictors ($\beta = -0.110$, $P = 0.043$ and $\beta = 0.122$, $P = 0.004$, respectively).

Table 5 displays the results from the regression analyses for the 12-month self-reported functional outcomes, after outlier

Table 3. Bivariate correlations (Pearson *r*) between baseline hip predictors and 12-month functional outcomes

	Repeated Chair Rise	Gait Speed	6MWT	Quebec LBP Disability Questionnaire	LLFDI Basic LE	LLFDI Advanced LE
Hip ROM						
Flexion	−0.109	0.137*	0.082	−0.064	0.138*	0.082
Extension	−0.292[a],*	0.157*	0.150*	−0.070	0.151*	0.184[a],*
Abduction	−0.220*	0.208*	0.185[a],*	−0.173[a],*	0.221[a],*	0.170*
Adduction	−0.022	0.122	0.109	−0.107	0.055	0.028
Internal rotation	0.039	−0.076	−0.076	0.039	−0.045	−0.092
External rotation	−0.077	0.234[a],*	0.164*	−0.110	0.159*	0.122
Hip strength						
Flexion	−0.285*	0.304*	0.439*	−0.340*	0.299*	0.333*
Extension	−0.323*	0.365*	0.503*	−0.354*	0.385*	0.371[a],*
Abduction	−0.365[a],*	0.459[a],*	0.583[a],*	−0.383[a],*	0.419[a],*	0.368*
Adduction	−0.333*	0.425*	0.523*	−0.345*	0.341*	0.310*
Internal rotation	−0.316*	0.396*	0.526*	−0.299*	0.362*	0.316*
External rotation	−0.336*	0.426*	0.544*	−0.333*	0.331*	0.312*

Abbreviations: LBP, low back pain; LE, lower extremity; LLFDI, Late-Life Function & Disability Instrument; ROM, range of motion; 6MWT, 6-min walk test.
[a] Selected for multiple linear regression analyses.
* $P < 0.050$.

Table 4. Multiple linear regression models evaluating the association between baseline hip measures and 12-month performance-based functional outcomes, with adjustment for covariates

Baseline Variables	Unstandardized β	SE	Standardized β	P
Outcome: 12-month repeated chair rise (n = 185; 12 outliers removed); Adjusted R^2 (P value) = 0.556 (≤0.001)				
Age	0.064	0.028	0.128	0.023*
Sex	−0.348	0.389	−0.054	0.371
BMI	0.035	0.032	0.061	0.280
CIRS	0.090	0.050	0.100	0.074
Composite LBP intensity	−0.164	0.119	−0.072	0.169
Repeated chair rise	0.360	0.039	0.512	<0.001*
Hip ROM: extension	−0.063	0.031	−0.110	0.043*
Hip strength: abduction	−0.369	0.075	−0.297	<0.001*
Outcome: 12-month gait speed (n = 210; 0 outliers removed); Adjusted R^2 (P value) = 0.646 (≤0.001)				
Age	−0.003	0.002	−0.092	0.052
Sex	−0.006	0.024	−0.013	0.789
BMI	−0.003	0.002	−0.075	0.104
CIRS	−0.007	0.003	−0.114	0.017*
Composite LBP intensity	0.010	0.007	0.059	0.173
Gait speed	0.643	0.053	0.606	<0.001*
Hip ROM: external rotation	0.003	0.001	0.122	0.004*
Hip strength: abduction	0.014	0.005	0.160	0.003*
Outcome: 12-month 6MWT (n = 195; 12 outliers removed); Adjusted R^2 (P value) = 0.896 (≤0.001)				
Age	−1.788	0.535	−0.092	0.001*
Sex	−8.404	7.547	−0.032	0.267
BMI	−2.501	0.646	−0.107	<0.001*
CIRS	0.901	1.009	0.025	0.373
Composite LBP intensity	0.776	2.213	0.009	0.726
6MWT	0.804	0.036	0.777	<0.001*
Hip ROM: abduction	0.141	0.473	0.007	0.767
Hip strength: abduction	7.480	1.490	0.159	<0.001*

Abbreviations: BMI, body mass index; CIRS, Cumulative Illness Rating Scale; LBP, low back pain; ROM, range of motion; 6MWT, 6-min walk test.
* $P \leq 0.050$.

removal. Each model had good overall fit ($P \leq 0.001$). After we adjusted for potential covariates, hip abduction strength was a significant predictor of both Quebec LBP Disability Questionnaire and LLFDI basic lower extremity scale scores. Hip abduction ROM was a significant predictor of the LLFDI basic lower extremity scale score but not of the Quebec LBP Disability Questionnaire score. Similar to the models for performance-based function, the standardized β coefficients for hip abduction strength in the Quebec LBP Disability Questionnaire ($\beta = -0.152$, $P = 0.003$) and LLFDI basic lower extremity scale ($\beta = 0.171$, $P = 0.005$) models suggest that this measure was the most important factor in the prediction of future self-reported physical function, aside from baseline outcome scores. The standardized β coefficient for hip extension ROM in the prediction of the LLFDI advanced lower extremity scale score ($\beta = 0.090$, $P = 0.007$) suggests that this factor was an important contributor to the model. Interestingly, although hip extension ROM was a significant predictor of the LLFDI advanced lower extremity scale score, hip extension strength was not.

Potential covariates had varying associations across models. In all cases of significant association, older age, higher BMI, greater comorbidity burden, and higher composite LBP were predictive of worse outcomes. Sex largely did not predict 12-month outcomes, with the exception of LLFDI advanced lower extremity scale scores, in which being female was associated with worse scores than being male ($P = 0.029$).

The addition of the hip OA by hip ROM/strength interaction terms did not significantly contribute to the variance explained in any model. Thus, models without interaction terms are presented. See Supplement 2 for complete exploratory analyses.

DISCUSSION

This study is the first, to our knowledge, to explore the longitudinal relationship between clinical hip impairments associated with OA (ROM and strength) and physical function among older adults with chronic LBP. The key finding from this study is that hip strength and ROM are strongly predictive of performance-based

Table 5. Multiple linear regression models evaluating the association between baseline hip measures and 12-month self-report functional outcomes, with adjustment for covariates

Baseline Variables	Unstandardized β	SE	Standardized β	P
Outcome: 12-month Quebec LBP Disability Questionnaire (n = 219; 0 outliers removed); Adjusted R^2 (P value) = 0.652 (≤0.001)				
Age	0.176	0.113	0.071	0.122
Sex	−0.881	1.709	−0.026	0.607
BMI	0.212	0.139	0.068	0.128
CIRS	0.360	0.209	0.079	0.087
Composite LBP intensity	0.681	0.528	0.058	0.199
Quebec LBP Disability Questionnaire	0.690	0.051	0.667	<0.001*
Hip ROM: abduction	−0.119	0.110	−0.047	0.281
Hip strength: abduction	−0.940	0.312	−0.152	0.003*
Outcome: 12-month LLFDI basic LE (n = 217; 0 outliers removed); Adjusted R^2 (P value) = 0.529 (≤0.001)				
Age	−0.169	0.109	−0.083	0.122
Sex	−0.418	1.616	−0.015	0.796
BMI	−0.341	0.132	−0.138	0.011*
CIRS	−0.362	0.203	−0.097	0.075
Composite LBP intensity	−0.926	0.499	−0.096	0.065
LLFDI basic LE	0.545	0.069	0.463	<0.001*
Hip ROM: abduction	0.234	0.105	0.114	0.026*
Hip strength: abduction	0.894	0.315	0.171	0.005*
Outcome: 12-month LLFDI advanced LE (n = 202; 10 outliers removed); Adjusted R^2 (P value) = 0.818 (≤0.001)				
Age	−0.140	0.082	−0.057	0.087
Sex	−2.634	1.200	−0.079	0.029*
BMI	−0.110	0.109	−0.037	0.312
CIRS	0.216	0.167	0.046	0.197
Composite LBP intensity	−0.022	0.375	−0.002	0.953
LLFDI advanced LE	1.024	0.050	0.856	<0.001*
Hip ROM: extension	0.267	0.098	0.090	0.007*
Hip strength: extension	0.034	0.169	0.007	0.839

Abbreviations: BMI, body mass index; CIRS, Cumulative Illness Rating Scale; LBP, low back pain; LE, lower extremity; LLFDI, Late-Life Function & Disability Instrument; ROM, range of motion.
* $P \leq 0.050$.

and self-reported physical function at 12 months' follow-up, independent of potential covariates. Furthermore, these relationships do not appear to differ between those with and without symptomatic hip OA. Identifying risk factors for poor health outcomes is a critical step in developing evidence-based interventions, and these results will help inform future clinical trials.

Research demonstrating the link between chronic LBP and hip impairments associated with OA is growing. Prior evidence established that LBP and hip OA are often comorbid (2–4), and these conditions may present with similar impairments, such as reduced hip strength and ROM (5–8). Hip muscle deficits may similarly impact the clinical course of these conditions: impaired hip abductor muscle characteristics may be implicated in the development and persistence of LBP (37) and are associated with the radiographic and clinical severity of hip OA (38,39). Of note, although prevalence estimates of concomitant LBP and hip OA vary widely, the prevalence in our study (66%) is broadly consistent with other work (3,4).

Importantly, we found that ROM and strength impacted functional outcomes similarly among individuals with and without

symptomatic hip OA. Rundell et al (40) found that individuals with LBP and hip OA symptomatology reported worse disability than individuals with LBP alone. Our work extends these findings: hip ROM and strength, which are commonly impaired by hip OA, account for declines in physical function. Thus, it is possible these hip impairment measures mediated the group differences seen in that study.

Hip strength and ROM have been shown to be cross-sectionally related to various performance-based functional measures among other older populations (14,15), but our study is the first to demonstrate these relationships prospectively among older adults with chronic LBP. Because performance-based and self-reported measures of physical function have robust predictive ability regarding poor health outcomes (26,41,42) and because older adults with chronic LBP are at higher risk for physical function decline (43,44), it is imperative to identify potentially modifiable factors for intervention. Our results indicate hip strength and ROM may be critical targets for intervention in this population. Prior evidence has established that hip impairments associated with OA are amenable to rehabilitation interventions, such

as manual and exercise therapies (45,46); thus, manual and exercise therapies may effectively mitigate the downstream effects of hip impairments in older adults with chronic LBP.

The clinical implications of our data are clear. Unstandardized β coefficients from our regression models illustrate the amount of change in the outcome variable to be expected, for one unit change in the independent variable of question. For example, for every 1-kg increase in hip abduction strength at baseline, there are improvements in performance and self-report measures at 1 year: a 0.37-second decrease in repeated chair rise time, a 0.014-m/second increase in self-selected gait speed, a 7.5-m improvement in 6MWT distance, a 1-point decrease on the Quebec LBP Disability Questionnaire score, and a 1-point increase on the LLFDI basic lower extremity functioning scale score. Minimal clinically important difference (MCID) and minimal detectable change (MDC) scores have been established in community-dwelling older adults for many of these outcome measures, including self-selected gait speed (MCID = 0.05 m/second) (47), 6MWT performance (MCID = 20 m) (47), the Quebec LBP Disability Questionnaire score (MDC = 11 points) (28), and the LLFDI basic lower extremity functioning scale score (MCID = 3 points) (48). By extension, a 3-kg increase in hip abduction strength in isolation (ie, without change in any other variable) would yield meaningful improvements for many of these outcomes, with the exception of LBP-related disability.

However, physical therapy interventions for hip dysfunction are often multimodal, targeting both ROM and strength (49). Models in which hip ROM and strength independent variables are both statistically significant (repeated chair rise test performance, gait speed, 6MWT distance, and LLFDI basic lower extremity functioning scale outcomes) indicate that more modest changes in each hip measure would be needed to generate a clinically meaningful improvement in the outcome. For example, a 2-kg improvement in hip abduction strength, coupled with a 7-degree improvement in hip external rotation ROM, may generate a meaningful improvement in gait speed.

Interestingly, the impact these hip measures have on LBP-related disability appears to be somewhat weaker. As noted, hip abduction strength has a significant relationship with Quebec LBP Disability Questionnaire scores, but our findings indicate that nearly a 12-kg increase in strength would be required to yield clinically meaningful improvement. Recently, in a case series of older adults with chronic LBP, Peterson et al (50) found that targeting hip abductor weakness yielded meaningful changes in LBP-related disability on a similar instrument, the Oswestry Disability Index; however, this study should be interpreted with caution given the weakness of case series study designs and the different methodology used for hip strength assessment. Chronic LBP is a complex and multifactorial phenomenon, with several potential underlying mechanisms that may affect pain-related disability (9). Our findings indicate that future work should comprehensively identify other factors most important to LBP-related disability.

From an analytical perspective, a Bonferroni correction could be applied to correct for multiple models. However, these analyses were not the primary aim of the original study; we felt a more liberal approach of setting $\alpha = 0.05$ was justifiable. Importantly, if a Bonferroni correction was applied ($\alpha = 0.008$), seven of nine clinical hip measures would retain statistical significance as predictors, whereas hip extension and abduction ROM would lose statistical significance in models for 12-month repeated chair rise and LLFDI basic lower extremity functioning outcomes, respectively.

Of note, although we opted for an approach to prevent multicollinearity in regression models by selecting a single movement from each measurement category (ROM and strength), there were several movements within measurement categories that shared significant correlations with the chosen outcomes (Table 2). Therefore, it is possible that other motions within each measurement category should also be addressed in a comprehensive treatment program to improve physical function. Nevertheless, hip abduction regularly recurred as the most important strength measure relative to physical function. From a biomechanical perspective, our findings are unsurprising, given the role these muscles and this motion plays in resisting ground reaction forces during activities assessed through these outcome measures, such as standing, walking, stair climbing, and transitional motions (eg, sit-to-stand).

Strengths of our study include the longitudinal design, large sample size, rich assessment of both hip-related impairment measures and physical function, masked examiners, and robust findings. However, some limitations should be noted.

Our approach allowed us to select only a single movement from each measurement category. Also, our findings, although strong, should be cautiously interpreted in context: the extent to which impairments are modifiable likely varies between motions; for example, using the same ROM testing methodology as in our study, Prather et al (20) found that in a sample of asymptomatic young and middle-aged adults, normal hip abduction ROM was approximately 40 degrees, whereas normal hip extension ROM was approximately 17 degrees. Although a certain amount of ROM loss due to age may be expected, the capacity for change may be smaller for certain motions, such as extension, compared with other motions, such as abduction. In other words, a 5-degree change in hip abduction ROM would be much more modest and achievable compared with a 5-degree change in hip extension. Furthermore, ROM and strength testing methodologies vary greatly between studies, making it difficult to establish reliable, normative values; thus, comparing values between studies should be done carefully.

It should also be noted that we used ultrasound imaging to detect hip osteophytes, which can be reliably performed by rehabilitation clinicians; however, radiography is the traditional imaging method to diagnose hip OA (32). Also, the erythrocyte sedimentation rate and the presence of joint space narrowing, in conjunction with hip pain and osteophytes, are recommended in the diagnosis of hip osteoarthritis; however, Altman et al (32) found

that that hip pain with osteophyte presence alone performed comparably to a decision tree including these additional criteria. Furthermore, the degree of missing data related to hip OA classification does not permit us to make definitive conclusions. Hence, we consider the analyses concerning hip OA interactions exploratory. As noted above, however, our prevalence estimates of hip OA in this sample were broadly consistent with previous work (3,4); this gives us a greater degree of confidence in the validity of our exploratory findings. Nevertheless, these findings should be corroborated in a population-based study by using radiography and other hip OA-related measures.

Finally, some may argue that examining the relationship between the change (baseline to 12 months) in hip measures and the change physical function outcomes may be more appropriate for drawing conclusions regarding the change needed in hip ROM/strength to generate clinically meaningful change in physical function. However, our original aim was to determine whether poor hip ROM and strength were risk factors for declines in physical function. Examining the relationship between the change in hip measures and the change in physical function does not allow us to investigate the temporal nature of the relationship: it is impossible to tell whether changes in hip ROM/strength precede changes in physical function with this approach.

Reduced hip strength and ROM are important risk factors for decline in physical function among older adults with chronic LBP; it appears those relationships are similar among those with and without hip OA. Poor hip strength, particularly in abduction, and ROM predict declines in performance-based and self-reported physical function, beyond the influence of age, sex, BMI, comorbidity burden, and LBP intensity. Future clinical trials investigating the impact of intervening on hip strength/ROM are warranted.

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All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be published. Drs. Coyle and Hicks had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
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