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# Static and dynamic abductor function are both associated with physical function 1 to 5 years after total hip arthroplasty

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ABSTRACT

*Background:* A subset of total hip arthroplasty patients experience functional impairments past the first post-operative year. Poor hip abductor function is common before and in the early postoperative period. It is not known if abductor impairment is associated with long-term functional impairment. This study evaluated the relationships between static and dynamic abductor function and performance-based and self-reported function > 1 year post-total hip arthroplasty.

*Methods:* Eighteen adults 1–5 years post-total hip arthroplasty participated. Static and dynamic abductor function were assessed through dynamometry and gait analysis, respectively. Subjects completed four physical performance tests and two self-report instruments.

*Findings:* Higher peak isometric abductor strength was associated with better performance-based function ($P \leq 0.001$–$0.030$) and with self-reported function ($P \leq 0.001$–$0.012$). Higher peak external adduction moment was associated with better results on 3 of 4 performance tests ($P = 0.007$–$0.026$). Together, static and dynamic abductor function predicted 35–77% of the variation in physical function. Abductor strength best predicted walking test results and self-reported function, while dynamic abductor function best predicted tests involving sit-to-stand

*Interpretation:* Static and dynamic abductor function were associated with physical function 1–5 years after total hip arthroplasty. These results support further investigation of interventions targeting abductor function for persons experiencing persistent impairments.

## 1. Introduction

Total hip arthroplasty (THA) is a common orthopedic procedure, offering pain relief and restoration of function for people with severe hip osteoarthritis. With THA, along with postoperative physical therapy (PT), these aims are met for most patients, but not all. A subset of THA patients report persistent functional impairment after surgery, and some have no clinically meaningful improvement (Beswick et al., 2012; Foucher, 2017; Hawker et al., 2013; Judge et al., 2010; Judge et al., 2013; Singh and Lewallen, 2013). Typical PT programs continue for no more than 4 months after surgery (Judd et al., 2014; Minns Lowe et al., 2009; Minns Lowe et al., 2015). Because many functional impairments persist past the first postoperative year (Beswick et al., 2012; Judge et al., 2013; Singh and Lewallen, 2013), improving THA outcomes may require a longer-term perspective. Most studies on functional recovery have focused from the early post-operative period up to 12 months after surgery (Dayton et al., 2016; Gilbey et al., 2003; Judge et al., 2010; Monaghan et al., 2017; Nankaku et al., 2016; Shih et al., 1994; Vaz et al., 1993). Identifying functional impairments that can be improved through targeted interventions prescribed a year or more after surgery, well after PT typically ends, holds the potential to improve patient satisfaction and quality of life.

One of the most commonly reported impairments after THA is poor hip abductor function (Bertocci et al., 2004; Rasch et al., 2010; Sicard-Rosenbaum et al., 2002). Consequently, improving abductor function offers a logical focus for rehabilitation. Surprisingly, the link between abductor function and functional outcomes has not been fully established. Moreover, abductor contribution to physical function is complex

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and can be measured in different ways. One commonly used measure of abductor function is static strength, measured as peak isometric torque, typically assessed with dynamometry (Judd et al., 2016; Shih et al., 1994; Widler et al., 2009). A second measure of abductor performance is dynamic function as assessed through gait analysis. Gait analysis enables calculation of external moments, the rotational forces in each plane about the hip. To maintain equilibrium at each point in time, an external moment must be balanced by an equal and opposite internal moment produced by muscles and other joint structures. The peak external adduction moment, which is balanced by the hip abductors, is often interpreted as a reflection of net demand on abductors during walking. We have previously linked gait measures, including the hip adduction moment, to clinical response to THA in the first post-operative year (Behery and Foucher, 2014; Foucher, 2017). To gain a more complete understanding of the relationship between abductor performance and THA outcomes, both static abductor strength and dynamic abductor function should be assessed.

The purpose of this cross-sectional study was to evaluate the relationships between abductor function and physical performance and self-reported function in community dwelling adults 1–5 years post-THA. A more complete understanding of abductor function in THA recipients could support targeted interventions to improve impairments persisting more than 1 year after surgery. We asked the following study questions: (1) Is peak isometric abductor strength significantly associated with performance-based function and self-reported function? (2) Is peak external adduction moment significantly associated with performance-based function and self-reported function.

## 2. Methods

### 2.1. Design

To evaluate our study questions, we designed a cross-sectional study of community dwelling adults 1–5 years post-THA. All protocols were approved by the Institutional Review Board of the University of Illinois at Chicago. Each subject provided written informed consent before participating.

### 2.2. Participants

We recruited community dwelling adults in the Chicago area. Eligibility criteria included: (i) THA occurring at least 1 year and no more than 5 years before testing; (ii) the ability to walk unassisted for 10 min; (iii) not actively participating in PT; and (iv) no other medical conditions that would interfere with safe completion of the protocol (e.g. stroke or symptomatic musculoskeletal injury). The sample consisted of 6 male and 12 female individuals (Table 1).

### 2.3. Measures of abductor function

#### 2.3.1. Static abductor strength

Hip abductor strength was measured as peak isometric torque for the operated-side hip. Subjects were positioned in side-lying position (Widler et al., 2009)on the reclined seat of a dynamometer [Biodex System 4 Pro, Biodex Medical System, Inc., Shirley, NY, USA], with the axis of the dynamometer arm aligned with the subject's greater trochanter, and the arm's cuff fastened just above the knee joint. Limb weight was measured at 20 degrees of static abduction with the limb relaxed and supported. Isometric torque was then measured as the subject pushed against the padded surface of the dynamometer arm. Testers encouraged subjects to give consistent maximal effort but not to the point of pain. After set-up and instructions, subjects performed three 5 s bouts, alternated with 30 s of rest. We averaged the peak isometric torque measured from the three bouts and normalized the result to body mass (Nm/kg) (Bazett-Jones et al., 2011).

**Table 1**
Subject characteristics (n = 18, 12 female).

| Characteristics | Mean (SD) or N | Range |
|---|---|---|
| Age (years) | 57 (8) | 45–76 |
| BMI (kg/m$^2$) | 33.2 (10.1) | 19.5–59.2 |
| Time post-surgery (months) | 25 (10) | 12–48 |
| 12–24 months post-surgery (N) | 9 | |
| 24–48 months post-surgery (N) | 9 | |
| Abductor measures | | |
| Peak isometric hip abductor strength (Nm/kg) | 0.90 (0.35) | 0.26–1.60 |
| Peak external adduction moment (% body weight x height) | 4.5 (1.5) | 1.3–6.4 |
| Performance tests | | |
| 6 min walk test (m) | 413 (93) | 234–569 |
| 40 m fast walk (m/s) | 1.5 (0.3) | 0.8–2.1 |
| 30 s chair stand test | 10 (3) | 5–17 |
| Timed up and go (s) | 7.5 (2.2) | 5.0–12.4 |
| Self-reported function | | |
| HOOS/function scale | 79 (23) | 29–100 |
| PROMIS/physical function | 46 (9) | 35–66 |

#### 2.3.2. Dynamic abductor function

Dynamic abductor function was evaluated through gait analysis, with the variable of interest being peak external adduction moment. The gait analysis facility consisted of an 8-meter carpeted walkway with two imbedded force plates [AMTI, Newton, MA, USA] and surrounded by an eight-camera motion capture system [Motion Analysis Corporation, Santa Rosa, CA, USA]. Each subject was marked with 22 passive reflective markers (modified Helen Hayes marker set). Subjects were instructed to walk the length of the walkway at a normal pace, then return to the starting point. The motions of the reflective markers were recorded at 120 Hz. The marker positions were tracked, processed, and analyzed using commercial software [Cortex and OrthoTrak, Motion Analysis Corporation, Santa Rosa, CA]. Hip joint centers were calculated by the OrthoTrak software using a standard regression equation. Hip center estimates through OrthoTrak software have been found clinically acceptable (Harrington et al., 2007; Kiernan et al., 2015). Trials were continued until a subject made a full step on a force plate with the affected side a total of five times. We averaged the peak external adduction moment from the five trials, and normalized the result to subject body weight and height (Moisio et al., 2003).

### 2.4. Performance tests

We assessed physical performance with 4 tests recommended by the Osteoarthritis Research Society International (OARSI) (Dobson et al., 2013). Two of the tests involved walking, and two of the tests involved more dynamic stand/sit movements.

#### 2.4.1. Walking tests

The 6 Minute Walk Test (6MWT) evaluates walking at a self-selected pace over a distance, combining tests of walking function and endurance. For the 6MWT, a 40 m indoor walkway was used, with subjects instructed to walk at a normal pace up and down the walkway. Total distance covered in 6 min was recorded.

The 40 m fast-paced walk tests short distance walking with acceleration (Dobson et al., 2013). We used cones to establish a track, with 20 m marked in tape on the floor between the cones. Subjects were instructed to walk at a fast pace and make a full circuit around the cones. Testers recorded time between the 20 m tape marks during a full circuit, totaling 40 m. Subjects performed two trials, with the mean walking speed (m/s) used.

#### 2.4.2. Stand/sit tests

The 30 s chair stand tests sit-to-stand ability (Dobson et al., 2013), requiring a combination of strength, power generation, and balance.

For the 30 s chair stand, subjects sat on an armless chair, seat height 40 cm, with arms crossed in front of their chest. Subjects were instructed to stand up completely and sit down the maximum number of times possible in 30 s. Total repetitions were recorded. The Timed Up-and-Go (TUG) tests ambulatory transitions, combining sit-to-stand ability, walking a short distance, and turning while walking (Dobson et al., 2013). For the TUG, subjects sat on an armed chair with a 40 cm high seat and were instructed to stand up and walk as quickly as possible around a cone 3 m in front of the chair. Subjects performed two trials with the mean time used.

### 2.5. Self-reported function

For self-reported function, we used a hip-specific survey, the Hip Disability and Osteoarthritis Outcome Score (HOOS)/Function subscale, and a general survey, the Patient-Reported Outcomes Measurement System (PROMIS)/Physical Function 12a scale. The HOOS/Function subscale poses 17 questions about function over the previous seven days, with responses given using a Likert scale (0 to 4) (Nilsdotter et al., 2003). For the total Function subscale score, a normalized score is calculated (0 indicates extreme symptoms and 100 indicates no symptoms). The HOOS/Function subscale has been validated in THR patients (Naal et al., 2009; Nilsdotter et al., 2003). The PROMIS Physical Function SF 12a poses 12 questions concerning physical function and activity. Responses are given using a Likert scale (5 to 1). Raw scores range from 12 to 60 (lowest to highest level of physical function). We converted raw scores to T-scores based on responses from a general US population, using the scoring manual provided on the PROMIS website (www.healthmeasures.net). A T-score of 50 represents an average level of function for US adults, and a T-score of 60 represents a function level that is one standard deviation better than average. The PROMIS Physical Function scale has been validated across a variety of clinical samples (Schalet et al., 2016).

### 2.6. Statistical analyses

Statistical analyses were performed using SPSS v24 [IBM Corp, Armonk, NY, USA]. Shapiro-Wilk tests were used to evaluate normality of variable distributions. For normally distributed data, Pearson correlations were used to examine relationships. For the one variable that did not meet the Shapiro-Wilk test (HOOS/Function), Spearman's correlation was used. Confidence intervals (95%) were established with a bootstrapping procedure. A p-value of $< 0.05$ was considered statistically significant. To evaluate both the combined and individual relationships between static and dynamic abductor performance and each outcome variable, linear regression analyses were performed, with peak isometric abductor strength and the peak external adduction moment as the independent variables and each functional variable as the dependent variable.

## 3. Results

Before evaluating our hypotheses, we confirmed that no significant associations existed between any outcome measure and BMI ($R = -0.370$–$0.092$; $P = 0.131$–$0.727$), or months since surgery ($R = -0.445$ to $-0.139$; $P = 0.064$–$0.811$). Similarly, we found no significant difference in outcome measures based on gender ($P = 0.259$–$0.871$).

Higher peak isometric abductor strength was significantly associated with better performance on each performance test (Fig. 1A–D) and with higher scores on both the hip-specific and general self-reported measures of function (Fig. 2A–B). Abductor strength explained up to 66% of the variation in performance tests and up to 57% of the variation in self-reported function.

Peak external adduction moment was significantly associated with better performance on one of the walking tests, the 6MWT, and on both stand/sit tests (Fig. 3A, C–D). The peak external adduction moment explained up to 44% of the variability in these measures. The association between the peak external adduction moment and 40 m fast-paced walk results was not statistically significant. (Fig. 3B). The associations between the peak external adduction moment and the self-reported measures of function were also not statistically significant (Fig. 4A–B).

Before conducting linear regression analyses, we confirmed that there was no statistically significant association between peak isometric abductor strength and peak external adduction moment ($R = 0.324$, $P = 0.259$). For each type of performance test and for each self-reported function measure (dependent variables), we entered the measure of abductor function (static or dynamic) that had the larger Pearson correlation coefficient with function into the model first. The other term was then forced into the model, and we evaluated the change in $R^2$ value based on a partial F test. For the walking tests, the regression models accounted for 77% (6MWT) to 65% (40 m fast-paced walk) of the variance in test results (Table 2). Isometric abductor strength was the best predictor of both 6MWT and 40 m fast-paced walk results. The regression coefficient for the peak external adduction moment was statistically significant in the model for 6MWT ($P = 0.047$); the $R^2$ value improved from 0.659 with abductor strength alone to 0.766 with both terms ($\Delta R^2 = 0.106$, $P = 0.047$). Adding the peak external adduction moment to the model predicting the 40 m fast-paced walk did not result in a statistically significant change to $R^2$ ($P = 0.165$).

For the stand/sit tests, the regression models accounted for 51% (30 s chair stand) to 48% (TUG) of the variance in test results (Table 2). The peak external adduction moment was the best predictor of sit-stand test results. Adding isometric abductor strength to the models did not result in a statistically significant change to the $R^2$ values ($P \geq 0.052$). For the 30s chair stand, however, the standardized coefficients were very close, which indicates that isometric abductor strength and the peak external adduction moment had comparable influence on test results.

For the two self-reported function measures, the regression models accounted for 59% (HOOS/Function) to 35% (PROMIS/Physical Function) of the variance in results (Table 2). Isometric abductor strength was the best predictor of both functional measures. Adding the peak external adduction moment did not contribute to the models for either instrument ($P = 0.185$–$0.236$) (Table 2).

## 4. Discussion

A subset of THA patients experience persistent functional impairment (Beswick et al., 2012; Foucher, 2017; Hawker et al., 2013; Judge et al., 2010; Judge et al., 2013; Singh and Lewallen, 2013), with poor hip abductor function one of the most commonly reported impairments (Bertocci et al., 2004; Rasch et al., 2010; Sicard-Rosenbaum et al., 2002). An unstated assumption has been that improving hip abductor function will improve overall function. However, the relationship between abductor function and functional outcomes has not been fully established. We were specifically interested in this relationship beyond the first postoperative year. While most THA studies and rehabilitation interventions are focused on periods within the first 12 months after surgery, many functional impairments persist past the 1 year point (Beswick et al., 2012; Judge et al., 2013). The rationale for this study was that a more specific understanding of the relationships between abductor function, physical performance, and self-reported function more than 12 months after THA could advance our understanding of the role of abductor function in functional outcomes. This, in turn, could help guide longer-term rehabilitation of THA recipients with persistent functional impairments.

We asked: (1) Is peak isometric abductor strength associated with performance-based function and self-reported function? (2) Is peak external adduction moment associated with performance-based function and self-reported function? We found that peak isometric abductor strength, our measure of static abductor function, was significantly

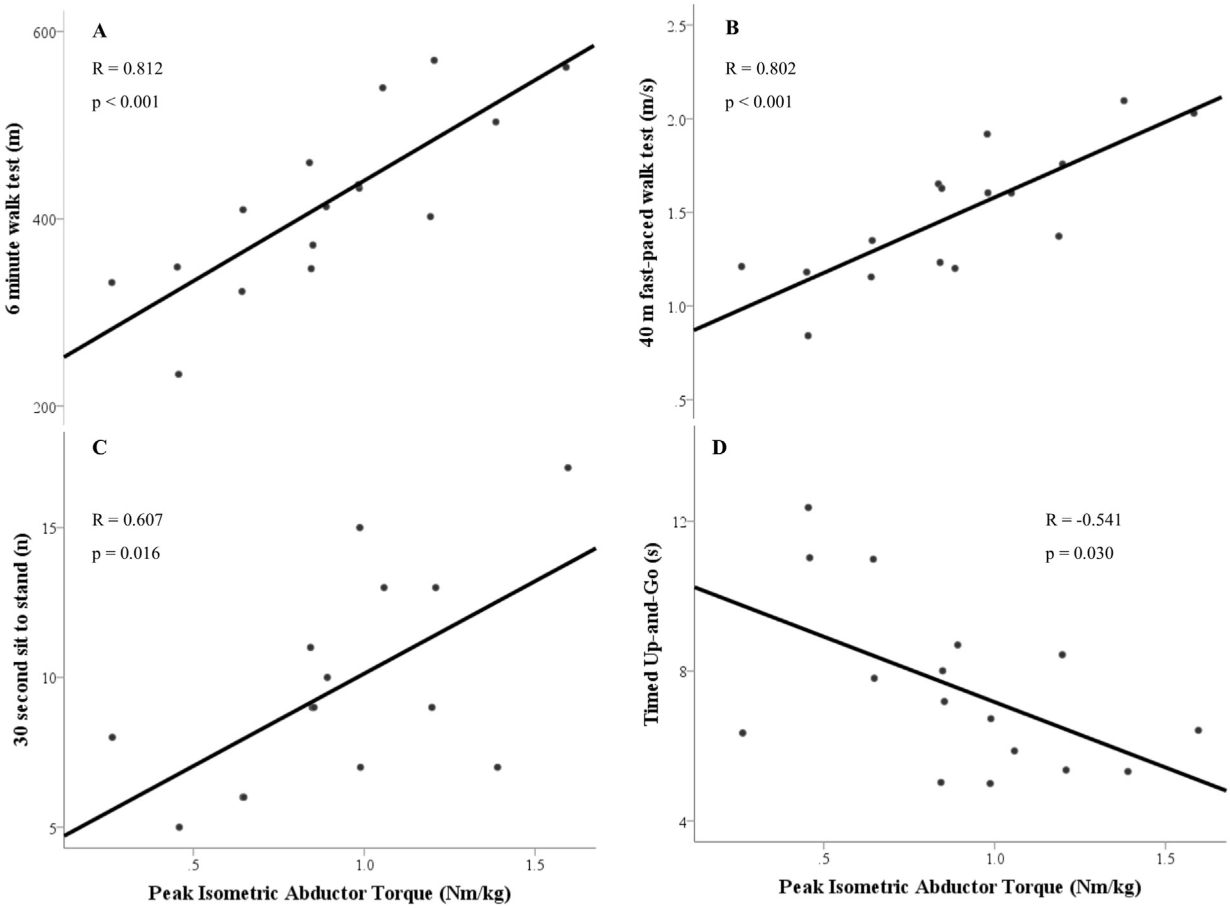

**Fig. 1.** A–D. The scatterplots show that subjects with higher peak isometric abductor strength performed significantly better on each performance test.

correlated with the results of each physical performance test and with self-reported function on HOOS and PROMIS/Physical Function. We also found that peak external adduction moment (reflecting dynamic abductor function) was significantly correlated with the results from 3 of 4 performance tests, but was not significantly correlated with self-reported function.

### *4.1. Static abductor strength, physical performance, and self-report*

Peak isometric abductor strength was most significantly correlated with results in the walking tests ($P < 0.001$), predicting 64–76% of the variability in the 6MWT and the 40 m fast-paced walk. Given the importance of mobility to independent living, the relationship between isometric abductor strength and walking warrants close attention. So far, studies have shown that targeted hip strengthening can effectively improve hip abductor strength within the first months after surgery (Judd et al., 2016), more than six months after surgery (Tsukagoshi et al., 2014), and between 12 and 24 months after surgery (Unlu et al., 2007). Our study supports further investigation of abductor strengthening as an intervention for persons with functional impairment at even

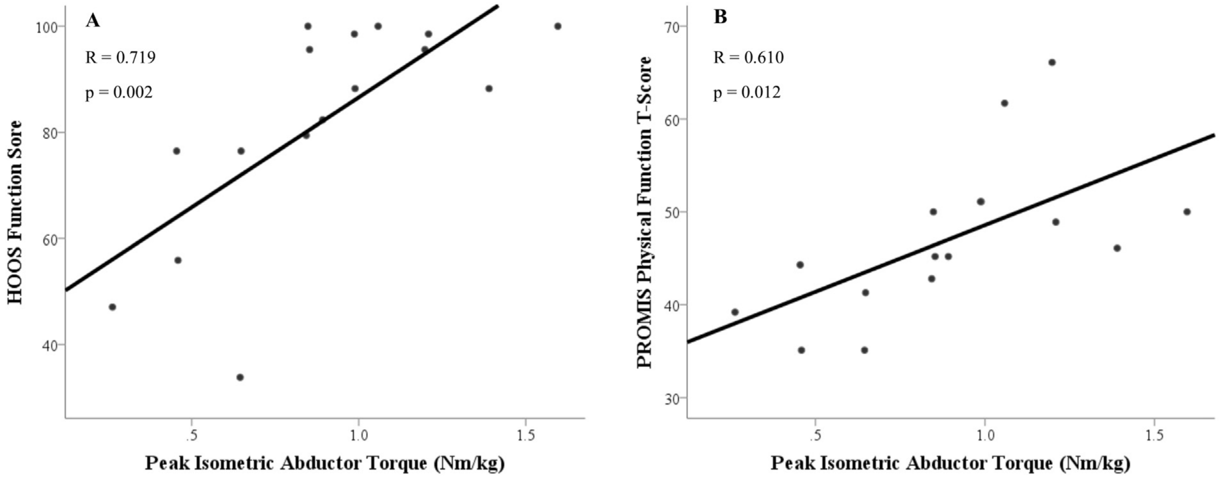

**Fig. 2.** A–B. The scatterplots show that subjects with higher peak isometric abductor strength reported significantly higher function on both a hip-specific instrument and general health instrument.

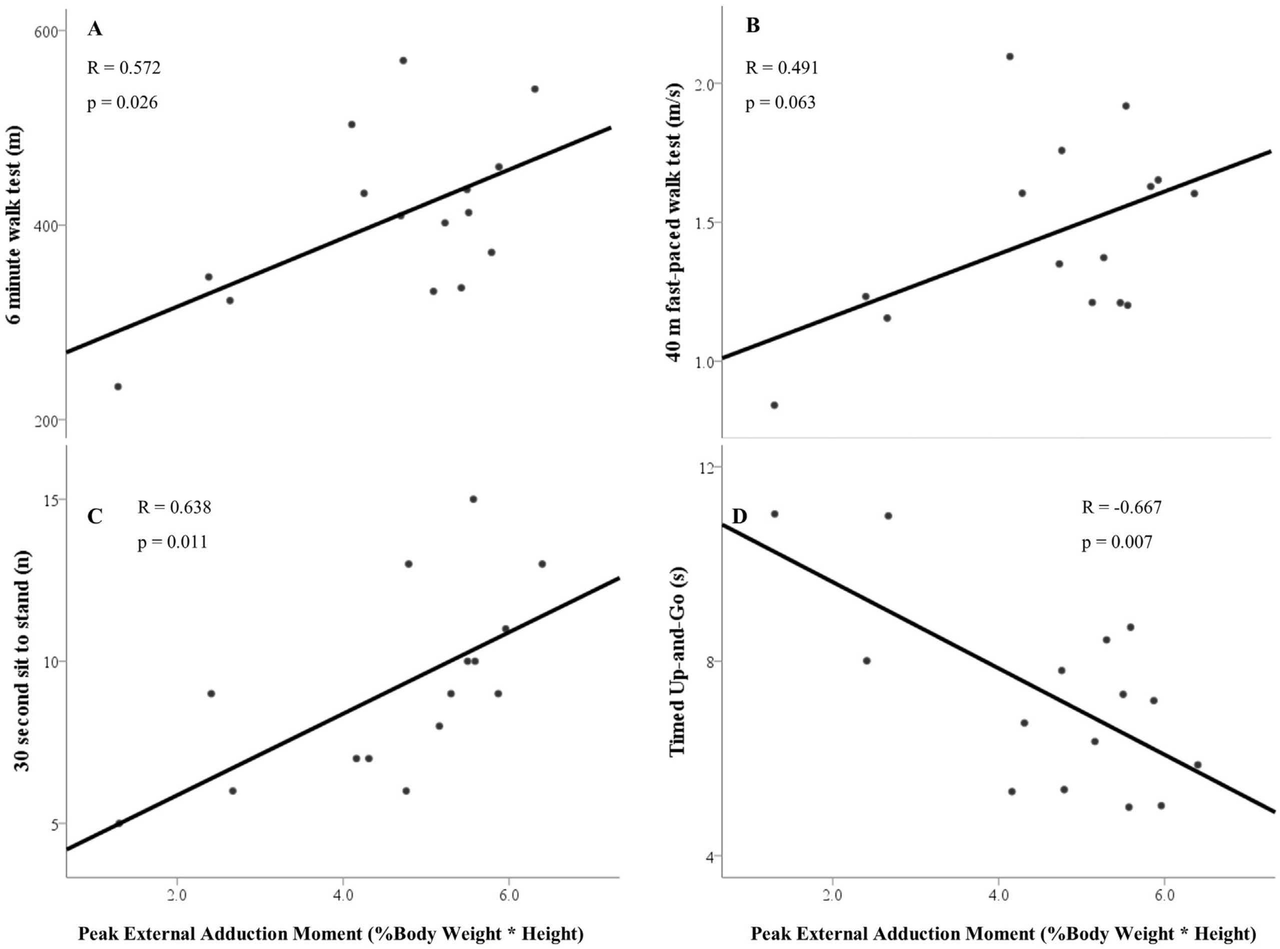

**Fig. 3.** A–D. The scatterplots show that subjects with higher peak external adduction moment performed significantly better on 3 of 4 performance tests.

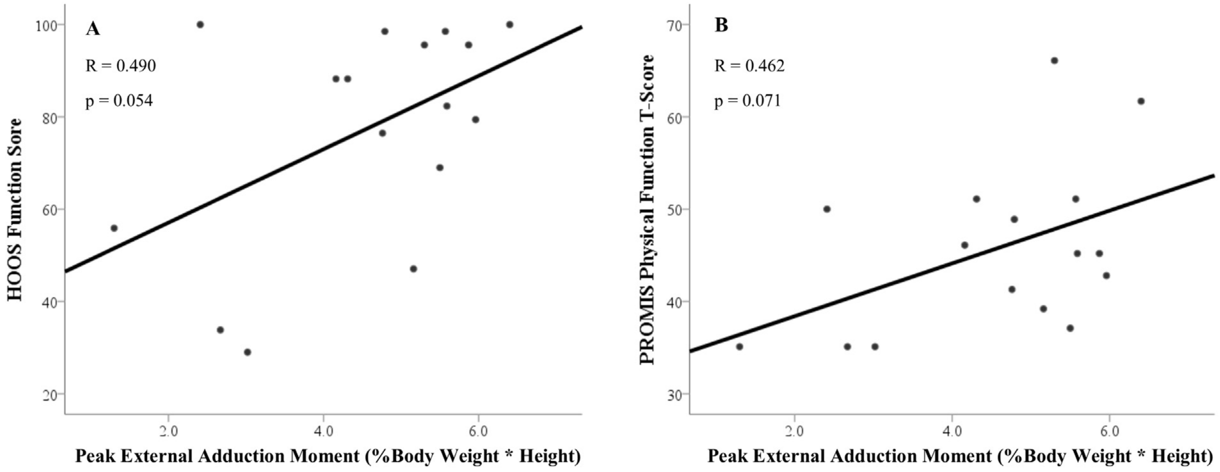

**Fig. 4.** A–B. The scatterplots show that subjects with higher peak external adduction moment reported significantly higher function on both a hip-specific instrument and general health instrument.

later postoperative time-points.

Peak isometric abductor strength was also significantly associated with the results of both sit/stand tests, but dynamic abductor function, discussed below, was more strongly correlated with performance on those tests.

We also found that peak isometric abductor strength was significantly correlated with both the hip-specific ($P = 0.002$) and general self-report instruments ($P < 0.012$) used in this study. While some studies assert that self-report measures do not correlate well to actual physical function (Judd et al., 2014; Stratford et al., 2004; Stratford and Kennedy, 2006) the use of self-report instruments remains common practice, providing efficient and reliable clinical assessment tools. Considering the association between abductor strength and self-reported function, lower self-reported function scores 12 months or more after THA could identify persons that could benefit from interventions to strengthen abductors.

**Table 2**

Linear regression analyses of peak isometric abductor strength and peak external adduction moment and each performance test and self-report measure.

| Dependent variable | Adjusted $R^2$ | p | Independent variable | B (95% CI) | Standardized β | p |
|---|---|---|---|---|---|---|
| 6 min walk | 0.766 | < 0.001 | Peak isometric abductor strength | 183.04 (94.33–271.74) | 0.700 | 0.001 |
| | | | Peak external adduction moment | 21.72 (0.35–43.10) | 0.345 | 0.047 |
| 40 m fast-paced walk | 0.649 | 0.001 | Peak isometric abductor strength | 0.71 (0.33–1.08) | 0.719 | 0.002 |
| | | | Peak external adduction moment | 0.06 (−0.03–0.15) | 0.258 | 0.165 |
| 30 s chair stand | 0.511 | 0.008 | Peak isometric abductor strength | 0.45 (−0.04–8.62) | 0.448 | 0.052 |
| | | | Peak external adduction moment | 0.49 (0.10–2.18) | 0.493 | 0.035 |
| TUG | 0.484 | 0.010 | Peak isometric abductor strength | −2.27 (−5.17–0.63) | −0.363 | 0.112 |
| | | | Peak external adduction moment | −0.83 (−1.53 – −0.13) | −0.550 | 0.024 |
| HOOS/function | 0.591 | 0.007 | Peak isometric abductor strength | 40.70 (11.55–69.84) | 0.626 | 0.011 |
| | | | Peak external adduction moment | 4.51 (−2.51–11.53) | 0.288 | 0.185 |
| PROMIS/physical function | 0.350 | 0.037 | Peak isometric abductor strength | 12.49 (−0.15–25.12) | 0.514 | 0.052 |
| | | | Peak external adduction moment | 1.74 (−1.31–4.78) | 0.296 | 0.236 |

### *4.2. Dynamic abductor function, physical performance, and self-report*

We found that dynamic abductor function, measured through peak external adduction moment, was also associated with physical function, but in different ways than static abductor strength. Peak external adduction moment was most significantly correlated with results in the stand/sit tests ($P = 0.007–0.011$), predicting up to 44% of the variability in 30 s chair stand and TUG. Both tests challenge dynamic balance (Bohannon, 2006; Podsiadlo and Richardson, 1991), suggesting that improved dynamic abductor function could contribute to greater frontal plane stability during dynamic movement. Peak external adduction moment was also significantly correlated with 6MWT ($P = 0.026$). The correlation between peak external adduction moment and the 40 m fast-paced walk, while positive, did not reach the level of significance, suggesting that dynamic abductor function may be less important in short bursts of accelerated walking. It is also possible that the correlation between the peak external adduction moment and walking speed is not linear at faster speeds or is governed by a threshold effect in which there is no association beyond a certain speed. It is important to note that the peak external adduction moment was assessed at a self-selected speed. If measured at a walking speed closer to the fast walking speed of the 40 m fast-paced walk, the values may have been correlated as we have previously shown that the peak external adduction moment is sensitive to walking speed (Behery and Foucher, 2014).

### *4.3. The combined associations of static and dynamic abductor function and physical performance*

Our regression analyses supported that static and dynamic abductor function are both associated with physical performance, but in different ways. For the walking tests, the models showed that the combination of peak abductor strength and peak external adduction moment explained 77% (6MWT) and 65% (40 m fast-paced walk) of the variance in outcomes, with peak abductor strength the most significant contributor to variance in each case (Table 2). For the stand/sit tests, the models showed that the combination of peak abductor strength and peak external adduction moment explained 51% (30 s chair stand) and 48% (TUG) of the variance in outcomes, with peak external adduction moment the most significant contributor to outcome measure variance. Our results showed that static abductor strength alone does not fully explain physical performance, especially activities involving standing and sitting, underscoring that dynamic abductor function is important to evaluate when considering persistent functional impairments.

Several studies have found that improving hip abductor function after THA is significantly associated with improvement in measures of physical function (Heiberg et al., 2012; Tsukagoshi et al., 2014; Unlu et al., 2007). But we are aware of no study evaluating the effects of abductor-targeted interventions specifically on THA recipients with persistent functional impairments. Further research is required to determine if a causal connection exists between poor abductor function and persistent impairments. If so, lower performance test results or survey results in clinic more than 12 months after THA could identify persons needing additional abductor-specific rehabilitation. Indeed, a recent case series described an approach that focused on both static and dynamic abductor function in an 8-week postoperative rehabilitation intervention with positive results (Judd et al., 2016). Further research, including controlled trials involving persons with persistent functional impairments, will help develop targeted rehabilitation protocols. For the subset of the THA population experiencing persistent impairments, abductor-targeted interventions could hold the promise of restoring function and improving quality of life.

### *4.4. Limitations*

Our study has limitations. First, the cross-sectional study design precludes inferring causation between poor abductor function and impaired physical function. Our findings do provide support for the next steps in this inquiry, studies to evaluate directionality of the relationships, and the development and testing of standardized interventions to improve persistent functional impairments. Second, while the cohort was small, the sample size was similar to other biomechanical studies of THA patients (Ewen et al., 2012; Kolk et al., 2014). Third, we did not have information regarding the surgical approach, implant manufacturer or the perioperative physical therapy protocol and we therefore did not control for these factors. This was, however, by design. Our objective was to evaluate community dwelling adults > 1 year post-THA because there is a lack of evidence-based rehabilitation protocols for people with functional impairments persisting past the acute period. Moreover, while some studies suggest that surgical approach affects abductor function (Amlie et al., 2014; Berstock et al., 2015), most studies comparing gait mechanics and different surgical approaches do not show differences beyond the early postoperative period (Foucher et al., 2011; Queen et al., 2014; Rathod et al., 2014). Finally, post-THA PT varies in protocol and duration, and the specific effects of PT on functional outcomes remain unclear (Minns Lowe et al., 2009; Minns Lowe et al., 2015). The decision to evaluate a heterogeneous sample also increases the likelihood that these results will be generalizable to other THA populations.

## 5. Conclusions

We found that both static and dynamic abductor function were significantly associated with physical performance in THA recipients > 12 months after surgery, however each measure of abductor function was associated with physical function in different ways. Both static and dynamic measures may be necessary to fully characterize, and ultimately improve, function. Extending this line of research to populations with persistent functional impairments after THA holds the potential for developing targeted rehabilitation programs that will improve patient satisfaction, reduce costs, and enhance quality of life.

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## Declaration of Competing Interest

None.

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