The role of hip abductor strength on the frontal plane of gait in subjects with medial knee osteoarthritis

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Conflict of Interest Statement

The authors have no conflict of interest to disclose.

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Objective: This study aimed to investigate the relationship of hip abductor strength with external hip and knee adduction moments, pain and physical function, and trunk, pelvis, and hip kinematics in the frontal plane during walking in subjects with medial knee osteoarthritis.

Methods: Twenty-five subjects with medial knee osteoarthritis were evaluated through an isokinetic strength test for hip abductor, three-dimensional gait analysis (kinetics and kinematics), pain and physical function scores. Regression models were used to control the influence of other parameters such as pain, age, gender, severity, walking speed, mass and height.

Results: No relationship was found of hip abductor strength with peak of external knee adduction moment and knee adduction angular impulse. Hip abductor strength explained 17% of contralateral pelvic drop and 21% of hip adduction angle. In addition, hip abductor strength explained 4% and 1% of the variance in the WOMAC physical function score and 40 meter fast paced walk test, respectively.

Conclusion: Considering the relationship of hip abductor strength with contralateral pelvic drop and hip adduction angle, specific exercises might improve physical function and lower limb dynamic alignment during gait.

Keywords: Biomechanical Phenomena; Gait; Kinetics; Osteoarthritis, Knee.

Introduction

Hip abductor strength has been found to be weak in subjects with knee osteoarthritis (KOA) compared to a healthy control group (Costa, Oliveira, Watanabe, Jones, & Natour, 2010; R. S. Hinman et al., 2010; Sled, Khoja, Deluzio, Olney, & Culham, 2010). Weakness of hip abductor could be linked to an increased risk of disease progression, as it allows greater contralateral pelvic drop, shifting the center of mass away from the stance limb, and increasing the medial knee compression force (Chang et al., 2005; Pohl et al., 2015). Radiographic imaging has been shown that joint space narrowing is more common in the medial compartment in comparison to the lateral knee compartment (Vincent et al., 2012). In addition, during dynamic movements such as gait, knee malalignment places the joint into a varus position, which results in increased medial knee compression force (Vincent, Conrad, Fregly, & Vincent, 2012). The medial knee compression force has been estimated using inverse dynamics during three-dimensional gait analysis measuring the external knee adduction moment (EKAM) and the knee adduction angular impulse (KAAI), which is normally increased in this population (Maly et al., 2015; Miyazaki et al., 2002; Sharma et al., 1998). Studies have shown that hip abductor strength has a positive but not significant relationship with external hip adduction moment (EHAM) and EKAM (Kean, Bennell, Wrigley, & Hinman, 2015; Rutherford, Hubley-Kozey, & Stanish, 2014). In addition, despite studies have shown that hip abductor strengthening exercises reduce pain and improve physical function, no change on external knee and hip adduction moments was observed in subjects with KOA (Bennell et al., 2010; Sled et al., 2010). It is important to highlight that hip abductor function might be influenced by the behavior of trunk, hip, and pelvis (Hunt et al., 2008; Powers, 2010). For instance, trunk lean toward the stance limb is considered a compensation to reduce the effort of hip abductor (M. Henriksen, Aaboe, Simonsen, Alkjaer,

& Bliddal, 2009; Powers, 2010). In the same way, contralateral pelvic drop and hip adduction during gait are controlled by hip abductor function (R. S. Hinman et al., 2010; Pohl et al., 2015). More recently, Dunphy and colleagues (Dunphy, Casey, Lomond, & Rutherford, 2016) found that contralateral pelvic drop increases EKAM and KAAI. Investigating the influence of hip abductor strength on trunk, pelvis and hip kinematics would contribute to understand its role on the kinematics in the frontal plane during walking and its role on the medial knee load. It also would provide important information for the development of intervention strategies.

Previous studies have suggested that hip abductor strength influences the kinematics of the pelvis and the lower limb (Linley, Sled, Culham, & Deluzio, 2010; Powers, 2010). For instance, hip abductor strength stabilizes the pelvis and hip on the frontal plane, which means that an increased contralateral pelvic drop (Trendelenburg sign) and/or a higher hip adduction angle may represent hip abductor weakness (Neumann, 2010; Powers, 2010). To our knowledge, there is no study to support this association in subjects with medial KOA. Finally, investigating the relationship of hip abductor strength with external hip and knee moments, and the kinematics of trunk, hip, and pelvis on the frontal plane would clarify the role of hip abductor strength during gait in subjects with medial KOA. This study aimed to investigate the relationship of hip abductor strength with external hip and knee adduction moments, and frontal plane kinematics of trunk, hip, and pelvis during walking in subjects with medial KOA. This study also aimed to investigate the relationship of hip abductor strength with pain and physical function. We hypothesized that hip abductor strength would have no relationship with external hip and knee adduction moments, however, hip abductor strength would present a negative correlation with ipsilateral trunk lean, contralateral pelvic drop, and hip adduction angle. We also hypothesized that hip abductor strength would present a negative correlation with pain and physical function in subjects with medial KOA.

Methods

Subjects

The sample size was calculated as the number of subjects necessary to reach a statistical significance level of 0.05, power of 95% and a medium effect size (d=0.5) (Resende, Kirkwood, Deluzio, Hassan, & Fonseca, 2016). Twenty-five subjects were included in the study (Table 1). All participants underwent anteroposterior semiflexed weight-bearing, lateral view, and skyline view radiographs. These were classified by a radiologist doctor according to the Kellgren and Lawrence (KL) criteria (Kellgren & Lawrence, 1957) and diagnosed as KOA if they met the American College of Rheumatology (clinical, radiographic, and history) criteria (Altman et al., 1986). In addition, only subjects with predominantly medial KOA were included, therefore subjects were excluded if they presented KL grades in the lateral or patellofemoral compartment greater than the medial compartment (Zeni, Rudolph, & Higginson, 2010). Volunteers were excluded for any of the following criteria: body mass index greater than 35kg/m^2, unable to walk without any aid, history of hip or knee arthroplasty or osteotomy, had undergone knee surgery or other nonpharmacological treatment in the 6 months prior to the study (Kean et al., 2015). For bilateral knee OA volunteers, the most symptomatic knee was evaluated. All participants provided written informed consent and the present study was approved by the Ethics committee for Human Investigations at the Federal University of São Carlos.

Pain and physical function evaluation

To evaluate pain and physical function we used the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire, Portuguese version (Serrao, Gramani-Say, Lessi, & Mattiello, 2012; Serrao et al., 2015). We considered all the 24 questions, scoring each one according to the Likert scale (none=0, slight=1, moderate=2, severe=3, extreme=4). The total score ranged from 0 to 96 points and the higher scores indicated worse pain, stiffness, and physical function (Bellamy, Buchanan, Goldsmith, Campbell, & Stitt, 1988). In addition, to complement the evaluation of physical function, specifically related to walking ability, participants performed the 40 meter fast paced walk test, a specific test for subjects with KOA as previously described (Dobson et al., 2013). In this test, subjects were instructed to walk as fast as possible without running (Dobson et al., 2013; Wright, Cook, Baxter, Dockerty, & Abbott, 2011). The speed (speed=distance/time) was used for analysis.

Hip abductor strength evaluation

An isokinetic dynamometer (Biodex Multi-Joint System 3, New York, USA) was used to evaluate hip abductor concentric peak torque. The assessment was not performed on the same day as gait evaluation. Participants were placed in the side-lying position with the non-tested hip and knee flexed (45° and 90°, respectively) and fixed with straps (Baldon Rde, Serrao, Scattone Silva, & Piva, 2014; Nakagawa et al., 2008). With the hip and knee with 90º of flexion, the axis of the dynamometer was aligned with the hip joint center, and the resistance arm of the dynamometer was attached to the lateral aspect of the thigh being tested, 5 cm above the base of the patella. The range of motion was from 0 (neutral position) to 30 degrees of hip abduction and we used 30°/s as angular speed.

"Insert Figure 1 near here"

Prior to the test, participants performed 3 submaximal and 2 maximal concentric contractions in order to familiarize with the movement and equipment, for the examiner to observe if any compensatory movements were used and evaluate if any pain was present. A one-minute rest interval separated the familiarization and 5 maximal concentric contractions. The peak torque of each contraction was used to calculate a mean and then the mean of peak torque was normalized by body mass (%Nm/kg). Participants received verbal encouragement during all trials but no visual feedback was given. The procedures described above presented excellent reliability, with an Intraclass Correlation Coefficient (Standard Error of Measurement) of 0.97 (0.07 Nm/kg)(Baldon Rde et al., 2009). To correct for the influence of gravity on the torque data, the limb was weighed prior to the test, according to the instruction manual for the dynamometer. A single examiner completed all hip abductor strength tests.

Gait evaluation

An eight-camera Qualisys Oqus 300 motion analysis system (Qualisys, Gothenburg, Sweden) and two force plates (Bertec Corporation, OH, USA) were used to record kinematic and kinetic data at sampling frequencies of 120 and 1200 Hz, respectively. Volunteers walked barefoot at a self-selected speed along an 8 m walkway. For each subject, a static calibration trial, followed by five successful trials were collected for kinetic and kinematic analysis. A trial was considered successful when the subject walked naturally, landing with the whole foot of the affected limb on the covered force plate (Chapman, Parkes, Forsythe, Felson, & Jones, 2015).

The following reflective markers were located on anatomical landmarks bilaterally: acromia, iliac crests, anterior and posterior superior iliac spines, greater trochanters of the femur, medial and lateral femoral epicondyles, medial and lateral malleoli, first, second and fifth metatarsal heads, base of the fifth metatarsal, and calcaneus. A single marker was placed on the sternal notch and spinous process at C7. Four clusters built with 4 noncollinear markers were placed over the lateral side of the right and left thigh and shank. Two additional clusters built with 3 noncollinear markers were positioned on the spinous process at T4 and T12. The medial and lateral malleoli, femoral epicondyles, seventh cervical vertebrae, greater trochanters, and acromia were removed after the static standing calibration trial was performed. These markers were used to construct the anatomical coordinate system for the trunk, pelvis, thigh, shank, and foot segments (Jones, Chapman, Parkes, Forsythe, & Felson, 2015; Selistre et al., 2017). The angular motion of all assessed joints was defined using Cardan angles in accordance with the recommendations of the International Society of Biomechanics (Wu et al., 2002).

The kinematic and kinetic data were processed using Qualisys Track Manager (Qualisys AB) and Visual3D software (C-motion Inc., Rockville, MD, USA). The data were filtered using a fourth-order, zero-lag, low-pass Butterworth filter at cut-off frequencies of 6 and 25 Hz, respectively. The external hip and knee adduction moments were calculated using three-dimensional inverse dynamics and normalized for body weight and height (Nm/BW*Ht%) (Hall et al., 2017; Rana S. Hinman, Bowles, & Bennell, 2009). KAAI (integral of the knee adduction moment with respect to time) was normalized by the body weight, height, and time (Nm.s/BW*Ht%) (Hall et al., 2017; Rana S. Hinman et al., 2009). The peak of each movement, and external hip and knee adduction moment were analyzed throughout the stance phase. The kinematics and EKAM data were normalized to 101 points throughout the stance phase (initial contact (IC) to toe-off), using the force plate to identify the stance phase, both were determined automatically in Visual 3D using the vertical GRF with a threshold of 20N. Walking speed was measured in the self-selected condition (as participants would normally walk).

Statistical Analyses

Statistical analyses were performed using SPSS software (Version 20, Chicago, USA). The normality of distribution of all variables (hip abductor strength, WOMAC pain score, WOMAC physical function score, 40 meter fast paced walk test, hip adduction angle, ipsilateral trunk lean, contralateral pelvic drop, external hip and knee adduction moments, and KAAI) was analyzed using the Shapiro-Wilk test. The Pearson’s correlation coefficient test was used to examine the relationship of hip abductor strength with external hip and knee adduction moments, WOMAC pain score, WOMAC physical function score, 40 meter fast paced walk test, hip adduction angle, ipsilateral trunk lean, and contralateral pelvic drop. The variables significantly correlated to the hip abductor strength were individually analyzed in a regression analysis. For the regression analysis, as kinematic variables (contralateral pelvic drop and hip adduction angle) did not present any relationship with pain, age, gender, and knee OA severity, a stepwise linear regression was performed to measure the portion of variance could be predicted by hip abductor strength. In addition, considering that EHAM, WOMAC physical function score, and 40 meter fast paced walk test could be influenced by pain, age, gender, and knee OA severity (Alnahdi, Zeni, & Snyder-Mackler, 2014; S. R. Piva et al., 2011), a bivariate correlation test was performed to evaluate their relationship. In the regression model, significant correlated parameters were entered in the first step. In addition, height and mass were controlled in all physical function analyses (Jaric, 2003), while walking speed was controlled only for EHAM analysis. The hierarchical linear regression had two steps. In the first step, the covariates were entered and in the second step hip abductor strength was entered. As body mass was used as the covariate for physical function analysis, the non-normalized hip abductor strength (Nm) data were entered in the regression model. As normalized data of KAAI (Nm.s/BW*Ht%), external knee and hip adduction moments (Nm/BW*Ht%) were used for all analysis, height and mass were not used as a covariate. Finally, an alpha level of 0.05 was set for all statistical tests.

Results

Descriptive values for subject demographics, WOMAC pain, and physical function scores, 40 meter fast paced walk test, KOA severity, and kinetics and kinematic variables are presented in table 1.

"Insert Table 1 near here"

No correlation was found of hip abductor strength with EKAM and KAAI (Table 2). In the same way, we found no correlation of hip abductor strength with WOMAC pain score and ipsilateral trunk lean. A significant correlation of hip abductor strength was found with the WOMAC physical function score, 40 meter fast paced walk test, peak EHAM, peak hip adduction angle, and contralateral pelvic drop (Table 2).

"Insert Table 2 near here"

The stepwise linear regression showed that hip abductor strength explained 17% of contralateral pelvic drop (B = -0.42 (95% CI: -0.10, -0.003), p = 0.03) and 21% of peak hip adduction angle (B = -0.46 (95% CI: -0.23, -0.21), p = 0.02) (Figure 1).

"Insert Figure 2 near here"

As we found a significant correlation between gender and peak EHAM, gender, and walking speed were entered as covariates in a hierarchical linear regression. Gender and walking speed explained 53% of EHAM variance, while hip abductor strength did not explain any additional variance (Figure 2).

In addition to height and mass, pain was controlled for the WOMAC physical function score regression model. Moreover, height, mass, pain, age, gender, and severity were controlled for the 40 meter fast paced walk test. Hip abductor strength explained an additional 4% and 1% of the variance in the WOMAC physical function score and 40 meter fast paced walk test, respectively (Table 3).

“Insert Table 3 near here”

Discussion

As hypothesized, hip abductor strength did not present a correlation with external knee adduction moments and after controlling by walking speed, EHAM presented the same result, showing that hip abductor strength does not explain any portion of external knee or hip adduction moments variance. In addition, the results did not support the hypothesis that hip abductor strength have a relationship with trunk lean and pain. Finally, it was confirmed the hypothesis that hip abductor strength explains a portion of the variation of contralateral pelvic drop, hip adduction angle, and physical function (WOMAC physical function score and 40 meter fast paced walk test). The main contribution of this study was to confirm that hip abductor strength has a relationship with contralateral pelvic drop and hip adduction angle, however, it has no relationship with external hip and knee adduction moments. In addition, despite hip abductor strength seem to be a contributor for physical function, this result is clinically questionable given hip abductor strength explained only 4% and 1% of WOMAC physical function score and 40 meter fast paced walk test respectively, in subjects with medial KOA.

The present findings demonstrated an inverse association (r= -0.46) between hip abductor strength and hip adduction angle during gait, confirming its role controlling hip adduction on the frontal plane. According to Neumann et al. (1988) (Neumann, Soderberg, & Cook, 1988) 10 degrees of hip adduction is the position where hip abductor strength can generate the highest torque, which may support the fact that the peak of hip adduction angle happened at average 8.5 (±5) degrees. During the stance phase, single-limb support requires an important function of hip abductor strength in controlling the pelvis on the frontal plane. Therefore, hip abductor weakness would result in contralateral pelvic drop. Our results confirmed this hypothesis given hip abductor strength presented a negative correlation with contralateral pelvic drop (r= -0.51), which means the higher the strength of the hip abductor strength the less contralateral pelvic drop. These findings reinforce the importance of hip abductor strengthening in subjects with medial KOA and also, specific exercises targeting control of the hip adduction angle and pelvis during walking should be prescribed (Marius Henriksen et al., 2014). Specific exercises for hip abductor strength are not only important to improve the quality of movement of pelvis and hip, but it may help to prevent injuries such as back pain, which is a common complaint in subjects with KOA (Wolfe, Hawley, Peloso, Wilson, & Anderson, 1996).

Chang et al. (Chang et al., 2005) suggested that hip abductor strength protect against medial knee load by controlling the pelvis in the frontal plane and decreasing the EKAM. However, this statement has been questioned given no difference in EKAM was found after an intervention program targeting hip abductor strengthening (Bennell et al., 2010; Sled et al., 2010). In addition, Rutherford et al. (Rutherford et al., 2014) found that hip abductor strength explained 9% of the variability in the peak of EKAM in subjects with KOA. More recently, Kean et al. (Kean et al., 2015) explored the relationship between hip abductor strength and external hip and knee adduction moments in subjects with medial KOA and found that hip abductor strength has a positive relationship with KAAI (r=0.24), explaining 6% of its variance. Despite the present study finding a negative correlation between hip abductor strength and EHAM (r= -0.42, p=0.02), after controlling by walking speed hip abductor strength did not predict any variance in EHAM. Therefore, our findings advocate that hip abductor strength cannot predict external hip and knee adduction moments. Additionally, these findings provide new information regarding the role of hip abductor strength in controlling the pelvis and hip in the frontal plane. As hip abductor strength explained 17% of the small pelvic movement (average 2.2 (±2.4) degrees) on the frontal plane, it suggests that hip abductor strength has a very small influence on contralateral pelvic drop, which is likely not enough to affect the medial knee load. Our results complement the current literature supporting that although hip abductor strength has an influence on contralateral pelvic drop, no influence was found on external hip and knee adduction moments. Therefore, hip abductor strengthening may be used for the rehabilitation of subjects with medial KOA aiming to reduce the hip adduction angle and improve pelvis control but not to reduce the medial knee load.

Despite trunk lean toward the stance limb having been indicated as a compensation when hip abductor weakness is present (Powers, 2010), the present study did not find a correlation between hip abductor strength and trunk lean. This result may indicate that trunk lean over the stance limb is not a logical compensation of hip abductor weakness, but is likely to be more related to a strategy to decrease the EKAM (Favre, Erhart-Hledik, Chehab, & Andriacchi, 2016; Hunt et al., 2008; Hunt, Wrigley, Hinman, & Bennell, 2010; Simic, Hunt, Bennell, Hinman, & Wrigley, 2012). Hunt et al. (2008) (Hunt et al., 2008) showed that trunk lean has a significant negative correlation with the first (r= -0.39) and second (r= -0.33) peak EKAM. A previous study (Simic et al., 2012) confirmed this relationship, demonstrating that trunk lean has a dose-response relationship with EKAM. Moreover, our findings are in agreement with another study(Pohl et al., 2015) which experimentally reduced hip abductor strength through a nerve block intervention in healthy subjects. Authors did not find changes in external hip and knee adduction moments or ipsilateral trunk lean, supporting our finding that trunk lean toward the stance limb may be not a compensation for hip abductor weakness.

The hypothesis that hip abductor strength is a predictor of physical function is based on previous studies (Bennell et al., 2010; Sled et al., 2010) showing an improvement in physical function after an intervention targeting hip abductor strengthening in subjects with KOA. In addition, it is relevant to evaluate the objective (40 meter fast paced walk test) and subjective (WOMAC questionnaire) physical function given they complement each other (Dobson et al., 2013). Our findings showed that hip abductor strength predicted 4% and 1% of the variance in the WOMAC physical function score and 40 meter fast paced walk test respectively. In contrast, Piva et al. (Sara R. Piva et al., 2011) found that hip abductor strength did not explain any additional variance in physical function measured by the WOMAC score and self-selected walking speed test in patients with total knee replacement (TKA). The role of hip abductor strength in predicting physical function performance might be related to the task, for instance hip abductor strength explained an additional 10% of the variance in the Stair Ascend/Descend test (S. R. Piva et al., 2011). Another study (Alnahdi et al., 2014) showed that hip abductor strength explained an additional 2.1% and 1.9% of TUG (Timed “Up & Go”) and SCT (Stair Climbing Test), respectively, however, no additional contribution to explaining the 6MWT (6-minutes’ walk test), KOS-ADLS (Knee Outcome Survey Activities of Daily Living Scale), or GRS (Global Rating Scale). Moreover, both studies (Alnahdi et al., 2014; Sara R. Piva et al., 2011) showed that other measures such as age, pain, and gender influence physical function measures. In the same way, the present study showed that not only body size but also pain, age, gender, and KOA severity should be considered, given that these variables explained the greatest portion of the variance (64% and 75% of WOMAC physical function score and 40 meter fast paced walk test, respectively) in physical function measures. Considering that hip abductor strength explained a very small portion of physical function, it should be carefully applied in the clinical practice. As physical function is influenced by many factors such as age, pain, gender, height, weight, and others (Alnahdi et al., 2014; Iversen, Price, von Heideken, Harvey, & Wang, 2016; Sara R. Piva et al., 2011), it was expected that hip abductor strength would explain only a small portion of this variable. Although previous studies have shown positive results after an intervention of hip abductor strengthening exercises (Bennell et al., 2010; Sled et al., 2010), which may be related to the increase of hip abductor strength and also to the effect of exercise (Tanaka, Ozawa, Kito, & Moriyama, 2013). Finally, no correlation between hip abductor strength and the WOMAC pain score was found. As studies have shown a reduction in pain after an intervention with hip abductor strengthening exercises (Bennell et al., 2010; Sled et al., 2010), this reduction may be explained as an effect of exercise rather than an influence of hip abductor strength (Tanaka et al., 2013). This hypothesis is supported by a study (Marius Henriksen et al., 2014) showing that exercise therapy decreases pain sensitivity in subjects with KOA.

The present study has some limitations. First, the cross-sectional design restricts a cause-and-effect relationship of hip abductor strength with physical function and pain. Longitudinal studies are needed to confirm our findings. Second, although we controlled our association analyses of hip abductor strength and physical function by pain, we measured this variable on a different day to the functional test, which might have influenced our results. Lastly, the results of this study may be only suitable for subjects with KOA predominantly on the medial compartment due to the characteristics of our sample. Future studies should measure pain during the functional test and use it as a covariate to better understand the effect of pain on performance-based physical function.

In conclusion, considering that hip abductor strength contributed to contralateral pelvic drop, hip adduction angle, and physical function, interventional studies might focus on the improvement of pelvis and lower limb movements in the frontal plane, prescribing specific exercises to improve physical function and the ability of hip abductor strength to stabilize the pelvis and hip adduction angle during walking.

Implications for Physiotherapy Practice

- Hip abductor strength does not predict external hip and knee adduction moments;
- Hip abductor strength explains a portion of the variance of contralateral pelvic drop and hip adduction angle but no relationship with trunk lean was found;
- Hip abductor strength explains a small portion of physical function but no relationship with pain was found;
- Strengthening exercises for hip abductor should emphasize the ability to control the pelvis and the dynamic lower limb alignment.

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Figure legends

Figure 1. Setup used to measure the hip abductor strength.

Figure 2. Scatterplots illustrating the relationship of hip abductor strength with hip adduction angle (left) and contralateral pelvic drop (right).

Tables

Table 1. Demographic and subject gait characteristics. Average time point in the gait cycle where the peak values occurred (% stance phase).

	Mean (SD)	
N	25	
Female (%)	48	
Age (years)	58.2 (4.7)	
Height (m)	1.67 (0.09)	
Mass (kg)	79.5 (13.6)	
BMI (kg/m^2)	28.4 (3.9)	
WOMAC Pain score	8.2 (3.8)	
WOMAC Physical Function score	24 (13.5)	
40 meter fast paced walk test (m/s)	1.71 (0.28)	
Disease characteristics	Number of subjects (%)	
Grade 2 (KL)	15 (60)	
Grade 3 (KL)	10 (40)	
Unilateral KOA	6 (24)	
Bilateral KOA	19 (76)	
		%Stance phase Mean (SD)
Gait Speed (m/s)	1.18 (0.16)	
Hip Abductor Strength (%Nm/kg)	97.6 (18.7)	
Peak EKAM (Nm/BW*Ht%)	3.02 (0.82)	25 (4.6)
KAAI (Nm.s/BW*Ht%)	1.19 (0.46)	-
Peak EHAM (Nm/BW*Ht%)	5.56 (1.01)	25.7 (3.4)
Peak Hip Adduction Angle (Degrees)	8.53 (5)	29.3 (8.4)
Contralateral Pelvic Drop (Degrees)	2.2 (2.4)	25.1 (5.0)
Ipsilateral Trunk Lean (Degrees)	3.3 (1.9)	24.8 (9.4)

SD: standard deviation, N: sample size, m: meters, kg: kilograms, m^2: meters squared, WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index, s: seconds, KL: Kellgren and Lawrence scale, Nm: Newton meters, EKAM: external knee adduction moment, Ht: height, KAAI: knee adduction angular impulse, EHAM: external hip adduction moment.

Table 2. Pearson's correlation coefficient of hip abductor strength with pain, physical function, kinetic, and kinematic variables in subjects with medial knee osteoarthritis.

	Hip Abductor Strength (%Nm/kg) r (P-value)
WOMAC Pain score	-0.27 (0.19)
WOMAC Physical Function score	-0.49 (0.01)*
40 meter fast paced walk test (m/s)	-0.65 (<0.01)*
Peak EKAM (Nm/BW*Ht%)	0.39 (0.06)
KAAI (Nm.s/BW*Ht%)	-0.27 (0.20)
Peak EHAM (Nm/BW*Ht%)	-0.42 (0.02)*
Peak Hip Adduction Angle (Degrees)	-0.46 (0.02)*
Contralateral Pelvic Drop (Degrees)	-0.51 (0.02)*
Ipsilateral Trunk Lean (Degrees)	0.08 (0.7)

R: value of correlation, m: meters, s: seconds, kg: kilograms, WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index, Nm: Newton meters, EKAM: external knee adduction moment, Ht: height, KAAI: knee adduction angular impulse, EHAM: external hip adduction moment.

Table 3. Hierarchical linear regression predicting physical function.

Dependent variable	Step	Independent variable	R	R^2	Adjusted R^2	ΔR^2	ΔF	p
WOMAC Physical Function Score	1	Height, mass, pain	0.80	0.64	0.59	0.64	12.7	<0.001
	2	Hip abductor strength	0.83	0.68	0.62	0.04	2.6	<0.001
40 meter fast paced walk test	1	Height, mass, pain, age, gender, severity	0.86	0.75	0.68	0.75	11.3	<0.001
	2	Hip abductor strength	0.87	0.76	0.68	0.01	0.7	<0.001

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index, m: meters.