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Peak Muscle Activity During Stance Phase in Women with Patellofemoral Pain versus Without Patellofemoral Pain

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Abstract

Background: Weak hip external rotation has been speculated to be connected to PFP. However, muscle activity of hip musculature has yet to be investigated during gait with individuals who report PFP.
Objective: The purpose of this study was to compare peak muscle activity in the hip during stance phase of a 10 meter walk between females with and without patellofemoral pain (PFP).
Methods: Eight females with PFP and eleven females without PFP volunteered for this study. Peak muscle activity of the adductor longus (AL), tensor fascia latae (TFL), gluteus medius (GMED), and gluteus maximas (GMAX) were measured using surface electromyography (EMG). Participants completed 3 trials of a 10m walk while surface EMG was recorded. Muscle co-activation, total time spent in stance, and total walk time were also compared between groups. Four separate independent sample t-test were conducted to compare participants without PFP (n = 11) and participants with PFP (n = 9) for peak muscle activation, muscle co-activation, total stance time, and total walk time.
Results: Peak muscle activity in the AL, TFL, GMED, and GMAX were not significantly different in female participants with and without PFP. Although, peak TFL muscle activity in participants with PFP (M = .1664, SD = .11360) was higher compared to participants without PFP (M = .1016, SD = 0.5937). There were no statistically significant differences in muscle co-activation or 10m walk time between participants with and without PFP. However, time spent in stance time approached statistical significance, p = .059.
Conclusion: There are no differences in peak muscle activity in the AL, TFL, GMED, and GMAX between females with and without patellofemoral pain (PFP) during stance phase of a 10m walk.

Introduction

Patella femoral pain (PFP) is described as pain around the knee that can be localized anteriorly or behind and/or medially at the knee joint (Collins et al., 2010; Crossely et al., 2016; Lack et al., 2018; Malek & Mangine, 1981). Persons diagnosed with patella femoral pain are more likely to be female (Bolgla et al., 2008; Boling et al., 2010) and under 50 years of age complaining of knee pain are most frequently diagnosed with patella femoral pain (PFP) which presumes that PFP effects both adolescent and adult populations (Boling et al., 2010; Lankhorst et al., 2012; Thijs et al., 2007). Discomfort with common task such as ascending and descending stairs, prolonged sitting, squatting, and running are associated with PFP (Collins et al., 2016; Crossley et al., 2004; Crossley et al., 2016; Lack et al., 2018; Willson & Davis, 2008). The cause for PFP is not well known and current research suggest that this common knee injury is multifactorial (Boling et al., 2010; Brunet et al., 2003; Lack et al., 2018; Power et al., 1996; Wilson

et al., 2009). Various anomalous factors during gait that are attributed to hip weakness (Somer, 1988) are believed to increased PFP (Barton et al., 2011; Fox et al., 2018; Powers, 2003; Salsich & Perman, 2007).

A popular theory suggests that weak hip abductor and external rotator muscles, during an activity, can cause PFP in females (Bolga et al., 2008; Cichanowski et al., 2007; Fulkerson, 2002; Ireland et al., 2003). It is believed that impaired control of the hip musculature contributes to patellofemoral malalignment which results in PFP. The link between weakened musculature and PFP is further discerned when strengthening of weakened muscles has shown to relieve pain (Clijsen et al., 2014; Fukuda et al., 2012; Mascal et al., 2003; Robinson & Nee, 2007). Considering peak muscle activation during stance phase may lead to further understanding the cause of PFP. Having the ability to better control the activation of these imperative muscle groups at the correct timing of gait may relieve PFP.

Existing research that observes gait for participants with PFP show a decreased in gait velocity (Barton et al., 2011; Powers et al., 1999), increased hip adduction and knee flexion (Paoloni et al., 2010), and shorter step length in PFP during gait (Willson et al., 2014). In addition, prolonged rear foot eversion (Levinger et al., 2007; Nadeau et al., 1997), reduced knee extensors moment (Paoloni et al., 2010; Powers et al., 1999), and pronation of the subtalar joint (Tiberio, 1987) have all been observed during terminal stance of participants with PFP. While there are many noted differences in participants with PFP compared to a healthy population during gait (Arazpour et al., 2016) the literature is lacking a detailed analysis relating to the peak timing of hip muscles during the gait cycle.

Although it has been recognized that impaired muscle activation is connected to PFP, peak muscle activation of various hip muscles during gait has not been investigated. The purpose of this study is to determine peak muscle activity of the of the adductor longus (AL), tensor fascia latae (TFL), gluteus medius (GMED), and gluteus maximas (GMAX) during the gait cycle for women with PFP compared women without PFP. Co-activation and stance time were also analyzed in this study to further understand the possible causes of PFP. It was hypothesized that peak muscle activity in the hip will differ from the control group at different phases of the gait cycle. It was hypothesized that peak muscle activity and muscle co-activation in the hip will differ from control group at different phases of the gait.

Method

Participants

Participants consisted of adult female (n = 19, age 18-55 years old) volunteers who were recruited from the surrounding community. Exclusion criteria for all participants included pathological condition causing the inability to walk safely during distances greater than 200 feet and history of patellofemoral joint surgery or patellar dislocation in either leg (Arazpour et al., 2016). Additional reasons for exclusions of participants included signs and symptoms of meniscal or other intra-articular pathologies, collateral or cruciate

ligament tenderness or laxity, knee effusion in either leg, hip pain, and lumbar referred pain (Cichanowski et al., 2007; Fox et al., 2018).

The participants were assigned to a control (n = 11) or an experimental group (n = 8). The control group comprised of participants that had a self-reported anterior or retropatellar pain of less than a 3 on a 10cm VAS, and any self-reported symptoms must have been present for at least 4 weeks (Boling et al., 2010; Ferber et al., 2015). Participants were assigned to the experimental group based on the following inclusion criteria. A self-reported anterior or retropatellar pain of at least 3 on a 10cm visual analog scale (VAS). Pain during at least two of the listed activities kneeling, prolonged sitting, squatting, ascending stairs, descending stairs, jumping, hopping, or running (Cowan et al., 2002). The onset of symptoms had to be unrelated to an injury or trauma present for at least 4 weeks. Lastly, pain was provoked during 20.3-cm step descent, during a double-legged squat, or with palpation of the patellar facets (Cowan et al., 2002; Crossley et al., 2004). This study was approved by the university Institutional Review Board and all participants signed an inform consent prior to beginning the screening.

Instrumentation

Electromyography. Muscle activity was measured using the Trigno electromyographic (EMG) wireless system (Delsys, Natick MA.) The system contains wireless Trigno Flex EMG sensors that are placed directly on the skin surface over the mid-muscle belly of the muscles being assessed and were fixed with double-sided adhesive tape. Joint angle was measured using wireless goniometers (Biometrics, Newport, UK) that were also fixated to the skin with double-sided adhesive tape and connected to Trigno Goniometer Adapters. Kinematics of gait were measured using Trigno-4 channel FSR sensors (Delsys, Natick MA) and foot switches that were placed bilaterally on the plantar aspect of the participant's feet in the following locations: (1) calcaneal tubercle (heel) and (2) distal base of 1st phalange. The foot switches were covered with double-sided adhesive tape and a thin nylon sheath. Surface EMG (sEMG) data was managed using EMGworks software. All kinematic data was integrated directly into the EMGworks software via wireless adapters provided by the manufacture to ensure proper timing during recording. An external trigger device (Delsys, Natick, MA) was used to initiate and cease data collection.

Visual Analog Scale A 10-cm Visual Analouge Scale (VAS), were used for assessment of subjective knee pain. The VAS was validated for a pain assessment of the knee and has been used to monitor knee pain (Flandry et al., 1991). Participants were asked to mark their level of lower extremity soreness along a line anchored by "no pain" and "worst possible pain" (Lewinson et al., 2013). The distance between the "no pain" anchor point and the participant's pain mark was measured to the nearest millimeter. The number of millimeters was then used to quantify the participant's pain rating.

Procedures

Participants signed the informed consent and then were screened for exclusion criteria by answering a health questionnaire that was then followed up by the researcher. Next, participants were screened for inclusion criteria and age was recorded. Inclusion criteria were assessed using a self-report pain symptom with functional activities. All testing procedures were performed with a licensed physical therapist and a certified athletic trainer. If self-reported criteria were met, the participant then performed a counterbalanced screening, during which the researcher assessed pain in the symptomatic knee with a step-down task, during a squat, or with palpation of the medial and lateral patellar facets. For the step-down test, the participant stood on a 20-cm wooden step with feet shoulder with apart. The participant then was asked to step forward to the floor, stepping onto her unaffected side. To assess knee pain during a squat the participant completed a double leg squat to a chair and then return to standing. The medial and lateral patellar facets were then palpated by the researcher with the participant in a supine position. After the participant completed all inclusion criteria screening and testing, height was assessed to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Hamburg, Germnay) and body mass was measured to the nearest 0.1 kg using a digital scale (Tanita Corporation, Model BF-522, Alrington Heights, IL)

All participants were instructed to avoid application of topical skin location prior to testing. Before the Trigno sensor and electronic goniometer sensor were placed, hair was shaved, if necessary, from all areas underlying sensor placement with a safety razor and then exfoliated with Redux Paste. Sensors were affixed with double-sided adhesive tape to the skin over the mid-muscle belly of the gluteus medias (GMED), adductor longus (AL), and tensor fascia lata (TFL) (Delmore et al., 2014; Hermans et al., 2017). For each muscle, a maximal voluntary isometric contraction (MVIC) was used as a normalization procedure for the surface EMG analyzers. Electronic goniometers were affixed on the lateral sides of the body for measurement of bilateral hip and knee joint angles. The distal measurement sensor was affixed over the lateral midline of the thigh, determined by a line drawn from the greater trochanter to the lateral femoral condyle. For knee joint angle, the distal goniometer sensor was affixed over the lateral tibia, determined by a line drawn from the fibular head to the lateral malleolus (Piriyaprasarth et al., 2008). These placements were then reinforced with Cover-Roll taping. Finally, the participant removed footwear and her bilateral feet were prepared by clearing of any debris or sweat with a paper towel. The FootSwitch electrodes were then placed on the bilateral aspect of the participant's feet. The research placed adhesive tape over the electrodes, along with a thin nylon stocking over the electrodes in order to reduce damage to the switches and to ensure that the electrodes are secure (Winchester et al., 1996).

10-Meter Walk Test

A meter stick was used to measure 10 meters and pieces of tape were placed on the floor at the start and end of the 10meters. Preceding the test,

the participants practiced the 10-meter walk test until they formed a comfortable pace. The participant attempted at least 3 repetitions, with a 1-minute rest period between repetitions to prevent fatigue. The participant was instructed to walk in a straight line on a level surface for 10-meters. The participant used the tape placed on the floor to determine where to start and where to stop walking once she reached 10 meters.

Data Processing

All EMG data was normalized to MVIC data collected for each participant to represent muscle activation of each muscle as a percent of peak muscle activity during MVICs. Surface EMG data were initially processed using a Nyquist resampling equation at 1000Hz. A Butterworth band-pass filter at frequencies of 20Hz and 450Hz. These data were then rectified and smoothed using a root-mean-square (RMS) filter with a 200ms window. Stance phase was determined by using foot switch and electric goniometer data. The peak muscle activity was obtained during three separate repetitions of the 10m walk from time during each stance phase and then averaged to obtain peak surface EMG signal. First and last strides were windowed off. Stance time was calculated by averaging the total time spent in phase across the 10m walk trials. This average peak EMG signal was then normalized to the previously-obtained MVIC values. Joint angle at time of peak activity was calculated by averaging the joint angle at peak muscle activity across the three trials. Muscle co-activation was calculated using the formula developed by Rudolph et al41, which is EMGs / EMGL x (EMGs + EMGL), where EMGs is the level of muscle activity in the less active muscle and EMGL is the level activity in the more active muscle.

Statistical Analysis

Descriptive statistics was provided for each participant and be expressed in means + standard deviations. An independent samples t-test was conducted to compare participants without PFP (n = 11) and participants with PFP (n = 9) AL, TFL, GMED and GMAX peak muscle activity during stance phase in a 10-meter walk. An independent sample's t-test was also run to determine differences in walk time and time spent in stance phase between the control (n = 11) and experimental group (n = 11). Effect sizes were calculated using Hedges' g. The alpha level was set at .05 for all statistical procedures.

Results

Descriptive statistics for participant characteristics can be found in Table 1. Peak muscle activity in the AL, TFL, GMED, and GMAX were not significantly different in female participants with and without PFP (Table 2). Although, peak TFL muscle activity in participants with PFP (M = .1664, SD = .11360) was higher compared to participants without PFP (M = .1016, SD = 0.5937), but was not statistically significant t(17) = 0.58, p = .123, 95% CI [-0.149, .019], Hedges' gs = 0.75. There were no statistical significant differences in muscle co-activation of the AL and the GMED (t(17) = .310, p = .760, 95% CI [-0.18, 0.13], Hedges' gs = 0.65) between partipcants with

and without PFP. There were also no statistical significant differences in muscle co-activation of the TFL and GMAX (t(17) = .882, p = .390, 95% CI [-0.02, 0.01], Hedges' gs = 0.41) between groups. No statistical significant differences were found in 10m walk time (t(17) = .796, p = .974, 95% CI [-1.03, 1.06], Hedges' gs = 0.24) when comparing female participants with and without PFP. However, time spent in stance time approached statistical significance (t(15.902) = 2.03, p = .059, 95% CI [-0.09, .001], Hedges' gs = 0.07).

Table 1. Participant Descriptive Characteristics.

Variable	*N*	M±SD	*SD*	*SE*
Age (years)	19	24±7.64	7.64	1.61
Height (cm)	19	166.68±7	7	2.58
Weight (kg)	19	70.10±11.23	11.23	2.58
BMI (kg/m^2)	19	25.31±4.37	4.37	1.00

Table 2. Peak Muscle Activity During Stance Phase of a 10m Walk.

	Control	**Experimental**				
Variable	**M±SD**	**M±SD**	***t***	***p***	**Hedges' *g***	**95% CI**
AL	0.39±0.28	0.33±0.36	0.41	0.68	0.19	[0.19, 3.14]
TFL	0.11±0.06	0.17±0.11	1.6	0.12	0.75	[-4.67, -0.85]
GMED	0.24±0.13	0.35±0.24	1.3	0.22	0.59	[0.01, 1.19]
GMAX	0.13±0.11	0.19±0.13	1.1	0.29	0.24	[-2.37, -0.23]

Abbreviation: AL, adductor longus; **TFL**, Tensor fascia latae; **GMED**, gluteus medius; **GMAX**, gluteus maximus

Discussion

The purpose of this study was to compare peak muscle activity in the adductor longus (AL), tensor fascia latae (TFL), gluteus medius (GMED), and gluteus maximus (GMAX) between females with and without PFP during stance phase of a 10m walk. Contrary to our hypothesis, no statistical differences were found in peak muscle activation of the AL, TFL, GMED, and GMAX. Literature that has analyzed peak muscle activity during gait have only observed the GMED and GMAX; which present contradicting results. Souza and Powers (2009) found significantly greater GMAX activation in females with patella femoral pain syndrome (PFPS) during running, but not statistically significant differences in GMED activity. The authors theorized that this increase in gluteus maximus activation in PFP participants may be an attempt to recruit a weak muscle to counteract a decrease in hip extension strength and increase in hip internal rotation. A more recent study observing gluteal muscle activation during

running in females with and without PFPS found no differences in peak muscle activity for GMED and GMAX (Willson et al., 2011). These results match the outcome of this study where no significant differences were found in GMED or GMAX peak activation in participants with and without PFP. This could mean that there are other muscle imbalances that may cause excessive hip internal rotation.

To date, there are not many articles that observe EMG activity of the adductor longus (AL) muscle during gait for individuals with PFP. However, the several studies have compared strength measures of the adductor longus and have opposing results. Cichanowski et al. (2007) discovered no significant differences in muscle strength of the adductor muscles between injured and non-injured leg in collegiate females with PFP. Similarly, Magalhães et al. (2010) noted no significant differences in hip adduction strength when comparing sedentary females with and without PFPS. On the other hand, Niemuth, Johnson and Myers (2005) found significantly higher adductor strength in the injured leg in individuals with PFP. The results of our study showed no significant differences in AL muscle activity between females with and without PFP during a 10m walk and no significant differences in muscle co-activation of the AL and GMED. While increased internal rotation of the hip is a common theory behind PFP, the adductor longus may not play a role in this increased internal rotation. Thus, weak external rotators may have a greater influence in the cause of PFP.

Participants with PFP displayed greater activation of the TFL during stance phase in 10m walk, but no statistical differences were found between groups. The TFL is a unique muscle that can act as a primary mover in hip flexion and hip abduction, but also acts as a secondary mover in hip internal rotation (Neumann, 2010). During stance phase, the TFL is the major muscle involved in counter-balancing the force of the body weight and stabilizes the hip (Al-Hayani, 2009; Evans, 1979; Kaplan, 1958). It is possible that increased TFL activation during stance phase is meant to compensate for other weaker hip abductor muscles such as the GMAX and GMED. If this is the case, then weak external rotators will not be able to provide equal or opposite action against hip flexion and hip internal rotation created by the TFL. In other words, increased TFL muscle activity and weak external rotators muscle activity may produce greater hip internal rotation, which has been observed in those with PFP.

An older study by Powers et al. (1999) found decreased free walking gait velocity in participants with PFP, creating a slower walk time during a 10m walk. This was supported by a more recent study by Barton et al. (2011) who found reduced gait velocity in participants with PFP compared to controls. Contrariwise, Levinger and Gilleard (2007) found no significant changes in walking velocity in participants with PFPS compared to healthy controls. A present study by Kellish et al. (2020) also found no significate changes in gait cadence between participants with and without PFPS. The results of this study support the findings of Levingar and Gillard and Kellish, no significant

difference was found in total 10m walk time or time spent in stance phase between participants with and without PFP.

The main limitation of this study was insufficient sample size and unequal groups. The control group had eleven participants, while the experimental group only had nine. Thus, making the likelihood of a Type II error was high. Future studies should focus on muscle activity during functional movements and further investigate gait velocity in participants with PFP.

Conclusion

There are no differences in peak muscle activity in the adductor longus (AL), tensor fascia latae (TFL), gluteus medius (GMED), and gluteus maximus (GMAX) between females with and without patellofemoral pain (PFP) during stance phase of a 10m walk. There are also no statistically significant differences in muscle co-activation between the AL and GMED and the TFL and GMAX. There are no differences in 10m walk time and total time spent in stance phase between groups. The results of this study revealed that muscle activity of hip musculature during stance phase of a 10m walk may not be the cause for patellofemoral pain and the exact cause for patellofemoral pain syndrome continues be eluded. Future research is needed to understand the role of hip muscle activation during other daily functional movements, such as ascending and descending steps, in individuals with PFP.

Key Points

Findings: When comparing females with and without patellofemoral pain (PFP), there are no statistically significant differences in peak muscle activity or muscle co-activation in the adductor longus (AL), tensor fascia latae (TFL), gluteus medius (GMED), and gluteus maximus (GMAX) during stance phase of a 10m walk. There are also no statistically significant differences between 10m walk time or time spent in stance for when comparing females with and without PFP.

Implications: The results of this study showed that participants with PFP displayed greater activation of the TFL during stance phase in 10m walk, but no statistical differences were found between groups. This implies that the TFL should be further investigated when discussing possible muscle imbalances in participants with PFP.

Caution: The most important limitation of this study was sample size.

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