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Title

Comparison of Gluteus Medius Muscle Activation in Females with and without Patellofemoral Pain

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ABSTRACT

Context: Females with patellofemoral pain (PFP) commonly have hip muscle weakness in comparison to females without PFP. One underlying mechanism for this muscle weakness is inhibition. Although the presence of muscle weakness is well documented in females with PFP, few authors have investigated gluteus medius inhibition in this population. Females are twice as likely to suffer from PFP when compared to males, therefore this study will focus on the female population.

Objective: To compare voluntary activation of the gluteus medius between females with and without PFP.

Design: Case-control study.

Setting: Laboratory.

Patients or Other Participants: 28 female participants: 13 pain-free controls (age = 21.6 ± 3.6 years, height = 1.66 ± 0.06 m, mass = 65.4 ± 11.3 kg) and 15 with PFP (age = 22.3 ± 3.2 years, height = 1.66 ± 0.07 m, mass = 75.3 ± 22.6 kg, duration of pain = 3.5-96 months).

Main Outcome Measure(s): Standing hip abduction normalized strength (N·m/kg), superimposed burst force and gluteus medius central activation ratio (CAR). Linear modeling was utilized to compare forces and CAR between groups while controlling for age, mass, and hip abduction force.

Results: Females with PFP had lower gluteus medius CAR than controls. Overall, after controlling for participant age, mass and gluteus medius MVIC, the PFP group had an average gluteus medius CAR 2.5% lower than the pain-free control group (Control= 98.4±.01%, PFP=95.9±.65%, *p*=.004).

Conclusions: Females with PFP had reduced voluntary activation of the gluteus medius, when assessed with a superimposed burst. Due to the wide range of CAR values found (74-99%), inhibition was present in some of the participants. This provides evidence that assessment of gluteal voluntary activation could assist with targeted treatment programs for individuals presenting with PFP.

Key Words: anterior knee pain, inhibition, hip muscle, assessment

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Key Points:

- Females with patellofemoral pain had reduced activation of the gluteus medius muscle.
- Identifying the presence of inhibition may be useful for clinicians to determine the most appropriate treatment techniques.

Patellofemoral pain (PFP) affects as much as 7.3% of all patients who seek care from an orthopedic physician in the United States.[1] PFP accounts for approximately 25% of all knee injuries among physically active populations[2] and the prevalence of PFP is twice as common in women compared to men.[1] PFP commonly presents as diffuse pain across the anterior knee that increases with activities such as running, squatting, and walking up and down stairs.[3] The etiology of PFP is multifactorial, since there are numerous underlying factors associated with development and progression of this condition, including but not limited to muscle weakness, abnormal motor activation patterns, abnormal joint kinematics and abnormal joint stress.[3–5]

Clinicians and researchers place a large focus on the gluteus medius in the evaluation and management of PFP. The gluteus medius is an important stabilizer muscle functioning to maintain neutral alignment of the lower extremity in the frontal plane during dynamic movement.[6] To prevent excessive lower extremity malalignment in the frontal plane, adequate strength and activation of the gluteus medius are important. However, deficits in strength and activation are common in individuals with PFP.[6–10] It has been theorized that abnormal gluteus medius muscle function is related to excessive hip adduction and internal rotation, causing dynamic knee valgus and contributing to the development of PFP.[11]

Although current treatment strategies aim to improve hip musculature function, there are inconsistent findings in how these strategies lead to improved strength or movement patterns.[12–14] The lack of improvements in strength or movement patterns for some individuals with PFP may imply additional underlying neuromuscular factors which should be considered in the evaluation and management of PFP. Therefore, it would be beneficial to investigate additional assessment tools that could detect specific deficits in hip function beyond strength and movement patterns.

One underlying explanation for abnormal gluteus medius activation in individuals with PFP could be related to muscle inhibition. An inhibited muscle is not capable of recruiting all available motor units, resulting in reduced force output. One suggested explanation for inhibition occurring in the gluteus medius is disrupted neural signaling transmission.[15] This is suggested to occur when mechanoreceptors located inside the tissues of a strained joint are excessively activated, which in the case of PFP could be caused by excessive hip adduction. This heightened joint afference leads to an inhibitory response to the surrounding musculature, reducing their voluntary activation.[15] The superimposed burst technique is commonly used to measure muscle voluntary activation and is quantified as the central activation ratio (CAR).[16–18] CAR indicates the level of voluntary activation of a specific muscle, ranging from 0 to 100%. Although CAR is a valid and reliable measure in individuals with PFP, this has been limited to the quadriceps.[16,17] Hart et al[16] found that patients with anterior knee pain had 78.6% quadriceps inhibition and suggested this may lead to muscle weakness and kinematic changes. Researchers recently provided initial evidence that CAR is a valid and reliable measure of gluteus medius and maximus activation in a healthy cohort.[18] Gluteal CAR has been assessed in a small cross-sectional study, but has not been compared directly to a healthy cohort.[19] Determining gluteal CAR for females with PFP could assist in investigating the lack of improvements in strength sometimes found after rehabilitative treatment. Therefore, the purpose of this study was to compare gluteus medius CAR of females with and without PFP. We hypothesized that females with PFP would present with reduced CAR in comparison to the pain-free controls.

METHODS

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist for case-control studies was utilized to assist in providing quality methodology.[20] In this

case-control study, we compared group differences between females with PFP and pain-free controls. The independent variable was group (PFP, Control). The dependent variables were CAR of the gluteus medius and maximal voluntary isometric contraction (MVIC) of the gluteus medius.

Participants

Twenty-eight female participants volunteered for this study: 13 pain-free controls, and 15 with PFP. As an inter-institutional collaborative study, participants with PFP were collected from two Universities and surrounding communities. Both the University of XXXX and University of XXXXX obtained institutional review board approval. Prior to data collection, participants were screened for inclusion and exclusion criteria (Table 1) adhering to the International Patellofemoral Pain Consensus statement.[21] Once confirmed, written informed consent was acquired. All participants with PFP were screened by a licensed athletic trainer with 10+ years of clinical experience to confirm diagnosis based upon their symptomology. Any participant who reported PFP bilaterally was instructed to self-select their most symptomatic side to be used for testing.

Instrumentation

Gluteus medius CAR was calculated using the superimposed burst technique.[16–18] Isometric hip abduction force was assessed with a Biodex System 3 Pro dynamometer (Biodex Multi-Joint System 3; Biodex Medical Systems, Inc, Shirley, NY). Force data points were obtained with a 16-bit acquisition system at 125 Hz (MP150; BIOPAC Systems, Inc, Santa Barbara, CA).[17] A sequence of manually delivered electrical stimuli were applied to perform the superimposed burst with a Grass Stimulator S48 (Grass Technologies, West Warwick, RI) and a Stimulus Isolation Unit (Grass Stimulator; Grass Technologies, West Warwick, RI).

Procedures

Participants reported to the research laboratory for a single data collection session. For pain-free controls, the dominant extremity (i.e., preferred leg to kick a ball) was chosen for testing.

During the session, two measures were collected: hip abduction MVIC force (F_{MVIC}) and MVIC force with a superimposed burst (SIB) of electrical stimulation (F_{SIB}). Prior to testing, participants completed a 5-minute walking warm-up on a treadmill at their preferred walking speed with 0% incline. Then, two 5x9 cm adhesive electrodes (Axelguard, Fallbrook, CA) were placed over the participant's gluteus medius, with one placed directly inferior to the iliac crest and the second directly superior to the greater trochanter.[18] Assessment of hip abduction strength was performed with the participant in a standing position. The dynamometer axis of rotation was lined up with the anterior superior iliac spine while the arm of the dynamometer was attached to the leg, approximately 5 cm proximal to the lateral femoral condyle. The Biodex chair was positioned to assist with stabilizing trunk motion. The chair height was adjusted so that a bolster placed on the chair would be at the level of the participant's contralateral hip to prevent trunk and pelvic motion (Figure 1). When testing was being completed, participants were instructed to stand up straight with their arms held across their chest.

As described previously[18] to acclimate participants to the task, they performed a sequence of submaximal isometric contractions at 25%, 50%, and 75% of their self-determined maximal ability with a 1-minute rest in between each trial. Participants were instructed to perform these contractions by ramping up to the defined intensity and hold for 3 to 5 seconds. Participants were then instructed to perform two contractions of maximal effort, while also being given verbal feedback from the investigator and visual feedback on a computer monitor. The verbal and visual

feedback was provided to encourage the participant to perform at true maximal effort. The visual feedback was a line graph representing the amount of force the participant was producing in real time. The participant then performed six MVICs with a superimposed electrical burst stimulation. The first three trials were performed with maximal contraction and with submaximal stimulus amplitude at 25%, 50% and 75%. The last three trials were performed with a 100% superimposed burst stimulation which was applied with a stimulus isolation unit. This produced a 100-millisecond train of 10 square-wave pulses at an intensity of 125 V (pulse duration: 600 μs and frequency: 100 Hz).[18] The superimposed burst stimulus was administered when the investigator saw a plateau in the real-time torque display. One-minute of rest was given in between each trial. The last three trials of maximal contractions were used as the hip abduction MVIC force (F_{MVIC}) and SIB force (F_{SIB}).

Data Analysis

Hip abduction F_{MVIC} data were converted to torque (Nm) and normalized to body mass (Nm/kg). Hip abduction F_{MVIC} was calculated with the average torque produced over a 100-millisecond epoch prior to the stimulus, averaged over the three trials. The calculation for CAR uses this same average torque prior to the SIB and the maximal torque output that occurs with the stimulus (F_{SIB}), multiplied by 100, represented by the equation below[18]:

$$\text{CAR} = \frac{FMVIC}{(FMVIC+FSIB)} * 100$$

CAR is displayed as a percentage, between 0% to 100%, and represents the level of muscular activation. 100% indicates full activation of the muscle is achieved voluntarily.

Statistical Analysis

A general linear model was used to determine if there was a significant difference in average gluteus medius CAR between groups while controlling for age, mass, and average hip

abduction MVIC. The variables of age, mass and average hip abduction MVIC were included to 1) make sure that each variable is not a confound of Group, i.e. group differences may be explained by mass rather than the effect of group, and 2) identify the independent effect of group when controlling for possible effects of age, mass and gluteus medius MVIC on CAR. This is particularly relevant because hip abduction directly influences CAR, as it is a part of the equation. Body mass has been shown to be associated with PFP[22], and age has been shown to influence hip strength.[23]

The raw values of gluteus medius CAR presented a high left skewness due to several participants having a gluteus medius CAR near 100%. To meet the assumption of normality we transformed gluteus medius CAR by raising it to the 20th power (CAR^20; Shapiro-Wilk test p = .07, W = .93).[24] If there was a significant difference of group, we back transformed the data of the mean difference between groups by raising it to the power 1/20 so that inferences could be made based on the original gluteus medius CAR unit scale.[24] To control for multicollinearity between independent variables, we scaled variables of age, mass, and hip abduction MVIC and confirmed low collinearity by calculating the variance inflation factor for each variable. Presence of outliers was determined based on the calculated Cook's distance of each data point with a threshold of less than 0.5. Significance was accepted when $p<0.05$ (R version 4.4.1). After transformation of CAR (CAR^20) no outliers needed to be removed.

RESULTS

The participant demographics and characteristics are presented in Table 2. The results of the general linear model demonstrated a statistically significant main effect of group ($F(1, 26) = 10.4$, $p = 0.004$). Females with PFP had lower gluteus medius CAR than females without PFP even after accounting for age (p=0.29), mass (p=0.24), and hip abduction MVIC (p=0.29). We

confirmed that results of the analysis possessed no outliers and collinearity between predictor variables was in the appropriate range. The estimated differences between groups were -0.28 gluteus medius CAR (95% CI = [-0.45; -0.1], average controls gluteus medius CAR = 0.72, average gluteus medius CAR PFP = 0.44). Back transformation of the estimated mean group difference equated to 2.5% gluteus medius CAR (average gluteus medius CAR controls = 98.4%, PFP = 95.9%, estimated effect size = 1.35, 95% CI = .39; 2.3. Large effect). Overall, after controlling for participant age, mass, and hip abduction MVIC, the PFP group had an average gluteus medius CAR score 2.5% lower than that of the pain-free control group. Figure 2 shows the results found for gluteus medius CAR and gluteus medius MVIC.

DISCUSSION

The purpose of this study was to determine if individuals with PFP have lower CAR for the gluteus medius when compared to pain-free controls. The main observation of this study indicated females with PFP have significantly lower CAR than pain-free controls. It is important to note that although a difference was found, the gluteus medius activation levels ranged from 74% to 99% within the PFP group. This is not surprising, since PFP is multifactorial, with numerous underlying factors associated with the development and progression of the condition, which results in a patient population that presents with a diverse range of symptoms and functional abnormalities. Both findings, including reduced CAR and varied activation levels, agree with the first study[19] conducted that examined whether females with PFP exhibit lower gluteal muscle activation. This study utilized the same methodology for CAR assessment of the gluteus medius with a smaller cohort of females with PFP.[19]

The average gluteus medius CAR for females with PFP was 95.9% while the pain-free controls were at 98.4%. Our findings for gluteus medius activation were slightly higher for both

groups compared to prior research where healthy females were between 96.1-96.6%[18] and females with PFP were 90.5%[19]. These previous studies differed in that one had a smaller cohort of female participants with PFP (n=7) and did not include a healthy cohort for direct comparison.[19] The second study only assessed a healthy cohort (n=20) with both males and females to establish validity and reliability of CAR for the gluteal muscles.[18]

One interesting finding was that the PFP group in our study had similar hip abduction torque (1.36 N·m/kg) when compared to the control group (1.15 N·m/kg). This could indicate that although the PFP group had similar hip abduction strength, due to decreased activation of the gluteus medius, they may rely on other muscles to compensate and generate the abduction torque (i.e. tensor fasciae latae, gluteus maximus, etc.). The gluteus medius is an important stabilizer muscle functioning to maintain neutral alignment of the lower extremity in the frontal plane during dynamic movement.[6] During functional activities, such as running, the demand on the gluteus medius has been found to peak at an activation at 112.4% of MVIC and on average 81.4% in a group of females with PFP, which was not significantly different from the comparison healthy control group.[25] However, female participants with PFP did display gluteus medius activation that was delayed and shorter in duration during running.[25] This provides another example to illustrate the importance of using specific assessment tools to examine different aspects of neuromuscular control.[25]

Although a standard of care exists for the treatment and rehabilitation of PFP, the long-term outcomes are poor, resulting in abnormal findings such as: persistent pain[26–28], restrictions in both daily[26,27] and physical[26,28] activities and no improvements in hip[29,30] and quadriceps[31] strength. A recent theoretical model suggests some of these abnormal findings, specifically lack of improved strength, could be related to an underlying influence of muscle inhibition[15] which

provided the motivation for the current study. The findings from our study could provide some insight to explain why some individuals with PFP may be unresponsive to strengthening of the gluteus medius. For example, our study had four participants with CAR < 95%, suggesting altered gluteus medius muscle function for these individuals. This also indicates that not all individuals with PFP exhibit impaired gluteus medius voluntary activation, but some do. This heterogeneous symptomology provides justification to consider adjusting our current practice for evaluation and treatment of PFP for individuals identified with reduced voluntary activation.

One way to address heterogeneous symptomology could be subgrouping patients by their prominent impairment, such as impaired voluntary activation, and then designing their treatment with interventions focused on the prominent impairment. Subgrouping of individuals with PFP has been suggested and studied with success and improved outcomes.[32,33] The wide range in gluteus medius activation found in our study (74-99%) would support the concept of subgrouping.

Subgrouping was recommended after it was determined that one-third of patients in a randomized-controlled clinical trial were unresponsive to a strengthening protocol[30] and three subgroups[33] were first suggested after 127 patients were evaluated for similarities. Current clinical practice for PFP does not involve specific approaches to address inhibition, which could mean clinicians aren't able to provide optimal treatment. In addition, there currently is not a clinician-friendly approach to determine if a patient has muscle inhibition since very specific equipment is necessary to assess CAR. Therefore, it could be suggested that a subgroup should be created for patients who are unresponsive to strengthening protocols to attempt to determine if this is related to impaired voluntary activation. Future research could evaluate non-responders to determine if muscle inhibition may explain their lack of success with a traditional strengthening

protocol. Establishing muscle inhibition's connection to non-responders could lead to research that could determine effective treatment strategies for individuals with PFP who demonstrate inhibition of the gluteus medius. Disinhibitory modalities, such as focal joint cooling or conventional TENS to the knee joint, have been used for treating inhibition,[34] however, clinicians should be aware these interventions have only been evaluated for quadriceps inhibition and not for gluteal inhibition. Before tailored rehabilitation for individuals with gluteal inhibition can be recommended, future research should compare potential interventions that have been successful at addressing inhibition of other muscles.

Clinical Implication

Assessment tools to detect specific muscle function deficiency are important for interventions aimed to improve long-term outcomes associated with PFP. Although some patients seek care for PFP, patients who undergo standard care continue to have ongoing difficulties from 4[26,27] to 8[28] years after diagnosis, including persistent pain,[26–28], and restrictions in both daily[26,27] and physical activities.[26,28] In addition, some patients with PFP are not responsive to traditional strengthening treatments.[29–31] The results of this study indicated a wide range of gluteus medius activation exists among females with PFP. For this reason, identifying the presence of impaired voluntary activation may be useful for clinicians to determine the most appropriate treatment techniques.

Limitations

One potential limitation for this study may be the testing position used for assessing hip abduction. We performed hip abduction with the participant standing as opposed to side-lying. Although side-lying would provide greater comfort to the participant, we found during pilot testing participants were not able to exert maximal contractions, likely because of gravity and

instability during side-lying. Since the superimposed burst technique requires maximal contraction, the standing position was preferred and utilized. Moreover, the standing position is the only reliable and valid method to assess gluteus medius CAR.[18] Second, participants with bilateral PFP performed testing on the most symptomatic side. Consequently, the contralateral side still provided sufficient stabilizing force as the stance leg and this demand could affect the performance of those with bilateral PFP. Third, we only assessed voluntary activation of the gluteus medius in this study. We focused on the gluteus medius since deficits in strength and activation are common deficits found in individuals with PFP.[6–10] However, differences in voluntary activation may exist since additional muscles also contribute to hip abduction. Fourth, this study involved females only, which will limit the generalizability of our findings. Lastly, current PFP pain was not an outcome measure for this study. It is possible that experiencing pain while completing CAR testing could influence the participant's ability to fully activate the gluteus medius. Future CAR research should include a pain measure to determine how the presence of pain may influence voluntary activation of the gluteus medius.

CONCLUSIONS

Females with PFP had reduced voluntary activation of the gluteus medius and presented with a wide range of gluteus medius activation levels. Moreover, inhibition was not present in all females with PFP indicating further that assessment of gluteus medius voluntary activation should occur in patients with PFP to determine the most effective treatment strategies.

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Legends to Figures

Figure 1. Positioning of participant on Biodex System 3 for hip abduction.

Figure 2. (A) Gluteus medius central activation ratio (%) and (B) gluteus medius strength (N·m/kg) compared to controls.

382 **Legends to Figures**

383 **Figure 1.** Positioning of participant on Biodex System 3 for hip abduction.

384 **Figure 2.** (A) Gluteus medius central activation ratio (%) and (B) gluteus medius strength

385 (N·m/kg) compared to controls.

Table 1. Inclusion and Exclusion Criteria

Inclusion: Pain-free Control

- Female, between 18-35 years old
- Physically active: exercise three times per week for at least 30 minutes each time

Inclusion: PFP

- Female, between 18-35 years old
- Physically active: exercise three times per week for at least 30 minutes each time
- Insidious onset of anterior knee pain
- Have retro-patellar pain for greater than 3 months
- Have pain during 2 of the following activities: jumping, kneeling, running, squatting, stair ambulation, prolonged sitting, or contracting quadriceps

Exclusion (Both Groups)

- Lower extremity injuries (other than PFP) within the last 6 months
- Previous lower extremity or low back surgery
- History of patella subluxation or dislocation
- Lower limb fracture
- Concussion in the last 6 months
- Knee ligamentous instability
- Hypersensitivity to electrical stimulation
- History of neurological impairments
- Pregnancy

Table 2. Participant Characteristics

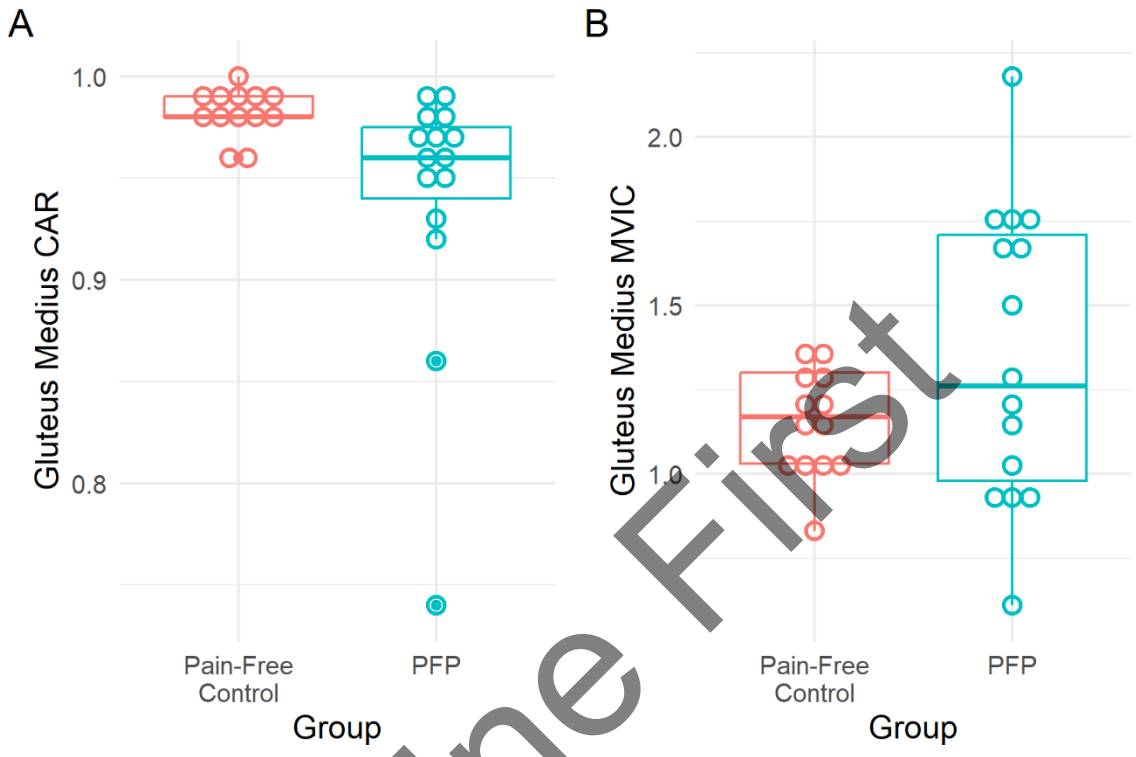
Characteristic	Pain-free (n=13)[1]	PFP (n = 15)[1]	p-value[2]
Age, y	21.6 ± 3.6	22.3 ± 3.2	0.5
Mass, kg	65.4 ± 11.3	75.3 ± 22.6	0.2
Height, m	1.66 ± 0.06	1.66 ± 0.07	>0.9
Pain duration, mo	N/A	41.4 ± 27.9	N/A
Gluteus Medius MVIC	1.15 ± 0.16	1.36 ± 0.44	0.3
Gluteus Medius CAR	0.98 ± 0.01	0.94 ± 0.06	0.004

[1]Mean (SD)
[2]Wilcoxon rank sum test

Abbreviations: PFP – patellofemoral pain, MVIC – maximal voluntary isometric contraction, CAR – central activation ratio, SD – standard deviation

Figure 1. Positioning of participant on Biodex System 3 for hip abduction.

Figure 2. (A) Gluteus medius central activation ratio (%) and (B) gluteus medius strength (N·m/kg) compared to controls.



Abbreviations: PFP – patellofemoral pain, MVIC – maximal voluntary isometric contraction, CAR – central activation ratio