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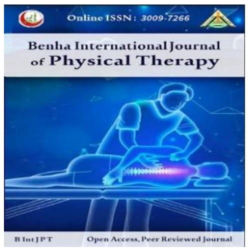

Original research

Mechanical Responses to Hip versus Knee Induced Muscle Fatigue in Patellofemoral Pain Syndrome.

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Abstract

Background: Impaired muscular endurance is recognized as a significant factor contributing to the development of patellofemoral pain syndrome (PFPS). Despite its importance, there remains a lack of comprehensive understanding regarding the specific impacts of muscle fatigue on hip and knee function in patients with PFPS. **Purpose:** This study aimed to investigate the effects of induced fatigue in hip abductors and knee extensors on knee proprioception and hip and knee muscle strength in female patients with PFPS. **Methods**: Fifteen female patients participated in two testing sessions, spaced 3 days apart. Each session included an isokinetic fatigue protocol targeting the hip abductors and knee extensors. Pre- and post-fatigue measurements were conducted using an Isokinetic dynamometer. **Results:** The result demonstrated a significant decrease in knee muscle strength following hip abductor fatigue ($p < 0.05$). Following the hip fatigue protocol, knee proprioception showed impairment reflected by an increased knee absolute angular error (AAE). Although there was an increase of AAE, its value did not reach statistical significance ($p = 0.07$). Furthermore, no significant changes were noted in hip abductor peak torque after knee fatigue. **Conclusion**: These findings underscore the clinical importance of assessing and rehabilitating hip endurance in the management of patellofemoral pain syndrome. By addressing hip muscle fatigue, clinicians can potentially improve outcomes and reduce symptoms associated with PFPS.

Keywords: Knee muscle performance, Muscle fatigue, Patellofemoral pain, Proprioception.

INTRODUCTION:

A change in patellofemoral contact pressure due to lateral translation or tilt of the patella is a characteristic of patellofemoral pain syndrome (PFPS) [1]. There are proximal, local, and distal variables involved in this multifactorial disease[2]. Three basic causes are linked to the development of patellofemoral pain: overuse, muscular imbalance, and patellar malalignment. The patellar malalignment is considered the main cause of patellofemoral pain syndrome [3,4,5]. It has been reported that adduction and internal rotation of the femur, caused by weakening of the proximal hip abductors and external rotators, is the main cause of functional mal-alignment instead of the knee joint [6,7].

Proprioception is essential for regulating muscle activity, allowing for joint stability and proper muscle activation that produces smooth movement [6]. Proprioception acting as an action-reaction mechanism, relies on voluntary and spinal reflexes to communicate with muscles so that they can respond and protect movement [8]. Thus, if the muscles are fatigued, voluntary and spinal reflex time increases and proprioception performance decreases, resulting in decreased joint stability and balance which enhances probability of injury [9]. It has been demonstrated that patients with PFPS have inadequate muscular endurance, particularly in the hip abductors, which can make repetitive movements like stair climbing or extended walking more painful [10,11].

Isolated hip muscle fatigue has been linked to impaired neuromuscular control and compensatory changes in postural balance methods, supporting a link between proximal weakness and distal dysfunction [12,13]. Furthermore, although patients with PFPS often show strength deficits in the hip abductors, the evidence regarding endurance impairments is more variable [10],[14].

While strength training has been commonly prescribed, studies suggest that improvements in hip muscle strength alone may not be sufficient to normalize lower limb biomechanics in PFPS patients [6,15]. This raises interest in exploring other factors such as proprioception and isolated muscle fatigue that may better explain the persistence or recurrence of symptoms [16].

Thus, this study was conducted to compare the effects of induced hip versus knee muscle fatigue on knee proprioception, isokinetic peak torque of hip and knee muscles reflecting muscle strength. From a clinical viewpoint, understanding the effect of fatigue on such variables as greater predictors of hip and knee function may provide important insight into the role of muscle weakness in the development of PFPS. Further, the findings of this study may assess the potential contribution of muscle endurance exercises in prevention and rehabilitation of patients with PFPS.

METHODS

Participants:

This study involved a within-subject experimental design in which one group of patients was tested under two fatiguing conditions. Fifteen female patients (age 19.6 ± 1.7 yrs, height 161 ± 0.03 cm, body mass 56.75 ± 7.8 kg) with PFPS participated in the current study. All patients were students recruited from the Faculty of Physical Therapy, Cairo University, Egypt. Patients were allowed to randomly select the order of the two isolated fatigue protocols by drawing folded papers of the tested conditions from a container

Ethical Considerations:

- The study was approved by the ethical committee of the Faculty of Physical Therapy, Cairo University (P. TREC/012/00727).
- The study complied with the ethical standards of the Declaration of Helsinki.

Procedures:

A. Evaluation Procedure

Each patient received a brief orientation regarding the study's methodology, objectives, and tests to be completed. All the patients had signed informed consent after assessing the inclusion and exclusion criteria. The inclusion criteria include: Anterior or retro patellar knee pain after performing at least two of the following activities: ascending or descending stairs, stair climbing, squatting, and prolonged sitting [17,18]. Patients were excluded if they had a history of meniscal tear, other intra-articular pathologic conditions; cruciate or collateral ligament involvement, or any neurological deficit [19].

Pain and disability levels were evaluated using a 10-cm visual analogue scale and the Kujala Patellofemoral Scale to standardize a base line of the level of performance [20]. Its scoring level ranged from 3–10 and 65–84, respectively [21]. The patients shouldn't undergo any physical therapy program in the 30 days before the study to avoid muscle fatigue. The tested limb was the affected one in unilateral PFPS affection and the most symptomatic in bilateral affection.

B. Measurement procedure

Patients followed the testing procedure in the following steps:

- Assessing knee proprioception
- Measuring isokinetic muscle strength
- Performing the selected fatigue protocol
- Re-assessing knee proprioception
- Re-measuring isokinetic muscle strength

I. Fatigue protocol

Isokinetic dynamometer was used to induce isolated fatigue protocols of hip and knee muscles with rest period 3- days in- between. Three practice trials of sub-maximal and three of maximal contractions were performed. Following a 60-second rest, three repetitions of maximal concentric-eccentric contraction were carried out without stopping to determine the peak torque. Peak torque was defined as the maximum torque produced during the three repetitions. Patients were instructed to continuously contract the target muscle maximally concentric-eccentrically at 60 degrees per second for two to three minutes, or until the torque output fell below 50% of the peak torque for three consecutive contractions. [20,22.] Positioning was as per manufacturer's guidelines. For knee testing, the range was 90° to 0° of flexion in a seated position. For hip abductors, participants were side-lying, hips flexed to 45°, knees at 90°, and toes pointing forward. Testing was performed within the available range of abduction.

II. Knee proprioception assessment

Knee proprioception was assessed using the isokinetic dynamometer through measuring the knee absolute angular error (AAE). The purpose of this work was to compare two types of isolated fatigue protocols. It is possible that during closed kinetic chain, a greater number of proprioceptive afferents originated from sources outside the examined knee [19.] Therefore, knee proprioception was measured from non-weight-bearing position. The position accuracy for the Biodex system was reported as ± 1 degree for the difference between the presented and reproduced angles. Any increase or decrease in knee AAE means impairment in knee proprioception.

Testing was done in the following manner:

1- Each patient was blinded to eliminate any visual signals regarding the joint position. The dynamometer then passively moved the patient's leg from its initial 90° knee flexion angle to the tested angle of 45°.
2- Each patient was given five seconds to allow for joint perception. When the tested leg was in the presented angle position, all patients were instructed to actively reproduce the presented joint angle by pressing the "hold switch."
3- Each patient performed 3 trials at the tested angle and the average was recorded for statistical analysis.

III. Muscle strength assessment

The concentric/eccentric mode of muscular contraction was used for all isokinetic strength testing, and the angular velocity was set at 60° per second. An eccentric peak torque was taken for further statistical analysis. Each strength test was conducted in two sets of five repetitions each, separated by a 10-second rest interval. Five practice sessions were used to allow familiarization with the equipment. Patient positioning in the isokinetic dynamometer was the same as in fatigue protocols.

Statistical Analysis

Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS) for windows, version 20 with the significance level set at 0.05. Data were initially screened for normality assumption using Shapiro-Wilks normality tests. Two-way within subject Multivariate Analysis of Variance (MANOVA) was conducted to compare the tested variables of interest at different levels of both fatigue type and time. Multiple pairwise comparison tests were used to locate significant difference between both tested conditions.

RESULTS

This study was conducted to examine the effect of hip abductors versus knee extensors fatigue protocol on knee proprioception (AAE), hip and knee muscle strength in patients with PFPS. Regarding knee Proprioception: following hip fatigue protocol, knee proprioception showed impairment reflected by an increased knee absolute angular error (AAE). Although this did not reach statistical significance ($p = 0.07$). No similar effect was seen with knee fatigue.

About knee Extensor Strength: Eccentric peak torque of knee extensors decreased significantly post-hip fatigue ($p < 0.05$), indicating a reduction in knee strength. This supports the notion that proximal muscle fatigue can indirectly compromise distal strength output. For hip abductor strength: No significant changes were noted in hip abductor peak torque after knee fatigue.

The mean values and Multiple pairwise comparison tests (post hoc tests) for the three tested dependent variables at both fatiguing conditions are shown in **Table I and II**.

Table I. Descriptive statistics for the tested dependent variables (Mean ±SD):

Fatigue type	knee		hip	
Fatigue time	**pre**	**post**	**pre**	**post**
Knee AAE	4.6 ± 2.5	5.3 ± 1.9	4.2 ± 1.7	5.9 ± 3.02
Eccentric knee extensors' PT (Nm/kg)	71.6 ± 14.4	35.8 ± 7.2	71 ± 16.1	56.5 ± 16.1
Eccentric hip abductors' PT (Nm/kg)	73.3 ± 12.0	74.1 ± 14.0	74.3 ± 15.4	37.3 ± 7.74

*Significant at alpha level <0.05
AAE: absolute angular error; PT: peak torque; SD: standard deviation.

Table II. Multiple pairwise comparison test of the data outcome at (P <0.05):

p-value	Pre-test vs. post-test		Knee vs. Hip	
	knee	**Hip**	**pre**	**post**
Knee AAE	0.411	0.075	0.704	0.530
Eccentric knee extensors' PT (Nm/kg)	0.000	0.005	0.885	0.000
Eccentric hip abductors' PT (Nm/kg)	0.963	0.000	0.819	0.000

*Significant at alpha level <0.05
AAE: absolute angular error; PT: peak torque.

The Mean values of knee AEE, the eccentric hip abductors peak torques and eccentric knee extensors peak torque; "pre" and "post" tests of hip and knee fatigue protocols **(Figures 1, 2 and 3).**

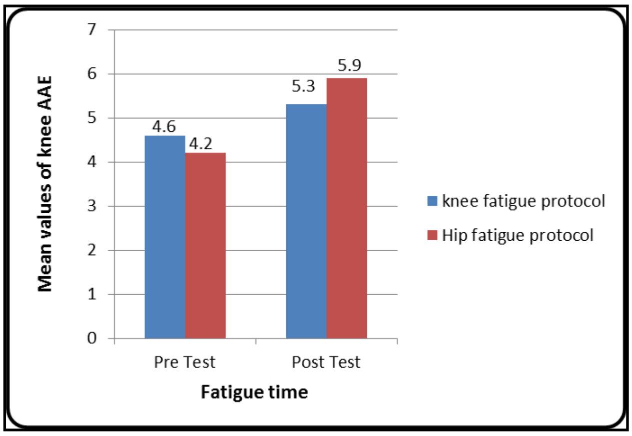

Figure 1: Mean values of knee AAE at "pre" and "post" tests of hip and knee fatigue protocols.

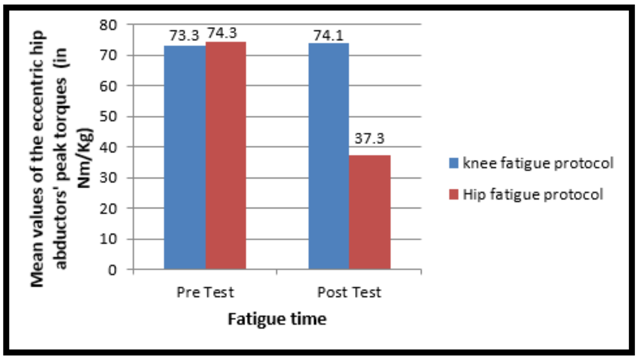

Figure 2: Mean values of the eccentric knee extensors' peak torque at 60°/sec at "pre" and "post" tests of hip and knee fatigue protocols.

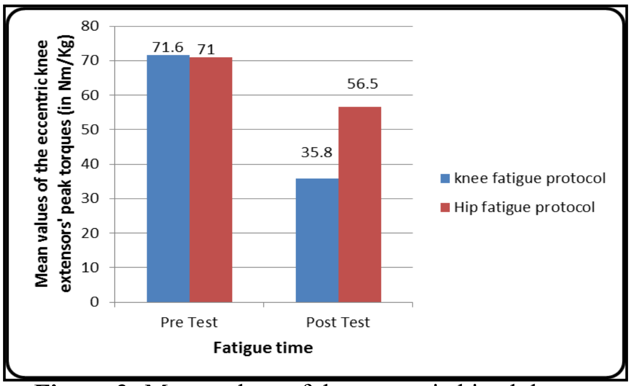

Figure 3: Mean values of the eccentric hip abductors' peak torques at 60°/sec at "pre" and "post" tests of hip and knee fatigue protocols.

DISCUSSION

The results of the current study revealed impaired knee proprioception (increased knee AEE) following hip muscle fatigue, but did not reach statistical significance. It supports previous research linking altered hip mechanics with sensory deficits at knee [16]. This could be attributed to the greater femoral adduction and internal rotation; the patella had a tendency to be displaced medially with respect to the anterior superior iliac spine (ASIS) altering the tracking of patella [4,7]. Chronic patellar position changes caused increased tension and pressure of the underling patellar surface; which affect proprioception [11].

Increased compressive force on the patellofemoral joint due to alteration in hip mechanics caused knee pain and functional disability of knee muscle strength. This could explain why patients report pain at patellofemoral joint during hip abductor fatigue. There is a negative impact of pain severity regarding knee extensor eccentric peak torque.

As, the alpha motor neuron inhibition caused by pain, prevents the full activation of quadriceps muscle [11, 12.] Previous studies verified that such alterations in lower limb kinematics are more evident under fatigue conditions [12, 13.]

The decreased eccentric knee extensors peak torque post hip fatigue supports the concept of central fatigue mechanism, where neural drive to the muscle becomes insufficient after prolonged exertion [22,23.] Central fatigue may reduce motor unit firing frequency, resulting in the observed decreased strength [23.]

Conversely, knee fatigue did not significantly affect hip strength. The insignificant effect of knee fatigue on hip muscle strength might be due to different functions concerning monoarticular and biarticular muscles during seated knee fatigue protocol [21.] During this protocol, the recruitment pattern of quadriceps femoris muscle varied among muscle fibers. The rectus femoris (RF) muscle regulates the distribution of the net moment about the hip and the knee joints; demonstrates more recruitment pattern than VMO and VL, as a result, an ineffective transfer of torque from the knee to hip joint occurred during seated knee fatigue protocol [21,22.]

Our finding revealed that proximal muscles are more important for maintaining proprioception which control balance than distal muscles. This comes in the line with study by Negahban et al [20.] These researchers discovered that the disturbance of dynamic standing balance is more affected by the fatigue of the thigh abductor muscles than by the fatigue of the knee extensors.

Overall, these findings highlight the importance of addressing proximal endurance and sensorimotor control during rehabilitation. Strategies that enhance hip endurance may decrease patellofemoral loading and improve functional outcomes in patients with PFPS [8, 10, 14, 19.]

Limitations:

This study had several limitations. First, the isokinetic dynamometer measures gross joint torque and does not separate the contribution of individual muscles, which restrict the interpretation of isolated muscle performance. Second, the sample size was relatively small and only female participants were included which reduced the generalizability of the findings to broader populations, including males and other age groups. Although the sample achieved adequate statistical power, a larger and more diverse cohort would enhance external validity and allow for subgroup analyses. Third, control group of healthy individuals did not used in the study design, limiting the ability to determine whether the observed responses were specific to PFPS or represent general fatigue effects. Lastly, psychological and pain-related factors such as fear of movement (kinesiophobia), pain perception variability, and effort motivation were not measured; however, these factors may influence both proprioceptive accuracy and muscle activation under fatigue.

CONCLUSION

The current findings hold important clinical implications, emphasizing the detrimental impact of hip muscle fatigue on knee muscle strength and proprioception in individuals with patellofemoral pain syndrome (PFPS).

These results highlight the need for clinicians to assess and target not only the endurance of knee extensors but also that of hip muscles when evaluating and managing patellofemoral joint dysfunction. Incorporating endurance testing and training for the hip abductors should be a fundamental part of rehabilitation programs.

More future research is necessary to investigate the long-term effects of endurance-based interventions for both hip and knee muscles on lower limb function and symptom resolution. In addition, integrating proprioceptive and neuromuscular training strategies may help reduce muscular imbalances and prevent injuries in both athletic and clinical groups.

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Conflict of interest:

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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