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CASE REPORT

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A NOVEL EXPERIMENTAL APPROACH FOR IDENTIFYING BIOMECHANICAL PARAMETERS ASSOCIATED WITH PATELLOFEMORAL PAIN: A CASE REPORT

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ABSTRACT

Purpose: Patients with patellofemoral pain (PFP) may show muscle strength asymmetries that disrupt movement patterns and joint mechanics. Biomechanical measurements of neuromuscular and kinematic changes can improve understanding and management of PFP. This study investigates the change of ground reaction force (GRF), knee valgus angle and muscle activation patterns of the quadriceps muscle group on the affected and unaffected sides in an patient with PFP.

Methods: A 38-year-old right-dominant woman with right-sided PFP participated in the study. Marker-based motion capture, a force plate and surface electromyography (EMG) were used to measure physiological, kinematic and kinetic parameters during isometric contraction at half-squat position to evaluate the biomechanical effects of PFP.

Discussion: The muscle activation patterns of right vastus medialis (VM), vastus lateralis (VL), and left VM, VL and rectus femoris (RF) at the affected and non-affected sides showed strong positive linear correlations ($r > 0.774 \pm 0.010$) with GRF-time history except for right RF (r: 0.654 ± 0.112). The integrated EMG value of the right RF was less than that of the left RF, which aligns with the lower correlation. The valgus angle in the left knee was $8.23^{o} \pm 2.98^{o}$ and $2.76^{o} \pm 1.32^{o}$ in the right knee.

Conclusion: Muscle activations were lower on the affected side, while the non-affected side exhibited a higher valgus angle. It might indicate that a compensatory mechanism on the non-affected side may counterbalance the increased valgus angle on the affected side, potentially contributing to pain. On the other hand, this finding should be supported by multiple participants with the proposed experimental setup.

Key Words: Patellofemoral Pain, Kinematics, Ground Reaction Force, Quadriceps Muscle Activation

ÖZET

Amaç: Patellofemoral ağrısı (PFA) olan bireylerde, hareket paternlerini ve eklem mekaniğini bozan kas kuvveti asimetrileri görülebilir. Nöromüsküler ve kinematik değişikliklerin biyomekaniksel yöntemler kullanılarak ölçülmesi, PFA'nın anlaşılmasını ve yönetilmesini geliştirebilir. Bu çalışma, PFA'sı olan bir bireyde etkilenen ve etkilenmeyen taraflardaki kuadriseps kas grubunun aktivasyonlarındaki, yer reaksiyon kuvvetindeki (YTK) ve diz valgus açısındaki değişimi araştırmaktadır.

Yöntem: Çalışmaya sağ PFA olan, 38 yaşında, sağ dominant, bir kadın gönüllü katıldı. Deney düzeneğinde yarım çömelme pozisyonunda, maksimum izometrik kasılma sırasında fizyolojik, kinematik ve kinetik parametreleri ölçmek için işaretleyici tabanlı hareket yakalama sistemi, bir kuvvet platformu ve yüzey elektromiyografi (EMG) kullanıldı.

Bulgular: Etkilenen ve etkilenmeyen taraftaki sağ vastus medialis (VM), vastus lateralis (VL) ve sol VM, VL ve rektus femoris (RF) kaslarının aktivasyon paternleri, sağ RF hariç (r: 0.654 ± 0.112), zamana bağlı YTK eğrisi ile güçlü pozitif doğrusal korelasyonlar gösterdi ($r > 0.774 \pm 0.010$). Sağ RF'nin integral EMG değeri sol RF'ye kıyasla daha düşük bulundu ve bu da YTK ile gösterdiği düşük korelasyonla uyumluydu. Sol ve sağ dizdeki valgus açısı sırasıyla $8.23^{o} \pm 2.98^{o}$ ve $2.76^{o} \pm 1.32^{o}$'dir.

Sonuç: Etkilenen tarafta kas aktivasyonları daha düşüktü, etkilenmeyen tarafta valgus açısı görüldü. Bu, etkilenmeyen taraftaki kompanse edici mekanizmaların etkilenen taraftaki artan valgus açısını dengeleyebileceğini ve ağrı kontrolü üzerinde olumlu etkisi olabileceğini düşündürmektedir. Öte yandan, bu bulgu önerilen deneysel kurulumla birden fazla katılımcı tarafından desteklenmelidir.

Anahtar kelimeler: patellofemoral ağrı, kinematik, yer tepki kuvveti, kuadriseps kas aktivasyonu

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INTRODUCTION

Patellofemoral Pain (PFP) is a common musculoskeletal disorder affecting a wide demographic, spanning various age groups, activity levels, and athletic and non-athletic populations (1). Characterized by pain localized to the anterior region of the knee joint, PFP is often aggravated by activities that involve knee flexion and extension, such as squatting, running, stair climbing, or even prolonged sitting (2). The impact of PFP is significant, not only due to the pain and discomfort it causes but also because of its potential to limit daily function, reduce activity levels, and negatively affect quality of life (2-4).

Muscle imbalances in PFP can be more subtle and may not always be immediately apparent through visual examination (5). Electromyographic (EMG) assessments have become critical in identifying these slight alterations in muscle activation patterns, muscle fatigue and any musculoskeletal injury (6). EMG assessments have become critical in identifying these slight alterations in muscle activation patterns. EMG studies have shown that patients with PFP often exhibit lower muscle activation on the affected side compared to the unaffected side, indicating the presence of neuromuscular dysfunction. This reduced activation can be observed in both the quadriceps and other muscles surrounding the knee (7, 8).

Ground reaction force (GRF), which reflects the forces exerted by the ground on the body during movement, offers valuable insights into the biomechanical stresses affecting the knee by analyzing GRF alongside knee valgus angles and quadriceps activation patterns, a more holistic understanding of the neuromuscular and kinematic disruptions in PFP can be achieved (9, 10).

This research aims to observe the neuromuscular factors on PFP using a novel experimental setup and biomechanical measurement methods. We used biomechanical measurement methods to analyze the effects of PFP on muscular activity of the quadriceps muscle group knee valgus angle, as well as exerted GRF and joint kinematics. Using biomechanical measurement methods to observe neuromuscular, kinetic and kinematic variables can better understand effective management through objective evaluations (11). Concerning the biomechanical features of the human body, we suggested that under a compression-type voluntary isometric contraction, the effects of PFP could be observed due to the intersegmental forces. Therefore, we treated the human body as a constrained mechanical system and designed an experiment to observe those effects using biomechanical measurement methods.

METHODS

Study Design

This research employed a single-case experimental design. The participant received all detailed information about the study's purpose and procedures and provided written informed consent before participating. The study protocol was reviewed and approved all procedures by The University Institutional Ethical Review Board (GO18/372-42).

Participant

A 38-year-old female participant who reported experiencing right-dominant and right-side PFP was recruited for this study. An orthopedist evaluated the patient for patellofemoral joint symptoms, pain during activities like stair climbing or squatting, and tenderness on a positive patellar compression test. The participant provided informed consent. The participant's anthropometric data, including height (1.68 m), weight (62 kg), and body mass index (21.96 kg/ m^2), were recorded before the experiment. Her dominant leg was determined based on self-reported preference, with the right leg identified as the dominant leg. The participant has been experiencing PFP for over three years, with the pain intensity fluctuating over time. At the time of assessment, the pain intensity was rated 4 on the Visual Analog Scale. The participant has not received any prior treatment for the condition.

Data Collection

Experimental Setup: The experimental procedure involved the participant performing a maximal isometric contraction while lifting a loaded bar positioned on supports (Figure 1). The bar was loaded with 150 kg that the participant could not lift, so a compression-type isometric contraction between the bar and force plate would be performed. The height of the loaded bar was adjusted accordingly to ensure that the participant's knee angle during the contraction was consistent with a 65-degree flexion for loading the patellofemoral joint (12). The bar was placed in front of the participant, and the position of the knee joint was carefully monitored to maintain the desired knee angle in a half-squat posture. This experimental setup induces bilateral stress on the patellofemoral joint while participants maintain a maximal isometric contraction. The design allows direct observation of kinematic variations and muscle activation patterns at the knee in patients with PFP while a maximal effort is given to lift the load.

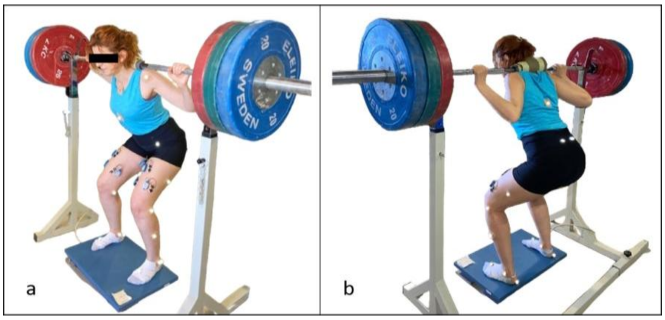

Figure 1. The subject performing isometric contraction in the experimental setup. (a) frontal and (b) back view.

Motion Capture and Marker Placement: Twenty reflective markers were placed on the participant's lower limbs to capture three-dimensional motion during the task. These markers were bilaterally positioned at specific anatomical landmarks, including the anterior superior iliac spine, posterior superior iliac spine, lateral and medial femoral epicondyle, lateral and medial malleolus, along the shank and thigh segments and foot to track the participant's posture accurately (13).

A 10-camera (8 Vantage, 2 Vue) motion capture system (Vicon Ltd, Bilston) was calibrated and synchronized with the force plate and EMG system. The marker trajectories during the motion were recorded using Nexus software at 100 Hz. The participant's static pose was recorded for scaling purposes. The recorded marker data allowed the reconstruction of the participant's lower limb kinematics during the isometric contraction. The recorded marker trajectory data were exported as *.trc* files (Track Row Column).

Electromyography: A 16-channel Noraxon EMG system assessed muscle activation during the maximal isometric contraction. The EMG electrodes were placed over the VM, VL, and RF muscles on both legs. These muscles were selected due to their quadriceps activation during the squat-like task. The skin was prepared by shaving and lightly rubbing the area to ensure optimal electrode contact. The electrodes were attached to the skin surface, following the standard procedures for EMG recording. The EMG signals were amplified, digitized, and recorded at 2000 Hz during the contraction.

Force Plate and Isometric Contraction: The participant was instructed to perform a maximal isometric contraction to lift the bar while standing on an AMTI (BMS400600) force plate. The force plate measured the GRF during the contraction at 1000 Hz, which was used to analyze the participant's force production capabilities. The participant was verbally encouraged to exert maximal effort, and force data were continuously recorded during the contraction duration. The participant performed three isometric contractions in three consecutive motion capture sessions.

Kinematic Analysis and Knee Valgus Angle Calculation: The valgus angle was obtained following three-phase post-processing in OpenSim (14). First, the "gait2392_simbody" model was modified, and two more degrees of freedom were added to the knee joint. Thus, the knee joint could perform flexion/extension, varus/valgus, and internal/external rotations. The model was scaled to the subject using static pose marker trajectories. Then, the valgus angle during the isometric contraction was calculated using the inverse kinematics tool of OpenSim.

Data Analysis

The force plate, EMG and kinematic data were imported into MATLAB (R2023b). The force plate data were used to assess the GRF produced during the isometric task, and the relationship between muscle activation and force output was explored. The force plate data were filtered using a zerophase 2nd-order low-pass Butterworth filter with a cut-off frequency of 15 Hz and downsampled to 100 Hz to match the kinematic data. The resultant force vector was computed using the components of the three axes. The magnitude of the resultant force vector exceeding two times the body weight was detected for further statistical analyses.

EMG data were analyzed to evaluate the activation patterns of the VM, VL, and RF muscles during the maximal isometric contraction. The EMG signals were downsampled to 100 Hz and full-wave rectified. The rectified signals' root mean square (RMS) was calculated within 15 ms. The RMS data was then normalized by the maximum values obtained during the maximal contractions. The RMS data was integrated to show the total muscular activity throughout the contraction.

The knee valgus angle was calculated using the OpenSim inverse kinematics (IK) tool. The output of the IK tool (joint angles) was imported into MATLAB and plotted with the EMG and force data.

Pearson's correlation coefficients (r) were computed for each muscle on both the affected and non-affected sides to evaluate the relationship between muscle activation and the GRF-time histories. The correlation coefficient quantifies the strength and direction of the linear relationship between the integrated EMG values and the GRF-time history, with a value close to +1 indicating a strong positive correlation (15).

RESULTS

The isometric contractions lasted 8.87 ± 1.17 s during the experiments. The measured peak GRF and calculated knee valgus angles can be seen in Table 1. The valgus angle in the left knee was 8.23º ± 2.98º, and 2.76º ± 1.32º was in the right knee. The integrated EMG values that represent the total activity of the muscles during the contraction period are presented in Table 2. The biggest difference between the left and right knees was obtained for the RF muscle when the mean values for the repetitions were considered (Table 2, Figure 2). Accordingly, the EMG activity of the right RF muscle consistently showed the lowest linear correlation with the GRF-time history (Table 3). The mean change of GRF and EMG activity of the muscles, knee valgus angles and integrated EMG values can be seen in Figure 3.

Table 1: The detected contraction durations, peak ground reaction force and knee valgus angles for each repetition.

	Repetition 1	Repetition 2	Repetition 3	Mean ± SD
Contraction duration (s)	9. 70	7.53	9.39	8.87 ± 1.17
Peak Ground Reaction Force (N)	1363.48	1448.07	1406.40	1405.98 ± 42.29
Peak Ground Reaction Force (bodyweight)	2.24	2.38	2.31	2.31 ± 0.07
Left Knee Mean Valgus Angle (degrees)	8.23º ± 3.37º	8.47º ± 3.66º	7.99º ± 3.61º	8.23º ± 2.98º
Right Knee Mean Valgus Angle (degrees)	3.33º ± 1.55º	2.70º ± 1.62º	2.26º ± 1.65º	2.76º ± 1.32º

Note: Values are indicated as mean ± standard deviation.
Abbreviations: SD: Standard deviation.

Table 2. The integrated EMG values of the muscles during the contraction period for each repetition.

	Integrated EMG during the contraction (mV.s)					
	Left VM	**Right VM**	**Left VL**	**Right VM**	**Left RF**	**Right RF**
Repetition 1	68.37	63.67	65.72	63.86	69.40	55.59
Repetition 2	53.52	55.33	57.73	50.37	56.85	52.88
Repetition 3	77.01	68.04	80.47	64.87	74.18	64.57
Mean ± SD	66.30 ± 11.88	62.34 ± 6.45	67.97 ± 11.53	59.69 ± 8.09	66.81 ± 8.95	57.68 ± 6.11

Note: Values are indicated as mean ± standard deviation.
Abbreviations: VM: Vastus medialis, VL: Vastus lateralis, RF: Rectus femoris, SD**:** Standard deviation.

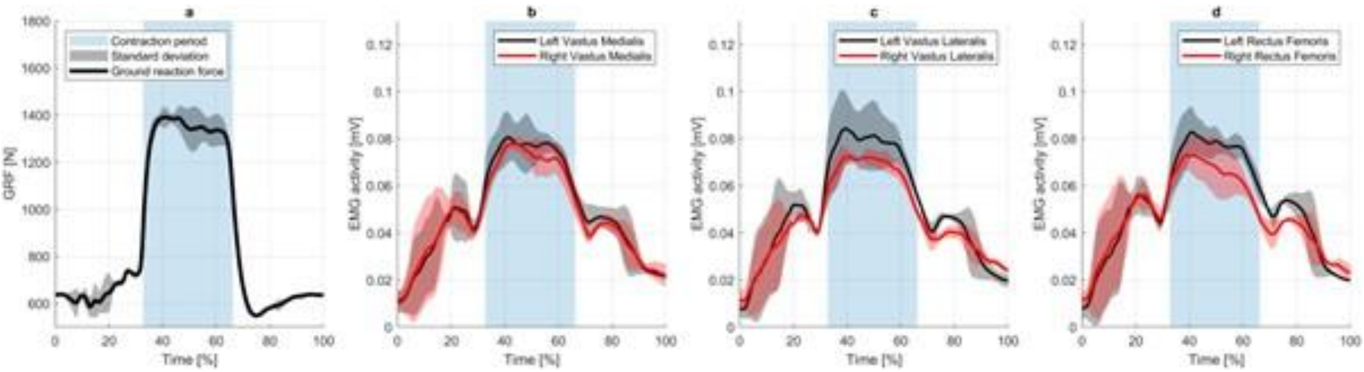

Figure 2. (a) The GRF-time history, the EMG activity-time histories of (b) vastus medialis, (c) vastus lateralis, and (d) rectus femoris muscles of the left and right legs with standard deviations (shaded areas).

Table 3. The linear correlation coefficients between GRF and EMG activity of the muscles for each repetition.

	Linear correlation coefficient (r)					
	Left VM - GRF	**Right VM - GRF**	**Left VL - GRF**	**Right VL - GRF**	**Left RF - GRF**	**Right RF - GRF**
Repetition 1	0.866	0.707	0.786	0.818	0.785	0.496
Repetition 2	0.825	0.859	0.780	0.826	0.777	0.747
Repetition 3	0.793	0.827	0.830	0.839	0.760	0.720
Mean ± SD	0.828±0.030	0.798±0.065	0.799±0.022	0.828±0.009	0.774±0.010	0.654±0.112

r: Pearson's correlation coefficients
Note: Values are indicated as mean ± standard deviation.
Abbreviations: VM: Vastus medialis, VL: Vastus lateralis, RF: Rectus femoris, SD: Standard deviation.

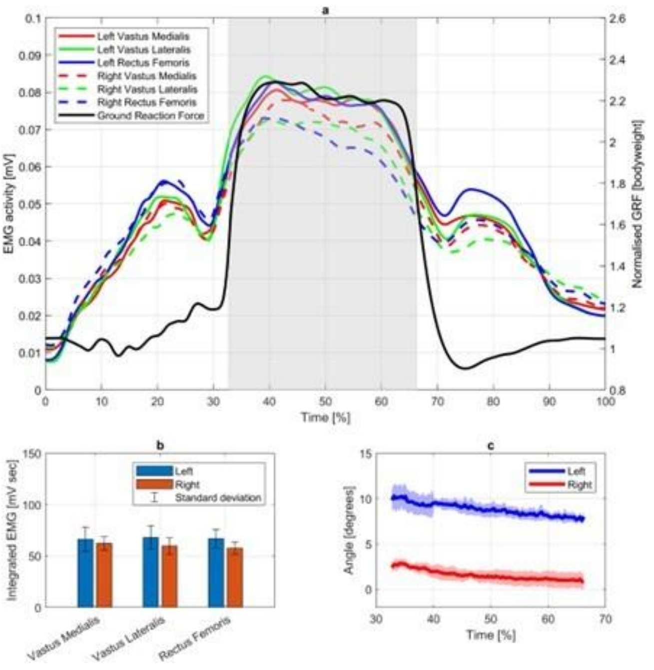

Figure 3. (a) The mean normalized GRF and EMG activity of the muscles, (b) the mean integrated EMG of the muscles with standard deviations during the contraction period (grey shaded area), (c) the mean valgus angle-time histories of the left and right knees with standard deviations (shaded areas) during the contraction period.

DISCUSSION

This study was conducted to safely observe the biomechanical factors with the proposed experimental setup on patients with PFP. We had the opportunity to follow the biomechanical changes in the knee joint and to measure and compare muscle activations and ground reaction force in the experiment. Although the study was limited to one participant, key findings include lower muscle activation on the affected side and a greater valgus angle on the non-affected side. These results suggest that the body may rely on the non-affected side to maintain stability, potentially reducing load and pain on the affected knee. As expected, there are differences in the knee affected by PFP compared to the unaffected knee, but some changes were also observed in the unaffected knee. The observed reduction in muscle activation on the affected side, particularly in the right RF, is consistent with previous literature highlighting decreased muscle activation in regions experiencing pain or injury (16-19). Reduced quadriceps activation on the affected side can compromise knee joint stability, leading to compensatory loading patterns. Lower activation of stabilizing muscles like the rectus femoris may impair patellar control, worsening pain and mechanical dysfunction (20), which aligns with studies showing pain alters muscle recruitment patterns, affecting lower limb stabilization (7, 21, 22). As in this study, compensatory movement patterns may be observed in patients with unilateral lower limb pain and increased valgus motion on the non-affected side (8, 23, 24). These compensatory strategies may reduce the load on the injured leg but increase stress on the non-affected knee, potentially leading to secondary musculoskeletal conditions (25, 26). Reduced muscle activation on the affected side can hinder knee rehabilitation, leading to chronic pain and disability. Rehabilitation should target both limbs to restore muscle activation, improve stability, and address altered movement patterns, preventing further injury and ensuring balanced function (27, 28).

A complete biomechanical comparison of affected and unaffected legs would be possible if each foot were placed on a separate force plate. OpenSim is a software in which muscle forces can be distributed using a static optimization approach when the GRF exerted at each foot is known (18). However, for validation, the estimated muscle forces must be compared to the measured muscle activity, EMG. From this point of view, the current experimental setup includes promising measurement methods to analyze the biomechanical factors in PFP. In a future study, the experiment can be repeated in people with different levels of PFP, and the results of healthy patients and those with PFP can also be compared.

Limitations

In this study, an experimental protocol and analysis method were developed to investigate the biomechanical factors in subjects with PFP. Therefore, this study is limited to a single subject.

CONCLUSION

The results demonstrated that the current experimental setup and measurement methods are promising for evaluating a subject with PFP. The findings also suggest that compensatory mechanisms contribute to altered biomechanics, including reduced muscle activation on the affected side and increased valgus angle on the unaffected side. While these mechanisms may offer short-term relief, they may also increase the risk of further injury due to maladaptive changes. Rehabilitation strategies addressing muscle activation and joint kinematics on both sides of the body are crucial to restoring function and preventing long-term complications associated with unilateral knee pain.

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Author Contributions: Substantial contributions to the conception or design of the work or the acquisition, analysis, or interpretation of data for the work (DD, NÖ, SA). Drafting the work or reviewing it critically for important intellectual content (SA, NÖ, VBT). Final approval of the version to be published (DD, NÖ). Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved (DD, NÖ, SA, VBT).

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Conflict of Interest: The author(s) state that there are no potential conflicts of interest concerning the research, writing, and/or publication of this article.

Ethical approval: All procedures performed involving human participants were in accordance with the ethical standards of the local ethics committee (Approval for the study was granted by The University Institutional Ethical Review Board (GO18/372-42)).

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