Lower Extremity Biomechanics During a Drop-Vertical Jump and Muscle Strength in Women With Patellofemoral Pain

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Context: Patellofemoral pain (PFP) is one of the most prevalent knee conditions observed in women. Current research suggests that individuals with PFP have altered muscle activity, kinematics, and kinetics during functional tasks. However, few authors have examined differences in lower extremity biomechanics in this population during the drop-vertical jump (DVJ).

Objective: To determine how lower extremity electromyography, kinematics, and kinetics during a DVJ and lower extremity isometric strength differed between women with and those without PFP.

Design: Cross-sectional study.

Setting: Laboratory.

Patients or Other Participants: Fifteen healthy women $(age = 20.23 \pm 1.39 \text{ years}, height = 169.32 \pm 5.38 \text{ cm}, mass = 67.73 \pm 9.57 \text{ kg})$ and 15 women with PFP $(age = 22.33 \pm 3.49 \text{ years}, height = 166.42 \pm 6.01 \text{ cm}, mass = 65.67 \pm 13.75 \text{ kg}).$ Intervention(s): Three trials of a DVJ.

Main Outcome Measure(s): Surface electromyography, kinematics, and kinetics were collected simultaneously during a DVJ. Lower extremity strength was measured isometrically. Independent-samples t tests were performed to assess group differences.

Results: Normalized muscle activity in the vastus medialis (healthy group = 120.84 \pm 80.73, PFP group = 235.84 \pm

152.29), gluteus maximus (healthy group = 43.81 ± 65.63, PFP group = 13.37 ± 13.55), and biceps femoris (healthy group = 36.68 ± 62.71, PFP group = 11.04 ± 8.9) during the landing phase of the DVJ differed between groups. Compared with healthy women, those with PFP completed the DVJ with greater hip internal-rotation moment (0.04 ± 0.28 N/kg versus 0.06 ± 0.14 N/kg, respectively) and had decreased knee-flexion excursion (76.76° ± 7.50° versus PFP = 74.14° ± 19.85°, respectively); they took less time to reach peak trunk flexion (0.19 ± 0.01 seconds versus 0.19 ± 0.02 seconds, respectively) and lateral trunk flexion (0.12 ± 0.07 seconds versus 0.11 ± 0.04 seconds, respectively).

Conclusions: During the DVJ, women with PFP had increased hip internal-rotation moment and decreased knee-flexion excursion with less time to peak trunk flexion and lateral flexion. Muscle activation was increased in the vastus medialis but decreased in the gluteus maximus and biceps femoris. This suggests that altered motor-unit recruitment in the hip and thigh may result in changes in biomechanics during a DVJ that are often associated with an increased risk of injury.

Key Words: knee kinematics, hip kinematics, knee kinetics, hip kinetics

Key Points

- Compared with the healthy control group, the patellofemoral pain group demonstrated differences in muscle activity during the landing phase of the drop-vertical jump in the vastus medialis, gluteus maximus, and biceps femoris.
- Differences were also present in hip internal-rotation moment, knee-flexion kinematic excursion, time to peak trunk flexion, and time to peak lateral trunk flexion during the drop-vertical jump.
- Altered motor recruitment of the hip and thigh may result in biomechanical changes during a drop-vertical jump that are often associated with an increased risk of injury.

P atellofemoral pain (PFP) is one of the most common orthopaedic injuries and one of the most prevalent knee conditions observed in an active population.¹ This condition affects between 1.5% and 7.3% of patients seeking medical care in the United States, and up to 25% of those with knee injuries have PFP.^{1,2} Among those experiencing PFP, women are twice as likely to be diagnosed as men.¹ Those with PFP typically have pain completing everyday tasks and during activities such as sitting, running, lunging, jumping, stair ascent and descent, and squatting.^{2,3} The cause is multifactorial and includes abnormal patellar tracking, quadriceps weakness, and

abnormal lower extremity biomechanics and is often categorically different between males and females.⁴ Treatment outcomes for patients with PFP are suboptimal, with up to 74% decreasing or stopping activity and reporting pain that persists for up to 4 years.⁵

Current researchers have suggested that individuals with PFP have altered neuromuscular control of the lower extremity. The most commonly acknowledged deficit in patients with PFP is muscle weakness, specifically in the quadriceps and gluteus medius (GMed) muscles.^{6,7} Many authors have observed that individuals with PFP have decreased peak hip external rotation and decreased peak hip

Knee

Table 1. Baseline Participant Characteristics

	Group, Mean ±		
Characteristic	Patellofemoral Pain (n = 15)	Healthy (n = 15)	P Value
Age, y	22.33 ± 3.49^{a}	20.23 ± 1.39	.01
Height, cm	166.42 ± 6.01	169.32 ± 5.38	.66
Mass, kg	65.67 ± 13.75	67.73 ± 9.57	.56
Duration of pain, mo	21.60 ± 24.31^{a}	0.00 ± 0.00	.002
Anterior Knee Pain Scale score	74.47 ± 7.88^{a}	0.00 ± 0.00	<.001
Lower Extremity Functional Scale score	80.66 ± 10.92^{a}	100.00 ± 0.00	<.001
Current visual analog scale pain score	1.62 ± 1.78^{a}	0.00 ± 0.00	<.001
Worst visual analog scale pain score in past 72 h	4.44 ± 1.93^{a}	0.00 ± 0.00	<.001

^a Indicates difference (P < .05).

abduction across various functional tasks.⁴ These tasks include the single-legged squat,⁸ stair ascent and descent,¹ walking,⁹ and jogging.¹⁰ However, very few investigators thus far have focused on a jumping task, possibly because of increased pain during jumping in patients with PFP. Jumps that have been examined were the single-legged triple hop¹¹ and the drop-vertical jump (DVJ),¹² but electromyography (EMG) was not used as a measure of muscle activity.

Pain with jumping is commonly evaluated on patientreported outcome measures (PROMs) such as the Anterior Knee Pain Scale (AKPS)¹³ and the Lower Extremity Functional Scale.¹⁴ Researchers who studied patients with PFP used scores on these PROMs as inclusion criteria.¹⁵ Authors dos Reis et al¹¹ discussed the abundance of PFP studies that looked at walking, jogging, stair ambulation, and other functional tasks, yet disability or pain with jumping tasks seemed to be overlooked. The DVJ is a common functional task in the literature and is used as a screening tool for various knee conditions. In patients after anterior cruciate ligament injury, the DVJ identified knee valgus through the measurement of the knee-abduction angle and external abduction moment and demonstrated the risk for subsequent injury.¹⁶ Investigators^{11,12} who have assessed jumping suggested that it may be a more representative task of sports movements, especially those that require jumping. To understand differences in jumping strategies between healthy and PFP groups and permit generalization to athletic tasks, EMG activity, kinematics, and kinetics must be examined simultaneously in these cohorts. Therefore, the purpose of our study was to determine how lower extremity muscle activity, kinematics, kinetics, and hip and knee strength differed during a DVJ between women with PFP and a healthy population.

METHODS

This cross-sectional study compared group differences between a healthy cohort and a cohort with PFP. The independent variable was group (healthy control, PFP). The dependent variables were normalized EMG amplitude of lower extremity muscles; trunk, knee, and hip kinematics and kinetics during a DVJ; and knee and hip strength. We assessed EMG amplitude in the vastus medialis oblique (VMO), vastus lateralis (VL), gluteus maximus (GMax), GMed, and biceps femoris (BicFem). Knee, hip, and trunk kinematics were assessed in the frontal, sagittal, and transverse planes (knee flexion and extension, knee abduction and adduction, knee rotation, hip flexion and extension, hip abduction and adduction, hip rotation, trunk flexion, trunk lateral flexion, and trunk rotation) during the DVJ. Knee and hip strength were assessed in the knee flexors, knee extensors, hip extensors, hip adductors, hip abductors, hip internal rotators, and hip external rotators.

Participants

Thirty women (15 healthy, 15 with PFP) volunteered to participate in this study (Table 1). Institutional review board approval was granted, written consent was obtained before the start of data collection, and volunteers with PFP were prescreened over the phone. This study was part of a larger study,¹⁷ so participants in this study were from a sample of convenience. Inclusion criteria for healthy participants were a score of 0 for knee pain as measured on a visual analog scale (VAS), a score of 100 on the AKPS questionnaire, and no surgery or injury to the lower extremities. Inclusion criteria for participants with PFP were based on previously described¹⁸ guidelines: the insidious onset of knee symptoms unrelated to a traumatic event with pain lasting for more than 3 months and the presence of peripatellar or retropatellar knee pain during at least 2 of the following functional activities: stair ascent or descent, running, kneeling, squatting, prolonged sitting, jumping, isometric quadriceps contraction, or palpation of the medial or lateral facet of the patella. In addition, they must have scored ≤ 85 on the AKPS questionnaire¹⁰ and >3.0 on the VAS for worst pain over the past 72 hours.¹⁹ An athletic trainer evaluated all participants with PFP to ensure they met the inclusion criteria. Individuals with bilateral PFP self-selected the most painful limb at the time of testing. This limb was considered the injured limb throughout the duration of testing. Participants were excluded if they had a history of knee surgery, internal derangement such as a rupture of any knee ligament or an injury to the meniscus, ligamentous instability, other sources of anterior knee pain, or neurologic involvement or cognitive impairment. Although this was not a concern in our study, we would have also excluded participants if the DVJ was too painful or if they displayed stress regarding the jumping task.

Instruments

Surface EMG was measured using a 16-channel Trigno Wireless EMG system (Delsys, Natick, MA) and data were collected using a 2000-Hz sampling rate. Before the electrodes were applied, the area was shaved, debrided, and cleaned. Parallel bar electrodes $(37 \times 26 \times 15 \text{ mm})$ were placed on the GMed, GMax, VL, VMO, and BicFem

of the involved limb.²⁰ Electrode placement adhered to recommendations, and the signal was visually confirmed during quiet standing and throughout manual muscle testing. The VAS for knee pain assessed the worst pain in the past 24 hours, current pain, and pain immediately after the DVJ. The 10-cm VAS ranged from *not at all severe* to *extremely severe*.

A 12-camera motion-capture system (Vicon Motion Systems, Ltd, Oxford, UK; standard error of measurement $= 0.75^{\circ}-2.3^{\circ}$) and a split-belt instrumented treadmill (Bertec Corp, Columbus, OH) were used to collect kinematic and kinetic data during the DVJ task. Kinematic data were sampled at 250 Hz and ground reaction forces were sampled at 1000 Hz via 2 force plates embedded in the treadmill. Data were synchronized, exported, and filtered using a Butterworth filter at 14.5 Hz and MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL).

Testing Procedures

After screening, participants completed the PROMs (AKPS, Lower Extremity Functional Scale) and current pain was assessed using the VAS.

Strength. Isometric strength of the knee flexors, knee extensors, hip flexors, hip extensors, hip adductors, hip abductors, hip internal rotators, and hip external rotators was assessed using a handheld dynamometer (Omnitest-MMT; Accelerated Care Plus, Reno, NV). We chose handheld dynamometry over an isokinetic dynamometer as it is less expensive and more widely used in clinical practice. Moment arms were measured (in centimeters) before testing and marked on the participant's limb to ensure consistent dynamometer placement over multiple trials. Positioning for testing of the knee flexors, hip extensors, hip internal rotators, and hip external rotators was prone with the knee flexed to 90°; positioning for testing of the hip abductors was side lying on the contralateral limb with the hips and knees extended; and positioning for testing of the knee extensors and hip flexors was in short sit with the hips and knees flexed¹⁷ to 90°. The dynamometer was placed on the distal posterior thigh to assess the hip extensors, distal anterior thigh for the hip flexors, distal lateral thigh for the hip abductors, distal medial thigh for the hip adductors, distal lateral shank for the hip external rotators, distal medial shank for the hip internal rotators, distal anterior shank for the knee extensors, and distal posterior shank for the knee flexors. Three trials of a 5-second isometric hold were collected for each measure. All strength measures (newtons) were normalized to body weight in kilograms and moment arm in meters.²¹

Drop-Vertical Jump. Eight clusters of retroreflective markers were attached to the thorax and sacrum and bilaterally over the lateral midthigh, lateral midcalf, and forefoot. The participant was digitized using the anatomical landmarks of the medial and lateral malleoli, medial and lateral knee joint lines, L5, T12, C7, and bilateral anterior-superior iliac spine to identify the joint centers. Participants completed a 30-second quiet-standing task so that we could collect the EMG, Motion Monitor, and Vicon Nexus system data in unison before the DVJ. The DVJ task was performed as described by Nguyen et al.²² Participants were instructed to drop off the front of the 30-cm-high box onto the force plate and, on landing, immediately rebound

into maximal-height jump. The participants were allowed to use their arms as desired. Practice trials were conducted until the participant were able to complete the task as instructed, with 3 subsequent trials collected for data analysis.

Data Processing

Force-plate data were analyzed from initial contact (IC) to 200 milliseconds after IC. A 20-N threshold, as defined by the vertical ground reaction force, was used to identify IC.²³ We chose this time epoch in order to visualize landing strategies in the early stage of the landing phase.

Electromyography. Data were filtered with both a 10- to 500-Hz band-pass filter and a 60-Hz notch filter. A 50-sample moving-window root mean square algorithm was used to smooth the data. Muscle activity for the 200 milliseconds of the DVJ task was normalized to the muscle activity during the quiet-standing trial for each muscle. The area under the curve was calculated to quantify the EMG activity of the muscles of interest and was timed to correlate with the same 200-millisecond post-IC time epoch (EMGWorks Acquisition version 4.1.1; BioPac Systems, Inc, Goleta, CA).

Kinematics. A low-pass, fourth-order Butterworth filter with a cutoff frequency of 14.5 Hz was used to filter the kinematic and kinetic data. We used Euler rotations (Y, X, Z) to calculate joint rotations of the hip and knee, which are presented as flexion and extension, adduction and abduction, and internal and external rotation. Kinematic excursions were calculated as the difference between kinematic values at IC and peak kinematic values during the task (IC until 200 milliseconds after IC). Time to peak was calculated as the time from IC until the peak kinematic angle within 200 milliseconds after IC.

Kinetics. Internal joint moments were used to calculate kinetics, with normalization to each participant's body mass (newton meters per kilogram).

Statistical Analysis

Skewness, kurtosis, and normality of variance (P > .05) proved the data for the dependent variables were normally distributed. Parametric statistical analyses were conducted for all variables of interest. Independent *t* tests were used to compare demographics, PROM scores, lower extremity EMG, kinematics, and kinetics during the DVJ landing phase, and knee and hip isometric strength measures between the healthy and PFP groups. An a priori α level for all analyses was set at <.05.

We calculated Cohen d effect sizes with 95% confidence intervals (CIs) to compare the magnitudes of difference in EMG activity kinematics, kinetics, VAS scores, and strength assessments between the healthy and PFP groups, with thresholds of 0 to 0.2 considered *trivial*, 0.21 to 0.5 as *small*, 0.51 to 0.8 as *moderate*, and >0.8 as *large*.²⁴

RESULTS

Demographics

Height and mass did not differ between the groups (Table 1). However, differences in patient demographics were identified for age, subjective function, and pain (Table 1). Inherent in our inclusion and exclusion criteria was the

Table 2. Lower Extremity Muscle Activation During a Drop-Vertical Jump Normalized to Quiet Standing

	Group, % of Quiet Standing (Mean \pm SD)			
Muscle	Patellofemoral Pain	Healthy	P Value	Effect Size (95% Confidence Interval)
Vastus medialis oblique	134.42 ± 131.30^{a}	110.78 ± 65.26	.01	0.36 (-0.37, 1.10)
Vastus lateralis	47.32 ± 86.35	52.61 ± 45.81	.51	-0.12 (-0.84, 0.61)
Gluteus maximus	13.37 ± 13.55^{a}	43.81 ± 65.63	.01	-0.46 (-1.20, 0.27)
Gluteus medius	7.02 ± 6.34	20.78 ± 31.14	.05	-0.44 (-1.18, 0.30)
Biceps femoris	11.04 ± 8.91^{a}	36.68 ± 62.71	.01	-0.41 (-1.14, 0.33)

^a Indicates difference (P < .05).

expectation of differences in subjective function and pain between groups.

Electromyography

During the landing phase of the DVJ, differences in muscle activity normalized to quiet standing were found in the VMO (healthy = 110.78 ± 65.26, PFP = 134.42 ± 131.30, P = .01), GMax (healthy = 43.81 ± 65.63, PFP = 13.37 ± 13.55, P = .01), and BicFem (healthy = 36.68 ± 62.71, PFP = 11.04 ± 8.91, P = .01; Table 2). Effect sizes for these differences were small. No differences were seen in the VL or the GMed during the DVJ task (P > .05).

Kinematics

Knee-flexion kinematic excursions between the PFP and healthy groups differed (Table 3). The PFP participants exhibited less knee flexion from IC to peak knee flexion during the 200-ms time epoch (healthy = $76.76^{\circ} \pm 7.50^{\circ}$, PFP = $74.14^{\circ} \pm 19.85^{\circ}$, P < .05), with a small effect size (d = -0.35; 95% CI = -1.07, 0.37). The PFP participants took less time to reach peak trunk flexion (healthy = 0.19 ± 0.01 seconds, PFP = 0.19 ± 0.02 seconds, P < .05) and trunk lateral flexion (healthy = 0.12 ± 0.07 seconds, PFP = 0.11 ± 0.04 seconds, P < .05). The effect size for time to peak trunk flexion was moderate (d = -0.66; 95% CI = -1.29, -0.02) and did not cross zero; however, all other effect sizes were trivial or small and did cross zero (Table 4).

Kinetics

Women with PFP completed the DVJ with greater hip internal-rotation moments (healthy = 0.04 ± 0.28 Nm/kg, PFP = 0.06 ± 0.14 Nm/kg, P < .05) However, all effect sizes were small and crossed zero (Table 5).

Strength

No differences in muscle strength normalized to body mass (kilograms) and moment arm (meters) were seen between the groups, with all *P* values >.05. The hip external rotators demonstrated a large effect size (d = -0.73; 95% CI = -2.44, 0.98), but it crossed zero (Table 6).

DISCUSSION

The purpose of our study was to determine how muscle activity, kinematics, and kinetics during a DVJ and lower extremity isometric strength compared between women with PFP and healthy women. The participants with PFP had a decrease in subjective knee function and more pain than the healthy cohort. In the 72 hours before testing, our PFP group rated their worst pain at approximately 4.4 cm on the VAS, which was consistent with the 4.4 cm of females in the week before testing as described by Bolgla et al² and a little lower than the 5 cm noted by Boling and Padua²⁵ in the prior week. In our study, the PFP cohort scored higher on the AKPS than other cohorts of PFP participants, showing they had less pain during daily activities.^{25,26} Because many differences have been noted between the sexes for this condition, we focused our study on women, who have a higher incidence of PFP.¹ Although no differences in isometric muscle strength were present, women with PFP had increased activity of the VMO, decreased activity of the GMax and BicFem, less kneeflexion excursion, greater hip internal-rotation moment, and less time to peak trunk flexion and lateral flexion during the landing phase of the DVJ.

Strength

Strength did not differ between the healthy and PFP populations. This result is contrary to the findings of previous studies and our hypothesis. Previous authors found

Table 3. Knee, Hip, and Trunk Kinematic Excursions From Quiet Standing to the Peak Kinematic Value From Initial Contact to 200Milliseconds Post-Initial Contact During a Drop-Vertical Jump

	Group, Mean \pm SD $^\circ$			
Kinematic Excursion	Patellofemoral Pain	Healthy	P Value	Effect Size (95% Confidence Interval)
Knee flexion	74.14 ± 19.85^{a}	76.76 ± 7.50	.02	-0.35 (-1.07, 0.37)
Knee adduction	9.82 ± 9.36	7.04 ± 5.97	.18	0.47 (-0.26, 1.19)
Knee internal rotation	3.87 ± 6.53	5.74 ± 7.63	.65	-0.25 (-0.96, 0.47)
Hip flexion	50.33 ± 16.85	60.70 ± 10.85	.16	-0.96 (-1.71, -0.20)
Hip adduction	5.26 ± 9.66	3.18 ± 4.14	.16	0.50 (-0.22, 1.23)
Hip internal rotation	$\textbf{2.46}\pm\textbf{6.82}$	3.87 ± 4.04	.19	-0.35 (-1.07, 0.37)
Trunk flexion	34.16 ± 13.89	30.24 ± 15.86	.58	0.25 (-0.38, 0.87)
Lateral trunk flexion	5.03 ± 2.99	5.27 ± 4.66	.18	-0.05 (-0.67, 0.57)
Trunk rotation	3.29 ± 3.15	3.26 ± 2.91	.73	0.01 (-0.61, 0.63)

^a Indicates difference (P < .05).

Table 4. Time to Peak Kinematics From Initial Contact to 200 Milliseconds Post-Initial Contact During a Drop-Vertical Jump

	Group, s (Mean \pm SD)			
Time to Peak Kinematics	Patellofemoral Pain	Healthy	P Value	Effect Size (95% Confidence Interval)
Knee flexion	0.19 ± 0.02	0.19 ± 0.02	.96	0.00 (-0.72, 0.72)
Knee adduction	0.12 ± 0.06	0.15 ± 0.07	.23	-0.43 (-1.15, 0.30)
Knee internal rotation	0.10 ± 0.06	0.10 ± 0.06	.93	0.00 (-0.72, 0.72)
Hip flexion	0.19 ± 0.02	0.19 ± 0.02	.99	0.00 (-0.72, 0.72)
Hip adduction	0.10 ± 0.07	0.09 ± 0.08	.05	0.13 (-0.59, 0.84)
Hip internal rotation	0.14 ± 0.07	0.13 ± 0.06	.88	0.16 (-0.55, 0.88)
Trunk flexion	0.19 ± 0.03^{a}	0.19 ± 0.01	.01	-0.66 (-1.29, -0.02)
Trunk lateral flexion	0.11 ± 0.04^{a}	0.12 ± 0.07	.01	-0.22 (-0.84, 0.41)
Trunk rotation	0.08 ± 0.05	0.09 ± 0.05	.75	-0.19 (-1.90, 1.51)

^a Indicates difference (P < .05).

decreased torque in hip extension, hip abduction,^{18,26} knee extension,²⁷ and hip external rotation¹⁸ as compared with control participants. We expected to find many differences in hip and knee strength, so it is interesting that we found none. We believe this lack of difference can be attributed to our participants being on the healthier end of the spectrum. These individuals were a sample of college-aged students who self-selected for this study and rated their pain at the lower end of the scale: a VAS of 3 was required, and the average for our participants with PFP was 4.4.

Electromyography

Electromyographic analysis in this study was conducted from IC to 200 milliseconds post-IC. We focused on the landing and initial deceleration phases of this task, as most participants with PFP have pain with increased loading. This time epoch was selected in order to visualize the most painful and typically biomechanically challenging portion of the DVJ. Variations in muscle activity were observed in the VMO, GMax, and BicFem, indicating differences in the way the lower extremity musculature performed during a functional task. Participants with PFP had more activation of the quadriceps and less activation of the GMax and hamstrings. Souza and Powers²⁷ found that during the descent phase of a step-down task, the VMO had a later onset of activation than the VL in the PFP group. Although Souza and Powers²⁷ were examining muscle-activation timing and not simply peak activation, they did observe differences in the VMO. The increase in quadriceps activation we noted could increase the patellofemoral contact pressure. Contact pressure within the patellofemoral joint increases as the knee flexes, and more quadriceps activity would further increase the contact pressure.²⁸ Increased contact pressure can result in a loss of tissue homeostasis.²⁹ As one of the musculoskeletal components that receives the highest load,³⁰ the patellofemoral joint is among the most difficult systems to restore to full functionality once homeostasis is lost.³¹

Examination of GMax activation during a jumping task in the population with PFP has been extremely limited. The decreased activation we observed during the landing and initial descent phases showed that the GMax may have been either ineffective during the task or activated more after the time epoch we examined. Similarly, regarding the BicFem, the decreased activation has not been examined across other tasks in patients with PFP. Although it was not significant, the *P* value for muscle activity in the GMed was .054, at the threshold of significance. Conflicting evidence has characterized GMed activation during other functional tasks in individuals with PFP, with some studies showing increased and others decreased activation.³²

Although strength of the quadriceps, GMax, and hamstrings did not differ, activation did. Also, the PFP group reached peak trunk flexion and lateral flexion more quickly. Thus, muscle activation of the GMax and hamstrings may be a concern, with an inability to provide eccentric control during the landing phase of this task, contributing to the high variance in the amount of kneeflexion excursion. If the GMax fails to recruit enough motor units, then it cannot control frontal-plane motion, which could influence hip internal-rotation moment.³² An increase in VMO activation could be a compensatory motion attempting to decrease knee-flexion excursion. Our 200millisecond assessment window may not have been long enough to fully demonstrate other compensations that may occur with muscle activation. If the body's ability to sense excessive knee excursion has been impaired, a delay occurs in the compensatory increase in joint contact and in activation of the muscles that decrease this motion as well as activation of the muscles that limit it.

Table 5.	Peak Kinetics From Initia	I Contact to 200 Milliseconds	Post–Initial Contact During a	a Drop-Vertical Jump
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	Group, Nm/kg (Mean \pm SD)			
Kinetics	Patellofemoral Pain	Healthy	P Value	Effect Size (95% Confidence Interval)
Knee flexion	1.23 ± 0.47	1.28 ± 0.66	.26	-0.08 (-0.69, 0.54)
Knee adduction	0.04 ± 0.29	0.18 ± 0.52	.34	-0.27 (-0.88, 0.34)
Knee internal rotation	0.06 ± 0.28	0.01 ± 0.32	.94	0.16 (-0.46, 0.77)
Hip flexion	1.09 ± 0.62	1.35 ± 0.71	.71	-0.37 (-0.98, 0.25)
Hip adduction	0.08 ± 0.59	0.05 ± 0.54	.77	0.06 (-0.56, 0.67)
Hip internal rotation	0.06 ± 0.14^a	0.04 ± 0.28	.03	0.07 (-0.54, 0.68)

^a Indicates difference (P < .05).

Table 6. Torque Normalized to Body Weight in Kilograms and Moment Arm in Meters per Muscle Group

	Group, Nm/kg (Mean \pm SD)			
Torque	Patellofemoral Pain	Healthy	P Value	Effect Size (95% Confidence Interval)
Knee flexors	0.61 ± 0.14	0.64 ± 0.16	.95	-0.19 (-0.79, 0.41)
Knee extensors	1.09 ± 0.32	1.15 ± 0.44	.36	-0.14 (-0.74, 0.46)
Hip flexors	1.25 ± 0.29	1.35 ± 0.33	.65	-0.30 (-0.91, 0.30)
Hip extensors	0.97 ± 0.29	0.92 ± 0.47	.30	0.11 (-0.49, 0.71)
Hip adductors	0.88 ± 0.27	0.85 ± 0.25	.89	0.12 (-0.48, 0.72)
Hip abductors	0.98 ± 0.26	1.06 ± 0.28	.49	-0.29 (-0.89, 0.32)
Hip internal rotators	0.41 ± 0.09	0.45 ± 0.09	.86	-0.44 (-1.05, 0.16)
Hip external rotators	0.44 ± 0.09	0.52 ± 0.11	.91	-0.73 (-1.35, -0.11)

Kinematics and Kinetics

We found a difference in knee-flexion kinematic excursions. However, frontal-plane excursions did not differ, contrary to our original hypothesis. During a single-legged squat, participants with PFP had greater hip adduction and knee abduction than healthy control participants.⁸ Similarly, during single-legged squats, running, and single-legged jumps, women with PFP had greater knee external rotation, hip adduction, and hip internal rotation.¹⁰ Participants with PFP have been shown to complete functional tasks with faulty movement patterns, specifically dynamic knee valgus,³³ which is not consistent with our findings. The PFP groups in those studies^{8,10,33} also displayed differences in hip and knee strength and range of motion compared with the healthy control groups. However, most of the tasks were unilateral. Furthermore, because hip and knee strength did not differ between our groups, it would be reasonable to conclude that either our subset of participants with PFP was not sufficiently impaired to show altered frontal-plane movement patterns or not all of our participants had pain or altered function during this particular task. A timing problem that we were unable to identify may have caused altered biomechanics distally and was possibly related to the internal-rotation moment. We saw an increase in internal rotation; however, some caution is needed when interpreting these data because of the lack of reliability of transverse-motion data in motion-capture analysis. Future researchers should evaluate this kinetic difference in the population with PFP. Increased stress and contact pressure at the patellofemoral joint, as explained by the increased VMO activity, has been linked with altered joint mechanics. Yet we did not observe altered frontalplane joint kinematic excursions in our PFP group. The GMed plays a large role in controlling frontal-plane movement, so the lack of altered frontal-plane kinematic excursion may have reflected the lack of difference in GMed motor-unit recruitment between groups. Kneeflexion excursion was different between groups, yet the time to peak knee flexion was not different. The standard deviation was very wide for the PFP group during kneeflexion excursion, which could have affected the results. Decreased knee-flexion excursion may have been a protective mechanism to avoid knee pain during the landing and deceleration phases, which commonly produce pain in this population.

The times to peak kinematics were different, with the PFP group achieving peak trunk flexion and lateral flexion more quickly. Our method of calculating the time to peak kinematics was unique, defined as the time (in seconds) to

peak kinematic angle within 200 milliseconds of IC. We were most interested in how the participants attenuated forces upon IC. Farrokhi et al³⁴ found that as trunk flexion increased during a lunge, gluteal muscle activation also increased. We determined that GMax activation was decreased in the PFP group, with less time to peak trunk flexion and lateral flexion. Our findings may have varied because the actual trunk excursions were not different between groups. Other authors have evaluated kinematic values from IC to peak knee flexion during a DVJ,35 from IC to takeoff for the rebound jump during a DVJ,³⁶ and from IC to toe-off during consecutive jumping.¹¹ According to dos Reis et al,¹¹ the PFP group took less time to achieve peak knee flexion but longer to reach peak hip adduction. Our participants with PFP took longer to reach peak hip adduction (P = .05). Although this value did not meet our criterion for significance, our findings are similar to those of dos Reis et al¹¹ in this regard. It should be noted that our task was a bilateral landing task, whereas previous research involved a single-limb landing task. Comparisons across multiple jumping tasks could be warranted to identify biomechanical differences within this population. Increased time to peak hip adduction in our PFP population could be associated with greater frontal-plane moments at the hip in internal rotation.

We sought to identify differences in this PFP population during a DVJ for many reasons: no previous investigators have attempted to identify activation differences between healthy and PFP populations during a task that is commonly difficult or painful for those with PFP while also assessing strength and biomechanical deficits. Our PFP group did not display strength or peak movement differences. Although we noted minimal differences in activation, kinematics, and kinetics, researchers^{8,10,24} demonstrated differences using other assessment methods and other functional tasks. A novel clinical assessment of joint moments and muscle activation is needed to determine how muscles are activating and how joints are attenuating forces. This may be best suited for participants who have increased pain during the DVJ, as we know PFP is a heterogenous condition and each patient presents differently.

Limitations

Our PFP group was older than the healthy group. This factor may have altered our findings in that the baseline demographics were not the same between groups. Participants with PFP were included if they met a minimal standard of physical activity. It is possible that we missed a subset of this population by excluding those who were not active enough in their everyday lives. All participants with PFP were examined as a group, which may not be the most effective form of dichotomization. It may also decrease the generalizability of lower extremity function during a DVJ for all patients with PFP. Those with PFP are known to complete fewer steps per day as compared with a healthy population, and this could be due to pain.³⁷ The heterogeneous presentation of PFP symptoms and severity of pain may have influenced movement patterns and muscle activity during the DVJ. It is possible that, because this recruited population was not seeking treatment intervention, we missed those who were in too much pain to complete this task as normally as our subset. Thus, categorizing participants with PFP into subgroups based on their pain or limitations may be appropriate. Muscle activity, kinematics, and kinetics during the DVJ task have not been simultaneously assessed in the PFP population. This makes it difficult to compare our results with those of any other study of individuals who have PFP.

CONCLUSIONS

Some biomechanical differences were seen between women with and those without PFP. Although strength and peak kinematics did not differ between the groups, muscle activation, kinematic excursions at the knees, and kinetics at the hips were different. We found increased muscle activity of the VMO and decreased activity of the GMax and BicFem during the landing phase of the DVJ in women with PFP, as well as greater hip internal-rotation moment, decreased knee-flexion excursion, and less time to reach peak trunk flexion and trunk lateral flexion than in healthy women. Our results suggest that altered motor recruitment of the hip and thigh may result in biomechanical changes during a DVJ that are often associated with an increased risk of injury.

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