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The relationship between quadriceps strength and joint position sense, functional outcome and painful activities in patellofemoral pain syndrome

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Abstract

Purpose The aim of this study was to investigate how strongly the concentric and eccentric quadriceps strengths were correlated with the joint position sense, functional outcomes and painful activities in patients with patellofemoral pain syndrome (PFPS).

Methods The study included forty-six women diagnosed with unilateral PFPS. Eccentric and concentric quadriceps strengths were recorded at 60 and 180°/s. Active knee joint position sense (JPS) was measured at 20° and 60° of flexion. Functional levels were determined by using Kujala patellofemoral scores. Pain levels during stair descending and ascending, squatting and prolonged sitting were measured using 0–10 cm visual analogue scale. The relationship of isokinetic quadriceps strength with JPS results, Kujala score and pain levels were evaluated using Spearman's correlation coefficient test.

Results Eccentric and concentric quadriceps strengths were significantly lower on involved side than uninvolved side. JPS results were poorer on the painful knee when compared to uninvolved side. While eccentric strength correlated with both JPS target angles, concentric strength was correlated only with 20°. Both eccentric and concentric strengths were significantly correlated with Kujala scores and pain levels.

Conclusion Quadriceps eccentric strength was correlated more to joint position sense than concentric strength. Both eccentric and concentric quadriceps strength related to pain and functional level in PFPS patients.

Keywords Eccentric strength · Joint position sense · Function · Pain · Patellofemoral pain syndrome

Introduction

The quadriceps muscle is typically weakened in patients with chronic patellofemoral pain syndrome (PFPS) [4, 11, 21, 22, 31, 33]. The concentric quadriceps strength is nearly 30 % lower in PFPS patients compared with healthy controls, while the eccentric strength is decreased by approximately 40 % [7]. Therefore, the activities requiring eccentric control are more challenging and painful for PFPS patients [23, 31]. Moreover, the decreased quadriceps strength, particularly in the case of eccentric knee extension, is accepted as an indicator of pain-related functional activities in PFPS patients [7, 11, 25, 31].

In addition to strength loss, proprioceptive changes have been documented in patients with PFPS [2, 4, 31]. Mechanoreceptor damage is described as the primary factor affecting knee proprioception; however, functional movement depends not only on the peripheral mechanoreceptor stimuli from the joints, muscles and deep tissues but also on the regulation of the appropriate joint position and muscle force [29, 30]. Impaired quadriceps strength and PFP negatively influence joint position sense (JPS) in PFPS patients [34]. Furthermore, an abnormal knee JPS can predispose to musculoskeletal pathologies by altering the alignment of

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the affected lower extremity and the control of movement, leading to increased PFP during daily activities [2].

In the present study, it is attempted to determine how eccentric or concentric strength is related to JPS, pain and functional levels. To the best of our knowledge, no previous investigation has comprehensively evaluated these factors in combination. Therefore, it is hypothesized that: (1) the quadriceps eccentric and concentric strength would correlate with the knee JPS, functional outcomes and painful activities. (2) The eccentric quadriceps strength would correlate more than the concentric strength with the knee JPS, functional outcomes and painful activities.

Materials and methods

A prospective case–control study design was used for the study. Each subject's uninvolved side served as her own internal control, using the uninvolved side of the patients for comparison.

Forty-six female patients with unilateral PFPS were included in this study. Patients were assessed by an experienced orthopaedist for patellofemoral pain occurrence during ascending and descending stairs, prolonged sitting or squatting. A positive patellar compression test or tenderness on medial or lateral facet with palpation was noted. Pain existence should be daily for the previous 3 months and a score of 4 or more on a 0–10 cm visual analogue scale (VAS). Patients between 20 and 40 years of age with characteristic clinical signs by a combination of active patellar grind test, Clarke's sign, direct patellar compression, pain with palpation of the medial articular border of the patella and palpation of the lateral articular border of the patella [11] were included in the study.

Patients were excluded if they had had a history of or clinical evidence of patellofemoral dislocation, subluxation and a history of lower extremity surgery; an absence of knee ligaments, bursae, menisci, and synovial plicae dysfunction, previous patellar fracture or patellar realignment surgery, acute meniscal or ligament injury, osteoarthritis, rheumatoid arthritis or other forms of inflammatory arthritis.

Peak concentric and eccentric knee extensor torques were determined at 60 and 180°/s with the use of Biodex System 3 Dynamometer (Biodex Corp., Shirley, NY, USA). Callaghan et al. [3] demonstrated that isokinetic quadriceps testing showed significant test–retest reliability with ICC values of 0.82–0.85. The patients were seated upright with an 85° hip flexion and the knee angle set at 90° flexion. The length of the dynamometer arm, which was fastened to the distal portion of the tibia via a Velcro® strap, was adjusted according to the length of the patient's leg. The monitor was placed in such a way as to allow the visual feedback. The range of motion (ROM) for the knee extension and flexion movements was set from 20° to 90° which represents a total 70° ROM to prevent increases in the patellofemoral reaction forces. For the eccentric knee extension, the patients were asked to resist the powered knee flexion movement as hard as they could and then relax. For the concentric knee extension, the patients were instructed to kick out as hard and fast as possible to full extension. Ten repetitions were applied for each speed, and the highest torque was recorded. A rest period of 5 min was given between each cycle of concentric actions and eccentric actions. Verbal encouragement was given during the test performance. The quadriceps index was used for determining the strength differences between the involved and uninvolved side. To calculate the quadriceps index, the following formula was used (quadriceps peak torque of the involved side/uninvolved side) × 100 [19].

JPS was measured using an active reproduction testing (ICC = 0.91–0.89) [9] with Biodex System 3 Dynamometer. The muscle testing position was used for JPS determination. To eliminate the visual input, the patients were asked to close their eyes during the testing. The patients moved their knees to the target angle of either 20° and 60° of the knee flexion actively for each repetition. Twenty degrees was chosen as the first target angle because the patella contacts with the femoral trochlea at this angle [2, 27], and it has been suggested that proprioceptive loss may interfere with optimal tracking of the patella in the trochlear groove. Sixty degrees was chosen as the second target angle because the previous movement analysis implied that this angle is critical for patellofemoral functioning [26, 28]. The angle was recorded from the on-screen goniometer, and a total of six repetitions were recorded. [28]. The difference between the perceived angle and each of the target angles (20° and 60° knee flexion) was noted.

A VAS with end range descriptors of 0 = no pain and 10 = extreme pain (0–10 cm) was used to assess the pain that patients experienced during climbing stairs, descending from stair, squatting and prolonged sitting with the knees flexed at 90°.

A validated Turkish version of the 13-item Kujala patellofemoral disorder score was used to determine each patient's perceived knee functioning capabilities [13, 14].

Ethical approval was received from the Ethical Committee of Hacettepe University (LUT 12/88-16). Written informed consent was obtained, and the patients were informed about the aims of the study and the testing procedure prior to their participation.

Statistical analysis

The data were visually analysed with histograms, Q–Q plots and Kolmogorov–Smirnov tests for normality of

Table 1 Mean demographics, Kujala and pain scores of the patients

Variables	Mean ± SD
Age (year)	32.4 ± 6.2
Height (cm)	164.4 ± 8.6
Weight (kg)	69.4 ± 6.4
Body mass index (kg/cm^2)	25.8 ± 3.3
Kujala score (point)	50.6 ± 11.8
Pain (VAS)	
Ascending stairs	4.9 ± 1.5
Descending stairs	7.7 ± 1.2
Squatting	6.5 ± 0.9
Prolonged sitting	5.1 ± 1.1

VAS visual analogue scale

distribution. All of the data were analysed using Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL., USA) version 17.0. Since the peak muscle torques and JPS values were normally distributed, a paired sample *t* test was used to compare differences between the involved and uninvolved sides. All *p* values were one-sided with a statistical significance was set at 0.05 alpha level.

The Kujala score and pain levels were not normally distributed. The relationship among eccentric and concentric quadriceps peak torques with JPS, Kujala score and pain levels were evaluated using Spearman's correlation coefficient with two-sided significance of *p* values, with calculated mean values and standard errors. All *p* values were one-sided with a statistical significance of 0.05.

A sample size of 46 patients yields 82 % power to detect a difference of −0.20 between the quadriceps strength and functional outcomes correlation of 0.49–0.69 using a two-sided correlation test with a significance level of 0.05. The methodology used for the statistical analysis was a per-protocol approach.

Results

The mean demographics, Kujala score and pain levels of the patients are presented in Table 1.

Peak torque and JPS results of involved and uninvolved side

The quadriceps eccentric and concentric strengths were lower on the involved side than on the uninvolved side (all $p < 0.05$) (Table 2). The mean quadriceps indices of the eccentric strength were 76.8 and 55.6 % for 60 and 180°/s angular speeds. For the concentric strength, the mean quadriceps indices were 89.3 and 80.5 % for 60 and 180°/s angular speeds.

Reproducing the active knee joint position was poorer on the involved side compared with the uninvolved side (all $p < 0.001$; Table 2).

Peak torque relationships with joint position sense

There were negative correlations between eccentric strength at 60°/s ($r = -0.30$, $p = 0.04$) and at 180°/s ($r = -0.29$, $p = 0.04$) with 20° joint position target angle. The eccentric strength at 60°/s was correlated negatively with 60° joint position target angle ($r = -0.37$, $p = 0.01$) (Table 3).

The quadriceps concentric strength was negatively correlated only with the 20° joint position target angle at 60°/s ($r = -0.53$, $p < 0.001$) and 180°/s ($r = -0.31$, $p = 0.03$; Table 3).

Peak torque relationships with pain levels

The quadriceps eccentric strength was significantly correlated with pain levels during stair descending ($r = -0.49$,

Table 2 The peak torques and joint position sense results on involved and uninvolved side of the patients

Variables	Involved side ($n = 46$) Mean ± SD	Uninvolved side ($n = 46$) Mean ± SD	*p* values
Peak torque (Nm)			
60°/s			
Quadriceps eccentric	107.8 ± 21.6	120.7 ± 22.7	<0.001*
Quadriceps concentric	92.3 ± 11.1	117.9 ± 13.5	<0.001*
180°/s			
Quadriceps eccentric	90.4 ± 16.2	98.5 ± 5.3	0.04*
Quadriceps concentric	76.8 ± 25.1	101.5 ± 10.9	<0.001*
JPS (°)			
20° Target angle	27.6 ± 2.5	22.1 ± 1.4	<0.001*
60° Target angle	69.7 ± 2.1	62.5 ± 1.6	<0.001*

JPS joint position sense

* Paired sample *t* test

Table 3 Correlation between quadriceps eccentric and concentric peak torques with joint position sense and Kujala score

Peak torque (Nm)	Speed	Joint position sense				Kujala	
		20° target angle		60° target angle			
		r	*p* value	*r*	*p* value	*r*	*p* value
Eccentric	60°/s	**−0.30**	**0.04***	**−0.37**	**0.010***	**−0.49**	**0.01***
	180°/s	**−0.29**	**0.04***	−0.14	n.s.	**−0.69**	**0.01***
Concentric	60°/s	**−0.53**	**<0.001***	−0.15	n.s.	**−0.60**	**<0.001***
	180°/s	**−0.31**	**0.03***	−0.20	n.s.	−0.15	n.s.

* Spearman correlation test, $p<0.05$

Table 4 Correlation between quadriceps eccentric and concentric peak torques with pain levels

Variables	Stair ascending		Stair descending		Squatting		Sitting	
	r	*p* value	*r*	*p* value	*r*	*p* value	*r*	*p* value
Eccentric peak torque (Nm)								
60°/s	−0.85	n.s.	**−0.48**	**0.01***	**−0.33**	**0.02***	**−0.38**	**0.01***
180°/s	−0.14	n.s.	−0.10	n.s.	−0.17	n.s.	−0.26	n.s.
Concentric peak torque (Nm)								
60°/s	**−0.32**	**0.02***	−0.06	n.s.	**−0.29**	**0.04***	−0.10	n.s.
180°/s	**−0.35**	**0.01***	−0.05	n.s.	−0.06	n.s.	**−0.30**	**0.04***

* Spearman correlation test, $p<0.05$

$p = 0.01$), squatting ($r = -0.33$, $p = 0.02$) and sitting ($r = -0.38$, $p = 0.01$) only at 60°/s angular speed (Table 4).

The correlations between quadriceps concentric strength and pain levels during stair ascending, squatting and sitting were significant and expressed as negative correlations at both 60 and 180°/s angular speeds (all $p < 0.05$) (Table 4).

Peak torque relationships with functional levels

The quadriceps eccentric (at all speeds) (all $p = 0.01$) and concentric strengths (only at 60°/s) were negatively correlated with Kujala score ($r = -0.60$, $p < 0.001$) (Table 3).

Discussion

The principal finding of the present study was that the quadriceps eccentric strength correlated more with JPS than concentric strength in patients with PFPS. Another important study finding from this investigation was that the correlation between functional outcomes and pain levels with the both eccentric and concentric quadriceps strengths was significant.

In previous studies, weakness in the quadriceps, mainly in eccentric contractions, was typically observed in patients with PFPS [4, 11, 32, 36]. One theory is that pain causes reflex inhibition of the quadriceps, which induces a decrease in the muscle fibre area or a loss of fibres [4, 15, 35]. It is suggested that reflex inhibition has an adverse effect primarily on the activation of type II muscle fibres, which are mainly responsible for maintaining the eccentric muscle force [1, 24, 31]. On the other hand, the decrease in eccentric quadriceps muscle strength was not observed in isolation; a loss in quadriceps concentric strength was also noted in patients with PFPS [7]. We have shown that the quadriceps index of eccentric strength is between 55.6 and 76.8 %, and the quadriceps index of concentric strength is between 80.5 and 89.3 %. Östenberg et al. [19] determined that the normative data of the quadriceps index were between 84 and 96 %. The results of the present study are in agreement with the previous findings that both the eccentric and concentric quadriceps strengths are lower on the involved side when compared with the uninvolved side [4, 7, 8, 11, 33].

In the present study, the reproduction of JPS was poorer on the involved side compared with the uninvolved side. Sense in joint position in patients with PFPS has been studied previously [2, 4, 8, 10, 12, 17, 34]. Callaghan and Oldham [4] described a subgroup of patients with PFPS having proprioception impairment. Similarly, Baker et al. [2] found abnormal knee joint proprioception in PFPS patients with their contralateral sides. Two main mechanisms are believed to contribute to the JPS loss in PFPS: one involves abnormal tissue stresses and motor control and the other involves pain. Abnormal tissue stresses may result from lateralization of the patella, which gives rise to dysfunction of the peri-patellar plexus [2, 36]. Deteriorations in motor control may lead to alterations in afferent input of the peripheral receptors, thus further compounding patellar mal-tracking [2]. Additionally, the presence of pain may lead to abnormal driving of muscle spindles in the painful leg, producing an abnormal sense of joint position [2, 36]. Of these mechanisms, the most important is likely to be the altered muscle activity, since previous research supports the dominant role that muscle receptors play in proprioception [2, 8, 34]. Our findings of JPS loss in PFPS patients support this claim.

Several studies have evaluated the effect of pain or quadriceps strength loss on knee JPS [2, 8]. Baker et al. [2] measured pain level during JPS assessment and reported no significant correlations between JPS and pain level. Hazneci et al. [8] applied an isokinetic quadriceps training program to the painful knee extensors and reported positive effects on JPS in PFPS patient. The results of the present study show that there is a relationship between both eccentric and concentric quadriceps strength with JPS in PFPS patients. While the concentric peak torque was correlated only with the 20° target angle, the eccentric peak torque was correlated with both target angles (20° and 60°). Therefore, the findings showed that eccentric strength was more related with joint position reproduction than concentric strength. This relationship differences might be due to the mechanical specificities of eccentric and concentric contractions. Considering that the muscle receptors are responsible for maintaining the sensorimotor control of the knee and the information transfer relates to muscle length and the velocity of stretch and the applied force [29], the eccentric contractions might be more related to JPS. Although a weak-to-good correlation was observed between quadriceps strength and JPS, the present study showed that quadriceps strength loss, particularly in the eccentric phase, has an adverse influence on joint position reproduction in these patients.

Two main biomechanical causes are described as patellar mal-tracking and mal-alignment of the lower extremity, for quadriceps strength loss in PFPS [6, 20]. Myer et al. [16] found that a mal-alignment of the lower extremity results in a dynamic valgus vector of the knee leading to lateralization of the patella. Several authors have suggested that an imbalance in the activity of vastus medialis relative to the vastus lateralis is related to patellar mal-tracking [5, 6, 16]. This phenomenon sets up a vicious cycle in which the impaired quadriceps strength increases abnormal patellar tracking resulting in chronic patellar mal-position [7]. In addition, as the quadriceps muscle strength difference between the involved and uninvolved side decreased, the functional outcome became more positive in patients with PFPS [18, 21, 34]. Yosmaoglu et al. [34] showed that the Kujala score was significantly correlated with the quadriceps concentric strength. Pattyn et al. [21] emphasized that eccentric quadriceps strength evaluation plays an important role in determining the functional outcomes in PFPS patients. The findings of the present study indicated that Kujala score was significantly correlated with eccentric and concentric quadriceps strength. A very good correlation was observed between Kujala score and eccentric quadriceps peak torque for both angular velocities (60 and 180°/s), while the correlation with the concentric peak torque was good only at 60°/s. Since the functions requiring eccentric control are the most challenging activities in PFPS patients, the eccentric quadriceps strength should be closely monitored during therapeutic exercises designed to improve the functional outcomes for PFPS patients.

It is well known that the loss of eccentric quadriceps strength provokes pain when climbing down stairs due to the diminished control of the patellofemoral joint and the increased patellofemoral reaction forces [23, 31, 32]. The results of the present study showed that while the concentric strength was correlated with going upstairs, the eccentric strength was correlated with going downstairs. These findings suggest that both eccentric and concentric quadriceps strength should be closely monitored to improve the prevalence of pain-free activities for PFPS patients.

The primary limitation of this study is that JPS was measured only using the active reproduction test in an open kinetic chain or non-weight bearing position. There are several test methods to evaluate the proprioception, but there is no consensus about which test provides the most reliable results. Another study limitation is that PFP was determined based on the patient's recall of her pain levels experienced during stair climbing, prolonged sitting and squatting activities. The patients' pain levels should have been evaluated during isokinetic strength testing. However, the pain level reported by PFPS patients correlated significantly with muscle strength.

This study identified the relationship between the quadriceps eccentric and concentric strength with JPS, functional outcomes and pain in PFPS patients. The quadriceps strengthening exercises, especially on the eccentric phase, seem to be an effective treatment option to increase JPS and functional outcomes in patients with PFPS. Therefore, the clinicians need to evaluate the eccentric and concentric strength of the quadriceps, and also, they need to consider the interrelationship between quadriceps muscle strength with the JPS, functional outcomes and pain when designing the exercise programs.

Conclusion

Knee JPS loss was correlated with both quadriceps eccentric and concentric strength among patients with PFPS. The relationship between JPS and eccentric quadriceps strength was better than the relationship between JPS and concentric strength. The most important factors affecting the functional level of patients with PFPS are quadriceps strength loss, particularly in terms of eccentric strength and also patellofemoral pain. Therefore, it is important to evaluate the quadriceps strength, since it is directly related to proprioception, pain and knee functions in PFPS patients.

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Conflict of interest All authors have no conflicts of interest with respect to the data collected and procedures used within this study.

Ethical standard The authors confirm this study meets the guidelines of the Declaration of Helsinki. Ethical approval for the study was received, and written informed consent was provided from all subjects.

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