Comparison of Knee Muscle Balance at Different Knee Flexion Angles between Patients with Patellofemoral Pain Syndrome with Healthy Subjects

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Abstract

Patients with patellofemoral pain syndrome (PFPS) have been found to have a knee muscle imbalance that can be investigated by conventional concentric strength ratio of hamstrings to quadriceps (H:Q). The aim of this study was to compare, at different knee angles and the angle at peak torque, between healthy and PFPS subjects. Thirty-four subjects (23 males, 11 females) participated in this study. Participants were tested by the isokinetic concentric strength-open kinetic chain (OKC) procedure at 60 °/sec. The H:Q ratio was recorded and compared at knee flexion angles 15, 30, 45, 60 and 75 degrees and the angle at knee peak torque between healthy and PFPS subjects. The H:Q ratio in PFPS subjects was significantly greater than healthy subjects at knee flexion angles 15, 30, 45, 60 and 75 degrees. The measurement of H:Q ratio at specific knee angles may be a suitable clinical technique to represent the specific angle of knee muscle imbalance in PFPS patients that have been recommended to improve their quadricep muscle strength in counterbalance to the hamstring muscle.

Keywords: Hamstrings to quadriceps ratio, patellofemoral pain syndrome, muscle balance, isokinetic

Introduction

Patellofemoral pain syndrome (PFPS) is a common retropatellar and peripatellar pain among adolescents and young adults who are physically active in lower extremity movement, such as jumping and running [1-4]. A significantly higher PFPS incidence rate in females than males following long-time training was reported in a previous study, while no significant association between gender and prevalence of PFPS was noted at the time of recruitment [1]. Patellofemoral tracking and contact mechanics are known to be factors in disorder development [5]. Patellofemoral tracking in patients with PFPS deviates from the normal tracking pattern, showing a higher total contact area than in healthy participants [5]. Moreover, several impairments are associated with activities or physical functions in patients with PFPS [6]. The etiology of PFPS has not been clearly stated, and it has been proposed that PFPS may arise from abnormal alignment of the lower extremity, muscular weakness, aggravating activities, and thigh muscle imbalance. These biomechanical factors alter tracking of the patella and lead to PFPS [2,5,7,8]. The mechanisms of PFPS have been investigated to find ways to improve the treatment of patients, e.g., specific exercise, taping methods, physical therapy, and surgery [9,10]. The effects of thigh muscle imbalance have been investigated in several studies as potential risk factors for overuse knee injuries [11,12]. Conventional and functional isokinetic strength ratios of hamstrings and quadriceps muscle (H:Q) have been found to be valuable in the detection of muscle imbalance [13-15]. The conventional H:Q ratio has been analyzed in concentric and eccentric muscle contraction phases in clinical and scientific research that proved to be useful in identifying and monitoring rehabilitation in pathologic conditions [14,15]. The functional H:Q ratio for muscle co-activation was determined to be eccentric and concentric moments that occur and take place through opposing contraction modes [13,14]. The functional H:Q ratio technique is a deeper physiological and functional investigation than the conventional H:Q ratio [14]. However, evaluation by the isokinetic method should also comprise absolute muscle strength data, in addition to functional and conventional H:Q ratio absolute muscle strength data [13]. The conventional concentric H:Q ratio, with its normative value of 0.6 (values ranging from 0.43 - 0.90), has been reported at different joint angular velocities [11,13-15]. A previous study reported that the functional H:Q ratio increased in patients with PFPS [11]. Assessment of muscle balance, represented by peak moment ratios in each muscle involved in knee function, accounts for the main muscle groups of the thigh, but is limited by the angle-specific moment ratio. Aagaard *et al.* [13] noted in their research of the isokinetic H:Q muscle strength ratio that there is a trend to increase with extended knee joint position. At the present time, there is no data available concerning the conventional concentric H:Q ratio in patients with PFPS. A more angle-specific moment ratio approach is required to assess muscle balance for PFPS management. The purpose of this study was to determine the conventional concentric H:Q ratio at knee flexion angles 15, 30, 45, 60 and 75 degrees and the angle at knee peak torque between healthy participants and patients with PFPS.

Materials and methods

Subjects

A total of 34 subjects (23 males, 11 females) participated in this study. Twenty healthy subjects (15 males, 5 females; mean age of 25.05 ± 6.29 years, mean height of 168.10 ± 7.76 cm, and mean weight of 60.65 ± 7.08 kg), and 14 subjects with PFPS diagnosis by physicians or physical therapists (8 males, 6 females; mean age of 26.79 ± 5.31 years, mean height of 172.57 ± 11.88 cm, mean weight of 69.79 ± 16.68 kg) volunteered for the study. Prior to the study, informed consent with protection of the legal rights of the subjects was obtained. All participants completed the screening questionnaire. Subjects with PFPS were re-assessed by a physical therapist at the Department of Physical Therapy, Thammasat University. This study considered that the knee had to be clinically diagnosed with PFPS following the diagnostic criteria: patients 1) had had anterior or retropatellar knee pain in the last 6 months prior to the study, and were diagnosed as a PFPS case by a physician or physical therapist; 2) had reported that at least 3 of 5 of the following activities exacerbated their symptoms- physical examination, pseudo-locking and clicking with or without pain, prolonged sitting with or without joint stiffness, ascending or descending stairs, and squatting, and 3) had a positive sign in Clarke's test. All participants in the control group had no history of patellofemoral pain syndrome. Participants were excluded if they had any sign or symptom of meniscal lesion, ligamentous instability (within the 3 previous months), a history of lower extremity surgery, or clinical evidence of other knee pathologies, such as plica or patellofemoral joint instability [11,16,17].

Procedure

The procedure of this study was approved by the Ethical Committee on Research Involving Human Subjects, Thammasat University. Participants completed a standard warm-up lasting 10 min. The warm-up consisted of sub-maximal cycling and static stretching of hamstrings and quadriceps. After the warm-up session, an isokinetic concentric strength-open kinetic chain at 60 °/s was measured using the Biodex System 3 isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA). Individual participants were positioned at approximately 85 ° of hip flexion with standard stabilization fixation. The axis of the dynamometer was aligned with the lateral condyle of the femur at 90 ° of knee flexion. The length of the lever arm was individually adjusted for the length of each participant's leg. Following direct measurement of the mass of the lower limb lever system at 0 ° of knee extension, gravity correction procedures were applied to reduce the risk of inaccurate data. The knee muscle strength was assessed from 90 to 0 ° of knee flexion angle. Each participant was instructed to perform a submaximal isokinetic test in the first set (50 % of maximum effort) 6 times and rest for one minute. Then, the participants were required to perform with maximum efforts 4 times in the second set. The ratio of hamstring and quadricep strength at knee flexion angles 15, 30, 45, 60 and 75 degrees and the angle at knee peak torque was recorded and analyzed. After testing, the participants were instructed to perform a cool down and stretching session to prevent injury.

Statistical analysis

The mean and standard deviation values were calculated for each knee flexion angle. The Mann-Whitney U test was used to compare the H:Q ratios at knee flexion angles 15, 30, 45, 60 and 75 degrees and the angle at knee peak torque between the healthy and PFPS subjects, with a significance level of 0.05.

Results and discussion

Thirty-four subjects participated in this study (20 healthy subjects and 14 patients with patellofemoral pain syndrome). The right leg was dominant in all subjects, while PFPS was found 6 times on the right side, 4 times on the left side, and 4 times on both sides. Mean and standard deviation (SD) values for the H:Q ratios at knee flexion angles 15, 30, 45, 60 and 75 degrees and the angle at knee peak torque in an open kinetic chain (OKC) between healthy and PFPS participants are shown in **Table 1**. Statistically significantly different mean H:Q ratios were observed between healthy and PFPS subjects at knee flexion angles 15, 30, 45 and 75 ° in OKC ($p < 0.05$).

Table 1 Comparison of mean and standard deviation (SD) values of H:Q ratios at different angles of knee flexion in open kinetic chain between healthy (Control) and patellofemoral pain syndrome (PFPS) subjects.

Angle of knee flexion	H:Q, Control (*n* = 20)		H:Q, PFPS (*n* = 14)		p-value[a]
	Mean	SD	Mean	SD	
Angle at peak torque	0.61	0.29	0.62	0.15	0.451
15 °	0.75	0.27	1.02	0.23	0.010*
30 °	0.61	0.19	0.80	0.13	0.003*
45 °	0.50	0.10	0.70	0.34	0.004*
60 °	0.55	0.24	0.68	0.36	0.189
75 °	0.49	0.10	0.60	0.13	0.008*

[a] = Mann-Whitney U Test
* = Significantly different at $p < 0.05$

The mean angle at knee peak torque of hamstrings and quadriceps muscles between healthy and PFPS subjects in OKC were not significantly different ($p < 0.05$), as shown in **Table 2**.

Table 2 Mean angle at knee peak torque (degree) of hamstring and quadricep muscles of healthy (Control) and PFPS subjects.

Muscle	Angle at knee peak torque, Control (n = 20)		Angle at knee peak torque, PFPS (n = 14)		p-value[a]
	Mean	**SD**	**Mean**	**SD**	
Quadriceps	55.90	7.42	54.50	10.82	0.527
Hamstrings	42.70	13.79	36.64	13.65	0.083

[a] = Mann-Whitney U Test
* = Significantly different at $p < 0.05$

The mean peak torque per body weight of hamstrings muscle between healthy and PFPS subjects in OKC were significantly different ($p < 0.05$), as shown in **Table 3**.

Table 3 Mean peak torque per body weight of hamstring and quadricep muscles of healthy (Control) and PFPS subjects.

Muscle	Peak torque per body weight, Control (n = 20)		Peak torque per body weight, PFPS (n = 14)		p-value[a]
	Mean	**SD**	**Mean**	**SD**	
Quadriceps	214.01	50.84	211.61	58.81	0.849
Hamstrings	106.13	33.64	122.65	25.07	0.047*

[a] = Mann-Whitney U Test
* = Significantly different at $p < 0.05$

PFPS is a common retropatellar and peripatellar pain that involves daily activities. The changes in strength of the lower extremity muscles in persons with PFPS are not clearly defined at different angles of knee flexion. Therefore, this study aimed to comparatively investigate the H:Q ratio at different knee flexion angles between healthy persons and persons suffering from PFPS. The results indicate that different knee angles significantly influence the H:Q ratio. This study presents the conventional concentric H:Q strength ratio that has been used in the orthopedic examination of knee muscle balance. It is calculated by peak torque angle of knee flexor to knee extensor, **Table 2**. Although the mean peak torque per body weight of hamstring muscles between healthy and PFPS subjects in OKC was significantly different, with a different angle at knee peak torque, these results showed hamstring and quadricep values at different knee angles may not represent the relationship between hamstring and quadricep strength to guide in injury prevention or progress in rehabilitation.

The conventional H:Q ratio at the same angle appeared to clearly reflect the agonist-antagonist knee muscle balance. In addition, the results showed that the range of H:Q ratios measured in the healthy group (0.43 to 0.90) was similar to values reported in previous studies [13-15,18,19] and that the mean H:Q ratio was higher in PFPS patients with decreased knee extensor torque [11,20-22]. In addition, the results were significantly different at knee flexion angles 15, 30, 45 and 75 degrees in an open kinetic chain. In the open kinetic chain exercise with the dynamometer, Tang *et al.* [17] and Makhsous *et al.* [23] found that the quadricep contraction was smaller in the PFPS symptomatic group with the notion of pain when the knees were more flexed. Similarly, in this study, several PFPS subjects complained of minor knee pain during knee evaluation. There is a relationship between joint loading and quadricep function, and the knee extension torque was significantly less in PFPS conditions [1,5]. Knee extensor mechanism change may relate to the vastus medialis oblique and vastus lateralis ratio (VMO:VL). In a previous study, VMO:VL activity ratio in PFPS subjects was smaller than in healthy subjects at knee flexion angles 15, 75 and 90 degrees [17]. In healthy subjects, VMO and VL help to extend the knee and to maintain the patella in the femoral trochlea. These findings might be related to the previously reported excessive lateral tracking during knee extension in PFPS subjects [2]. VMO and VL activity may support the knee extension function at different angles. The decrease of knee extensor torque could be explained by muscle reflex [11]. The muscle reflex arc was inhibited by overload at the joint and chronic pain associated with low angular velocity [11]. Abnormal patellar tracking was found in PFPS patients with increased contact area between the patellar and femur at low knee flexion angles (15 - 30 ° of knee flexion angle). The joint surface was damaged and associated with pain and knee extensor weakness [5]. In 2014, Papadopoulos *et al*. [24] reported differences in the Thomas test and lower extremity functional scale between healthy and PFPS groups. The evaluation of PFPS patients should include much information from patient history and physical examination [4,8]. Furthermore, many studies have shown that rehabilitation techniques that may help knee extensor mechanism change, such as isokinetic exercise and kinesio tape application, in patellofemoral pain syndrome [25,26]. However, previous studies demonstrated that it is difficult to find a specific clinical assessment to differentially diagnose PFPS from other anterior knee pain conditions, such as plica syndrome or patellar instability [6,7,27]. It has been suggested that PFPS diagnosis may be best ruled in after ruling out other conditions through use of imaging, such as computed tomography scan or magnetic resonance imaging, given that the radiography X-ray cannot be used to define PFPS [28-32].

Further research on the patellofemoral pain syndrome is required. Witvrouw *et al.* [10] offered a classification system to guide the development of physical examination for each individual with PFPS. This classification could help to identify the causes of patellofemoral pain, and to select appropriate treatment for patients with PFPS. At present, treatment and rehabilitation procedures are ambiguous. Commonly, they are based on a sound theoretical rationale, but with limited evidence, to support the use of patient-specific physical interventions [9]. In addition, the type of muscle contraction also affected knee muscle activity in patients with patellofemoral pain syndrome [21].

Conclusions

The H:Q ratios in PFPS participants were higher than in healthy participants at knee flexion angles 15, 30, 45 and 75 degrees in an open kinetic chain. Impairment by PFPS was better represented by H:Q ratios at specific angles than by the H:Q ratio at peak torque angle used in previous studies. The conventional H:Q ratio is based on peak torque of hamstring and quadricep muscles that occurs at different angles of knee flexion. The hamstrings peak torque in the PFPS group occurred at a lower angle of knee flexion compared to the healthy group. These findings could help in the design of a PFPS-specified measurement at different angles of knee flexion and may be used to improve quadricep muscle strength to counterbalance the hamstring muscle in specific angles that relate to each movement. Therefore, a knee muscle balance test should also be performed at these knee flexion angles in an open kinetic chain.

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