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Relationship Between Hip Muscle Strength and Kinematics of the Knee Joint during Single Leg Squatting and Dropping

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Abstract. [Purpose] The aim of this study was to determine relationship between hip muscle strength and kinematics of the knee joint during single leg squatting and dropping. [Subjects] Twelve healthy subjects participated in this study. [Methods] The knee medial displacement was measured during single leg squatting and dropping using a high-speed camera. Peak isometric muscle strengths of the following muscles were measured hip abductors, hip adductors, hip external rotators, hip internal rotators, knee extensors and knee flexors. [Results] Muscle strength of hip external rotators was associated with knee medial displacement during both single leg squatting (r=–0.69) and dropping (r=−0.59), and muscle strength of knee flexors was associated with knee medial displacement during dropping (r=−0.58). [Conclusion] The present results suggest that hip muscles' strength, particularly hip external rotators' strength are closely associated with knee medial displacement.
Key words: Patellofemoral pain syndrome, Knee medial displacement, Kinematics

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INTRODUCTION

Patellofemoral pain syndrome (PFPS) is a common problem experienced by active adults and adolescents. The symptoms are typically exacerbated by sustained sitting (movie-goers knee) and activities requiring high levels of quadriceps activity (i.e. running, squatting, and negotiating stairs)[1]. From a functional standpoint, ascending stairs is one of the most painful activities of daily living for persons with PFPS[2]. However, its etiology has remained vague and is controversial[3]. An abnormal patella tracking is believed to cause PFPS through lateral compressive patellofemoral joint stress, and many have researchers determined increased femoral frontal and quadriceps angle (Q-angle) effects on PFPS[4]. Patella lateral tracking phenomenon has been described by Fulkerson et al.[5] as the "law of valgus" and it occurs because of two primary forces acting on the patella, the resultant quadriceps force vector and the patellar tendon force vector, which are not collinear. Thus, contraction of the quadriceps brings a lateral force to the patella. Three factors of lower limb motions may influence on the Q-angle: tibial rotation, femoral rotation and knee valgus[6]. Therefore, abnormal motion of the tibia and femur in the transverse and frontal planes may have an effect on patellofemoral joint mechanics. It was reported that differences in muscle strength and lower extremity kinematics are believed to have an influence on PFPS while weight bearing[7], and it has been hypothesized that the weakness of hip abductors and hip external rotators may cause excessive hip adduction and hip internal rotation, respectively, thus contributing to patellofemoral joint stress[5,8]. Ireland et al.[9] reported hip abductor and hip external rotator weakness in women would have an insidious effect on the onset of PFPS. Nevertheless previous studies were reported from either the viewpoint of kinematics of the knee joint or hip muscle weakness, and is unclear whether hip and knee muscle weakness affect on knee medial displacement during some movements. The purpose of this study was to determine the relationship between hip muscle strength and kinematics of the knee joint during single leg squatting and dropping. We hypothesized that these two procedures would reveal 1) hip muscle strength influences on kinematics of knee medial displacement, and 2) particularly hip abductors and hip external rotators influence knee medial displacement during single leg squatting and dropping.

SUBJECTS AND METHODS

Twelve healthy women (mean ± SD: age 20.9 ± 0.7 years, height 159.0 ± 5.9 cm, weight 54.4 ± 6.7 kg) participated in the study. All subjects were without low back and lower extremity pain, traumatic injury and foot deformities.

All subjects were informed about the study and signed an informed consent before participating in the study. If subjects felt pain during the measurement, they were permitted to give up at any time. The subjects wore shorts, and a T-shirt, and they perfomed the procedures in bare feet. The subjects executed single leg squatting and dropping procedures after two practices to become familiar with the procedures. Both procedures were performed with the right leg. Single leg squatting was performed from the standing position to approximately 60 degrees of knee flexion followed by a return to the start position. The dropping procedure was started with the right leg because the right knee medial displacement was measured on the second step. Steps for dropping consisted of two boxes which were 40 cm height and 10 cm height. The stance phase of dropping began at the point when the initial toe contacted the second step. Before the measurements, subjects were not instructed to control any movement of the knee in the frontal plane. While performing the single leg squatting and dropping, subjects received instructions to keep their trunk upright, not to get off balance, to keep the right foot directed straight, and to keep their arms to the sides. Reflective markers were placed on the following landmarks: anterior superior iliac spine (ASIS), greater trochanter, center of the patella, lateral femoral condyle, lateral and medial malleolus and their midpoint. The angle of knee flexion was defined as the used to intersection of the greater trochanter, lateral femoral condyle and lateral malleolus. Knee medial displacement was the angle determined by three points: the anterior superior iliac spine (ASIS), center of patella and midpoint of the medial and lateral malleolus. The knee medial displacement angle of single leg squatting was measured at the point when the knee was flexed approximately 60 degrees, and during dropping when the foot was flat on the second step. Knee medial displacement angle was recorded using two high speed cameras (Casio EX-FH100) at a capture speed of 120 fps, which were set 2.5 m from the subjects. The height of the camera was adjusted the height of each subject's patella. Images of videos were processed using motion analysis software (Silicon COACH Pro 6.1 motion analysis). Data from last three trials out of a total of five were analyzed for both the single leg squatting and dropping procedures. The knee medial displacement used in the analysis was the average of three trials. Hip and knee muscle strengths were measured using a hand held dynamometer (HHD; Anima Corp, μ-Tas F-1) as isometric muscle strength referring to Katoh's method[10]. The interrater reliability of this measurement method which uses a belt to fix the HHD has been demonstrated. Velcro straps are used to fasten the sensor to the surface of a subject's limb. The muscles measured muscles were: hip abductors, hip adductors, hip external rotators, hip internal rotators, knee extensors and knee flexors. The hip abductors and adductors were tested in the supine position with the pelvis stabilized by examiners to prevent rotation. The other muscles (hip internal rotators, external rotators, knee extensors, and knee flexors) were tested in the sitting position on a table while keeping the trunk upright and the legs hanging free. The subjects were instructed to push against a force plate at maximal effort for approximately 4 to 5 seconds and the peak torque was recorded as the measured value. Each test was performed a total of three times with intervals of five seconds rest, and the average of the three values was normalized to subject's body weight; the normalized value was used in the analysis.

Spearman's rank correlation was used to examine the relationship between lower leg muscle strength and knee medial displacement angle during single leg squatting and dropping. For all tests, $p<0.05$ was considerd statistically significant. SPSS version 17.0 was used to perform all statistical analyses.

RESULTS

The knee medial displacement angle during squatting was 163.2 ± 12.4°, and during dropping was 173.5 ± 6.1°. The muscle strength results are shown in Table 1. The correlation results are shown in Table 2. Hip external rotators were significantly associated with knee medial displacement during single leg squatting ($r=-0.692$, $p=0.013$) and dropping ($r=-0.589$, $p=0.044$), and knee flexors were significantly associated with knee medial displacement during dropping ($r=-0.579$, $p=0.049$). Hip abductors showed no significant relationship.

DISCUSSION

We hypothesized hip muscles would influence knee kinematics. Bolgla[3] suggested that persons with PFPS had significant weakness of the hip muscles but did not compare with hip and knee kinematics. A previous study reported single leg squatting can be used as a functional test of lower-extremity function and alignment[8], and the femoral frontal angle of individuals with PFPS is significantly large[4]. We also hypothesized hip muscle strength would influences kinematics of knee medial displacement, and our results partially support these hypotheses. Willson[11] reported that hip external rotation torque correlated most significantly with frontal plane projection angle values. The present study showed the same result suggesting that decreased strength of hip external rotator muscles causes a high amount knee medial displacement. We additionally hypothesized hip abductors and external rotators would influence on the knee medial displacement more than the other hip muscles. However, only hip external rotators significantly correlated with knee medial displacement during single leg squatting and dropping. We think that compensatory internal rotation of the femur occurs leading to knee extension because of screw-home mechanics. And it was reported that the excessive internal rotation of the femur forces patella medial movement with respect to the movement of ASIS and tibial tuberosity, thereby increasing the Q-angle and lateral

Table 1. Lower leg muscle strengths (N/kg)

	Hip				Knee	
	abductors	adductors	external rotators	internal rotators	flexors	extensors
Muscle strengths	2.6 ± 0.5	1.8 ± 0.5	1.4 ± 0.2	1.7 ± 0.2	2.0 ± 0.4	4.3 ± 0.9

Table 2. Results of Spearman's rank correlation coefficient and p values for the association between lower leg muscle strength and knee medial displacement angle during single leg squatting and dropping

		Hip				Knee	
		abductors	adductors	external rotators	internal rotators	flexors	extensors
Single leg squatting	R	–0.597	–0.316	–0.692*	–0.439	–0.214	0.116
	p value	0.854	0.316	0.013	0.153	0.503	0.720
Dropping	R	0.102	–0.255	–0.589*	–0.421	–0.579*	–0.091
	p value	0.753	0.483	0.044	0.173	0.049	0.778

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

component of the quadriceps muscle vector[6]. Therefore, we suggested the muscle strength of hip external rotators is one of the important factors for external rotation of the femur. However, it has also been shown that hip abductors are not related to knee medial displacement. Lawrence[12] reported that pre-activation of the gluteus medius did not significantly influence the peak valgus knee angle. We think it is possible that hip abductors would correlate in a dynamic action and reduced activation of the gluteus medius would increase knee valgus. In addition it has been revealed that knee flexors correlate with knee medial displacement during dropping. Palmieri-Smith[13] reported that gracilis, which has a better moment arm than the gluteus medius to counteract applied valgus loads and restrict valgus motion, is more important than the gluteus medius for limiting valgus angulation of the knee joint. Some researchers have suggested, from EMG data, that activity of the hamstring muscle is affected slightly by the presence of either varus or valgus force in individuals without knee pathology. They have reported that the semitendinousus demonstrated activity in resisting valgus loads, but activity of the biceps femoris appeared to be unaltered by varus forces in individuals with intact ligaments[14,15]. Therefore, we think that the knee flexors acting directly at the knee work as the first line of defense against valgus loads, while the hip muscles are a secondary restraint. We think it is possible that the pes anserinus group engages in the dynamic stabilization of the knee on the medial side. It was reported that active tension in the pes muscles resists knee external rotation and valgus loads applied to the knee along with the medial collateral ligament (MCL) and posterior medial capsule[16]. In the present study, the knee flexors correlated with knee medial displacement only during the dropping procedure. The dropping procedure may require more dynamic action by subjects than single leg squatting. The result of the present study suggest hip external rotator weakness is one of the main risks for PFPS. This result further supports the trend of incorporating hip muscle strengthening in PFPS rehabilitation, especially for patients with hip muscle weakness.

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