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Comparison of Knee Muscle Strength of Non-injured and Injured Sides following Anterior and Posterior Cruciate Ligament Reconstruction

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ABSTRACT
Purpose: The purpose of this study was to compare knee muscle strength of non-injured and injured legs after reconstruction of the anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL).
Methods: Thirteen volunteers (males) with anterior ligament injury and 10 volunteers (males) with posterior ligament injury participated in this study. Post reconstruction, the peak torque, total work, and hamstrings to quadriceps (H/Q) ratio were calculated at angular velocities of 60°/sec and 180°/sec in both groups using an isokinetic dynamometer. A t-test was used to compare the mean difference within-group and between-group comparisons. The data were analyzed using SPSS version 18.0 for Windows.
Results: In the within-group comparison of muscle strength and muscle endurance in the affected side and unaffected side at angular velocities of 60°/sec and 180°/sec, there was a significant difference in extensor strength in the ACL injury group and a significant difference in flexors and extensor strength in the PCL injury group ($p<0.05$). In the between-group comparison of the muscle strength and endurance of the affected side, flexors in the PCL injury group showed significantly higher muscle strength and endurance than those in the ACL injury group ($p<0.05$). No significant between-group difference in extensor strength was observed ($p>0.05$). In within-group comparisons, there was a significant difference in the H/Q ratio in the ACL injury group when the angular velocity was 60°/sec ($p<0.05$). At an angular velocity of 180°/sec, the H/Q ratio of the affected side in the ACL injury group was higher than that of the unaffected side, and the H/Q ratio in the PCL injury group was higher for the affected side than unaffected side, with a significant difference ($p<0.05$). In the between-group comparison of the H/Q ratio of the affected side, the value in the PCL injury group was higher than that in the ACL injury group when the angular velocity was 60°/sec, and the result was statistically significant ($p<0.05$). The H/Q ratio in the ACL injury group was significantly higher than that in the PCL injury group when the angular velocity was 180°/sec ($p<0.05$). Loss of extensor muscle strength was greater in the ACL group than in the PCL group. The PCL injury group showed loss of both extensor strength and flexor strength, with greater loss of flexor muscle strength than extensor strength.
Conclusion: These results suggest that individuals with ACL injury should focus on exercises for muscle strength and endurance in knee extensors and that those with PCL injury should concentrate on exercises for muscle strength and endurance in both knee flexors and extensors, especially knee flexors.
Keywords: Anterior cruciate ligament, Posterior cruciate ligament, Reconstruction, Muscle strength
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INTRODUCTION

Knee joint injuries occur frequently during sports activities, as the knee joint is weight bearing and unstable.[1,2] The frequency of cruciate ligament injuries is particularly high.[3]
Many patients with cruciate ligament injury do not receive proper rehabilitation due to the extended treatment time. Financial reasons may also preclude treatment[4]. Subsequently, they experience a limited range of joint motion, weakened muscle strength, joint instability, and secondary complications.[4] Cruciate ligament injury causes pain, instability, degenerative changes, and malfunction of the knee joint. Secondarily, it can result in osteoarthritis and diverse problems, such as weakened muscle strength and atrophy of the hamstring muscle group, all of which can affect quality of life.[5-9]
The functional stability of the knee joint is provided by the interactions between the dynamic muscle system and the surrounding structures, such as ligaments, tendons, meniscus, and joint capsule.[10] The anterior cruciate ligament (ACL) acts as a static stabilizer, preventing hyperextension of the knee joint, anterior tibial translation, and rotatory movements and also restricts valgus and varus movements in all ranges of flexion.[11] The posterior cruciate ligament (PCL) basically limits posterior tibial displacement [12] and provides stability against valgus, varus, and external rotation.[13]
ACL injury occurs most frequently during sports activities,[14] particularly during activities involving excessive power, such as landing on one foot, rapid deceleration, pivoting, twisting, and cutting movements.[15] PCL injury commonly occurs when the proximal tibia is in posterior translation and the knee joint is in flexion[16-18] or when excessive force is put on the PCL during hyperflexion or extension of the knee joint.[19]
Treatment methods for cruciate ligament rupture are divided into surgical (ligament reconstruction) and nonsurgical (physical therapy), depending on the extent of the injury.[20]
Ligament reconstruction is one of the most frequently implemented therapy methods in orthopedics clinics. Fixation, which is used to restrict the contraction of knee muscles after cruciate ligament reconstruction, has a negative impact on the neighboring muscles.[21] A rehabilitation protocol focusing on muscle strength and muscle endurance is required to prevent injuries caused by unbalanced muscle strength.
Although previous studies emphasized the importance of early rehabilitation exercise before and after cruciate ligament reconstruction,[22-25] most of these studies assessed muscle strength. There is insufficient research on the various muscle groups that need to be reinforced according to the type of cruciate ligament injury. Understanding the extent of muscle strength loss of the affected side compared to the unaffected side when each cruciate ligament is damaged is very important for establishing the direction of therapy after surgery.
The purpose of this study was to conduct a comparison analysis of the muscle strength of knee flexors and extensors of the affected side and unaffected side of patients who

underwent knee reconstruction due to ACL and PCL rupture and to propose a postoperative rehabilitation guideline.

METHODS

1. Subjects

The subjects in this study consisted of 23 adult males who had undergone cruciate ligament reconstruction at General Hospital K in Daegu, South Korea due to cruciate ligament rupture and not taken part in an established rehabilitation program post-surgery. There were 13 subjects in Group 1 (ACL) and 10 subjects in Group 2 (PCL). All the subjects had ACL or PCL rupture on only one side and no surgical history on the same or opposite side. Subjects with combined ligament injuries that could affect the stability of the knee joint, except for meniscus injury, were excluded. All the subjects volunteered to take part in the study and provided written informed consent. Table 1 summarizes the physical characteristics of the research subjects.

2. Experimental procedures

The experiment design was intended to test the muscle strength of the affected side and unaffected side in the two groups. In the experiment, muscle strength and muscle endurance in each of the affected sides and unaffected sides post-surgery were assessed using an isokinetic muscle function measuring device (Biodex system 3; Biodex Medical systems, Inc., New York, USA) (Fig. 1). The measurement was conducted while the subjects were sitting with 110° flexion of the hip joint. The subject's back was completely supported, and a Velcro strap was used to immobilize the trunk, lower back, and leg while obtaining the measurements on the affected side. A resistance pad was located 3 cm above the ankle joint, and the knee joint was aligned to the rotational axis of the dynamometer. Before the measurement, the subjects warmed up by cycling for 10 min and performing quadriceps and hamstring stretching for 5 min. Before the isokinetic exercise, the subjects performed submaximal exercise of knee flexors and extensors four times to enable them to become accustomed to the exercise, which was performed at angular velocities of 60° and 180°/sec.

The experiment consisted of five sets of the exercise at an angular velocity of 60°/sec and 10 sets of the exercise at an angular velocity of 180°/sec, with a 1-min rest time between the measurements at the different angular velocities. The measurements were conducted on the unaffected side first and then on the affected side after resting for 3 min. During the test, the exercise was stopped if a patient felt discomfort or complained of pain.

3. Measurement items

Muscle strength and endurance were evaluated at angular velocities of 60°/sec and 180°/sec. Three items were measured: peak torque, total work, and the hamstring to quadriceps ratio (H/Q ratio).

4. Data processing

The statistical program SPSS version 18.0 for Windows was used to calculate the means and standard deviations of all data. The Shapiro–Wilk test was used to test the normality of the data. An independent t-test was conducted to compare between-group differences on the injured side. A paired *t*-test was used to compare within-group differences between the non-injured and injured sides after surgery. The significance level of the statistical tests was set at $p<0.05$.

RESULTS

1. Comparison of muscle strength at an angular velocity of 60°/sec

1) Muscle strength of extensors

In both the ACL and PCL injury groups, the peak torque and total work in the unaffected side were significantly higher than those in the affected side ($p<0.05$) (Table 2). In the between-group comparison of the affected side, both the peak torque and total work in the PCL injury group were significantly higher than those in the ACL injury group ($p<0.05$) (Table 2).

2) Muscle strength of flexors

There was no significant difference in peak torque and total work in the ACL injury group ($p>0.05$) (Table 3). In the PCL injury group, peak torque and total work of the unaffected side were significantly higher than peak torque and total work of the affected side ($p<0.05$) (Table 2). In the between-group comparison of the affected side, there was no significant difference in either peak torque or total work ($p>0.05$) (Table 2).

3) H/Q ratio

In the within-group comparison, the H/Q ratio of the affected side was significantly higher that of the unaffected side in the ACL injury group ($p<0.05$) (Table 2). In the between-group comparison, the H/Q ratio in the PCL injury group was significantly higher than that in the ACL injury group ($p<0.05$) (Table 2).

2. Comparison of muscle strength at an angular velocity of 180°/sec

1) Muscle strength of extensors

In both the ACL and PCL injury groups, the peak torque and total work of the unaffected side were significantly higher than the peak torque and total work of the affected side ($p<0.05$) (Table 3). In the between-group comparison of the affected side, the peak torque in the PCL injury group was significantly higher than that in the ACL injury group ($p<0.05$) (Table 3).

2) Muscle strength of flexors

In the ACL injury group, there was no significant difference in peak torque and total work ($p>0.05$) (Table 3). In contrast, the peak torque and total work of the unaffected side in the PCL injury group were significantly higher than the peak torque and total work of the affected side ($p<0.05$) (Table 3). In the between-group comparison of the affected side, there was no significant difference in either the peak torque or total work ($p>0.05$) (Table 3).

3) H/Q ratio

In the within-group comparison, the H/Q ratio of the affected side in the ACL injury group was significantly higher than that in the unaffected side. In the PCL injury group, the H/Q ratio of the unaffected side was significantly higher than that of the affected side ($p<0.05$) (Table 3). In the between-group comparison, the H/Q ratio in the ACL injury group was significantly higher than that in the PCL injury group ($p<0.05$) (Table 3).

DISCUSSION

This study analyzed and compared the postoperative isokinetic muscle strength of the affected side and unaffected side of the knee joint in 23 adults who had undergone knee reconstruction due to cruciate ligament injury (ACL injury, $n = 13$; PCL injury, $n = 10$) for the purpose of suggesting a guideline for rehabilitation therapy.

In the within-group comparison of the muscle strength of the affected and unaffected sides at angular velocities of 60°/sec and 180°/sec, there was a significant difference in extensor strength between the unaffected and affected sides in the ACL injury group. In the PCL injury group, there was a significant difference in flexors and extensor strength between the unaffected side and affected side. In the between-group comparison of extensor strength of the affected side, the values in the PCL injury group were significantly higher than those in the ACL injury group at angular velocities of 60°/sec and 180°/sec. There was no significant between-group difference in the muscle strength of the flexors.

The quadriceps are antagonists of the ACL. Contraction of the quadriceps causes tension in the ACL.[26-28] The hamstring muscle is an antagonist of the PCL. Flexion of the knee joint following the activation of the hamstring causes tension in the PCL.[28] During voluntary flexion of the knee, the hamstring causes the tibia to actively slide backward against the femur. In general, the muscle strength of the quadriceps decreases over time after ACL injury, and it is known to be severer than the loss of strength of hamstring.[29] A previous study reported that weakening of the quadriceps was more severe than that of the hamstring in patients with knee joint lesions.[30] Kim[31] reported that extensor strength decreased during the first 3 months after PCL reconstruction and increased thereafter, whereas flexor strength began to significantly increase after PCL reconstruction. The anatomic size of the PCL is approximately twice that of the ACL, and the PCL has strong tensile force. Thus, once damaged, the PCL requires a longer rehabilitation duration and a longer recovery period than does the ACL.[32]

In the within-group comparison of the H/Q ratio at an angular velocity of 60°/sec, the H/Q ratio of the affected side was significantly higher than that of the unaffected side in the ACL injury group. In the between-group comparison, the H/Q ratio of the affected side in the PCL injury group was significantly higher than that in the ACL injury group. In the within-group comparison of the H/Q ratio, at an angular velocity of 180°/sec, the ratio was higher on the affected than the unaffected side in the ACL injury group. In contrast, the H/Q ratio of the unaffected side in the PCL injury group was higher than that of the affected side, with a significant difference. In the between-group comparison, the H/Q ratio of the affected side was significantly higher in the ACL injury group as compared with that of the affected side in the PCL injury group. These results pointed to large loss of muscle strength of the extensors of the affected side in the ACL injury group and flexors in the PCL injury group. A high H/Q ratio implies relatively weak muscle strength of quadriceps compared to hamstrings, whereas a lower ratio implies the opposite.

ACL injury causes weakening of extensors. Hence, rehabilitation aimed at increasing the muscle strength and endurance of extensors is necessary. Strengthening of flexors is also important for the prevention of excessive stress on the ACL.[33] PCL injury causes weakening of both flexors and extensors and requires rehabilitation to increase the muscle strength and endurance of flexors and extensors. Muscle strength and endurance exercise of flexors are particularly important due to the weakening of flexors. Performing muscle strengthening exercise, focusing on flexors first, followed by extensors in the case of ACL injury and extensors first, followed by flexors in the case of PCL injury can aid rehabilitation by reducing the instability of the knee joint.

This study had some limitations. The daily activities of the individual subjects could not be controlled, and the individual variation of pain and recovery was not considered. Furthermore, concern among the subjects about potential re-injury may have affected their performances in the exercises. Based on our results, systematic and effective measurement methods of muscle strength are needed in patients with ACL and PCL injuries.

Further research is required to identify ways of enhancing the stability of the knee joint and preventing re-injury in postoperative rehabilitation programs in clinics.

CONCLUSION

This study examined differences in the muscle strength of the affected side and unaffected side of subjects who underwent knee reconstruction due to ACL injury or PCL injury, as assessed by measurements of peak torque, total work, and the H/Q ratio at angular velocities of 60°/sec and 180°/sec. The results have implications for early return to daily life and sports activities. In the case of ACL injury, rehabilitation exercise aimed at the recovery of strength and endurance of extensors is effective. In the case of PCL injury, rehabilitation exercise that can increase the muscle strength and endurance of flexors and extensors is recommended with a particular emphasis on exercise of flexors. The selection of rehabilitation exercise according to the type of cruciate ligament injury can aid the recovery of muscle strength and endurance and enhance the stability of the knee joint. Future studies should apply a rehabilitation program according to differences in muscle strength and muscle endurance after cruciate ligament reconstruction and test the effect of the rehabilitation by assessments of the functional performance of the knee joint and measurements of muscle strength.

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Table 1: Physical characteristics of the subjects

Group	*N*	Age (y)	Height(cm)	Weight (kg)	Period (wk)	Injured side	
						Right	Left
ACL	13	40.46±11.94	170.08±7.14	71.08±9.60	12.62±0.96	9	4
PCL	10	29.60±10.88	176.00±5.14	72.30 10.01	12.40±1.58	5	5

Mean ± SD, ACL: ACL: Anterior cruciate ligament, PCL: posterior cruciate ligament,
N: number of subjects, Period: postoperative test period

Table 2: Comparison of muscle strength at an angular velocity of 60°/sec

Variable		Group	IS	NS	Within group	Between groups
					P	
Knee extension	Peak torque (ft-lbs)	ACL	90.69±27.90	128.03±33.00	0.000*	0.003*
		PCL	133.85±34.62	179.31±37.80	0.001*	
	Total work (ft-lbs)	ACL	517.16±190.00	697.62±267.60	0.002*	0.005*
		PCL	779.8 4±206.08	1002.8 8±221.72	0.003*	
Knee flexion	Peak torque (ft-lbs)	ACL	56.73±21.53	57.03±16.82	0.914	0.691
		PCL	60.03±16.36	80.67±15.09	0.001*	
	Total work (ft-lbs)	ACL	329.96±138.42	333.83±136.04	0.816	0.774
		PCL	312.91±97.91	487.61±111.84	0.000*	
H/Q ratio (%)		ACL	63.31±17.15	44.55±6.00	0.002*	0.004*
		PCL	42.29±8.97	45.50±6.32	0.939	

Mean ± SD, *$p<0.05$, ACL: anterior cruciate ligament, PCL: posterior cruciate ligament, H/Q: hamstring to quadriceps, IS: injured side, NS: non-injured side

Table 3: Comparison of muscle strength at an angular velocity of 180°/sec

Variable		Group	IS	NS	Within group	Between groups
					P	
Knee extension	Peak torque (ft-lbs)	ACL	70.66±22.22	96.89±31.97	0.000*	0.018*
		PCL	91.49±14.72	116.57±20.01	0.000*	
	Total work (ft-lbs)	ACL	814.16±320.82	1049.95±459.49	0.002*	0.050
		PCL	1052.24±187.66	1407.84±314.31	0.004*	
Knee flexion	Peak torque (ft-lbs)	ACL	44.73±13.92	43.28±12.89	0.547	0.810
		PCL	43.36±12.77	62.78±16.12	0.001*	
	Total work (ft-lbs)	ACL	483.13±220.15	436.67±215.16	0.142	0.518
		PCL	428.31±164.77	723.17±176.00	0.000	
H/Q ratio (%)		ACL	65.42±17.11	46.06±10.65	0.000	0.005
		PCL	46.97±8.66	54.03±10.87	0.037	

Mean±SD, $p<0.05$, ACL: anterior cruciate ligament, PCL: posterior cruciate ligament, H/Q: hamstring to quadriceps, IS: injured side, NS: non-injured side

Figure 1: Isokinetic dynamometer