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Effects of accelerated rehabilitation exercise on quadriceps femoris and postural stability after anterior versus posterior cruciate ligament reconstruction

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This study aimed to investigate the effect of a 12-week accelerated rehabilitation exercise program on isokinetic strength and dynamic balance ability of thighs in 20 adult men who underwent anterior cruciate ligament reconstruction (ACLR) or posterior cruciate ligament reconstruction (PCLR) and to analyze intergroup differences in recovery patterns. In this study, we examined 10 patients who underwent ACLR and 10 who underwent PCLR. These patients participated in an accelerated rehabilitation exercise program 5 times weekly for 12 weeks. The participants' isokinetic strength, muscular endurance, and dynamic balance ability of the femoral muscles were measured before and 12 weeks after reconstruction surgery. Isokinetic knee muscle function showed no significant difference between the ACLR and PCLR groups at 60°/sec. Both the groups demonstrated significant increases in muscle strength between the flexors and extensors. However, a between-group difference was noted in knee muscular endurance at 180°/sec, with ACLR patients showing significant differences between extensors and flexors, unlike PCLR patients. Assessment of the dynamic balance ability revealed that overall knee stability did not significantly differ between groups, and both the ACLR and PCLR groups exhibited improved dynamic balance ability. However, significant differences were found in anteroposterior and left-right stabilities. Patients who underwent ACLR had significantly improved anteroposterior and left-right stability, wherever patients who underwent PCLR showed no significant difference. This accelerated rehabilitation exercise program improved the muscle strength and muscular endurance of patients who underwent ACLR and PCLR, suggesting its potential efficacy in recovering dynamic balance ability, particularly after ACLR.

Keywords: Anterior cruciate ligament, Posterior cruciate ligament, Reconstruction, Rehabilitation exercise, Isokinetic strength, Dynamic balance ability

INTRODUCTION

Rapid economic development has led to drastic improvements in human quality of life. Consequently, there has been a growing interest in sports participation and leisure activities by non-professional athletes as means to enhance the quality of life. This, in turn, has led to a corresponding increase in musculoskeletal injuries. Knee joint injuries are common among people participating in various sports, particularly anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) injuries (Arundale et al., 2017; Fong et al., 2009).

Injuries to the ACL and PCL can cause significant challenges. Injuries to the ACL can result in pain and instability in the anterior and anterolateral areas of the knee, accompanied by patellar dislocation and osteoarthritis, as well as weakening and atrophy of the quadriceps femoral muscles (Filbay and Grindem, 2019), whereas injuries to the PCL can result in knee joint instability, degenerative changes in the femoral and medial compartments, and damage to peripheral tissue (McGuire and Wolchok, 2003). The severity of cruciate ligament injuries determines the treatment

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approach, wherein conservative therapy is used for mild injuries and surgical reconstruction for severe injuries. Recent advancements in arthroscopic reconstruction techniques have allowed for minimally invasive procedures, enabling quicker recovery with restored joint range of motion and load-bearing capacity. In addition, early rehabilitation exercises after surgery have shown positive effects on patients' motor functional recovery and return to daily activities (Grant, 2013).

Conventional rehabilitation exercise programs restricted weight-bearing during a 8-week postoperative cast immobilization period to promote tendon healing and prevent inflammation. These programs also recommend the use of crutches for 12 weeks and prohibition of early contraction of the quadriceps femoris to prevent loosening of the transplanted tendons (Escamilla et al., 2012). However, prolonged immobilization/fixation can prevent full restoration of the knee joint and lead to knee joint stiffness and limited range of motion, weakening the quadriceps and hamstrings (Escamilla et al., 2012). In contrast, current rehabilitation exercise programs avoid knee joint immobilization after reconstruction and instead focus on early walking, joint exercises, and accelerated rehabilitation programs, including patellar tendon stretching. These early rehabilitation programs have shown improvement in knee joint function and stability (An et al., 2015). In a study by Shelbourne and Nitz (1990), participants were allowed to walk on the first day after ACL reconstruction (ACLR) and an accelerated rehabilitation program was initiated on the 14th postoperative day, with knee joint range of motion recovered to ≥100°. As a result, isokinetic testing conducted 60 days after the surgery revealed 70% recovery of strength on the affected side compared with that of the unaffected side. Similarly, Wilk et al. (2003) demonstrated increased knee joint range of motion and rapid recovery of strength, as well as a decrease in complications such as adhesions and fibrosis at the surgical site. In addition, reports have highlighted the benefits of early accelerated rehabilitation exercises that do not involve ligament relaxation. These exercises shorten the time required for athletes to return to sports and field activities after surgery. The emphasis on postoperative early rehabilitation exercises underscores their importance in promoting a faster and more effective recovery process.

Several previous studies have investigated the impact of accelerated rehabilitation exercise programs after cruciate ligament reconstruction on functional changes in the knee joints; however, relatively fewer studies have compared the effects of these programs on ACL injuries versus PCL injuries. Therefore, this study aimed to analyze the effects of a 12-week accelerated rehabilitation program on the strength of thigh muscles and postural stability in patients after ACLR or PCLR and to present rehabilitation guidelines for these populations.

Table 1. Physical characteristics of the participants

Subject	ACLR (n=10)	PCLR (n=10)
Age (yr)	23.14±3.71	24.53±5.11
Height (cm)	175.50±7.15	177.33±5.93
Weight (kg)	67.81±5.18	66.73±8.83

Values are presented as mean±standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

MATERIALS AND METHODS

Subject

This study included a total of 20 adult male patients who visited Korea University Hospital in Seoul, Korea (10 patients underwent ACLR and 10 patients underwent PCLR). This study was approved by the Institutional Review Board of Korea University (approval number: KU-IRB-12-67-A-2). The participants' characteristics are summarized in Table 1.

Experimental procedure

All the patients were assessed before surgery and after the 12-week accelerated rehabilitation exercise program. The peak torque of the extensors and flexors at angular velocities of 60°/sec and per unit body weight at 180°/sec were measured using a Biodex System 3 (Biodex Medical Systems, Shirley, NY, USA) to examine thigh muscle strength and muscular endurance, while dynamic balance ability was investigated using a Biodex Balance System SD (Biodex Medical Systems). In this study, the three-stage accelerated rehabilitation exercise program was used based on the accelerated rehabilitation exercise program published by Wilk et al. (2003). The program was applied to patients according to their condition and compliance, and ice was applied to the affected side after each exercise session (Table 2).

To assess thigh muscle strength, the participants performed warm-up exercises and sat in the chair with the hip joints flexed at 90°. The knee joints were aligned with the rotational axis of the dynamometer. The upper body and pelvis were fixed with waist and pelvic belts, and the ankles were fixed with a belt, using the medial malleolus as a reference point, to prevent compensatory action from regions of the body other than the knee joint during the measurement. The measurements were taken once after the ligament injury (before the reconstruction) and once after the 12-week accelerated rehabilitation program. The participants practiced once

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Table 2. Accelerated rehabilitation exercise program

Step	Exercise program	Exercise method
1 Step Operation–week 1	Passive knee extension	10 sec/3–5 sets
	Ankle pump	10 times/5 sets
	Passive active knee flexion	10 sec/10 times/5–10 sets
	4-Point straight leg raise	10 times/5 sets
	Quadriceps setting	10 sec/10 times/3–5 sets
	Hamstring stretching	10 times/5–10 sets
	Hamstring curl	10 times/3–5 sets
	Mini-squat	10 times/2–3 sets
2 Step Week 2–week 3	Week 2 (include top workouts)	
	Leg press (0°–30°)	10 times/2–3 sets
	Leg extension (90°–40°)	10 times/2–3 sets
	Half squat (0°–40°)	10 times/3–5 sets
	Hamstring curl	10 times/3–5 sets
	Cycle	10 min
	Patellar mobilization	5 min
	Week 3 (include top workouts)	
	Passive ROM (0°–115°)	5 min
	Cycle	5–10 min
	Leg extension (90°–40°)	10 times/3–5 sets
	Side stair climb	10 times/2–3 sets
	Front stair climb	10 times/2–3 sets
3 Step Week 4–week 12	Week 4–7 (include top workouts)	
	Wall squat (0°–30°)	10 times/3–5 sets
	Calf raise	15 times/3–5 sets
	Week 8–9 (include top workouts)	
	Walking	10–20 min
	Week 10–12 (include top workouts)	
	Tilt board balance	5–10 min
	Isokinetic exercise	10 times/5 sets

ROM, range of motion.

before the tests. Five measurements were taken at 60°/sec, whereas 10 measurements were taken at 180°/sec; a 1-min rest period was provided between the tests. To familiarize the participants with the tests, the movements were performed on the unaffected side followed by the affected side. Dynamic balance ability was measured using the Biodex Balance System SD (Biodex Medical Systems). The equipment consists of an anteroposterior and left-right tilt platform, a monitor used to visually confirm reaching the target point, a computer that quantitatively analyzes movements, and a printer.

During the measurement, participants stood on a 60-cm-diameter circular platform and positioning their feet accordingly. Following a built-in program, they were required to keep their balance stable over the center of the circle, as displayed on the monitor, without lifting their feet off the platform. The measurements were taken twice: once after the ligament injury but before reconstruction and once after the 12-week accelerated rehabilitation exercise program. A single practice session was conducted before the actual measurement to enable the participants to familiarize themselves with the test. Stability was graded on a scale from 1 to 8. A lower score indicated better balancing ability.

Table 3. Maximum extension force at 60°/sec angular velocity

Group	Before rehabilitation exercise	After rehabilitation exercise
ACLR	110.31 ± 49.06	155.25 ± 53.63
PCLR	116.66 ± 36.16	146.62 ± 40.10
$F_{group*time}$ = 0.621 (0.441), F_{group} = 0.004 (0.950), F_{time} = 15.531 (0.001)		

Values are presented as mean ± standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

Table 4. Maximum flexion force at 60°/sec angular velocity

Group	Before rehabilitation exercise	After rehabilitation exercise
ACLR	35.41 ± 19.01	78.26 ± 19.28
PCLR	44.31 ± 22.34	83.88 ± 36.60
$F_{group*time}$ = 0.046 (0.833), F_{group} = 0.755 (0.396), F_{time} = 28.899 (0.000)		

Values are presented as mean ± standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

Statistical analyses

All data analyses in this study were conducted using IBM SPSS Statistics ver. 22.0 (IBM Co., Armonk, NY, USA). The measurements are presented as means and standard errors, and repeated measures analysis of variance was performed to identify statistical significance ($P < 0.05$).

RESULTS

Changes in knee strength

Changes in the maximum extension force at an angular velocity of 60°/sec are shown in Table 3. There was no interaction between group and time of measurement. Although no main effect in groups observed, significant difference in times was observed ($F = 15.531$, $P = 0.001$).

Changes in the maximum flexion force at an angular velocity of 60°/sec are shown in Table 4. There was no interaction between group and time of measurement. Although no main effect in groups observed, significant difference in times was observed ($F = 28.899$, $P = 0.000$).

Changes in the maximum extension force per unit body weight at an angular velocity of 180°/sec are presented in Table 5. An interaction was noted between group and time ($F = 5.301$, $P = 0.034$). Significant differences were observed in the extensors of ACLR

Table 5. Maximum extension force per unit weight at 180°/sec angular velocity

Group	Before rehabilitation exercise	After rehabilitation exercise	F (P-value)
ACLR	776.53 ± 257.03	1,113.13 ± 393.90	7.964 (0.020)
PCLR	991.52 ± 601.05	1,000.24 ± 616.50	0.002 (0.961)
$F_{group*time}$ = 5.301 (0.034)			

Values are presented as mean ± standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

Table 6. Maximum flexion force per unit weight at 180°/sec angular velocity

Group	Before rehabilitation exercise	After rehabilitation exercise	F (P-value)
ACLR	252.44 ± 145.62	658.92 ± 243.16	29.535 (0.000)
PCLR	393.94 ± 185.86	569.50 ± 224.56	2.966 (0.185)
$F_{group*time}$ = 5.686 (0.028)			

Values are presented as mean ± standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

Table 7. Overall dynamic balance ability of affected side

Group	Before rehabilitation exercise	After rehabilitation exercise
ACLR	1.56 ± 1.02	0.94 ± 0.45
PCLR	2.25 ± 0.86	1.55 ± 0.65
$F_{group*time}$ = 0.041 (0.841), F_{group} = 4.566 (0.047), F_{time} = 15.638 (0.001)		

Values are presented as mean ± standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

patients (F = 7.964, P = 0.020) but not of PCLR patients.

Changes in the maximum flexion force per unit body weight at an angular velocity of 180°/sec are presented in Table 6. An interaction was noted between group and time (F = 5.686, P = 0.028). Significant differences were observed in the flexors of ACLR patients (F = 29.535, P = 0.000) but not of PCLR patients.

Changes in dynamic balance ability of knee joint

Table 7 displays the mean overall dynamic balance ability scores for the affected side. No interaction was noted between group and time. As a result of testing the main effect, there was a difference in groups (F = 4.566, P = 0.047) and times (F = 15.638, P = 0.001).

Table 8 displays the mean anteroposterior dynamic balance scores for the affected side. A significant interaction was observed between group and time (F = 4.432, P = 0.049). In particular, significant differences were noted in anteroposterior dynamic balance ability before and after rehabilitation in ACLR patients (F = 8.321, P = 0.021) but not in PCLR patients.

Table 8. Anteroposterior dynamic balance ability of affected side

Group	Before rehabilitation exercise	After rehabilitation exercise	F (P-value)
ACLR	1.33 ± 0.88	1.00 ± 0.51	8.321 (0.021)
PCLR	1.64 ± 0.75	1.52 ± 0.76	0.310 (0.575)
$F_{group*time}$ = 4.432 (0.049)			

Values are presented as mean ± standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

Table 9. Left-right dynamic balance ability of affected side

Group	Before rehabilitation exercise	After rehabilitation exercise	F (P-value)
ACLR	0.96 ± 0.52	0.71 ± 0.41	9.294 (0.014)
PCLR	1.25 ± 0.49	1.27 ± 0.56	0.068 (0.801)
$F_{group*time}$ = 4.566 (0.047)			

Values are presented as mean ± standard error of the mean.
ACLR, anterior cruciate ligament reconstruction; PCLR, posterior cruciate ligament reconstruction.

Table 9 displays the mean left-right dynamic balance scores for the affected side. A significant interaction was observed between group and time (F = 4.566, P = 0.047). In particular, significant differences were noted in left-right dynamic balance ability before and after rehabilitation in ACLR patients (F = 9.297, P = 0.014) but not in PCLR patients.

DISCUSSION

Return to daily life and sports after ACLR or PCLR are crucial factors for improving the quality of life, with femoral muscle strength being vital for smooth performance. To facilitate such activities, the recovery of quadriceps and hamstring strength is essential as they provide knee joint stability, which is a critical indicator for resuming daily and sports-related activities (Arundale et al., 2017). Implementation of early rehabilitation programs has a positive impact on improving knee muscle function and muscle strength (Atkinson et al., 2010). Lee et al. (2005) applied an accelerated rehabilitation exercise program to participants after ACLR and measured the isokinetic strength at weeks 4 and 12. They reported that extension at 60°/sec was significantly increased from 110.5 Nm in week 4 to 201.2 Nm in week 12, and flexion at 60°/sec was also significantly increased from 66.2 Nm in week 4 to 128.7 Nm in week 12. Fitzgerald et al. (2003) compared the effects of a traditional exercise program and current accelerated rehabilitation exercise program for 12 weeks after patellar tendon reconstruction and reported that femoral muscle strength was significantly in-

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creased after the current accelerated rehabilitation exercise program but not after traditional exercise program.

In the present study, the 12-week accelerated rehabilitation exercise program after both ACLR and PCLR significantly increased the extension and flexion strength at 60°/sec, demonstrating the efficacy of accelerated rehabilitation exercise program. Furthermore, our findings suggest that the use of an early accelerated rehabilitation exercise program aids in the quick recovery of muscle strength after ACLR or PCLR. In contrast, at 180°/sec, a significant increase was noted in extensor muscular endurance in ACLR patients, whereas flexor muscular endurance changed in both ACLR and PCLR patients, but the change was only significant in ACLR patients.

In a study by Kim et al. (2022), extension and flexion strengths at 60°/sec were increased after PCLR. However, the increase was more significant at 6–12 months postreconstruction than at 0–3 months postreconstruction. Additionally, extension strength at 180°/sec was decreased during the first 3 months postreconstruction and then significantly increased at 3–6 months and at 6–12 months. In contrast, flexion strength was significantly increased at 3-, 6-, and 12-month postreconstruction. Margheritini et al. (2002) found that PCLR recovery took relatively longer than ACLR recovery and reported that the rehabilitation process was more critical for the former. Based on the findings of previous studies, the recovery of muscle strength and endurance is believed to be delayed in PCL injuries compared to ACL injuries. This delay can be attributed to the fact that the PCL is larger than the ACL and possesses the most potent tensile force among knee ligaments. As a result, damage to the PCL takes a longer time to heal, and its primary function is to prevent retrodisplacement of the tibia (backward movement of the shinbone). This delayed healing process may impact the recovery of muscle strength and endurance in patients with PCL injuries.

Knee joint balance and stability are maintained by proprioceptors in the ligaments and surrounding structures, which are essential to motor ability because they detect voluntary and involuntary movements through mechanoreceptor stimulation and transmit information to the central nervous system (Kennedy et al., 1982). ACL and PCL rupture suppresses the myotropic neural reflex and reduces the feedback response of these mechanoreceptors, consequently reducing the proprioceptive sense. This further affects knee joint balance and stability, resulting in instability with repetitive damage. Therefore, recovery of the proprioceptive sense after reconstruction is essential. Active early rehabilitation is essential to a patient's rapid recovery (Hoffman and Payne, 1995).

Choi and Shin (2012) showed that performing early rehabilitation exercises after ACLR significantly improved dynamic balance ability and proprioceptive sense at 4 and 8 weeks postoperative. Furthermore, while exercises supporting adequate weight soon after PCLR reportedly improved muscle strength and proprioceptive abilities (Lee et al., 2014), Clark et al. (1996) argued that active rehabilitation be performed to improve muscle strength and balance abilities because the proprioceptive sense decreases after PCLR. In this study, the results showed that both ACL and PCL patients had improved overall dynamic balance ability on the affected side after the 12-week accelerated rehabilitation program, but there was no significant difference between the two groups. Both the groups showed significant improvements in dynamic balance after the 12-week intervention, which likely stimulated the proprioceptive sense through muscle strengthening. However, when we analyzed anteroposterior balance and left-right balance separately, the changes were significant only in patients who underwent ACLR.

To enhance knee joint stability and balance, it is crucial to improve quadriceps and hamstring strength, as strong quadriceps facilitate faster gait cycles and prevent posterior displacement of the tibia, which helps to prevent knee instability (Akbari et al., 2015). While our study did not identify significant differences in muscle strength improvements between ACLR and PCLR patients, the improved dynamic balance ability in ACLR patients might be attributed to a higher degree of improvement in extensor and flexor endurance due to the accelerated rehabilitation exercise program in ACLR patients compared with that noted in PCLR patients.

In conclusion, the present study demonstrated that an accelerated rehabilitation exercise program that enhances muscle strength and muscular endurance proves can effectively improve the proprioceptive sense and dynamic balance ability of ACLR patients. However, our findings also suggest that PCLR patients may require more time to recover muscular endurance, indicating the potential need for a tailored rehabilitation program for PCLR patients.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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