

Correlation between Hamstring Flexor Power Restoration and Functional Performance Test: 2-Year Follow-Up after ACL Reconstruction Using Hamstring Autograft

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Purpose: To evaluate the restoration of the flexor power and the correlation between the flexor power and functional performance tests (FPTs) after anterior cruciate ligament (ACL) reconstruction with hamstring autograft.

Materials and Methods: Twenty-three men, who underwent ACL reconstruction with hamstring autograft, were evaluated using Lysholm, Subjective IKDC, Tegner activity score, isokinetic flexion and hyperflexion power test, and the FPTs at 1 and 2-year follow-up. We analyzed the mean change from 1 to 2 year and the correlation between both the flexion and hyperflexion power deficit with the FPTs at each follow-up.

Results: Mean age of the patients was 30.9 years (range, 19 to 44). Tegner activity score was significantly increased from 5.7 to 6.3 ($p=.010$). Hyperflexion power of the involved knee deficits significantly decreased at 2 year follow-up compared with 1 year ($p<.001$). There was a correlation between the flexor power deficit and the co-contraction, carioca, and involved one-legged hop test at each follow-up. However, no significant correlations were revealed between the hyperflexion power deficit and the FPTs.

Conclusions: Hyperflexion power deficit after ACL reconstruction with the hamstring autograft decreased at 2 year follow-up compared to 1 year and does not affect the results of the FPTs.

Key words: Hamstring autograft, Anterior cruciate ligament reconstruction, Flexion power, Hyperflexion, Functional performance test.

Introduction

The importance of hamstring on the stability of the anterior cruciate ligament (ACL) during sports activities has been documented in various studies^{1,2}. Unfortunately, knee flexor strength assessed in the sitting position can persist after ACL

reconstruction using hamstring autograft^{3,4}. According to Noyes and Sonstegard⁵, the semitendinosus and gracilis that form the pes anserinus play a primary role during $\geq 75^\circ$ hyperflexion of the knee. Nakamura et al.⁶ reported that the active knee flexion angle after ACL was significantly lower in the group where the gracilis tendon and semitendinosus tendon were harvested as grafts than in the group where the semitendinosus tendon only was harvested. Regarding the hamstring tendon regeneration after harvest for ACL reconstruction, Carofino and Fulkerson⁷ reported that the tendon became similar to normal by 18 months after harvest and suggested that postoperative strength recovery could be facilitated by stimulation of the regeneration process. However, most of these studies were based on <1 year short-term follow-up and did not elaborate on the relationship between the muscle strength deficit and knee function.

The purpose of this study was to investigate the influence of the recovery of flexion and hyperflexion deficit on knee function after ACL reconstruction using hamstring autograft. For this purpose, we assessed the flexion and hyperflexion deficit rates

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at 1 year and 2 years after surgery and analyzed the correlations with the functional performance tests (FPTs). Our hypothesis was that flexion deficit rate would not change between 1 year after surgery and 2 years after surgery but have a correlation with knee function, whereas a hyperflexion deficit rate would change between 1 year after surgery and 2 years after surgery but have no influence on knee function.

Materials and Methods

1. Materials

Of the patients who underwent ACL reconstruction using hamstring (semitendinous tendon and gracilis tendon) autograft between March 2006 and September 2010, 23 patients who were available for subjective tests, muscle strength test, and FPTs at 1 year and 2 years after surgery were included in this study. All the patients were young, active males who presented with an ACL injury alone, a combined meniscus injury that required partial meniscectomy or surgical repair, or a combined medial collateral ligament injury that required non-surgical treatment. Patients with other combined injuries were excluded from the study. The mean interval from injury to surgery was 24.2 ± 12.4 days. Female patients were excluded from the study for the following reasons: 1) direct comparison with males was impossible due to the significant intergender difference in the muscle volume increase during muscle strength training⁸; and 2) female patients have relatively low levels of activity, which makes mean value calculation difficult.

2. Surgical Technique

An autologous quadrupled hamstring tendon was used in all cases. A femoral tunnel was drilled at the 10 o'clock position for the right knee and 2 o'clock position for the left knee within the femoral notch. Femoral fixation was performed with

bioabsorbable cross pins. For tibial fixation, bioabsorbable interference screws were used and staples or cortical screws and washers were used. All the operations were performed by one surgeon.

3. Assessment Methods

For subjective assessment, Lysholm knee score, International Knee Documentation Committee (IKDC) subjective knee score, and Tegner activity score were used. Muscle strength testing was performed in the sitting position and in the prone position. The FPTs included co-contraction test, shuttle run test, carioca test, and one leg hop test.

1) Isokinetic strength test

Muscle strength was measured using Biodex (Biodex Corp., Shirley, NY, USA) dynamometer with the patient in a sitting position. The lateral femoral condyle was aligned with the rotational axis of the dynamometer. The knee flexion peak torque was determined from 4 trials that were performed at 90° at an angular velocity of $60^\circ/\text{sec}$ with full extension considered as 0° . For the assessment of the hyperflexion strength, peak torque was measured between 60° - 120° at an angular velocity of $60^\circ/\text{sec}$ in prone position and determined from 4 trials (Fig. 1). The interlimb difference was recorded in percent to obtain flexion deficit rate.

2) Co-contraction test

The co-contraction test was designed to reproduce rotational forces at the knee that necessitates tibial translation and counter-contraction of the femoral muscles. The test was performed with a Velcro belt secured around the patient's waist. The belt was attached to a rubber tube with a length of 122 cm (48 inches) and a diameter of 2.54 cm (1 inch). The tube was secured on a wall 154 cm (60 inches) above the floor. A semicircle with a radius



Fig. 1. (A) Isokinetic flexor test. At 0° - 90° with 4 trials in the sitting position. (B) Isokinetic hyperflexion test. At 60° - 120° with 4 trials in the prone position.

of 244 cm (96 inches) was painted on the floor. The patient was asked to run along the semicircular line 5 times and the time to completion was measured (Fig. 2).

3) Shuttle run test

The shuttle run test was designed to reproduce acceleration and deceleration forces that are common in sports activities. The patient ran back and forth on a 6.1-meter course twice for a total of 24.4 m and the fastest speed was recorded (Fig. 3).



Fig. 2. Co-contraction test. Co-contraction test is to step along the half circle line with wearing a rubber strap at the waist with 4 directional changes.

4) Carioca test

The carioca test was designed to reproduce the pivot shift movement in ACL-deficient patients. The patient was asked to run laterally using a cross-over step on a 12-meter course from left to right and then in a reverse direction. The fastest speed was recorded (Fig. 4).

5) One leg hop test

The one leg hop test was designed to assess dynamic stability of the ACL-deficient knee. The patient was asked to jump on one



Fig. 4. Carioca test. The Carioca test is run with a cross-over step in the side position for 12 m of distance in each direction.



Fig. 3. Shuttle run test. Shuttle run test is to run for 6.1 m of distance with 3 changes in direction.



Fig. 5. One-leg hop test. One-leg hop test is to jump off for distance with one leg as far as possible and the distance is recorded.

leg as far forward as possible. The test started from the affected leg and the hop distance was measured (Fig. 5).

4. Statistical Analysis

All the data were analyzed using SPSS/PC ver. 18.0 (IBM, Armonk, New York, USA) for Windows to obtain means and standard deviations. Subjective test results were analyzed using nonparametric Wilcoxon signed rank tests. The FPT results and flexion strength at 1 year and 2 years after surgery were compared using parametric paired t-tests. Correlations between flexion strength deficit, hyperflexion strength deficit, and FPTs were determined using the Pearson’s correlation coefficient.

Results

The data from a total of 23 patients were analyzed. The mean age of the patients was 30.9 years (range, 19 to 44 years). Their mean height and mean weight were 171.7 cm and 77.3 kg, respectively (Table 1). On the subjective tests, a statistically significant change was found in the Tegner activity score only, from 5.7±1.1 at 1 year after surgery to 6.4±1.3 at 2 years after surgery (p=0.010) (Table 2). On the FPTs, the shuttle run test results were slightly

worse at 2 years after surgery. The co-contraction test, carioca test, and one leg hop test results were slightly improved at 2 years after surgery, but no statistically significant difference was noted (Table 3). No notable change was observed between the two follow-up assessments in the flexion strength deficit measured in a sitting position. On the hyperflexion strength test performed in the prone position, the muscle strength of the affected leg was significantly improved from 47±12 Nm at 1 year after surgery to 54±13 Nm at 2 years after surgery (p=0.022). The hyperflexion deficit rate was significantly decreased from 25%±13% to 12%±12% (p<0.001) (Table 4).

Significant correlations were found between the flexion deficit rate and the FPTs at 1 year and 2 years after the surgery. The 1 year and 2 years correlation coefficients were r=0.401 and r=0.432, respectively, for the co-contraction test; r=0.442 and r=0.451, respectively, for the carioca test; and r=-0.312 and r=-0.354, respectively, for the one leg hop test (Table 5). No significant correlations were found between the hyperflexion deficit rate and the FPTs, both at 1 year and 2 years after surgery (Table 6).

Discussion

The purpose of this study was to assess hamstring tendon

Table 1. Demographic Characteristics

Age	Height (cm)	Weight (kg)	From injury to surgery (day)
30.9±9.4	171.7±16.6	77.3±9.4	24.2±12

Table 2. Comparisons of Subjective Knee Scores between 1 Year and 2 Year

	1 year	2 year	p-value
Lysholm	91.6±6.6	91.4±9.0	0.889
IKDC	88.8±12.9	88.7±14.1	0.984
Tegner	5.7±1.1	6.3±1.3	0.010 ^{a)}

^{a)}p<0.05.

Table 3. Comparisons of Functional Performance Tests between 1 Year and 2 Year

	1 year	2 year	p-value
Co-contraction test	15.8±1.5	15.8±3.1	0.969
Shuttle run test	8.0±0.6	8.1±1.2	0.648
Carioca test	9.5±1.2	9.3±1.0	0.280
Hop involved leg	145±19.3	152±27.1	0.107
Hop uninvolved leg	161.3±17.7	164.2±20.2	0.343

p<0.05.

Table 4. Comparisons of Peak Torques of Flexor Muscle between the Test at 1 Year and at 2 Years

		1 year	2 year	p-value
Flexor	Uninvolved leg (Nm)	110.3±21.5	111.3±22.9	0.671
	Involved leg (Nm)	97.9±26.4	100.0±24.4	0.301
	Deficit (%)	12.6±16.2	11.2±11.2	0.411
Hyperflexor	Uninvolved leg (Nm)	63.8±13.4	61.9±12.2	0.390
	Involved leg (Nm)	47.6±12.3	54.6±13.6	0.019 ^{a)}
	Deficit (%)	25.4±13.1	12.3±12.8	0.000 ^{a)}

^{a)}p<0.05.

Table 5. Correlation Coefficient between Flexion Strength Deficit and Functional Performance Tests in 1 Year Test and 2 Year Test

	Flexion strength deficit	
	1 year	2 year
Co-contraction	0.401 ^{a)}	0.432 ^{a)}
Shuttle run	0.092	0.050
Carioca	0.442 ^{a)}	-0.451 ^{a)}
Hop involved leg	-0.312 ^{a)}	-0.354 ^{a)}
Hop uninvolved leg	-0.021	-0.001

^{a)}p<0.05.

Table 6. Correlation Coefficient between Hyperflexion Strength Deficit and Functional Performance Tests at 1 Year Test and at 2 Years Test

	Flexion strength deficit	
	1 year	2 year
Co-contraction	0.221	0.107
Shuttle run	0.124	0.118
Carioca	0.352	-0.068
Hop involved leg	0.012	-0.129
Hop uninvolved leg	-0.042	-0.094

p<0.05.

regeneration following harvest for ACL reconstruction and to investigate possible correlations between the recovery of muscle strength and the FPTs. The hyperflexion deficit rate was improved between 1 year after surgery and 2 years after surgery; the improvement in the Tegner activity score at 2 years after surgery was statistically significant. However, the subjective knee score was not improved and no statistically significant change was observed in the FPTs.

The flexion and hyperflexion strength deficit and regeneration of the hamstring tendon after harvest have not been clearly elucidated. Eriksson et al.⁹⁾ reported that magnetic resonance imaging (MRI) performed at 6 to 12 months after ACL reconstruction using a semitendinosus tendon graft showed a regeneration of the semitendinosus tendon with normal anatomical topographies to the level of the tibial plateau in 8 of the total 11 patients. Papandrea et al.¹⁰⁾ examined 40 patients who had undergone ACL reconstruction with semitendinosus and gracilis tendon autografts using ultrasound preoperatively and at 2 weeks and 1, 2, 3, 6, 12, 18, and 24 months postoperatively and observed that the anatomical structure of the donor site was similar to that of the normal tendon at 18 to 24 months postoperatively. Simonian et al.¹¹⁾ evaluated 9 patients who had undergone ACL reconstruction with semitendinosus and gracilis tendon autografts using MRI for a minimum of 3 year follow-up and concluded that tendon harvest did not significantly compromise function and strength in spite of the more proximal insertion of the tendons after harvest compared to the nonoperated side.

Keays et al.¹²⁾ found muscle strength deficit in only 10% of the 31 patients at 6 months after ACL reconstruction using semitendinosus tendon grafts. However, some recent studies have shown that statistically significant muscle strength deficit can persist in knees ≥ 2 years after ACL reconstruction. Ardern et al.¹³⁾ found about 27% isokinetic muscle strength deficit in the

operated limb compared with the nonoperated in 50 patients with high sports activity after a mean follow-up of 32.5 months. In this study, we obtained more favorable results compared to the previous studies: the muscle strength deficit rate in the operated limb compared to the nonoperated limb was 12% at 1 year after surgery and 11% at 2 years after surgery. We attribute these findings to the rigorous rehabilitation performed at least once a week until 6 months after surgery.

Onishi et al.¹⁴⁾ investigated the relationship between the EMG activity of the four different hamstrings and knee flexion angle and reported that the EMG activity of the semitendinous tendon increases at 70° and peaks between knee flexion angles of 90° and 105°. Tashiro et al.¹⁵⁾ reported that hamstring muscle strength weakness in the operated limb was observed at $\geq 70^\circ$ of flexion in the sitting position and prone position in 85 patients who underwent ACL reconstruction using hamstring tendon grafts. Adachi et al.¹⁶⁾ found no significant side-to-side difference in flexion strength in 58 patients who underwent ACL reconstruction using hamstring grafts, but the active knee flexion angle was significantly lower in the operated limb. Thus, they suggested that ACL reconstruction using hamstring tendon grafts should be followed by hyperflexion strength tests and be determined with care in patients who perform sports activities in which strong knee flexion strength is required in deep flexion angle of the knee. In this study, the mean hyperflexion strength deficit of 25.4% in the operated limb was significantly high compared to the nonoperated limb at 1 year after surgery, but it was decreased to 12% at 2 years after surgery, which was below the normal level of 15%.

In this study, the subjective test results had not changed significantly between 1 year after surgery and 2 years after surgery. This might have been because the Lysholm knee score and IKDC subject score were already close to normal at 1 year after surgery. Obtaining near normal scores before sufficient functional recovery can be explained by a ceiling effect, which means that the experimental treatment was so effective or the test level was so low that all the patients could obtain high scores. This result may also indicate that knee score cannot be helpful in assessing knee function in long-term follow-up. In contrast, the mean Tegner activity score was significantly improved from 5.7 points at 1 year after surgery to 6.3 points at 2 years after surgery. Thus, we believe that Tegner activity score can be useful for the long-term follow-up assessment of knee function. Beard et al.¹⁷⁾ and Ejerhed et al.¹⁸⁾ also reported that the mean Tegner activity score was improved to 4.3-6.5 at 2 years after surgery. On the other hand, Ejerhed et al.¹⁸⁾ reported that the Tegner activity level was

reduced by two to three units compared to the preinjury level. In our study, however, the mean Tegner activity level before injury was 6.4 and the value at 2 years after surgery was similar to the preinjury level.

Keays et al.¹⁹⁾ followed 62 patients who underwent ACL reconstruction using patellar tendon grafts (n=31) and hamstring tendon grafts (n=31) and compared them with normal healthy controls at 6 years after surgery. In their study, no significant intergroup differences were found in muscle strength. In terms of the results of FPTs (shuttle run test, carioca test, and one leg hop test), the hamstring tendon graft group was similar to the normal group, whereas the patellar tendon graft group was significantly different from the normal group. In our previous study²⁰⁾, we investigated the correlations among the FPTs (one leg hop test, co-contraction test, shuttle run test, and carioca test) in 40 active subjects who had a normal Tegner activity score of 6-7 points. The mean time for the co-contraction test, shuttle run test, and carioca test was 15.34 seconds, 7.67 seconds, 8.47 seconds, respectively. On the one leg hop test, the mean hop distance was 157.8 cm for the dominant leg and 160.1 cm for the non-dominant leg. In the current study, the mean time for the co-contraction test, shuttle run test, and carioca test was 15.8 seconds, 8.0 seconds, and 9.48 seconds, respectively, at 1 year after surgery and 15.8 seconds, 8.1 seconds, and 9.3 seconds, respectively, at 2 years after surgery. The mean co-contraction test value at 2 years after surgery was similar to that of the normal group, whereas the mean time for the shuttle run test and carioca test at 2 years after surgery was longer by 0.5 seconds and 0.9 seconds, respectively. The mean hop distance in the normal group was 157.8 cm for the dominant leg and 160.1 cm for the non-dominant leg. In the current study, the mean hop distance at 2 years after surgery was close to normal, 164.2 cm for the nonoperated leg and 152.5 cm for the operated leg.

On the relationship between the flexion deficit rate in the sitting position and the FPTs, the flexion deficit rate was associated with the co-contraction test, carioca test, and one leg hop test of the operated limb. Viola et al.²¹⁾ reported that ACL reconstruction using hamstring tendon grafts may result in a deficit in knee flexor strength and internal tibial rotation weakness, which could interfere with postoperative rehabilitation and potentially impair athletic performance. The correlation between the co-contraction test and the carioca test might be attributable to the fact that these two tests are to assess tibial rotation strength. However, they cautioned that since the importance of flexor strength and internal rotation weakness and functional role have not been defined yet, the adverse impact on athletic performance is not

clear.

In our previous study²²⁾, we evaluated correlations between the hyperflexion deficit recovery and the Lysholm knee score, IKDC subject score, Tegner activity score, KT-2000, Hop test, and three FPTs at 19 months after ACL reconstruction that had used hamstring autografts. There was no correlation between the hyperflexion deficit rate and the FPTs.

The weaknesses of this study include the small study population, the possibility of patient selection bias, and inclusion of male patients only. We believe further studies involving a larger study population and a long-term follow-up should be conducted to verify our results.

Conclusions

Hyperflexion deficit rate after ACL reconstruction with hamstring autografts at 2 years after surgery was lower than that at 1 year after surgery and had no influence on the FPT results.

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