Changes in Isokinetic Muscle Strength of the Lower Extremity in Recreational Athletes With Anterior Cruciate Ligament Reconstruction

Yukio Urabe, Mitsuo Ochi, and Kiyoshi Onari

Objective: To investigate changes in muscle strength in the lower extremity after ACL reconstruction. Design: Prospective case series. Dependent Variables: Isokinetic muscle strength measured in 6 movements (hip extension/flexion, hip adduction/abduction, knee extension/flexion) and circumference of the thigh/calf. Setting: Clinic and home. Patients: 44 (24 men, 20 women) between the ages of 16 and 47 years with an ACL rupture. All underwent reconstruction via a semitendinosus autograft. Main Outcome Measures: The peak torque for each joint movement was recorded. Repeated-measures ANOVA and power analysis were conducted to detect significant interaction effects. Results: The decline of muscle strength after ACL reconstruction remained not only in the knee extensors and flexors but also in the hip adductors. Conclusion: Rehabilitation programs that address the behavioral patterns and physiological characteristics of an ACL injury will benefit the athlete's whole body and lead to a full recovery. Key Words: ACL reconstruction, hip-adductor weakness, kinetic linkage, synergy


Over the last few years, several researchers investigating the rehabilitation of ACL injuries have concentrated their attention on a single knee-joint function, although the interrelationship between muscles and joints in the lower extremity is a fairly complex one. For example, Elmqvist et al1 and Kannus et al2 reported a decline in knee-extensor and -flexor muscle strength after the completion of appropriate rehabilitation exercises. Arvidson et al3 and Seto et al4 reported that muscle weakness in the injured knee joint can be observed 5–10 years after an ACL reconstruction. Other studies indicated that a combination of factors, such as reduced physical activity and lack of body-weight bearing after surgery, could account for the prolonged muscle weakness around the knee.3,5,6 Without clarifying issues such as how proximal muscle groups are affected by knee surgery and whether muscle-kinematic characteristics return to normal after successful surgery

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and proper rehabilitation, typical rehabilitation programs for ACL recon-
struction indicate a tendency to simply focus on the knee-joint function by
developing muscle strength.

Several recently published articles dealt with the issues related to dis-
rupted kinetic linkage in the lower extremity (eg, gait-pattern \(^7\) and knee-joint
instability \(^4\)) after an anterior cruciate ligament (ACL) rupture. For example,
Kibler stated that knee-joint movement is actually determined by the mo-
tion and position of adjacent links in the kinetic chain that operates during
various movements. \(^8\) As with all the possible factors in the etiology of ACL
injuries, the importance of other joints in the lower extremity is still not
clear. For rehabilitation of the knee joint to be most effective, some sort of
patterned conditioning programs such as monoarticular muscle activation
in activity-specific patterns should also be included.

Because the movement of the lower extremity is likely determined by
the motion and position of multiple joint links in the kinetic chain, we
hypothesized that the strength of both proximal and distal muscle groups
(eg, hip and ankle joints) is likely decreased, even after successful surgery
and proper rehabilitation, as a result of several factors such as the phys-
iological stress imposed by surgical intervention itself, a decrease in daily
activity level, and rehabilitation that does not focus on the recovery of
entire kinematic muscle characteristics of the lower extremity. In this study,
our purpose was to investigate the changes in muscle strength of all joint
segments in the lower extremity after knee rehabilitation following ACL
reconstruction.

### Methods

Three dependent factors— isokinetic muscle strength (hip extension/flexion,
hip adduction/abduction, and knee extension/flexion) and the circum-
ferences of the thigh and calf—were measured 5 times (preoperation and
3, 6, 9, and 12 months postoperation). In this investigation, all comparisons
were made by using the contralateral, uninjured leg as a control.

### Subjects

Forty-four subjects with a diagnosis of an ACL rupture volunteered for
the study, 24 men and 20 women with an average age of 32.7 years (range
16–47). All underwent a reconstruction only via semitendinosus autograft
at Hiroshima University Hospital. Before the ACL injury, they had been
participating in various sport activities such as skiing, basketball, soccer,
and volleyball on an irregular basis.

The types of ACL injury included an isolated ACL rupture, an ACL
rupture with a meniscus injury, and an ACL rupture with a cartilage in-
jury. Subjects with ACL injuries involving other knee ligaments such as
the medial, lateral, or posterior cruciate ligament were excluded from the study. The average time from injury to ACL reconstruction was 4.2 months. Each subject submitted written informed consent before participating in the study.

**Instrumentation and Measurement Procedures**

Patients were evaluated according to the International Knee Documentation Committee (IKDC) knee-evaluation form. Four problem areas—subjective assessment, symptoms, range of motion, and ligament examination—were included in this evaluation. Each parameter was then qualified as normal, nearly normal, abnormal, or severely abnormal. The worst group qualification was taken as the final total qualification.

To measure anterior tibial translation, the knee was flexed at 25° with 133 N of anterior stress applied with a KT-2000 knee arthrometer (MED Metric Inc, San Diego, Calif). The circumference of the thigh was measured 15 cm above the proximal border of the patella. The calf circumference was measured at the maximal contraction level. The same examiner performed all measurements.

For the measurement of isokinetic muscle strength in the lower extremity, we selected a Cybex-Norm dynamometer (Henley Health Care Co, Tex). Eight isokinetic movements (hip extension and flexion, hip adduction and abduction, knee extension and flexion, and ankle dorsiflexion and plantar flexion) were measured with reference to the Cybex-Norm instruction manual. After finishing practice sessions, all subjects attempted 5 repetitions of each movement with maximal effort. The best peak torque of 5 measurements for each joint movement was then recorded. The angular velocity was set at 60° and 180°/s for all measurements. These angular-velocity settings were selected in reference to previous research.

**Rehabilitation Procedures**

We designed our rehabilitation program to progress more slowly than Shel-bourne’s accelerated rehabilitation protocol because of the concern over the postoperative strength of a grafted part resulting from a surgical method used for ACL reconstruction.

After ACL reconstruction, each subject was given a soft-type knee brace (Konishi Apparatus Co, Japan) that prevents full extension of the knee. This brace is a flexible fabric brace with firm foam padding attached by a uniaxial hinge with an extension-range adjuster. For 2 months after surgery, the range of motion was limited to 10° of knee flexion with this brace. Postoperatively, there was no restriction placed on knee-flexion movement.

At 2 weeks postsurgery, subjects were instructed to do quadriceps isometric setting exercises at a joint position of 90° knee flexion, as well as
open kinetic chain (OKC) exercises for the hamstrings with rubber tubing. All patients were allowed full body-weight bearing on the operated leg by 3 weeks after surgery. After 3 weeks, each subject was instructed to do closed kinetic chain (CKC) exercises such as squats and lateral step-ups with gradual body-weight bearing. After 4 weeks, bike exercises were commenced. At 3 months postsurgery, most subjects were able to fully extend the knee and commenced walking/running exercises. Full participation in sport activities was restricted up to 8 months after surgery. Any ballistic-type exercises that would put stress on isolated hip extension/flexion, hip internal rotation/external rotation, and ankle dorsiflexion/plantar flexion were prohibited for up to 1 year after surgery.

For the first month after surgery, physical therapists were assigned for all patients to supervise their rehabilitation in the hospital, monitoring the compliance with the postoperative rehabilitation protocol. After 1 month of supervised rehabilitation, all patients were released with instructions for home-based rehabilitation programs. The progress of patients’ rehabilitation was then checked by assigned physical therapists once a week at the time of their hospital visits.

Statistical Analysis

Statistical analysis was conducted using the StatView 5.0J computer software system (SAS Institute). The following statistical tests were applied to the data. First, in all subjects, the Student paired t test was used to analyze the difference between isokinetic muscle strength and circumferences of the thigh and calf of operated and unoperated legs. Second, a correlational analysis was conducted to clarify the relationship between an anterior displacement of the tibia and isokinetic muscle strength of each joint in the lower extremity (ie, hip, knee, and ankle joints). This type of analysis was also conducted for the correlation between the decline of muscle strength in the knee and each joint in the lower extremity. Third, a repeated-measures analysis of variance was computed to evaluate the changes in muscle strength and circumferences over the course of the study. Finally, a Fisher least-significant-difference method was used to identify significant pairwise comparisons. All tests were 2-tailed with a significance level set at $P < .05$. We also performed postoperative power analysis on the isokinetic muscle strength of the knee and hip joints.

Results

According to the preoperative IKDC analysis, 13 patients considered their knees nearly normal, 26 patients regarded their knees as abnormal, and 5 patients regarded their knees as severely abnormal. The postoperative IKDC analysis at 12 months postsurgery revealed that 30 patients consid-
ered their knee function normal and 14 (31.8%) rated their knees as nearly normal. IKDC scores obtained from 31 patients (both abnormal and severely abnormal) indicated significantly lower knee-muscle strength than in 13 nearly normal patients. On the other hand, 30 patients with improved IKDC scores (up to normal) indicated a tendency of an insignificant decline of knee-muscle strength as compared with 14 nearly normal patients. Among these 30 patients with improved IKDC scores, the postoperative knee-muscle strength indicated an insignificant difference between injured and uninjured sides ($P < .05$).

Table 1 indicates the change in anterior tibial translation after surgery. At 12 months, a mean difference in anterior tibial translation between the injured and uninjured knees was 1.4 mm. Because we found a side-to-side difference between the uninjured and injured knees after surgery, anterior tibial translation was remeasured at 15 months ($x = 1.3, s = 2.9$). We found no statistically significant correlation, however, between isokinetic muscle strength in the hips, knees, or ankles and the degree of anterior tibial translation ($r = -.0023$ to .107).

According to our findings, the decline in muscle strength after ACL reconstruction occurred not only in the knee extensors ($-11.9\%$) and knee flexors ($-8.6\%$) but also in the hip adductors ($-7.1\%$). The weakness in isokinetic muscle strength of knee extension and knee flexion were also found on the injured side at 60°/s ($P < .001$; Figures 1 and 2). One year postsurgery, the isokinetic muscle strength of the quadriceps and hamstrings also decreased by 11.9% and 8.6%, respectively. The weakness in isokinetic muscle strength on the injured side disappeared in the hip extensors, hip flexors, hip abductors, and ankle dorsiflexor/plantar flexor at 6 months postsurgery. The hip adductors, however, continued to display weakness ($P < .001$; Figure 3).

With 80% to 90% power, we detected no statistically significant dif-

<table>
<thead>
<tr>
<th></th>
<th>Preoperation</th>
<th>3 mo</th>
<th>6 mo</th>
<th>9 mo</th>
<th>1 y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injured</td>
<td>13.5 (3.1)</td>
<td>6.7 (2.7)</td>
<td>8.7 (2.9)</td>
<td>9.5 (2.8)</td>
<td>9.8 (2.6)</td>
</tr>
<tr>
<td>Uninjured</td>
<td>7.8 (2.2)</td>
<td>8.4 (2.8)</td>
<td>8.2 (2.8)</td>
<td>8.3 (2.7)</td>
<td>8.5 (2.5)</td>
</tr>
<tr>
<td>Side-to-side difference</td>
<td>5.4 (2.2)</td>
<td>-1.7 (3.6)</td>
<td>0.5 (3.5)</td>
<td>1.2 (3.0)</td>
<td>1.4 (3.1)</td>
</tr>
</tbody>
</table>

*Among the 44 patients, there were no correlations between isokinetic muscle strength in the hips, knees, or ankles and the degree of anterior tibial translation ($r = -.023$ to .107). $P < .05$. 
References in isokinetic muscle strength among hip extensors, hip flexors, and hip abductors 6 months post surgery. The operated knees indicated an increase in isokinetic muscle strength to close to the preoperative level. Figures 1–3 show a gradual recovery of isokinetic muscle strength over a yearlong recording of rehabilitation progression. For example, the 1-year postoperative values seem to be almost the same as the preoperative values. At 2 years postsurgery, the correlation in isokinetic muscle strength between
the hip adductors and knee extensors, as well as between the hip adductors and knee flexors, was found to be statistically significant ($r = .403$ to $.433$, $P < .01$; Figures 4 and 5).

According to ANOVA, the changes in isokinetic muscle strength of the hip adductors, knee extensors, and knee flexors were statistically significant ($P < .001$). At 3 months postsurgery, isokinetic muscle strength decreased in the hip extensors, flexors, and adductors. No statistically significant differences were found, however, between the hip extensors and hip flexors after 6 months. The measurement of isokinetic movement revealed a significant decline of muscle strength in the hip adductors ($–6.6\%$), knee extensors ($–9.4\%$), and knee flexors ($–7.1\%$) at an angular velocity of $60°/s$ 1 year postsurgery ($P < .001$). According to the measurement of isokinetic movement at an angular velocity of $180°/s$, a significant decline of muscle strength in the hip adductors, knee extensors, and knee flexors was also confirmed 1 year after surgery (Table 2). From preoperation to 1 year after surgery, the $P$ values for isokinetic muscle strength of the hip adductors, knee extensors, and knee flexors ranged from $0.018$ to $0.096$. During the same period, there was no decrease in isokinetic muscle strength in the ankles (dorsiflexion and plantar flexion) at an angular velocity of $60°/s$. No significant difference in isokinetic muscle strength of the knee joint was found at $180°/s$ between preoperative and postoperative levels.

From preoperation to 9 months after surgery, the circumference of the thigh and calf decreased on the injured side ($P < .001$ to $0.02$; Figures 6 and 7). One year postsurgery, however, the decrease in circumference was
Figure 4  Correlation between isokinetic muscle strength of the hip adductors and knee extensors. The uninjured:injured ratio was calculated as follows: \( \left[ \frac{\text{Strength of muscles on the uninjured side}}{\text{strength of the muscles on the injured side} - 1} \right] \times 100 \). The correlation was statistically significant \((r = .40, P < .01)\).

Figure 5  Correlation between isokinetic muscle strength of the hip adductors and knee flexors. The uninjured:injured ratio was calculated as follows: \( \left[ \frac{\text{Strength of muscles on the uninjured side}}{\text{strength of the muscles on the injured side} - 1} \right] \times 100 \). The correlation was statistically significant \((r = .43, P < .01)\).
Table 2  Changes (in mm) in Isokinetic Knee-Extensor, Knee-Flexor, and Hip-Adductor Strength in 44 Patients After Anterior Cruciate Ligament Reconstruction, Nm/kg*

<table>
<thead>
<tr>
<th></th>
<th>Preoperation</th>
<th>3 mo</th>
<th>6 mo</th>
<th>9 mo</th>
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<tbody>
<tr>
<td></td>
<td>Injured</td>
<td>Uninjured</td>
<td>Injured</td>
<td>Uninjured</td>
<td>Injured</td>
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<tr>
<td>Knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>extension</td>
<td>1.31</td>
<td>1.40</td>
<td>1.05</td>
<td>1.38</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>(0.29)</td>
<td>(0.27)</td>
<td>(0.23)</td>
<td>(0.28)</td>
<td>(0.25)</td>
</tr>
<tr>
<td>Knee</td>
<td>1.03</td>
<td>1.08</td>
<td>0.82</td>
<td>1.10</td>
<td>0.96</td>
</tr>
<tr>
<td>flexion</td>
<td>(0.20)</td>
<td>(0.20)</td>
<td>(0.18)</td>
<td>(0.21)</td>
<td>(0.18)</td>
</tr>
<tr>
<td>Hip</td>
<td>1.51</td>
<td>1.54</td>
<td>1.34</td>
<td>1.54</td>
<td>1.40</td>
</tr>
<tr>
<td>adduction</td>
<td>(0.23)</td>
<td>(0.24)</td>
<td>(0.19)</td>
<td>(0.22)</td>
<td>(0.22)</td>
</tr>
</tbody>
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*The angular velocity was 180°/s. All differences between the involved and uninvolved knees at a given time were statistically significant in the knee extensor (t test, \(P < .05\) to \(.01\)), the knee flexor (t test, \(P < .05\) to \(.01\)), and the hip adductor (t test, \(P < .05\) to \(.01\)). Differences in knee-extensor, knee-flexor, and hip-adductor strength between the involved and uninvolved knees over time were also significant (ANOVA, \(P < .001\)).
found only in the thigh on the injured side. According to the result of power analysis on the circumference measurement of the calf, we obtained 82% power; therefore, our null hypothesis was not rejected. The mean decrease in circumference of the thigh was 0.8 cm (1.7%).

Discussion
In this prospective study, we confirmed a relatively desirable functional recovery for all subjects. In spite of successful ACL reconstruction and yearlong rehabilitation, however, the isokinetic characteristics finally did not show the complete improvement to preinjury levels or those of the contralateral, uninjured leg. The same results have also been obtained in previous studies.\textsuperscript{1-4} Although our yearlong rehabilitation program was unable to improve knee-muscle strength up to a preoperative level, it is difficult to speculate about a negative impact of our rehabilitation protocols on complete recovery of the injured knee, in consideration of IKDC scores and the results of KT-2000 measurement obtained in this study.

As the reason for the weakening of the hamstrings and hip-adductor muscles, we had to be concerned over the use of semitendinosus tendon as a grafting material for ACL reconstruction. Ohkoshi et al\textsuperscript{18} reported that harvesting of the autogenous semitendinosus tendon does not affect peak torque, but the possibility of tensile-strength loss in hamstrings tendon resulting from the grafting cannot be overlooked. Currently, patients’ objective satisfaction with the results of ACL reconstruction is not substantiated by concrete evidence of successful postoperative outcomes. One could speculate that a full recovery of muscle-kinematic characteristics is probably not possible and that they never reach the level of those of the uninjured, contralateral leg in spite of good surgery and sound rehabilitation protocols. We might not be able to restore the appropriate joint kinematics because a proprioceptive pathway has been unrecoverably destroyed with the rupture of the ACL.

To attain a sound kinetic linkage of the lower extremity, it is essential for all joints in the lower extremity to be activated in concert. In fact, in activities of either sport or daily life, the body does not operate in isolated segments but rather works as a dynamic unit.\textsuperscript{19} For example, the activation of proximal hip muscles is reported to be delayed in patients with severe ankle injury compared with uninjured controls during hip active extension.\textsuperscript{20} The possibility that injury to a distal segment affects this proximal-to-distal muscle-activation sequence, as well as normal motor programs, further supports the need to incorporate these motor programs throughout the rehabilitation process from an early stage.

Traditionally, knee rehabilitation has emphasized a phase of rest, control of inflammation, and isolated muscle strengthening. Such rehabilitation exercises also tended to isolate the involved tissue initially, while neglecting the contributions of adjacent body segments in the lower extremities, such as the hip joint.\textsuperscript{1-3,5,6,12,21,22} Thus, the components of functional rehabilitation programs, such as joint stabilization, proprioception, and CKC exercises, had been more or less neglected in traditional rehabilitation protocols.\textsuperscript{15,16}

The latest knee-rehabilitation protocols have begun to incorporate more functional-movement patterns. They emphasize more functional factors such as kinetic-linkage activation, intrinsic motor patterns, CKC
exercises, and proprioceptive neuromuscular facilitation. For example, for ACL-rehabilitation programs, a number of sports-medicine researchers are currently emphasizing hip-adduction and -abduction movements.\textsuperscript{8,17,23} They suggest hip-joint training for the prevention of claudication, as well as the recovery of joint kinematics in the lower extremity. Calmels et al\textsuperscript{11} investigated muscle strength of the hip, knee, and ankle after knee-flexion and -extension exercises (CKC and OKC) in a healthy population. According to their findings, unlike traditional single-joint exercises (eg, single-joint OKC exercises), such exercises produced more training effects not only for the knee but also for other joints in the lower extremity (the hip and ankle). Bose and Kanagasuntheram\textsuperscript{23} suggested that there is a synergistic relationship between the vastus medialis oblique (VMO) and the hip-adductor muscles. They found that the insertion of the VMO originates partially from the adductor longus tendon, adductor magnus tendon, and medial intermuscular septum, with the main origin from the tendon of the adductor magnus. Hanten and Schulthies\textsuperscript{24} and Karst and Jewett\textsuperscript{25} confirmed that the contraction of the VMO accompanied hip adduction and suggested that stimulating the VMO might indirectly activate the hip adductors. If it could be assumed that isokinetic characteristics of the hip-adductor muscles have a direct, synergistic relationship with the knee-extensor and -flexor muscles in ACL-deficient patients, the correlation of hip-muscle and knee-extensor strength between uninjured and injured sides could be understood (Figure 4). Future research should be conducted to investigate how the maintenance of hip-muscle strength (hip extensors and hip adductors) affects the recovery of knee-muscle strength after ACL reconstruction.

As regards other synergistic functions in the lower extremity, Basmajian reported the activity of hip adductors during knee flexion in adults.\textsuperscript{26} Lanz and Wachsmuth\textsuperscript{27} reported that the hip-adductor muscles could generate up to 99.4 kgm of contraction force and suggested that hip adduction would involve contraction forces from the knee flexors (the semitendinosus, semimembranosus, and biceps femoris) of up to 17.9\%. These statements are suggestive of possible synergistic characteristics between the hip adductors and knee flexors (Figure 5). A synergistic relationship between these muscle groups, however, probably has completely different muscle-kinematic characteristics from the one between the hip adductors and knee extensors. Our data indicate that contraction of the hip adductor produced a greater stimulus for the activation of both the knee-extensor and -flexor muscles (Figures 4 and 5). In future studies, investigating functional outcomes in relation to the muscle-kinematic characteristics of the lower extremity could lead to new findings of another interesting correlation.

The anatomical construction of the VMO muscle suggests that its contraction would likely provide irradiating stimuli for the activation of the knee-extension movement, even though its physiological relationship is
indirect. For example, with our rehabilitation programs including bike exercises, squat and step-up exercises, and walking/running, these exercise movements subsequently imparted great stimuli to the development of the hip muscles, although in our exercise prescription, there was no exercise assignment specifically aimed at improving hip-muscle strength. Our findings are highly suggestive of the presence of this functional association between the knee extensors/flexors and the hip adductors.

In the CKC approach, applying axial compression through the hip joint likely increases hip-joint stability at various levels of range of motion. This method likely restores normal movement patterns that are familiar to the neuromuscular system so that rehabilitation can occur within the framework of normal function. In knee rehabilitation, the hip muscles possibly assume primary importance by controlling the trunk in relation to the leg and by increasing quadriceps and hamstrings activation. A positive correlation between the reduction of hip-adductor strength and knee-extension and -flexion strength in this study would support this speculation (Figure 4 and 5).

As with other potential risk factors for ACL injuries, it is still not clear how major a role the hip and trunk play. From the results of our investigation, we believe that an ACL rupture subsequently influences hip-adductor muscle strength and its normal proximal-to-distal muscle-activation pattern in the lower extremity, which eventually lessens muscle strength and indirectly reduces the tolerable workload of the lower extremities as a whole. The presence of knee- and hip-muscle weakness after knee surgery would suggest the necessity of improving muscle strength by activating the entire lower extremity. Thus, in formulating ACL injury-prevention strategies, conditioning all the muscles of the trunk and extremity, not just the muscles around the knee, should be considered beneficial.

Successful leg rehabilitation depends on a complete, accurate diagnosis of the involved tissues, as well as a thorough understanding of the physiological relationship among the joints in the lower extremities (the hips, knees, and ankles). In addition, the potential for a mild postoperative rehabilitation protocol to result in findings that could differ from a more aggressive protocol (eg, Shelbourne’s accelerated ACL-rehabilitation program) should not be overlooked.

As a recommendation for future research, diagnostic-imaging devices such as MRI should be employed to examine the physiological process of muscle-size changes in the knee extensors, knee flexors, and hip adductors. Such examinations might help detect the relative mechanism of muscle atrophy in the lower extremities after surgery, so that intervention techniques can be implemented to prevent potential factors for muscle weakness. Currently, the complexity of the anatomical relationships in the lower extremities, coupled with the variance in subject population and data-collection procedures, only allows us to suggest an association between the knee and hip muscles. As another future research topic, an
uninjured subject should serve as a control, because ACL injuries have been reported to affect the contralateral leg, as well. A comparison of BPTB (bone–patellar-tendon–bone) grafting among competitive athletes would be another important research topic. Dividing the subjects into such groups might reveal other interesting correlations.

**Comments**

In spite of good ACL-reconstructive surgery and a sound rehabilitation program, the isokinetic characteristics of the injured leg likely remain different from those of the contralateral, uninjured leg. In this study, knee-extension and hip-adduction strength were diminished in comparison with the contralateral side up to 1 year postsurgery. The strength of knee-joint muscles also did not exceed a preoperative level, although a better IKDC score was obtained postoperatively than preoperatively. In an effort to reduce the lasting effects of ACL injury, the sports therapist should direct the focus of rehabilitation toward improving neuromuscular coordination of interdependent joint segments, not simply toward increasing strength and endurance of an individual joint. Rehabilitation programs that address the behavioral patterns and physiological characteristics of an ACL injury would more likely benefit the athlete’s whole body and lead to a full recovery.

Several concepts are important to remember in designing a knee-rehabilitation program after ACL reconstruction:

- Our investigation revealed that proximal muscle groups in the lower extremity are affected by ACL reconstruction.
- The results of our investigation suggest the presence of synergistic action among the knee extensors, knee flexors, and hip adductors.
- Isokinetic characteristics of the hip-adductor muscles likely have a direct relationship with the knee-extensor and -flexor muscles in ACL-deficient patients. It might be possible to encourage the recovery of the knee-muscle strength by maintaining strength at the hip joint.
- In structuring an effective and functional knee-rehabilitation program, isolated joint exercises do not appear to be beneficial enough. A traditional ACL-rehabilitation program would not be as effective as was previously thought for the recovery of dysfunctional activation or weakening of both local and distant muscles around the knee joint.
- Full recovery of muscle-kinematic characteristics is probably not possible, and they never reach the level of those of the uninjured, contralateral leg in spite of good surgery and good rehabilitation protocols.

**Acknowledgment**

We would like to thank Masaki Komatsu, MS, ATC, for his assistance in completing this study.
References


