

Comparison of Eccentric and Concentric Isokinetic Exercise Testing after Anterior Cruciate Ligament Reconstruction

Tae-sik Yoon and Jin-won Hwang

Abstract

Evaluation of muscle function can be helpful in rehabilitation programs with knee injuries. The purposes of this study were to evaluate muscle performance and functional level through eccentric and concentric isokinetic testing after anterior cruciate ligament reconstruction, and to determine whether eccentric and concentric isokinetic values were correlated with functional level using the Modified Cincinnati Scale (MCS). In order to compare the characteristics of eccentric and concentric parameters, we tested 24 male patients (mean age; 31.1 years) after primary reconstruction of ruptured anterior cruciate ligaments of the knee (mean duration; 20.2 months), at angular velocities of 60 degree/sec using Cybex 6000 isokinetic dynamometer. We also evaluated the functional level using the MCS. The values of peak torque of the involved knee extensors and flexors were significantly lower than the uninvolved limb in all eccentric and concentric tests ($p < 0.01$). The deficiency ratios of peak torque in knee extensors were significantly larger than knee flexors in both eccentric and concentric tests ($p < 0.01$). The MCS was inversely correlated with the deficiency ratio in peak torque of eccentric knee extensors ($p < 0.05$). These results suggest that eccentric knee extensor training is essential to restore the functional capacity of the injured knee and that isokinetic evaluation is necessary to plan rehabilitation programs to correct possible imbalances which may be predispose subjects to future injury.

Key Words: Anterior cruciate ligament reconstruction, eccentric, concentric, isokinetic tests

INTRODUCTION

The knee is a special and wonderful construction of our living tissues. The femorotibial joint surfaces are noticeably incongruent and offer just a two-point contact area. The hip joint, in contrast with its spherical head in its socket, as well as the ankle, have large contact surfaces for load transfer. How, then, can the knee function with only these two contact areas for heavy load transmission?¹

The key to the explanation of the manner in which the knee functions lie in the two crucial ligaments, that form the central pivot and their mechanical system of crossed four-bar linkage. Together, these two attributes allow the knee to move six degrees of freedom.¹

The cruciate ligaments guide and stabilize the knee, and with their elasticity they also attenuate local peak force stress to acceptable rates for the tissues.¹

The knee is the most frequently injured area of the body in sports activities. In recent years, an increase in the sporting population has meant that the incidence of knee injuries has also increased. Anterior cruciate ligament (ACL) injury is the most common and significant problem of all knee injuries, and if not properly treated, patients can encounter many complications such as muscle atrophy, limitation of range of motion, and degenerative changes of the knee joint.² Therefore, proper reconstruction for restoring the functional capacity and an intensive rehabilitation program is essential for ACL injuries.

Isokinetic testing of muscle performance has become commonplace in physical therapy since it was first introduced clinically in 1967. Numerous investigators have reported high reliability of neuromuscular performance parameters such as concentric peak torque, work, and power. However, almost all such literature has only dealt with normal, healthy subjects. Most of the clinical application of isokinetic

Received June 14, 2000

Accepted August 24, 2000

Department of Rehabilitation Medicine, Ewha Womens University College of Medicine, Seoul, Korea.

Address reprint requests to Dr. T. S. Yoon, Department of Rehabilitation Medicine, Ewha Womens University College of Medicine, Mokdong Hospital, 911-1 Mok Dong, Yang-Cheon Gu, Seoul 158-710, Korea. Tel: 82-2-650-5145, Fax: 82-2-650-5035, E-mail: yoonreha@mm.ewha.ac.kr

dynamometers is in assessment and training of patients. One cannot assume that testing a patient group yields measurements that are as reliable as those acquired from normal subjects.

The American Society for Sports Medicine recommends that the patient first undergoes isokinetic testing, after ACL reconstruction with a bone-patella tendon-bone graft, after 10–12 weeks. Several studies have investigated the concentric strength of the knee extensor and flexor muscles in patients that have undergone anterior cruciate ligament reconstruction. During the later stages of knee rehabilitation, the difference of the peak torque between injured and noninjured sides should be maintained at less than 10% and Esselman et al.³ reported that the evaluation of peak torque in isokinetic testing was the most objective and useful of all techniques.

In the past, rehabilitation in the acute stage has focused primarily on quadriceps rehabilitation with concentric exercise. In order to develop a kinetic chain exercise program for functional rehabilitation of the knee, the strength deficits present must first be identified and all musculature that surrounds the knee considered.

Natri et al.⁴ reported that the isokinetic thigh muscle strength tests observed in seventy patients a mean 3.5 years after their operations, that, at a speed of 60°/sec, the operated side exhibited average strength deficits of 14% and 6% deficit in extension and flexion respectively.

In studies⁵⁻⁷ of the functional ability of ACL deficient knees, Wilk et al.⁷ reported that the peak torque of the knee extensor is correlated with functional ability and Li et al.⁵ reported that the hamstring-to-quadriceps (H/Q) ratio, and the hamstring muscle group, showed the highest correlation with the functional score using the Cincinnati rating system.

The primary purpose of this study therefore, was to evaluate the muscle performance and functional level through eccentric and concentric isokinetic testing after anterior cruciate ligament reconstruction. A secondary objective was to determine whether eccentric or concentric isokinetic values were correlated with functional level using the Modified Cincinnati Scale (MCS).

MATERIALS AND METHODS

Subjects

Subjects for this study were 24 male patients who underwent ACL reconstruction at Ewha Woman's University, Tongdaemoon Hospital. All subjects had not undergone a proper rehabilitation program. They were fully ambulatory and physically active.

Methods

Tests included measurement of height, weight, and review of medical records such as cause of injury, associated injury, and the time interval between the operation and isokinetic testing.

Each subject underwent tests to measure isokinetic muscle strength at the knee while performing flexion-extension movements with both involved and uninvolved lower limbs. The tests were carried out using a Cybex 6000 (Cybex Division of Lumex, New York, USA) computer controlled isokinetic dynamometer in both concentric and eccentric modes. The apparatus consists of two positioning seats for the knee tests.

Subjects were seated with the backrest positioned at a 90° angle and were instructed to grip the sides of the seat during the testing. The thigh, pelvis, and trunk were stabilized with straps. An adjustable lever arm was attached to the leg by a padded cuff just proximal to the lateral malleolus. The axis of rotation of the dynamometer arm was positioned just lateral to the lateral femoral epicondyle. Gravity corrections to torque at 45° (0°=straight leg) were calculated by the computer software.

The tests were carried out on both lower limbs, beginning with tests on the uninvolved limb. Concentric and eccentric peak torques, and total works of knee extensor (quadriceps) and flexor (hamstring) muscle groups were measured by maximal voluntary contractions for the torque test at 60°/sec (4 repetitions). These test protocols were chosen because they are the common test protocols suggested by Cybex and have been widely used by clinicians and researchers.

During the tests the subjects were encouraged verbally to produce maximal efforts. A 20 minute rest was allowed between the concentric and eccentric tests. Eccentric tests were performed after concentric

tests because Komi⁸ has reported that, when compared to concentric contractions performed alone, greater forces are produced when eccentric contractions precede concentric contraction. This is attributable to the fact that muscle elastic potential energy improves following eccentric contraction.

Statistical analysis

The mean and standard deviation of each variable was calculated. One-way analysis of variance was carried out to compare (1) the uninvolved and involved sides, (2) the concentric and eccentric tests, and (3) the eccentric or concentric isokinetic values and functional level of the Modified Cincinnati Scale (MCS).

RESULTS

Physical characteristics of subjects

The mean age, height, and weight of the subjects were 31.1 years, 174.2 cm, and 72.4 kg, respectively. The mean interval from the operation to the isokinetic test was 20.2 months (3–6 month; 6 persons, 7–12 month; 4 persons, 13–24 month; 6 persons, 25–48 months; 7 persons, 52 month; 1 person) (Table 1).

The subjects were divided into two groups: 15 left side involved patients and 9 right side involved patients. All subjects were right leg dominant as determined by the preferred leg to kick a ball. The causes of injury were 19 cases in sports activities, 3 cases in traffic accidents, and 2 cases of falling. The

associated injuries amounted to 5 medial collateral ligament injuries, 6 medial meniscus injuries, and 7 lateral meniscus injuries (Table 2).

Isokinetic parameters of knee flexor and knee extensor in 60°/sec angular velocity

Means and standard deviations (SD) for knee flexion and knee extension parameters of concentric and

Table 1. Physical Characteristics of Subjects (n=24)

Age (years)	Weight (Kg)	Height (cm)	Interval (months)
31.1±8.1	72.4±9.7	174.2±4.0	20.2±15.2

Values are means with standard deviations.

Interval: interval from the operation to current isokinetic test.

Table 2. General Characteristics of Subjects

General characteristics		No. of cases (n=24)
Injury site	Right	9
	Left	15
Cause of injury	Sports injury	19
	Soccer	8
	Ski	7
	Judo	2
	Basketball	2
	Traffic accident	3
	Slip down	2
Associated injury	Medial collateral ligament	5
	Medial Meniscus	6
	Lateral Meniscus	7
	None	7

Table 3. Results of Isokinetic Evaluation of Knee Flexor at 60°/sec Angular Velocity

Parameter	Concentric		Eccentric	
	Uninvolved	Involved	Uninvolved	Involved
Peak torque (Nm)	97.5±24.4 [†]	82.6±23.0	127.8±32.2* [†]	104.2±30.0*
Angle of PT (°)	31.2±10.7	33.0±12.0	31.8±23.8	25.9±22.1
Total work (J)	125.5±34.5 [†]	103.7±33.1	160.2±41.7* [†]	129.0±41.2*
Average power (watts)	72.1±33.8 [†]	61.5±30.8	66.8±17.0* [†]	53.8±14.4*

Values are means with standard deviations.

PT, Peak torque.

*All values were significantly different between eccentric and concentric tests ($p < 0.01$).

[†]All values were significantly different between uninvolved and involved sides ($p < 0.01$).

Table 4. Results of Isokinetic Evaluation of Knee Extensor at 60°/sec angular velocity

Parameter	Concentric		Eccentric	
	Uninvolved	Involved	Uninvolved	Involved
Peak torque (Nm)	181.3±39.4 [†]	123.3±36.4	201.9±55.0* [†]	147.1±45.3*
Angle of PT (°)	69.5±6.5	62.0±11.0	74.6±9.0	67.2±12.7
Total work (J)	202.5±45.8 [†]	142.9±41.5	232.0±57.9* [†]	173.8±55.2*
Average power (watts)	110.2±26.1 [†]	79.9±22.4	89.7±21.6* [†]	70.0±18.0*

Values are means with standard deviations.

PT, Peak torque.

*All values were significantly different between eccentric and concentric tests ($p < 0.01$).

[†]All values were significantly different between uninvolved and involved sides ($p < 0.01$).

eccentric tests at 60°/sec angular velocity are shown in Table 3 and Table 4.

The average peak torque of knee flexors in uninvolved limbs was 97.5 ± 24.4 Nm in concentric tests and 127.8 ± 32.2 Nm in eccentric tests, and that of involved limbs is 82.6 ± 23.0 Nm and 104.2 ± 30.0 Nm, respectively. The average peak torque of knee extensors in uninvolved limbs is 181.3 ± 39.4 Nm in concentric tests and 201.9 ± 55.0 Nm in eccentric tests, and that in involved limbs is 123.3 ± 36.4 Nm and 147.1 ± 45.3 Nm, respectively. Eccentric peak torques are significantly greater than concentric measurements in both limbs ($p < 0.01$), and with uninvolved peak torques significantly greater than was observed in involved limbs in both tests ($p < 0.01$).

The average joint angle of peak torque of concentric knee flexors in concentric tests was $31.2 \pm 10.7^\circ$ in uninvolved limbs and $33.0 \pm 12.0^\circ$ in involved limbs, and that of eccentric tests is $31.8 \pm 23.8^\circ$ and $25.9 \pm 22.1^\circ$, respectively. The average joint angle of peak torque of knee extensors in concentric tests was $69.5 \pm 6.5^\circ$ in uninvolved limbs and $62.0 \pm 11.0^\circ$ in involved limbs, with that of eccentric tests measuring $74.6 \pm 9.0^\circ$ and $67.2 \pm 12.7^\circ$, respectively.

The total work of knee flexors in concentric tests was found to be 125.5 ± 34.5 J in uninvolved limbs and 103.7 ± 33.1 J in involved limbs, and that in eccentric tests was 160.2 ± 41.7 J and 129.0 ± 41.2 J, respectively. The total work of knee extensors in concentric tests was 202.5 ± 45.8 J in uninvolved limbs and 142.9 ± 41.5 J in involved limbs, and that of eccentric tests was 232.0 ± 57.9 J and 173.8 ± 55.2 J, respectively. Eccentric total work was found to be

significantly greater than concentric in both limbs ($p < 0.01$). The total work of uninvolved limbs was significantly greater than that of involved limbs in both tests ($p < 0.01$).

Given that the average power is the total work divided by total time in seconds, total time was read from the computer. The average power of knee flexors in concentric tests was 72.1 ± 33.8 watts in uninvolved limbs and 61.5 ± 30.8 watts in involved limbs. In eccentric tests this was measured at 66.8 ± 17.0 watts and 53.8 ± 14.4 watts, respectively. The average power of knee extensors in concentric tests was observed as measuring 110.2 ± 26.1 watts in uninvolved limbs and 79.9 ± 22.4 watts in involved limbs, and that in eccentric tests is 89.7 ± 21.6 watts and 70.0 ± 18.0 watts, respectively. The value in uninvolved limbs was significantly greater than involved limbs in both tests ($p < 0.01$), and concentric average power was significantly greater than eccentric in both limbs ($p < 0.01$).

Deficiency ratio of peak torque

The deficiency ratio of peak torque in concentric tests was $13.1 \pm 14.4\%$ in flexors and $31.5 \pm 20.9\%$ in extensors, and that of eccentric tests was measured at $16.4 \pm 13.4\%$ and $26.9 \pm 15.8\%$, respectively. The deficiency value of extensors was found to be greater than that of flexors in both tests (Table 5).

Hamstrings to quadriceps peak torque ratio

The hamstrings to quadriceps torque ratio in concentric tests was 0.52 ± 0.06 in uninvolved limbs and 0.70 ± 0.19 in involved limbs, and that of

Table 5. Deficiency Ratios of Peak Torque (n=24)

Deficiency ratio	Concentric		Eccentric	
	Flexor	Extensor	Flexor	Extensor
DRPT	13.1 ± 14.4	31.5 ± 20.9*	16.4 ± 13.4	26.9 ± 15.8*

Values are means with standard deviations (%).

$$\text{Deficiency ratio} = \frac{\text{Uninvolved} - \text{Involved}}{\text{Uninvolved}} \times 100$$

DRPT = Deficiency ratio of peak torque.

*All values were significantly different between flexor and extensor ($p < 0.01$).

Table 6. Ratio of Hamstrings to Quadriceps Peak Torque

Parameter	Concentric		Eccentric	
	Uninvolved	Involved	Uninvolved	Involved
H/Q ratio	0.52 ± 0.06	0.70 ± 0.19 [†]	0.63 ± 0.12*	0.76 ± 0.26* [†]

H/Q ratio, Hamstrings Peak Torque/Quadriceps Peak Torque.

*All values were significantly different between eccentric and concentric tests ($p < 0.01$).

[†]All values were significantly different between uninvolved and involved sides ($p < 0.01$).

Table 7. Correlations between the PTDR and Modified Cincinnati Scale

Correlation	r
Deficiency ratio of peak torque	
concentric knee flexor	-0.317
concentric knee extensor	-0.226
eccentric knee flexor	-0.144
eccentric knee extensor	-0.534*

PTDR, Peak Torque Deficiency Ratio.

*Correlation is significant at the 0.05 level.

eccentric tests was measured at 0.63 ± 0.12 and 0.76 ± 0.26 , respectively. Eccentric H/Q torque ratios were significantly greater than concentric in both limbs ($p < 0.01$), and uninvolved limbs were found to be significantly greater than involved limbs in both tests ($p < 0.01$) (Table 6).

Functional level using the modified cincinnati scale (MCS)

The average score of Modified Cincinnati Scale (MCS) was 86.8 ± 5.6 , and this functional scale seemed to correlate inversely with the deficiency ratio

of peak torque. Especially, MCS correlated inversely with the deficiency ratio of peak torque of eccentric knee extensors ($p < 0.05$) (Table 7).

DISCUSSION

Advantages of isokinetic exercise include the stability of subjects to perform at will and the subjectivity is standardized between subjects. Disadvantages include the difference experienced by the subjects between isokinetic exercise and functional use of the muscle. This may be attributed to the feeling of artificiality as contractions may be unfamiliar to most subjects.

Eccentric muscle action is a part of many normal activities such as descending stairs, running, and sitting down in a chair. Ostering et al.⁹ suggested that eccentric isokinetic exercise is essential for ACL reconstructed patients because it may have the capacity to counter forceful extensor concentric torque and produce less muscle activation per unit force than concentric action which may reflect reduced energy cost.

In order to isokinetic exercise, peak torque, joint angle of peak torque, total work, and average power

were used as evaluating parameters. Of these, the peak torque was used most often because of its high reliability. Maintaining the difference in the peak torque between involved and uninvolved sides at less than 10% is probably important to prevent occurrence and recurrence of injuries. To plan a through rehabilitation program and to correct possible imbalances which may predispose subjects to injuries, it is necessary to measure both concentric and eccentric muscle action variables.¹⁰⁻¹²

In the present isokinetic study, a mean 20.2 months after reconstruction, the values of peak torque of the injured knees were significantly lower than the uninjured knees in both eccentric and concentric tests. A plausible explanation for these results include the possibility that the subjects using the operated knee because of cast immobilization, knee pain and reduced range of motion. In addition, the lack of the knowledge of the aggressive rehabilitation resulted in avoidance of weightbearing and functional use of the involved knee.^{13,14}

In accordance with other studies,¹⁵⁻¹⁸ the majority of the eccentric variables of the knee muscles was significantly greater than those produced by concentric contraction. Therefore, during the latter stages of knee rehabilitation, eccentric contractions should be introduced to approach a more physiological mode of exercise.

The average joint angle of peak torque in knee extensors of uninvolved knees is 68.8° in concentric tests and 73.4° in eccentric tests. At involved knees the corresponding values were 64.0° and 67.6°, respectively. The values of eccentric tests are larger than those derived for concentric tests, and the average joint angle of peak torque in involved knees is smaller than those measured for uninvolved knees. This finding may be attributable to a possible lag or delay in exciting the contractile element of the injured or weakened muscle.¹⁹ A second possible explanation is based on the time delay required for momentum of the involved leg to overcome inertia.²⁰ The average power of concentric exercise is significantly larger than eccentric in both uninvolved and involved knee. It means that the eccentric exercise produces less muscle activation per unit force than concentric action which may reflect reduced energy cost.

Compared with the uninvolved knee, the involved knees exhibited an average 31.5% peak torque deficit

in concentric knee extension, and 13.1% deficit in flexion. During eccentric exercise, the corresponding deficits were 26.9% and 16.4%, respectively. In both concentric and eccentric tests, the knee extensor deficit is greater than the knee flexor deficit. The possible explanation for this is that the knee flexors are the agonists of the anterior cruciate ligament²¹ and the knee flexors therefore are not as weak given this compensatory mechanism after ACL injury. In addition, the patients with ACL-deficient knees showed a tendency to avoid the net quadriceps moment, tending to flex the knee during the middle portion of the stance phase.²²

The H/Q ratio has received the greatest amount of attention. In this study, the H/Q ratio in concentric tests was 0.52 ± 0.06 in uninvolved limbs and 0.70 ± 0.19 in involved limbs, and 0.63 ± 0.12 and 0.76 ± 0.26 in eccentric tests, respectively. Ghena et al.²³ reported an eccentric H/Q ratio of 0.646 and concentric H/Q ratio of 0.553 in healthy subjects. These values were recorded at a constant velocity of 60°/sec. Compared with observations by Ghena et al.²³ all of our eccentric and concentric H/Q ratios in uninvolved knees showed no significant differences. However, in involved knees, H/Q ratios were greater than those obtained for uninvolved. The explanation for this result is that the peak torque deficiency of knee extensors is greater than that of knee flexors. From the assessment of isokinetic characteristics of the quadriceps and hamstring muscles in both eccentric and concentric tests, and the correlation with the Cincinnati functional score, the deficiency ratio of peak torque of eccentric knee extensors shows the highest correlation with the decrease in functional score. As the study of Wilk et al,⁷ the peak torque of knee extensor testing 29 male patients (mean age; 23.7 years) after primary reconstruction of ruptured ACL is correlated to the functional ability. The result however is not in accordance with the study of Li et al.⁵ They tested 46 recreational athletes 2 weeks after arthroscopy using the Cybex II+ isokinetic dynamometer. and isokinetic muscle training was performed three times a week for six weeks. After the rehabilitation period, the second Cybex and Cincinnati rating scale tests were performed. They reported that the hamstrings to quadriceps (H/Q) ratio, and hamstring muscle group, showed the highest correlation with the functional score of the Cincinnati rating system. This may be because, during the early

period of the ACL injury, knee flexors are less weakened due to compensatory mechanisms after ACL injury.

Why then do we see eccentric weakness in the quadriceps of the injured knee? The answer can only be speculative, but perhaps decelerating activity is avoided after reconstruction resulting in diminished eccentric strength in the musculature involved. Many subjects described a reluctance to perform such activities as stair descent, sudden change in direction, and jumping.

This results indicate that the greater the peak torque deficiency of the knee, the lower the function of the knee will be. Especially, the restoration of eccentric knee extensor deficiency is kept in mind and followed up in order to maintain functional performance.

Thus, by testing 24 male patients, a mean 20.2 months after primary reconstruction of their ruptured ACL of the knee at angular velocity of 60°/sec using Cybex 6,000 isokinetic dynamometer, we are able to conclude the following:

The values of peak torque, total work, and average power of the involved knee extensors and flexors was significantly lower than those observed in the uninvolved knees in all eccentric and concentric tests ($p < 0.01$). Furthermore, although the eccentric values of the knee muscles were significantly greater than concentric values, the average power of eccentric exercise is significantly lower than observed for concentric exercise ($p < 0.01$). Eccentric exercise may therefore reflect reduced energy costs. The functional scale using the MCS, seemed to correlate inversely with the deficiency ratio of peak torque, especially with the deficiency ratio of peak torque exhibited by the eccentric knee extensors ($p < 0.05$). Thus, restoration of the deficiency of eccentric knee extensors is essential to bring the functional performance of all the knee muscles into equilibrium with respect to each other.

To plan a through rehabilitation program, and to correct possible imbalances which may predispose subjects to injury, it is necessary to measure both concentric and eccentric muscle action variables using isokinetic exercise. During the latter stages of knee rehabilitation, eccentric contractions should be introduced to approximate a more physiological mode of exercise.

REFERENCES

1. Muller W. Form and function of the knee. It's relation to high performance and to sports. *Am J Sports Med* 1996;24(Suppl):104-6.
2. Arnold JA, Coker TP, Heaton IM, Park JP, Harris WP. Natural history of anterior cruciate ligament tears. *Am J Sports Med* 1979;7:305-13.
3. Esselman PC, de Lateur BJ, Alquist AD, Questad KA, Giaconi RM, Lehmann. Torque development in isokinetic training. *Arch Phys Med Rehabil* 1991;72:723-8.
4. Natri A, Jarvinen M, Kannus P. Primary repair plus intra-articular iliotibial band augmentation in the treatment of an acute anterior cruciate ligament rupture. A follow-up study of 70 patients. *Arch Orthop Trauma Surg* 1996; 115:22-7.
5. Li RC, Maffulli N, Hsu YC, Chan KM. Isokinetic strength of the quadriceps and hamstrings and functional ability of anterior cruciate ligament deficient knees in recreational athletes. *Br J Sports Med* 1996;30:161-4.
6. Novak PJ, Bach BR Jr, Hager CA. Clinical and functional outcome of anterior cruciate ligament reconstruction in the recreational athlete over the age of 35. *Am J Knee Surg* 1996;9:111-6.
7. Wilk KE, Romaniello WT, Soscia SM, Arrigo CA, Andrews JR. The relationship between subjective knee scores, isokinetic testing, and functional testing in the ACL-reconstructed knee. *J Orthop Sports Phys Ther* 1994;20: 60-73.
8. Komi PV. The stretch-shortening cycle and human power output. *Human Kinetics* 1986;27-9.
9. Osternig L, James CR, Bercades DT. Eccentric knee flexor torque following anterior cruciate ligament surgery. *Med Sci Sports Exerc* 1996;28:1229-34.
10. Davis GJ, Ellenbecker TS. Eccentric isokinetics. *Orthop Phys Ther Clin N Orth Am* 1992;1:1059-516.
11. Kellis E, Baltzopoulos V. Isokinetic eccentric exercise. *Sports Med* 1995;19:202-22.
12. Kellis E, Baltzopoulos V. Muscle activation differences between eccentric and concentric isokinetic exercise. *Med Sci Sports Exerc* 1998;30:1616-23.
13. Davis GJ. A compendium of isokinetics in clinical usage and rehabilitation techniques. 4th ed. Wisconsin: S & S Publishers; 1992.p.3-32.
14. Konsei S, Ken N. Quantitative evaluation after arthroscopic anterior cruciate ligament reconstruction-allograft versus autograft. *Am J Sports Med* 1993;21:738-43.
15. Ellenbecker TS, Davis GJ, Robinsk MJ. Concentric versus eccentric isokinetic strengthening of the rotator cuff. *Am J Sports Med* 1988;16:64-9.
16. MacLean CL, Taunton JE, Clement BD, Regan W. Eccentric and concentric isokinetic moment characteristics in the quadriceps and hamstrings of the chronic isolated posterior cruciate ligament injured knee. *Br J Sports Med* 1999; 33:405-8.
17. Tomberlin JP, Basford JR, Schwen EE, Orte PA, Scott SG. Comparative study of isokinetic eccentric and concentric quadriceps training. *J Orthop Sports Phys Ther* 1991;

- 14:31-6.
18. Trudelle-Jackson E, Meske N, Highenboten C, Jacken L. Eccentric/concentric torque deficits in the quadriceps muscle. *J Orthop Sports Phys Ther* 1989;11:142.
 19. Yoon TS, Park DS, Kang SW, Chun SI, Shin JS. Isometric and isokinetic torque curves at the knee joint. *Yonsei Med J* 1991;32:33-43.
 20. Knapik JJ, Wright JE, Mawdsley RH, Braun J. Isometric, isotonic, isokinetic torque variations in four muscle groups through a range of joint motion. *Phys Ther* 1983;63: 938-47.
 21. Solomonow M, Baratta R, D'Ambrosia R. The role of hamstrings in the rehabilitation of the anterior cruciated ligament-deficient knee in athletes. *Sports Med* 1989; 7:42-8.
 22. Andriacchi TP, Birac D. Functional testing in the anterior cruciate ligament-deficient knee. *Clin Orthop* 1992;288: 40-7.
 23. Glens D, Kurth AL, Thomas M. Moment characteristics of the quadriceps and hamstring muscles during concentric and eccentric loading. *J Orthop Sports Phys Ther* 1991; 14:149-54.

Appendix 1. Modified Cincinnati Scale

Symptoms (50 points)**Pain**

- 20 No pain, normal knee
- 16 Occasional pain with strenuous sports or heavy work
- 12 Occasional pain with recreational sports or moderate work, frequently by sports
- 8 Pain usually brought on by sports, light recreational activities or moderate work
- 4 Pain is significant problem with activities as simple as walking and standing unable to do sports
- 2 Pain present all the time, not relieved with rest

Swelling

- 10 No swelling, normal knee
- 8 Occasionally swelling with strenuous sports or heavy work
- 4 Swelling brought on by simple walking activities and light work
- 0 Severe problem all the time

Giving way

- 20 No giving way, normal knee
- 16 Occasional giving way with strenuous sports or heavy work
- 12 Occasional giving way with light recreational activities or moderate work, not able to twist or cut suddenly
- 8 Giving way limits sports and moderate work
- 4 Giving with simple walking activities and light work
- 0 Severe problem with simple walking activities

Function (50 points)**Overall activity level**

- 20 No limitation normal knee
- 16 Perform sports including vigorous activities possible with rare symptoms, more strenuous activities cause problem
- 8 No sports or recreational activities possible, walking possible with rare symptoms
- 4 Walking activities of daily living cause moderate symptoms
- 0 Walking activities of daily living cause severe problems, persistent symptoms

Walking

- 10 Normal, unlimited
- 8 Slight/mild problem
- 6 Moderate problem: smooth surface up to 800 m
- 4 Severe problem: only 2-3 blocks possible
- 2 Severe problem: requires walking aids

Stairs

- 10 Normal, unlimited
- 8 Slight/mild problem
- 6 Moderate problem: 10-15 steps possible

Running activities

- 5 Normal, unlimited: fully competitive strenuous
- 4 Slight/mild problem: run 1/2 speed
- 3 Moderate problem: only 2-4 km possible
- 2 Severe problem: only 1-2 blocks possible
- 1 Severe problem: only a few steps

Jumping or twisting activities

- 5 Normal, unlimited: fully competitive strenuous
 - 4 Slight/mild problem: some guarding, but sports possible
 - 3 Moderate problem: gave up strenuous sports
 - 2 Severe problem: affects all sports, must constantly guard
 - 1 Severe problem: only light activity possible
-