Weakness of thigh muscles in individuals sustaining anterior cruciate ligament injury.

Itoh, H
Ichihashi, N
Maruyama, T
Kurosaka, M
Hirohata, K

(Citation)
The Kobe journal of the medical sciences,38(2):93-107

(Issue Date)
1992

(Resource Type)
departmental bulletin paper

(Version)
Version of Record

(URL)
https://hdl.handle.net/20.500.14094/E0034060

Kobe J. Med. Sci. 38, 93/107, April 1992

WEAKNESS OF THIGH MUSCLES IN INDIVIDUALS SUSTAINING ANTERIOR CRUCIATE LIGAMENT INJURY

HIROMITSU ITOH*, NORIAKI ICHIHASHI**, TAKAKI MARUYAMA*, MASAHIRO KUROSAKA***, AND KAZUSHI HIROHATA***

* Department of Physical Therapy, Kobe University Hospital

** Department of Physical Therapy,
School of Allied Medical Sciences, Kobe University
7-10-2 Tomogaoka
Suma-ku, Kobe 654-01
JAPAN

*** Department of Orthopedic Surgery,
Kobe University School of Medicine

INDEXING WORDS

quadriceps; hamstrings; anterior cruciate ligament; isometric strength; isokinetic strength

SYNOPSIS

The purpose of this study was to assess the quadriceps and hamstrings muscle strength deficits at different knee flexion angles (30° and 60°) in individuals who had sustained anterior cruciate ligament (ACL) injury, who had never had thigh muscle strengthening exercise. Isometric (0°/sec) and isokinetic (60°/sec and 180°/sec) torque measurements were performed on sixty-six patients (29 males and 37 females) with chronic ACL insufficiency.

Received for publication : March 5, 1992
Authors' names in Japaneses : 伊藤浩充, 市橋則明, 丸山孝樹
黒坂昌弘, 廣畑和志

Significant strength deficits of the quadriceps and hamstrings muscles in injured knees were found at both 30° and 60° of knee flexion in three testing conditions (0°/sec, 60°/sec, and 180°/sec). In the comparison of torque production at 30° and 60° knee flexion angles, for the male group, significantly greater deficits of the quadriceps torque were found at 60° knee flexion than at 30° knee flexion in the isometric and isokinetic 60°/sec testing modes. For the female group, significantly greater deficit of the quadriceps torque was found at 60° knee flexion than at 30° knee flexion only in isokinetic 60°/sec. There was no significant difference of the hamstrings torque deficit between 30° and 60° knee flexion in any testing modes. In the comparison of isometric and two isokinetic testing modes (60°/sec and 180°/sec), for the male group, significantly greater deficits of the quadriceps torque were found at 30° knee flexion in isokinetic 180°/sec and at 60° knee flexion in isokinetic 60°/sec as compared to the isometric test. There was no statistical difference in the hamstrings torque values. For the female group, significantly greater deficits of the quadriceps and hamstrings torque were found at 30° knee flexion in isokinetic 60°/sec and at 60° in isokinetic 60°/sec and 180°/sec as compared to the isometric test. It was concluded that long lasting instability without any muscle exercises may result in the weakness of not only the quadriceps muscle but also even hamstrings muscle, and that the quadriceps strength might be more susceptible to ACL insufficiency at 60° knee flexion angle than at 30° knee flexion angle, whereas, the hamstrings did not show any angular-specific torque deficits. These findings might resulted from characteristics of torque-curves of the quadriceps and hamstrings muscles. In addition, these findings may suggest that dysfunction of the quadriceps muscle influences on the dynamic torque production than on the static torque production, and that patients may subconsciously exert less quadriceps power in the dynamic knee extension. Moreover, less compensatory function of the hamstrings muscle against anterior tibial translation might be predicted in the female than in the male group.

INTRODUCTION

Disruption of the anterior cruciate ligament(ACL) has been described as one of the most common and debilitating injuries to the knee.[3,8-10,28] Progressive instability and disability are caused by the ACL injury in a high percentage of the cases.[29,30] Patients with ACL insufficiency experience a sensation of dynamic instability of the knees with pivoting motions. It has been suggested that the musculature acting across the knee joint may aid in stabilizing the instability following ACL injury.[12,22] Johnson and Pope[15] and more recently Butler et al[5] demonstrated that the quadriceps acted antagonistically the ACL function, whereas the hamstrings protected this ligament by preventing excessive anterior tibial translation. Solomonow et al[37] observed that the hamstring muscles were activated during extension in anterior cruciate insufficient knees indicating their function helping to dynamic stability. Based on these findings, current rehabilitation programs include conditioning of both the quadriceps and hamstring muscles with emphasis on strengthening of hamstrings to improve the dynamic stability of the knee.[12,22]

Muscle atrophy is a common clinical finding in patients with the ACL insufficiency even after they have been placed on a rehabilitation program.[4] Computerized tomographic studies of cross-sectional areas of thigh muscles demonstrated that muscle atrophy was greater in the quadriceps femoris than in the hamstrings.[4,11] Studies of thigh muscle strength have also shown that deficits were greater in the quadriceps femoris muscle.[16,26,39,40] However, since the patients in these studies had been trained following initial injury, actual strength deficits due to ACL insufficiency were not apparently shown. Also, there are few studies which have evaluated angular specific torques produced by quadriceps and hamstrings muscles.[26,41]

The purpose of this study was to assess and describe thigh muscle strength deficits at different knee flexion angles inindividuals who have sustained ACL injury, who had never had muscle exercise rehabilitation programs, and to identify the influence of torn ACL on thigh muscle strength.

MATERIALS AND METHODS

Twenty-nine males and thirty-seven females with ACL insufficiency were studied. Average age was 22.0 years (range 16 to 33) in males and 21.4 years (range 14 to 42) in females, respectively. All patients had sustained a unilateral knee joint injury more than two months before the evaluation. The mean interval between the initial injury and the evaluation was 2.3 years (range two months to ten years) in males, and 1.7 years (range two months to ten years) in females. The diagnosis of ACL insufficiency was made on the basis of positive Lachman test, anterior drawer test, and pivot shift test. Instrumented Lachman test with a KT-1000 Knee Ligament Arthrometer (MEDmetric Corp., San Diego, CA) with the load of 90 Newtons showed an injured to noninjured mean difference of 5.4 mm(range 0 to 14 mm) in males and 5.4 mm (range 0 to 12 mm) in females. All individuals who had significant injuries to the medial collateral ligament, lateral ligament complex, and posterior cruciate ligament were eliminated from the study. None of the patients had placed on a muscle rehabilitation program following ACL injury. Fifty-seven patients (86%) had arthroscopic evaluation and were documented ACL insufficiency after this study.

Isometric and isokinetic measurements of thigh muscles strength were conducted using the Cybex II R isokinetic dynamometer interfaced with Cybex data reduction computer, CDRC (Cybex, Division of Lumex, Inc., Ronkonkoma, New York). For both the quadriceps and hamstrings, muscle strength was measured at two different knee flexion angles of 30° and 60°. Angular velocities of 60°/sec and 180°/sec were used for isokinetic analysis, and isometric analysis was also conducted. The gravitational effect of limb mass was eliminated by the use of the CDRC software program, which added the weight of the limb to the torque values on extension and subtracted the weight of the limb from the torque values on flexion.

Simple descriptive statistical analysis was performed on all of the variables tested. These analyses included the mean and standard deviations of absolute values and deficit of isometric and isokinetic torques for the quadriceps and hamstrings at each flexion angle. Paired t-tests were used to determine the difference between the absolute torques of the injured and uninjured limbs at each flexion angle in each testing mode, between the torque deficits at 30° flexion and 60° flexion in each testing mode and between the torque deficits of isometric testing mode and isokinetic mode at each flexion angle. (STAX Statistical Software; Japan[1983]).

RESULTS

Mean values of the quadriceps torque of both injured and uninjured knee joints in the male group and the female group are summarized in Fig. 1 and 2. The isometric and isokinetic torque values of the quadriceps in injured knees were statistically significantly lower than those in uninjured knees ($p<0.01$) at any testing condition in both male and female groups. Also, the isometric and isokinetic torque values of hamstrings muscle in injured knees were statistically significantly lower than those in uninjured knees at any testing condition in both male and female groups (Fig. 3 and 4).

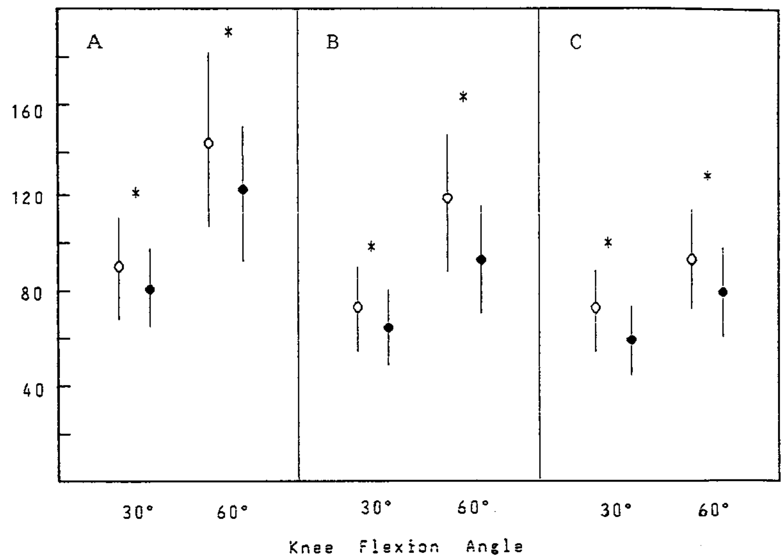

Fig. 1 Quadriceps torque of uninjured and injured knees at each flexion angle in males. Data were mean ± S.D. of 29 male patients. A, Quadriceps in isometric condition. B, Quadriceps in isokinetic condition(60°/sec). C, Quadriceps in isokinetic condition(180°/sec). (○ — ○), uninjured limb; (● — ●), injured limb. (*), P < 0.01.

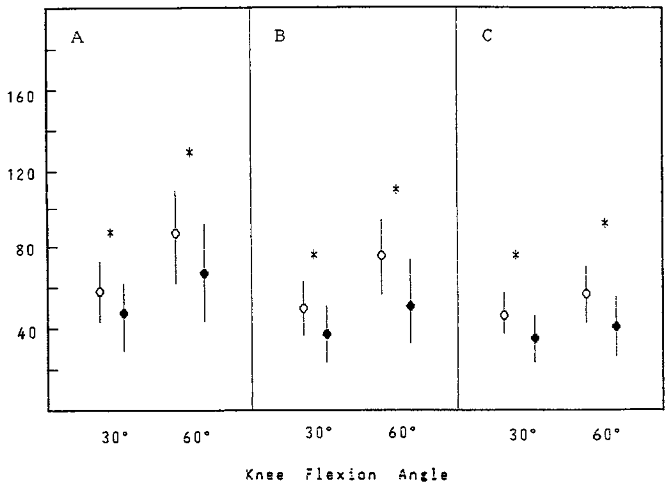

Fig. 2 Quadriceps torque of uninjured and injured knees at each flexion angle in females. Data were mean ± S.D. of 37 female patients. A, Quadriceps in isometric condition. B, Quadriceps in isokinetic condition(60°/sec). C, Quadriceps in isokinetic condition(180°/sec). (○ — ○), uninjured limb; (● — ●), injured limb. (*), P < 0.01.

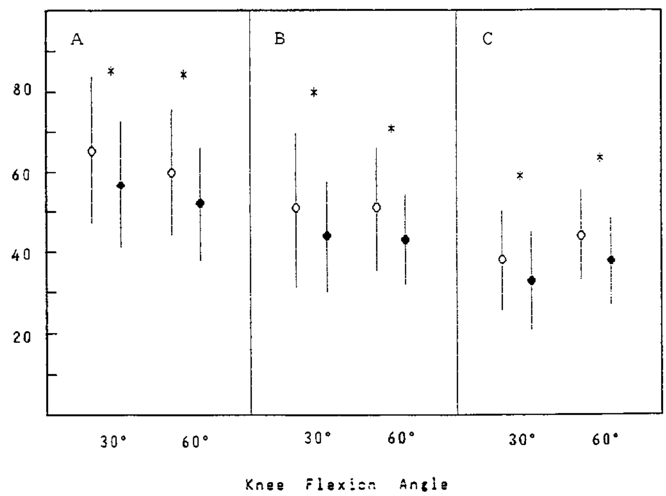

Fig. 3 Hamstrings torque of uninjured and injured knees at each flexion angle in males. Data were mean ± S.D. of 29 male patients. A, Hamstrings in isometric condition. B, Hamstrings in isokinetic condition(60°/sec). C, Hamstrings in isokinetic condition(180°/sec). (○ — ○), uninjured limb; (● — ●), injured limb. (*), P < 0.01.

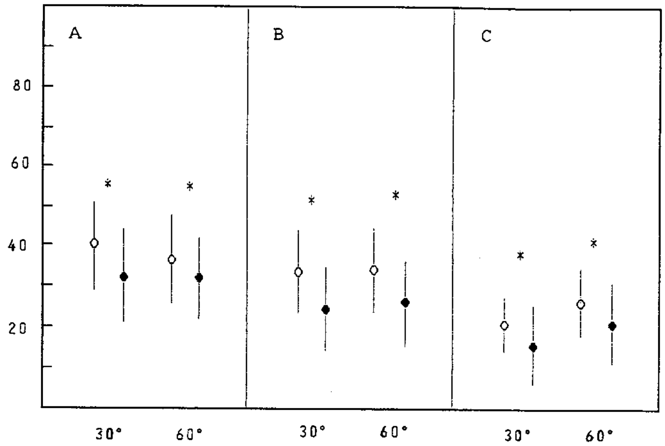

Fig. 4 Hamstrings torque of uninjured and injured knees at each flexion angle in females. Data were mean ± S.D. of 37 female patients. A, Hamstrings in isometric condition. B, Hamstrings in isokinetic condition(60°/sec). C, Hamstrings in isokinetic condition(180°/sec). (○ — ○), uninjured limb; (● — ●), injured limb. (*), P < 0.01.

In the comparison of torque production at 30° and 60° knee flexion angles, when deficits were viewed as percent of the uninjured side [(1 − injured leg torque ∕ uninjured leg torque) × 100] , average deficits of the strength of the quadriceps and

Table 1 A Comparison of Percent Torque Deficits at Different Flexion Angles in Males (N = 29)

Test Condition	30°		60°		P
	X[a]	s[a]	X[a]	s[a]	
Isometric					
QUADRICEPS	8.0	12.8	13.6	16.1	0.05
HAMSTRINGS	13.4	13.7	10.4	20.1	NS
Isokinetic(60°/sec)					
QUADRICEPS	12.3	17.7	20.1	15.6	0.01
HAMSTRINGS	6.9	35.6	13.5	17.9	NS
Isokinetic(180°/sec)					
QUADRICEPS	16.7	15.2	14.4	13.0	NS
HAMSTRINGS	11.0	22.3	10.9	19.8	NS

a. X indicates average torque and s represents standard deviation.

Table 2 A Comparison of Percent Torque Deficits at Different Flexion Angles in Females (N = 37)

Test Condition	30°		60°		P
	X[a]	s[a]	X[a]	s[a]	
Isometric					
QUADRICEPS	17.4	27.5	19.5	25.2	NS
HAMSTRINGS	17.2	24.7	12.5	24.0	NS
Isokinetic(60°/sec)					
QUADRICEPS	22.4	26.3	29.8	23.4	0.01
HAMSTRINGS	23.2	28.4	20.3	20.3	NS
Isokinetic(180°/sec)					
QUADRICEPS	24.6	26.6	26.6	21.7	NS
HAMSTRINGS	26.4	34.3	23.3	24.0	NS

a. X indicates average torque and s represents standard deviation.

hamstrings at each flexion angle(30°, 60°) are shown in Table 1 and 2 respectively. In the male group, significantly greater deficits

Table 3 A Comparison of Percent Torque Deficits at Different Testing Modes in Males (N = 29)

Test Condition	Isometric		60°/sec		180°/sec
	X[a] (s)[a]		X[a] (s)[a]		X[a] (s)[a]
30°flexion					
			**		
		ns		*	
QUADRICEPS	8.0 (12.8)		12.3 (17.7)		16.7 (15.2)
			ns		
		ns		ns	
HAMSTRINGS	13.4 (13.7)		6.9 (35.6)		11.0 (22.3)
60°flexion					
			ns		
		**		ns	
QUADRICEPS	13.6 (16.1)		20.1 (15.6)		14.4 (13.0)
			ns		
		ns		ns	
HAMSTRINGS	10.4 (20.1)		13.5 (17.9)		10.9 (19.8)

a. X indicates average torque and (s) represents standard deviation.
ns. not significant
* ; $P < 0.05$
**; $P < 0.01$

of the quadriceps torque were found at 60° knee flexion than at 30° knee flexion in the isometric and isokinetic 60°/sec testing modes(Table 1). In the female group, significantly greater deficit of the quadriceps torque was found at 60° knee flexion than at 30° knee flexion only in isokinetic 60°/sec. There was no significant difference of the hamstrings torque deficit between 30° and 60° knee flexion in any testing mode.

In the comparison of isometric and two isokinetic tesing modes(60°/sec and 180°/sec), torque deficits of each muscle are shown in Table 3 and 4. In the male group, significantly greater deficits of the quadriceps torque were found at 30° knee flexion in isokinetic 180°/sec and at 60° knee flexion in isokinetic 60°/sec as compared to the isometric test(Table 3). There was no statistical difference in the hamstrings torque values. In the female group, significantly greater deficits of the quadriceps torque were found at 30° knee flexion in isokinetic 60°/sec and at 60° in isokinetic 60°/sec and 180°/sec as compared to the isometric test(Table 4). And also, significantly greater deficits

Table 4 A Comparison of Percent Torque Deficits at Different Testing Modes in Females (N = 37)

Test Condition	Isometric		60°/sec		180°/sec
	$\bar{X}$ᵃ (s)ᵃ		$\bar{X}$ᵃ (s)ᵃ		$\bar{X}$ᵃ (s)ᵃ
30°flexion					
			ns		
		*		ns	
QUADRICEPS	17.4 (27.5)		22.4 (26.3)		24.6 (26.6)
			ns		
		*		ns	
HAMSTRINGS	17.2 (24.7)		23.2 (28.4)		26.4 (34.3)
60°flexion					
			*		
		**		ns	
QUADRICEPS	19.5 (25.2)		29.8 (23.4)		26.6 (21.7)
			*		
		*		ns	
HAMSTRINGS	12.5 (24.0)		20.3 (20.3)		23.3 (24.0)

a. X indicates average torque and (s) represents standard deviation.
ns. not significant
* ; P < 0.05
**; P < 0.01

of the hamstrings torque were found at 30° knee flexion in isokinetic 60°/sec and at 60° in isokinetic 60°/sec and 180°/sec as compared to the isometric test(Table 4).

DISCUSSION

Weakness of quadriceps femoris muscle is well recognized in patients with anterior cruciate insufficiency.[16,24-26,32,39-41] Nicholas et al[27] and Odensten et al[32] found a positive relationship between ligament instability and quadriceps weakness. We also reported in the previous study on maximal thigh muscle strength in patients with ACL insufficiency that the strength deficit was greater in the quadriceps than in the hamstrings.[14] The present study showed a significant decrease in strength of both the quadriceps and hamstrings in the injured knees. In these findings, weakness of the quadriceps was consistent with other studies,[16,32,39] whereas weakness of the hamstring muscles was not consistent with other studies.[16,32,39] The reason for this inconsistency is that we evaluated angular specific torque production, whereas the others studied peak torque production. In addition, as described above, the patients in this study did not participate in any rehabilitaion program prior to the present study. Therefore, long lasting instability without any muscle exercises may result in the weakness of even hamstrings muscle.

With regard to the weakness of the quadriceps muscle, one possible explanation of this finding is that the hamstrings act to antagonize anterior tibial displacement produced by a quadriceps contraction during dynamic knee extension. Walla[42] found active hamstrings control which functioned to reduce the pivot shift phenomenon in 95% of the patients with ACL insufficiency. Solomonow et al[37] also observed that hamstring muscles were activated during extension in anterior cruciate insufficient knees indicating their function in maintaining joint stability. These findings suggest the possibility that the quadriceps contraction has adverse effect on the hamstring control. Therefore, patients may subconsciously exert less quadriceps power in knee extension. Another possible explanation of the deficit in the quadriceps can be the effect of nerves which have inhibiting effect on thigh muscles, especially on the quadriceps muscle. Arnoczky[2] reported the existence of nerve fibers within the ACL substance which might serve a proprioceptive function. Abbott et al[1] presented an extensive review of knee injuries, in which he stated that the ligaments of the knee have rich sensory innervation that allows them to act as the first link in the "kinetic chain." They speculated that stressing the ligaments initiates strong impulses which result in a reflex muscle contraction. Therefore, loss of proprioceptive feedback from disrupted ACL could be contributing to the torque reduction of the quadiceps.[19] In addition, damage of other joint structures such as joint capusule and meniscus might influence on these declines. With regard to the hamstrings weakness, many studies have reported no significant reduction of hamstrings torque in ACL insufficient knees.[7,17,26,40] We found significant decrease in the hamstrings strength in each flexion angle of all testing modes. The reason for this finding is unclear. However, similar to the deficits in the quadriceps torque, loss of a proprioceptive function due to the disruption of the ACL might cause the deficit in the hamstrings torque.

As mentioned above, the majority of the previous studies on muscle strength deficiencies in patients with ACL insufficiency have reported the values of peak torque generated isometrically and isokinetically, however, there are few studies[26,41] on angular specific torque production. Disruption of the ACL changes the kinematics of the knee joint during active extension and flexion.[18] Therefore, there is a possibility that the torques of the quadriceps and hamstrings muscles can be influenced by knee flexion angles. On the basis of this hypothesis, we selected two different flexion angles, 30° and 60°, as being representative of the total range of motion, in order to identify the difference of strength deficits between at 30° and 60° knee flexion angles. The 30° flexion angle is the functional angle in which absence of the ACL is most likely to be detected,[34] and also is the angle at which maximal hamstrings strength is expected to be produced.[20,41] The 60° flexion angle is the angle at which maximal quadriceps torque is expected to be generated.[6,13,21,23,24,31-33,35,36,38,43] According to our results, specific torque deficits of the quadriceps were found at 60° knee flexion in the isometric and isokinetic 60°/sec tests in the male group, and at 60° knee flexion in the isokinetic 60°/sec test in the female group. Therefore, the quadriceps strength might be more susceptible to ACL insufficiency at 60° knee flexion angle than at

30° knee flexion angle, whereas, the hamstrings did not show any angular-specific torque deficits. These findings might result from characteristics of torque-curves of the quadriceps and hamstrings muscles.[41]

In the comparison of isometric test and isokinetic (60°/sec and 180°/sec) testing modes, we found that the quadriceps torque was more reduced in isokinetic testing than in isometric testing at each flexion angle in both the male and female groups. On the other hand, in the deficits of the hamstrings torque, there was no significant difference between isometric test and isokinetic tests in the male group, whereas, more reduced torque in isokinetic tests than isometric test were found in female group. These findings may suggest that dysfunction of the quadriceps muscle influences on the dynamic torque production than on the static torque production, and also, that patients may subconsciously exert less quadriceps power in the dynamic knee extension. Moreover, less compensatory function of the hamstrings against anterior tibial translation might be predicted in the female than in the male group.

REFERENCES

1. Abbott, L.C., Saunders, J.B. deC.M., Bost, F.C., and Anderson, C.E.: J. Bone Joint Surg. 1944. 26. 503/521. Injuries to the ligaments of the knee joint.
2. Arnoczky, S.P.: Clin. Orthop. 1983. 172. 19/25. Anatomy of the anterior cruciate ligament.
3. Arnold, J.A., Coker, T.P., Heaton, L.M., Park, J.P., and Harris, W.D.: Am. J. Sports Med. 1979. 7. 305/313. Natural history of anterior cruciate tears.
4. Baugher, W.H., Warren, R.F., Marshall, J.L., and Joseph, A.: Am. J. Sports Med. 1984. 12. 192/195. Quadriceps atrophy in the anterior cruciate insufficient knee.
5. Butler, D.L., Noyes, F.R., and Grood, E.S.: J. Bone Joint Surg. (Am) 1980. 62. 259/270. Ligamentous restraints to the anteri-or-posterior drawer in the human knee. A biomechanical study.
6. Currier, D.P., and Mann, R.: J. Orthop. Sports Phys. Ther. 1984. 5. 318/323. Pain complaint : comparison of electrical stimulation with conventional isometric exercise.
7. Czerniecki, J.M., Lippert, F., and Olerud, J.E.: Am. J. Sports

Med. 1988. 16. 327/331. A biomechanical evaluation of tibiofemoral rotation in anterior cruciate deficient knees during walking and running.
8. DeHaven, K.E.: Am. J. Sports Med. 1980. 8. 9/14. Diagnosis of acute knee injuries with hemarthrosis.
9. Feagin, J.A. Jr., and Curl, W.W.: Am. J. Sports Med. 1976. 4. 95/100. Isolated tear of the anterior cruciate ligament : Five-year follow-up study.
10. Feagin, J.A. Jr.: Orthop. Clin. North Am. 1979. 10. 81/90. The syndrome of the torn anterior cruciate ligament.
11. Gerber, C., Hoppeler, H., Claassen, H., Robotti, G., Zehnder, R., and Jakob, R.P.: J. Bone Joint Surg.(Am) 1985. 67. 1034/1043. The lower extremity musculature in chronic symptomatic instability of the anterior cruciate ligament.
12. Giove, T.P., Miller, S.J., Kent, B.E., Sanford, T.L., and Garrick, J.G.:J. Bone Joint Surg.(Am) 1983. 65. 184/192. Non-operative treatment of the torn anterior cruciate ligament.
13. Hamberg, P., and Gillquist, J.: Acta Orthop. Scand. 1984. 55. 172/175. Knee function after arthroscopic menisectomy.
14. Ichihashi, N., and Itoh, H. : Bull. Allied Med. Sci. (Kobe) 1989. 5. 59/64. Isokinetic muscular strength of the thigh muscles in patients with insufficiency of the anterior cruciate ligament.
15. Johnson, R.J., and Pope, M.H.: Am. J. Sports Med. 1977. 5. 38/62. Tibial fractures in skiing.
16. Kannus, P., Latvala, K., and Jarvinen, M.: J. Orthop. Sports Phys. Ther. 1987. 9. 223/227. Thigh muscle strengths in the anterior cruciate ligament deficient knee.
17. Kannus, P.: Phys. Ther. 1988. 68. 961/965. Ratio of hamstring to quadriceps femoris muscles' strength in the anterior cruciate ligament insufficient knee. Relationship to long-term recovery.
18. Karrholm, J., Selvik, G., Elmqvist, L-G., and Hansson, L.I. : Acta Orthop. Scand. 1988. 59. 158/164. Active knee motion after cruciate ligament rupture. Stereoradiography.
19. Kennedy, J.C., Alexander, I.J., and Hayes, K.C.: Am. J. Sports Med. 1982. 10. 329/335. Nerve supply of the human knee and its functional importance.
20. Knapik, J.J., Wright, J.E., Mawdsley, R.H., and Braun, J. : Phys. Ther. 1983. 63. 938/947. Isometric, isotonic, and iso-

kinetic torque variations in four muscle groups through a range of joint motion.

21. Lesmes, G.R., Costill, D.L., Coyle, E.F., and Fink, W.J. : Med. Sci. Sports 1978. 10. 266/269. Muscle strength and power changes during maximal isokinetic training.
22. McDaniel, W.J., and Dameron, T.B.: Clin. Orthop. 1983. 172. 158/163. The untreated anterior cruciate ligament rupture.
23. Mohr, T., Carlson, B., Sulentic, C., and Landry, R. : Phys. Ther. 1985. 65. 606/612. Comparison of isometric exercise and high volt galvanic stimulation on quadriceps femoris muscle strength.
24. Morrissey, M.C., Brewster, C.E., Shields, C.L., and Brown, M.: Am. J. Sports Med. 1985. 13. 40/45. The effects of electrical stimulation on the quadriceps during postoperative knee immobilization.
25. Morrissey, M.C., and Brewster, C.E.: J. Orthop. Sports Phys. Ther. 1986. 7. 310/313. Hamstrings weakness after surgery for anterior cruciate injury.
26. Murray, S.M., Warren, R.F., Otis, J.C., Kroll, M., and Wickiewicz, T.L.: Am. J. Sports Med. 1984. 12. 436/440. Torque-velocity relationship of the knee extensor and flexor muscles in individuals sustaining injuries of the anterior cruciate ligament.
27. Nicholas, J.A., Strizak, M.A., and Veras, G.: Am. J. Sports Med. 1976. 4. 241/248. A study of thigh muscle weakness in different pathological states of the lower extremity.
28. Norwood, L.A., and Cross, M.J.: Am. J. Sports Med. 1979. 7. 23/26. Anterior cruciate ligament: Functional anatomy of its bundles in rotatory instabilities.
29. Noyes, F.R., Mooar, P.A., Matthews, D.S., and Butler, D.L.: J. Bone Joint Surg.(Am) 1983. 65. 154/162. The symptomatic anterior cruciate-deficient knee. Part I : The long-term functional disability in athletically active individuals.
30. Noyes, F.R., Matthews, D.S., Mooar, P.A., and Grood, E.S.: J. Bone Joint Surg.(Am) 1983. 65. 163/175. The symptomatic anterior cruciate-deficient knee. Part II : The results of rehabilitation, activity modification, and counseling on functional disability.
31. Oberg, B., Moller, M., Gillquist, J., and Ekstrand, J.: Int. J. Sports Med. 1986. 7. 50/53. Isokinetic torque levels for

knee extensors and flexors in soccer players.
32. Odensten, M., Tegner, Y., Lysholm, J., and Gillquist, J. : Acta Orthop. Scand. 1983. 54. 924/928. Knee function and muscle strength following distal ilio-tibial band transfer (DIT) for anterolateral rotatory instability.
33. Pavone, E., and Moffat, M.: Arch. Phys. Med. Rehab. 1985. 66. 168/170. Isometric torque of the quadriceps femoris after concentric, eccentric and isometric training.
34. Renstrom, P., Arms, S.W., Stanwyck, T.S., Johnson, R.J., and Pope, M.H. : Am. J. Sports Med. 1986. 14. 83/87. Strain within the anterior cruciate ligament during hamstring and quadriceps activity.
35. Seaborne, D., and Taylor, A.W.: J. Sports Med. 1984. 24. 183/188. The effect of speed of isokinetic exercise on training transfer to isometric strength in the quadriceps muscle.
36. Selkowitz, D.M.: Phys. Ther. 1985. 65. 186/196. Improvement in isometric strength of the quadriceps femoris muscle after training with electrical stimulation.
37. Solomonow, M., Baratta, R., Zhou, B.H., Shoji, H., Bose, W., Beck, C., and D Ambrosia, R.: Am. J. Sports Med. 1987. 15. 207/213. The synergistic action of the anterior cruciate ligament and thigh muscle in maintaining joint stability.
38. Tegner, Y., Lysholm, J., Gillquist, J., and Oberg, B. : Acta Orthop. Scand. 1984. 55. 176/180. Two-year follow-up of conservative treatment of knee ligament injuries.
39. Tegner, Y., Lysholm, J., Lysholm, M., and Gillquist, J. : Acta Orthop. Scand. 1986. 57. 130/134. Strengthening exercises for old anterior cruciate ligament tears.
40. Tibone, J.E., Antich, T.J., Fanton, G.S., Moynes, D.R. and Perry, J.: Am. J. Sports Med. 1986. 14. 276/284. Functional analysis of anterior cruciate ligament instability.
41. Vegso, J.J., Genuario, S.E., and Torg, J.S.: Med. Sci. Sports 1985.17. 376/379. Maintenance of hamstring strength following knee surgery.
42. Walla, D.J., Albright, J.P., McAuley, E., Martin, R.R., Eldridge, V., and El-Khoury, G.: Am. J. Sports Med. 1985. 13. 34/39. Hamstring control and the unstable anterior cruciate ligament-deficient knee.
43. Williams, M., and Stutzman, L.M.: Phys. Ther. Rev. 1959. 39. 145/152. Strength variation through the range of joint motion