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Original paper

Relationship between muscle volume and muscle torque of the hamstrings after anterior cruciate ligament reconstruction

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Abstract

The muscle torque per unit volume of the hamstrings on the injured and uninjured sides in patients with ACL reconstruction were compared with participants with no history of knee injury to examine whether a similar mechanism leading to quadriceps weakness exists in the hamstrings of these patients. The study population consisted of 18 and 52 patients at ≤6 and 12 months after ACL reconstruction, respectively, and 35 healthy controls. The hamstring volume was measured on MRI. To identify the muscle torque per unit volume, the peak torque of knee flexion was divided by the hamstring volume. Most muscle torque per unit volume indexes were not significantly different between the patients at ≤6 months (injured side: 0.133 ± 0.03 N m/cm^3, 60°/s; 0.107 ± 0.03 N m/cm^3, 180°/s; uninjured side: 0.139 ± 0.02 N m/cm^3, 60°/s; 0.107 ± 0.02 N m/cm^3, 180°/s) and controls (0.170 ± 0.05 N m/cm^3, 60°/s; 0.121 ± 0.05 N m/cm^3, 180°/s). However, the muscle torque per unit volume of patients at 12 months in both injured (0.118 ± 0.03 N m/cm^3, 60°/s; 0.092 ± 0.02 N m/cm^3, 180°/s) and uninjured sides (0.120 ± 0.03 N m/cm^3 at 60°/s; 0.094 ± 0.02 N m/cm^3, 180°/s) were significantly lower than those of controls ($P < 0.01$). We found no evidence of recruitment disorder in the hamstrings of the patients. The results of this study indicated that the mechanism of muscle weakness of the hamstrings after reconstruction was different from that of the quadriceps, although the precise mechanism remains to be determined.

Keywords: Muscle volume; Torque; ACL reconstruction; Muscle weakness; Hamstrings

1. Introduction

Several surgical methods are currently available for reconstruction of the anterior cruciate ligament (ACL). One of the most common methods used in such surgery involves grafting of the knee flexor tendons. Previous studies have indicated that muscle strength of knee flexion could be recovered to at least 90% of that of the uninjured knee using this method.[1–3] It has also been shown that the semitendinosus tendon, after harvesting for use as an ACL graft, has the potential to regenerate more proximally[4–6] and with similar morphology to the native tendon.[1,4–8]

However, morphological factors, such as muscle atrophy, are not the only factors determining maximal strength in these patients; previous studies suggested that the lack of afferent feedback from the ACL attenuated normal activation of the gamma motor neurons on the muscle around the knee[9–17] and the neurological abnormality could hinder recruitment of motor units in muscles around the knee despite the absence of morphological abnormalities.[9–14] Therefore, even if knee flexors were morphologically normal due to tendon regeneration and neurological abnormalities such as hindrance of motor unit recruitment may hinder the function of knee flexors. Previous studies indicated neurological abnormalities even in the muscles around the knee of the uninjured side.[10,12,14,18,19] Therefore, even if the muscle strength of the flexors recovered as compared with the uninjured side in these patients, the possibility of muscle weakness due to neurological abnormalities cannot be excluded.

Furthermore, a previous study demonstrated that the muscle torque per unit volume of the quadriceps in patients with ACL was significantly lower than that in controls.[10] In the present study, the muscle torque per unit volume of the ham-

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strings on the injured and uninjured sides in patients with ACL reconstruction were compared with participants with no history of knee injury to examine whether there is a mechanism similar to that leading to weakness of the quadriceps in the hamstrings of these patients. In addition, we examined how the time after ACL reconstruction affected hamstring function in patients with ACL reconstruction.

2. Methods

The study population consisted of 18 and 52 patients at ≤6 months (11 male, 7 female; mean age, 20.7 ± 4.4) and 12 months (27 male, 25 female; mean age, 21.1 ± 5.3) after ACL reconstruction, respectively, and 35 controls with no history of knee injury (25 male, 10 female; mean age, 20.9 ± 1.1). The groups were age-matched as aging may affect the value of specific tension.[20] The ACL reconstruction patients showed various levels of activity (Table 1). All controls were competitive athletes at college level. A semitendinosus tendon was used in all patients in whom ACL repair was performed. Reconstruction of the ACL was performed by the senior orthopaedic surgeon at a university hospital. A quadruple semitendinosus tendon was used as the graft material in this study. The femoral side of the reconstructed ligament was fixed with EndoButton® (Acufex, Mansfield, MA, USA), while the tibial side was fixed with a post and screw. Double or triple semitendinosus grafts were used under arthroscopic control. The tendon of gracilis was preserved providing the length of the semitendinosus tendon was sufficient to allow reconstruction of the ligament. Participants with no history of knee injury were assigned to the control group. The injured and uninjured groups consisted of the injured side and the uninjured side in patients with ACL repair, respectively. All patients underwent rehabilitation according to the same protocol. Examination of the range of motion and weight-bearing exercises were begun three days after surgery. Knee flexion of more than 90° and walking with full weight-bearing, using double crutches were required for at least 2 weeks after surgery. Jogging was encouraged after 3 months. Various sporting activities were practiced in a step-by-step manner, and full sporting activities were allowed from 6 months after surgery. Medical checks were performed by the operating physician at the time of the study to determine abnormal physical findings, such as joint laxity, pain, and inflammatory signs. Participants with abnormal physical findings were excluded from the study. All participants gave their informed consent to participate in the study, and all procedures were approved by the Committee of Human Experimentation in Saitama Jikei Hospital.

A series of cross-sectional images of each participant's thighs were obtained by magnetic resonance imaging (MRI) scans with a Signa 1.5 (General Electric, Milwaukee, WI, USA). Each participant lies in the supine position with the knee extended and relaxed during imaging. Scanning of cross-sectional images was performed from the femoral greater trochanter to the tibial condyle. The slice thickness was 10 mm and the gap was 12 mm, so the slice interval of each image was 22 mm. The outlines traced on each image were scanned (GT-7000S; Epson, Tokyo, Japan) for analysis on a computer. The image processing software Scion Image (Scion Corp., Frederick, MD, USA) was used to estimate the cross-sectional area of each muscle on each image. To estimate the volume of muscle, the cross-sectional area on each image was summed and multiplied by the slice interval (22 mm). The distal 70% of the images were used, because it is difficult to distinguish each muscle component in the proximal part of the thigh. The semitendinosus, semimembranosus, and biceps femoris were identified in these images.

All of the participants performed warm-up exercises, and then learned to exert peak torque in a practice session before the measurements. All of the participants were asked to exert peak torque of concentric knee flexion from the 0° knee-extension position to full flexion. Isokinetic knee flexion torque at angle velocities of 60°/s and 180°/s were determined with a Cybex III-350 (Cybex, Medway, MA, USA). Each participant was placed in the sitting position with their shoulders, body, and thighs fixed in a harness. Isokinetic tests were performed 4 times for each velocity, and each trial was separated by a rest period of 2 min. The participants received verbal encouragement during the exertion of peak torque.

Table 1
Characteristics of participants.

	Patients at 12 months	Patients at ≤6 months	Control
Age (mean ± S.D.)	21.1 ± 5.3	20.7 ± 4.4	20.9 ± 1.1
Sex	27 Male 25 Female	11 Male 7 Female	25 Male 10 Female
Sports level	C: 39 R: 14 O: 10 N: 7	C: 18	C: 34 R: 1
Weight (kg; mean ± S.D.)	64.2 ± 12.1	65.7 ± 9.7	63.1 ± 6.3

C: competitive level athletes; R: recreational level; O: occasional participation in sports activities, defined as once or twice per week; N: none, did not participate in sports activities.