

Anterior laxity and MR signals of the knee after exercise

A comparison of 9 normal knees and 6 anterior cruciate ligament reconstructed knees

Yoshio Sumen¹, Mitsuo Ochi², Nobuo Adachi², Yukio Urabe³ and Yoshikazu Ikuta¹

9 healthy volunteers and 6 patients with anterior cruciate ligament (ACL) grafts underwent anterior knee laxity measurements and MRI examinations of their knees before and after intensive physical exercise. In the volunteer group, anterior displacement of the knee at 89 and 133 newtons of loading, measured with a KT-2000 knee arthrometer, increased after exercise, compared to before it. In addition, anterior terminal stiffness decreased at 133 newtons of anterior loading. In the ACL group, anterior displacement

at 89 and 133 newtons of loading also increased, while no difference was found in anterior terminal stiffness before versus after exercise. On MRI, the signal intensity of normal ACLs after exercise was higher than before it. In contrast, the signals from the grafts showed no differences before versus after exercise. Our findings suggest that the ACL grafts are biomechanically and biochemically different from normal ACLs, even 15 months after ACL reconstruction.

Departments of Orthopaedic Surgery, ¹Hiroshima University School of Medicine, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8551, Japan. Tel +81 82 257-5233. Fax -5234; ²Shimane Medical University, Shimane, Japan, and ³Institute of Health Sciences, Hiroshima University School of Medicine, Hiroshima, Japan
Submitted 98-07-25. Accepted 99-01-27

An increase in knee joint laxity after exercise has been reported by some investigators (Stoller et al. 1983, Skinner et al. 1986, Steiner et al. 1986). This phenomenon was thought to be caused by decreased resting muscle tone due to fatigue, the viscoelastic behavior of the ligaments and other structures surrounding the knee joint, or by an elevation in temperature (Woo et al. 1987, Fukubayashi et al. 1991). However, it is not known whether the knee joint with a grafted ACL shows a similar increase in laxity after exercise.

We examined the anterior laxity and MRI findings in both healthy volunteers and patients with ACL grafts, before and after exercise.

Subjects and methods

The healthy volunteers, consisted of 9 women aged 18–24 years, from a basketball team having no history of trauma or pain in their knee joints. The 6 (5 women) patients, aged 17–23 years, had undergone arthroscopic ACL reconstructions us-

ing double-looped, semitendinosus and gracilis tendon autografts. The postoperative periods ranged from 15 to 48 months, and all of the patients obtained good knee function and stability and returned to their preoperative level of sports activity.

Ligament arthrometer measurements were performed by an experienced examiner (YU) on 1 knee of each volunteer and on the reconstructed knee of each patient, using a KT-2000 knee ligament arthrometer (Med Metric, San Diego, CA). The measurements were performed before and at 10 min after exercise. They were made at 20° of knee flexion at 1) an anterior displacement of 89 newtons of loading, 2) 133 newtons of loading, and 3) anterior terminal stiffness. Anterior terminal stiffness was measured by drawing a tangent at the point of the 133 newtons of loading on a force-displacement curve (Figure 1). 5 anterior tests were made at a single examination and the average of the respective measurements was considered the resultant value. A paired t-test was used for preexercise versus postexercise comparisons.

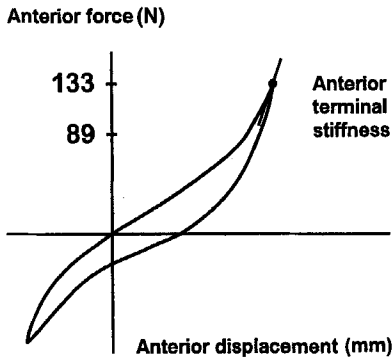


Figure 1. **Force-displacement curve.** Anterior terminal stiffness was measured by drawing a tangent at the point of the 133 newtons of loading.

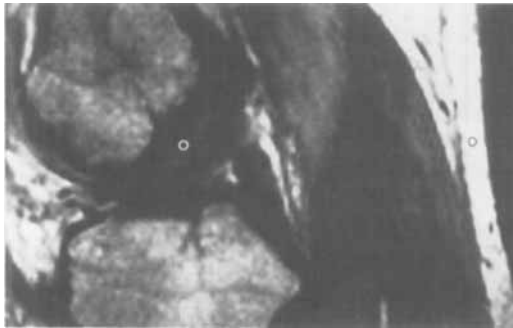


Figure 2. **Signal intensity measurement.** The signal intensity of the normal ACL and the graft was measured in a circular area 2 mm in diameter (white circle). The ratio of ACL to the fat tissue signal intensity (black circle) in each volunteer or patient was compared before and after exercise.

On the same knee, MR examinations were performed before and 20 min after exercise. All MR scans were performed with a 0.2-Tesla MR unit

Table 1. One-hour exercise protocol

200 m run	× 10
Rope skipping	5 min
Stair climbing (10 stairs)	up and down × 6
Shuttle running	30 seconds × 3
30 m dash	× 8
Side step jumping	20 seconds

(MRP20EX; Hitachi, Tokyo, Japan). In 3 volunteers, spin echo proton density (TR/TE = 2000/38) and T2-weighted (TR/TE = 2000/100) sagittal images of the ACLs were obtained. In 6 volunteers and 6 patients, 3D-gradient echo T2* (TR/TE = 100/23, flip angle 45°) sagittal images of the normal ACLs and the grafts were obtained. Signal intensity measurements were made from the middle part of the ligament with a manufacturer-provided software, in a circular area 2 mm in diameter. The intensity measurement was also obtained from the subcutaneous fat tissue in the popliteal area in each image, to allow normalization of the data from image to image (Figure 2). All the measurements were performed by an orthopedic surgeon (YS). The ratio of ACL to fat tissue signal intensity in each volunteer or patient was compared before and after exercise. A paired t-test was used for preexercise versus postexercise comparisons.

The exercise protocol consisted of a 200 m run, rope skipping, stair climbing, shuttle running, a 30 m dash and side step jumping. The volunteers and patients performed the same exercise for 1 hour (Table 1).

Table 2. Knee arthrometer (KT-2000) measurements and MR signal intensities obtained by 3D-gradient echo T2* imaging, mean (SD)

	Normal ACL		ACL graft	
	preexercise	postexercise	preexercise	postexercise
Anterior displacement (89 N) mm	5.9 (2.0)	6.9 (1.9) ^a	6.0 (2.2)	7.4 (2.9) ^a
(133 N) mm	7.8 (3.2)	8.8 (2.7) ^a	7.7 (2.9)	9.3 (3.3) ^a
Anterior terminal stiffness N/mm	72 (9.2)	66 (9.4) ^b	61 (8.2)	58 (1.7)
ACL/Fat signal intensity ratio	0.28 (0.02)	0.38 (0.08) ^b	0.23 (0.04)	0.22 (0.05)

Significant (^a $p < 0.01$, ^b $p < 0.05$) difference pre vs. post exercise



Figure 3. MRI of a normal anterior cruciate ligament before exercise.



The signal intensity after exercise was significantly higher than before it.



Figure 4. MRI of an anterior cruciate ligament graft before exercise.



There was no change in the signal intensity after exercise.

Results

In the volunteer group, there were significant increases in anterior displacement with 89 and 133

newtons of force, and a significant decrease in anterior terminal stiffness after exercise. In the ACL group, there were also significant increases in anterior displacement with 89 and 133 newtons of



Figure 5. MRI of a normal posterior cruciate ligament before exercise.



The signal intensity after exercise was significantly higher than before it.

force after exercise. However, there was no significant difference in anterior terminal stiffness before or after exercise (Table 2).

On the MR examination, no difference in signal intensity was observed before versus after exercise in all 3 normal ACLs, which were depicted using spin echo proton and T2-weighted images. On the other hand, in 5 of the 6 normal ACLs which were depicted using 3D-gradient echo T2* imaging, the signal intensity after exercise was significantly higher than before it (Figure 3). The image from the other normal knee, using 3D-gradient echo T2* imaging, was indistinct due to a body movement artifact, and therefore could not be evaluated. The MR intensity of 6 grafts which were depicted using 3D-gradient echo T2* imaging showed no differences before versus after exercise (Figure 4). In 5 normal ACLs depicted using 3D-gradient echo T2* imaging, there were significant increases in the ratio of ACL to fat tissue signal intensity after exercise. However, in 6 grafts, there was no significant difference before or after exercise (Table 2).

Discussion

We found a significant increase in anterior laxity in normal knees after exercise, supporting the results of previous studies (Stoller et al. 1983, Skinner et al. 1986, Steiner et al. 1986). The effects of exercise on knees with ACL grafts demonstrated that the change in the anterior laxity of the reconstructed knees was similar to that in normal knees. However, in contrast to normal knees, the anterior terminal stiffness of the reconstructed knees did not change after exercise. This may be due to a difference in the biomechanical behavior of normal ligaments versus hamstring grafts, or normal ligaments versus injured knees, although further investigation is necessary to determine how much this difference in stiffness influences knee function and sports performance.

On MR examination using 3D-gradient echo T2* imaging, we found that the signal intensity of the normal ACL increased after exercise. This change may represent the increase in water content induced by an increase in blood supply to the ACL and its surrounding synovia after exercise. In 3 normal ACLs depicted with spin echo images, no difference in signal intensity was observed be-

fore or after exercise. This may be explained because 3D-gradient echo T2* imaging is more sensitive to variations in water content than spin echo imaging.

In the ACL grafts, the MR signal did not increase after exercise, even using 3D-gradient echo T2* imaging. This probably means that the water content in the grafted ACL does not increase as much as a normal ACL after exercise. The ACL graft was depicted as a homogeneous low band before exercise, and was similar to the normal posterior cruciate ligament (PCL) rather than to the normal ACL. The signal intensity of the normal PCL increased after exercise as much as the normal ACL (Figure 5). Therefore, this study showed a difference between the normal ligaments and the graft in the biochemical components which were revealed by an MR examination following exercise.

Johnson (1993) studied second-look arthroscopies and histologic examinations of 20 autogenous semitendinosus grafts during the period of 20 days to 44 months after implantation and concluded that the ACL graft was a composite, consisting of the original hypovascular tendon graft plus a surrounding hypervascular reactive fibrous tissue. He observed no vascularity or bleeding from the tendon graft after the release of a tourniquet. Recently, findings of Howell et al. (1995) supported these results with MRI, using an intravenous contrast agent. They concluded that the unimpinged ACL graft acquired no discernible blood supply during the 2 years of implantation. It is impossible to apply directly our results to those of previous studies because the "ACL at rest" in

the previous studies may not be the same as the "ACL at work" in this study. However, our results may represent a difference in the structure of the components, such as the vasculature, or a difference in permeability from the blood supply between the normal ACL and the ACL graft. Further investigation is necessary to find out how long it takes for the reconstructed ACL to show the same appearance on MRI and the same biomechanical behavior, even after exercise.

We are most grateful to Mr. Shigeyuki Katou and Ms. Keiko Yanagimaru, both students from the Institute of Health Sciences, Hiroshima University School of Medicine, and to Dr. Masashi Osedo, for their kind assistance.

- Fukubayashi T, Miyanaga Y, Shimojo H, Shimoji F. Effects of exercise and temperature on the laxity of the knee (Japanese). *J Tokyo Knee Soc* 1991; 12: 33-7.
- Howell S M, Knox K E, Farley T E, Taylor M A. Revascularization of a human anterior cruciate ligament graft during the first two years of implantation: *Am J Sports Med* 1995; 23: 42-9.
- Johnson L L. The outcome of a free autogenous semitendinosus tendon graft in human anterior cruciate reconstructive surgery: A histological study. *Arthroscopy* 1993; 9: 131-42.
- Skinner B, Wyatt M P, Stone M L, Hodgdon J A, Barrack R L. Exercise-related knee joint laxity. *Am J Sports Med* 1986; 14: 30-4.
- Steiner M E, Grana W A, Chillag K, Schelberg-Karnes E. The effect of exercise on anterior-posterior knee laxity. *Am J Sports Med* 1986; 14: 24-9.
- Stoller D W, Markolf K L, Zager S A, Shoemaker S C. The effect of exercise, ice, and ultrasonography on torsional laxity of the knee. *Clin Orthop* 1983; 174: 172-80.
- Woo S L-Y, Lee T Q, Gomez M A, Sato S, Field F P. Temperature-dependent behavior of the canine medial collateral ligament. *Trans ASME* 1987; 109: 68-71.