Magnetic resonance imaging and spectroscopy of thigh muscles in cruciate ligament insufficiency

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In 21 patients with injury-related, chronic, anterior cruciate ligament insufficiency, ^{1}H-magnetic resonance (MR) imaging and ^{31}P-MR spectroscopy of the quadriceps muscles were performed with a systemic superconductive MR apparatus. The quadriceps of the noninjured side was used as the control. The quadriceps had a reduced cross-sectional area, but the knee flexors were not reduced. T_2 values were prolonged in the vastus lateralis, medialis, and intermedius, but those of the rectus femoris were not. Phosphocreatine per inorganic phosphate measured with ^{31}P-MR spectroscopy was decreased in the atrophied muscles, which correlated with the muscular cross-section. There was no difference in the muscular pH as recorded by the chemical-shift measurements of phosphocreatine and inorganic phosphate. Serial measurements of muscle cross-sectional area and high-energy phosphate bonds reflect the recovery of muscles.

Many attempts have been made to evaluate the functional condition of atrophied muscles after a knee injury, including volumetric analysis using computed tomography (Gerber et al. 1985), histochemical and biochemical analysis of biopsy samples (Edström 1970, Baugher et al. 1984, Gerber et al. 1985, Nakamura et al. 1986), as well as electromyography (Limbird et al. 1988). These reports suggest not only a decrease in the quantity of muscle mass, but also qualitative changes following anterior cruciate ligament insufficiency.

The magnetic resonance (MR) method has made it possible to analyze muscular cross-sectional images and relaxation time by ^{1}H-MR imaging, and high-energy phosphate bonds by ^{31}P-MR spectroscopy in vivo. We have evaluated the thigh muscles in anterior cruciate ligament insufficiency with ^{1}H-MR imaging and ^{31}P-MR spectroscopy.

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Patients and methods

The study was conducted on 21 patients with chronic, symptomatic, anterior cruciate-ligament insufficiency who had received the initial injury, on an average, 3 years earlier. Seven were males and 14 were females aged 22 (15–27) years. All of them had been injured unilaterally, and the diagnosis was confirmed by arthroscopy. The knee instability disabled all of these patients in their athletic activities and/or daily lives. The femoral circumference, measured 10 cm proximal to the patellar upper margin, was decreased on an average of 1.5 cm on the injured side as compared with that on the noninjured side.

With the patients supine and the knees extended, ^{1}H-MR images of the femoral cross section at 10 cm proximal to the patellar upper margin on both sides with an image plane of 10 mm were displayed with 256 x 256 matrix elements by a Siemens Magnetom superconductive magnet operating in a spin-echo technique at 1.5 tesla. Because ^{1}H-MR imaging with a repetition time of 2,000 ms and an echo time of 28 ms gave good soft-tissue contrast and showed the muscular form well, it was used to calculate the cross-sectional area (Figure 1) of the quadriceps and the knee flexors.

The T_1 and T_2 calculated images were obtained as repetition times of 600 and 2,000 ms and echo times of 28 and 75 ms by a spin-echo technique; T_1 and T_2 val-

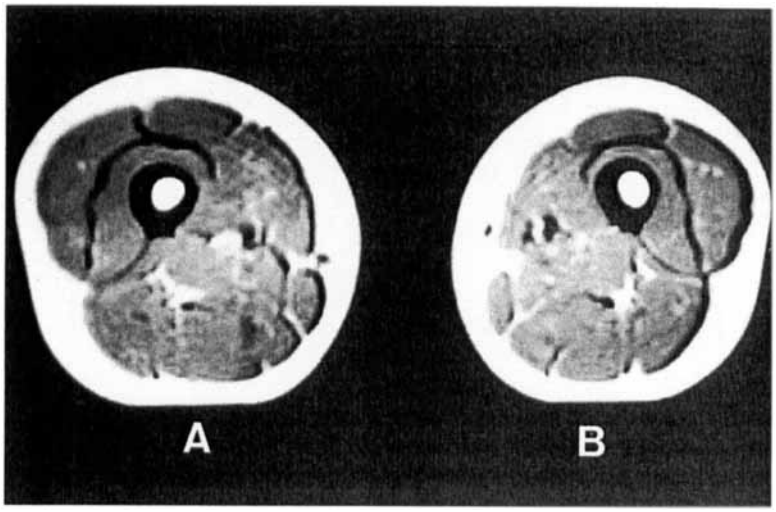

Figure 1. ^{1}H-MR image of bilateral thighs 10 cm proximal to the patellar upper margin in a spin-echo technique with a repetition time of 2,000 ms and an echo time of 28 ms showing the markedly reduced cross-sectional area of the quadriceps muscles on the injured side (B) compared with those on the noninjured side (A).

ues were calculated for each muscle of the femoral quadriceps.

The quadriceps was examined by ^{31}P-MR spectroscopy, using the same superconductive MR apparatus, by placing a 8-cm-diameter surface coil on the anterior surface of the thigh for detection of the ^{31}P-MR spectra. In ^{31}P-MR spectroscopy of the muscle, phosphocreatine (PCr), inorganic phosphate (Pi), and adenosine triphosphate (ATP) appear as peaks (Figure 2). Each peak area was calculated, and PCr/Pi and ß-ATP/Pi values were obtained. Muscular pH was determined by the chemical shifts of PCr and Pi.

^{1}H-MR imaging and ^{31}P-MR spectroscopy were performed under the same relaxed conditions for both right and left sides.

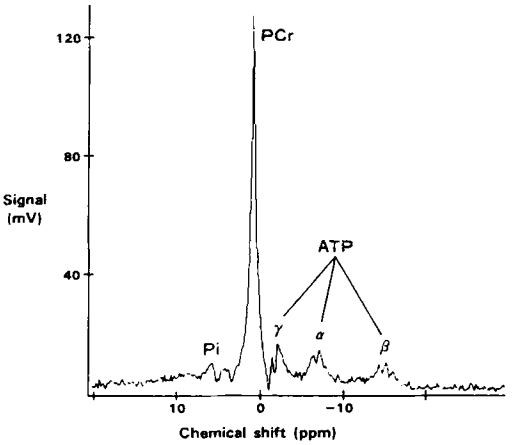

Figure 2. ^{31}P-MR spectroscopy. Phosphocreatine (Pr), inorganic phosphate (Pi), and adenosine triphosphate (ATP) appear as peaks with different chemical shifts.

Results

The cross section of the quadriceps was reduced to an average of 88 (73–96) percent of that of the noninjured side. The knee flexors including the biceps femoris, semitendinosus, semimembranosus, and gracilis were not reduced significantly (Table 1).

T_1 values showed no difference, whereas T_2 values were elevated on the injured sides in the vastus muscles, but not in the rectus femoris (Table 2).

In cases with less than a 90-percent-normal quadriceps cross section, the PCr/Pi values were decreased

Table 1. ^{1}H-MR imaging analysis of muscle area (cm^2) of thigh 10 cm proximal to the upper margin of the patella. Mean *SD*

		Quadriceps		Flexors		Percent of control	
	n	Control	Injured	Control	Injured	Q	F
Men	7	84 *10*	76 *7*	44 *5.1*	41 *4.5*	90 *7*	95 *7*
Women	14	62 *11*	54 *12*	34 *6*	33 *5.3*	87 *8*	97 *8*
Total	21	69 *15*	61 *14*	37 *7.2*	35 *6.4*	88 *8*	96 *8*

Table 2. Comparison of T_1 and T_2 values (msec) of quadriceps muscles of control and injured thighs. Mean *SD*

		Vm		Vl		Vi		Rf	
T_1	Control	925	*102*	923	*195*	975	*129*	1,032	*237*
		n 18	NS	n 19	NS	n 17	NS	n 15	NS
	Injured	954	*212*	909	*132*	937	*159*	935	*187*
T_2	Control	29.9	*2.1*	30.6	*1.8*	31.1	*3.0*	29.4	*2.1*
		n 17	$P<0.05^a$	n 20	$P<0.05^a$	n 18	$P<0.05^a$	n 16	NS
	Injured	32.0	*3.4*	32.5	*4.2*	33.3	*5.2*	29.7	*2.8*

Vm vastus medialis, Vl vastus lateralis, Vi vastus intermedius, rf Rectus femoris. [a] Paired *t*-test.

Table 3. Phosphocreatine per inorganic phosphate and ß-adenosine triphosphate per inorganic phosphate. Mean *SD*

Groups	n	PCr/Pi				β-ATP/Pi			
		Injured		Control		Injured		Control	
M	10	15.9	*2.3*	15.1	*1.7*	3.2	*0.4*	2.9	*0.5*
S	11	14.8	*5.1*	16.7	*5.8*	3.0	*1.0*	3.2	*0.9*
Total	21	15.3	4.1	15.9	4.4	3.1	0.8	3.0	0.9
		NS		NS		NS			
		$P<0.05^a$							

M moderately atrophied group, S severely atrophied group. [a] Paired *t*-test.

(Table 3). The quadriceps cross-sectional area was correlated with the PCr/Pi, but not with the ß-ATP/Pi ratio. There was no difference in the muscular pH determined by the chemical shifts of PCr and Pi, with a mean value of 7.1 (6.9–7.4).

Discussion

Our observations that instability of the anterior cruciate ligament affected predominantly the quadriceps and slightly the knee flexors agree with the results of computed tomography (Gerber et al. 1985), and would indicate the different liability between the flexor and extensor muscles of the knee to undergo atrophy.

In the analysis of relaxation time, the T_2 values were prolonged in the three vasti except for the rectus femoris. Although it is not clear what biological phenomenon is exactly responsible for the prolongation of the T_2 value, it appears that it indicates increased water content, for example, due to the fatty degeneration (Gerber et al. 1985). It is interesting that the rectus femoris on the affected side did not show any prolongation of the T_2 value. Because the rectus femoris has mechanical actions on both the knee and the hip, it may be less vulnerable to the knee-joint instability.

^{31}P-MR spectroscopy makes it possible to analyze high-energy phosphate in the muscle noninvasively, and is useful to study the muscle metabolism and pathophysiology (Edwards et al. 1982, Heppenstall et al. 1986, Newman et al. 1982, Ross et al. 1981, Sapega et al. 1985).

In our results, PCr/Pi values were reduced in the severely atrophied quadriceps. On the other hand, ß-ATP/Pi values did not show any difference. The ratios of the quadriceps cross-sectional area and the PCr/Pi value to the control showed the positive correlation. These data may indicate that phosphocreatine content decreases in the atrophied quadriceps, but ATP content remains uninfluenced. Probably these metabolic changes and the severity of muscle atrophy are correlated.

We conclude that the MR is useful for analysis of functional and volumetric changes in muscle atrophy.

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