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Abstract

We investigated the degree of local heat and swelling of the thigh muscles produced by exercise. Eleven university athletes aged from 19 to 23 years old performed isokinetic exercise of the right knee on a Cybex II. Then serial determination of thigh circumference and thigh temperature (up to 120 min after exercise) as well as serial magnetic resonance (MR) imaging (up to 60 min after exercise) was performed on both thighs. The circumference of the right thigh peaked at 5.6 +/- 2.1 min after exercise and returned to normal at 38.6 +/- 9.2 min. The temperature of the right thigh peaked at 14.2 +/- 5.7 min after exercise and was not normalized after 120 min except in two subjects. T2-weighted MR images showed a marked increase in the signal intensity of the right knee flexor and extensor muscles. The signal intensity peaked immediately after exercise and subsequently decreased gradually but did not return to normal after 60 min in some muscles. Changes in the thigh circumference were closely correlated with changes in the MR findings. The changes in the thigh muscles after knee exercise could be demonstrated using MR imaging, thigh circumference, and thigh temperature data. These parameters may provide indicators for managing muscle fatigue and recovery.

KEYWORDS: Cybex ?, magnetic resonance imaging, knee exercise, thigh muscles

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Evaluation of the Thigh Muscles after Knee Exercise on a Cybex II

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We investigated the degree of local heat and swelling of the thigh muscles produced by exercise. Eleven university athletes aged from 19 to 23 years old performed isokinetic exercise of the right knee on a Cybex II. Then serial determination of thigh circumference and thigh temperature (up to 120 min after exercise) as well as serial magnetic resonance (MR) imaging (up to 60 min after exercise) was performed on both thighs. The circumference of the right thigh peaked at 5.6 ± 2.1 min after exercise and returned to normal at 38.6 ± 9.2 min. The temperature of the right thigh peaked at 14.2 ± 5.7 min after exercise and was not normalized after 120 min except in two subjects. T2-weighted MR images showed a marked increase in the signal intensity of the right knee flexor and extensor muscles. The signal intensity peaked immediately after exercise and subsequently decreased gradually but did not return to normal after 60 min in some muscles. Changes in the thigh circumference were closely correlated with changes in the MR findings. The changes in the thigh muscles after knee exercise could be demonstrated using MR imaging, thigh circumference, and thigh temperature data. These parameters may provide indicators for managing muscle fatigue and recovery.

Key words: Cybex II, magnetic resonance imaging, knee exercise, thigh muscles

Since Fleckenstein *et al.* first reported in 1988 (1, 2) that exercise altered the signal intensity of muscles on magnetic resonance (MR) images, some other investigators have reported the alterations of the MR signal intensity after various exercises (3-5). Increased local heat, swelling, and muscle stiffness are common following exercise. To clarify the extent of these phenomena in the thigh, changes in thigh circumference and thigh temperature in addition to the MR imaging appearance of the thigh muscles after knee exercise were investigated in the present study. In addition, we tried to clarify the correlation among thigh circumference, thigh temperature and MR imaging appearance.

Subjects and Methods

The subjects were 11 male university athletes aged from 19 to 23 years (mean, 21.0 years). Before exercise, discoid temperature sensors with an accuracy of ± 0.1°C (Terumo Corporation Ltd., Tokyo, Japan) were attached to the frontal surfaces of both thighs 15 cm above the patella. The subjects were instructed to rest until the temperature readings of both thighs were stabilized. The bilateral thigh circumference at rest was measured 5 cm and 10 cm above the patella. Following this, right knee exercise was repeated 50 times with maximum effort at an angular velocity of 180°/sec using a Cybex II apparatus (Fig. 1). After exercise, each subject was instructed to rest again and the changes in the bilateral thigh circumference and temperature were determined at 2-min intervals up to 20 min and at 5-min intervals up to 120 min after exercise. The temperature in the room was constant (24 °C). Transverse MR images were taken of the region ranging from 5 cm to 12 cm above the patella of both thighs at 1-cm intervals. Images were obtained at rest and at 10-min intervals up to 60 min after exercise using a 1.5 T magnetom (Siemens Corporation, Germany). In six subjects, the intensity of the regions of interest (ROIs) in the rectus femoris and gracilis was serially determined on T2-weighted MR images. For normalization, each ROI value was divided by the intensity of intramedullary fat (determined simultaneously). In five subjects, a three-way comparison of the cross sectional area of rectus femoris 10 cm above the patella was conducted. The opposite side

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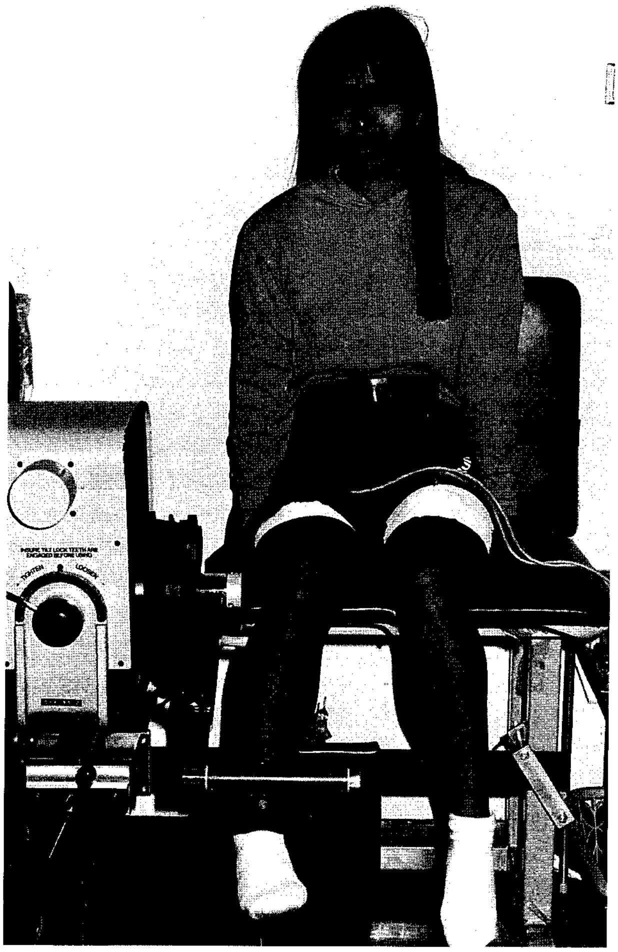

Fig. 1 Knee exercise using a Cybex II.

was measured at rest, and the exercised side was measured at both 20 and 50 min after exercise.

We averaged the serial data of each subject. The results were analyzed by a one-way analysis of variance. Pearson's correlation coefficient was used to compare the serial averaged datum at pre-exercise and at 10, 20, 30, 40, 50 and 60 min after exercise.

Results

Thigh circumference. The thigh circumference at 10 cm above the patella on the exercised side increased immediately after exercise and reached a maximum at 5.6 ± 2.1 min. Thereafter, it gradually decreased to return to the pre-exercise level after 38.6 ± 9.2 min. The mean maximum increase was 1.38 ± 0.41 cm (range, 0.6–2.1 cm). The circumference at 5 cm above the patella showed similar changes with that at 10 cm above the patella (Fig. 2). There were no changes in thigh circumference on the opposite side.

Thigh temperature. The temperature of the exercised thigh was elevated immediately after exercise in all subjects except one and reached a maximum at 14.2 ± 5.7 min after exercise. The maximum increase was 1.01 ± 0.46 °C (range, 0.5–1.8 °C). Thigh temperature showed a gradual decline after peaking. In two subjects, it returned to the pre-exercise level at 100 min and 110 min after exercise, respectively. However, in the other nine subjects, the temperature did not return to the pre-exercise level after 120 min (the end of the study period) and was still elevated by 0.2–1.2 °C. The thigh temperature of the opposite side was measured in seven subjects. After exercise, the temperature gradually increased and reached a maximum at about 40 min in three subjects (+ 0.5 °C, + 0.6 °C, and + 0.6 °C), followed by a gradual decline (peak type). In one subject, the temperature reached a maximum (+ 0.2 °C) at about 40 min after exercise and subsequently remained unchanged up to 120 min (plateau type). In the other three subjects, the temperature was still increasing gradually at 120 min after exercise (+ 0.2 °C, + 0.4 °C, and + 0.6 °C) (ascending type) (Fig. 3).

MR imaging findings. In T2-weighted MR images, the flexor and extensor muscles on the exercised side generally showed a high signal intensity. Although

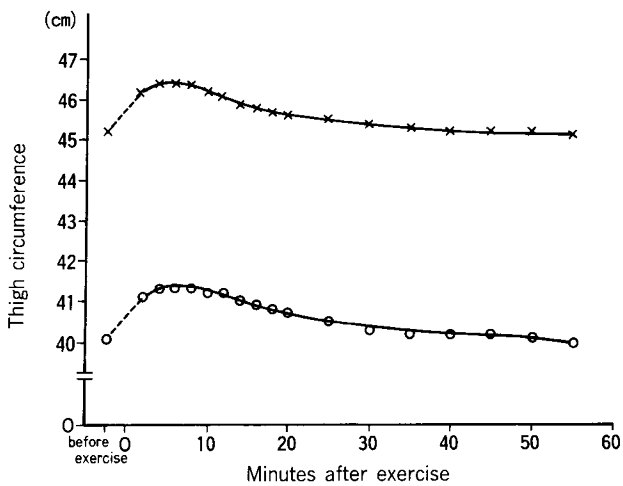

Fig. 2 The changes of thigh circumference 5 cm (○) and 10 cm (×) above the patella on the exercised side (Averaged data of 11 subjects).

there were individual differences in the muscles which showed the highest signal intensity, the signals tended to be maximal in the rectus femoris, semitendinosus, and gracilis. The muscles with a high signal intensity also had a large cross-sectional area. The images taken at 10 min after exercise (initial images) showed maximal signal intensities and cross-sectional areas, and the values then decreased gradually up to 60 min after exercise (end of the study). Some of the muscles did not show a return to pre-exercise intensity even after 60 min (Figs. 4 and 5). In contrast, T1-weighted and proton density MR images revealed no changes in signal intensity on the exercised side. All types of images showed no changes in the opposite side.

In all six subjects undergoing ROI assessment, ROI values reached a maximum at 10 min after exercise and subsequently decreased with time. The maximum values were 205 ± 37.2 % of the pre-exercise levels in the rectus femoris and were 171 ± 54.7 % in the gracilis. The values returned to the pre-exercise levels within 60 min in about half of the muscles but not in the remaining muscles (Fig. 4).

In all five subjects undergoing comparison of the cross-sectional area of rectus femoris, the largest area

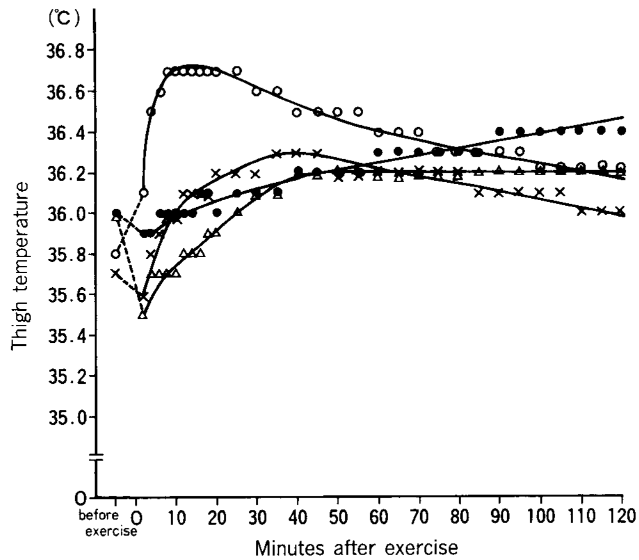

Fig. 3 The changes in thigh temperature on the exercised side and the opposite side (Averaged data of 11 subjects). ○: Exercised side; ×: Peak type, opposite side; △: Plateau type, opposite side; ●: Ascending type, opposite side.

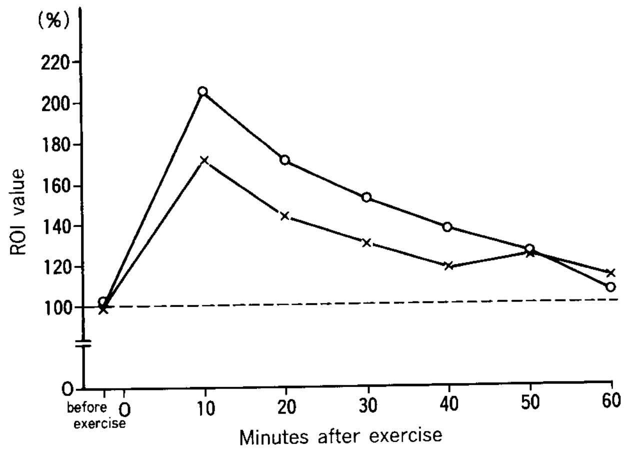

Fig. 4 The changes of the ROI value (T2-weighted images) of the musculus rectus femoris and the gracilis (Averaged data of 6 subjects). ○: Rectus femoris; ×: Gracilis. ROI: Intensity of the regions of interest.

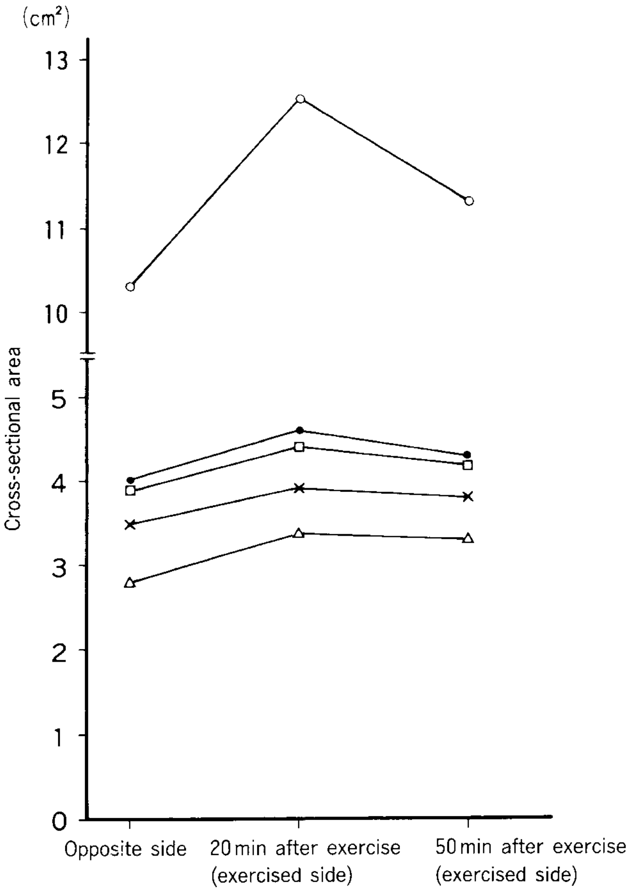

Fig. 5 The comparison of the cross-sectional area of the musculus rectus femoris in 5 subjects.

Table 1 The averaged data from the exercised side of each subject

	Pre-exercise	Maximum	Last
Thigh circumference 5 cm above the patella (n = 11)	40.1 ± 2.25 cm	41.3 ± 2.37 cm	40.1 ± 2.25 cm
Thigh circumference 10 cm above the patella (n = 11)	45.2 ± 2.33 cm	46.4 ± 2.51 cm	45.1 ± 2.27 cm
Thigh temperature (n = 11)	35.8 ± 0.42 °C	36.7 ± 0.25 °C	36.2 ± 0.20 °C
ROI value in the rectus femoris (n = 6)	100%	205 ± 37.2%	107 ± 11.3%
ROI value in the gracilis (n = 6)	100%	171 ± 54.7%	112 ± 26.0%

ROI: See legend to Fig. 4.

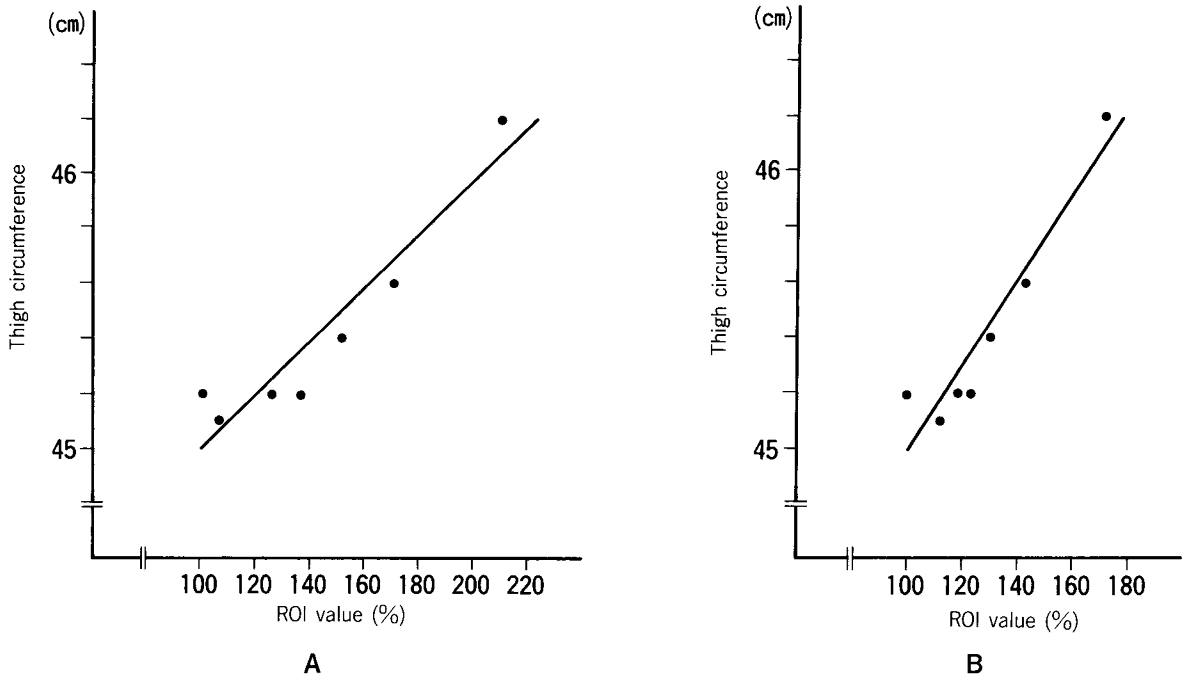

Fig. 6 The correlation of averaged data between the thigh circumference 10 cm above the patella and the ROI values. **A**: In the rectus femoris (r = 0.930, $P < 0.01$); **B**: In the gracilis (r = 0.946, $P < 0.01$). ROI: See legend to Fig. 4.

was on the exercised side at 20 min after exercise, followed by the exercised side at 50 min and the opposite side in that order (Fig. 5).

The serial data on the exercised side was significantly changed ($P < 0.01$) (Table 1). On the exercised side, the thigh circumference 10 cm above the patella and the ROI values in the rectus femoris were significantly correlated (r = 0.930, $P < 0.01$) (Fig. 6-A), and the thigh circumference 10 cm above the patella and the ROI values in the gracilis were significantly correlated (r = 0.946, $P < 0.01$) (Fig. 6-B).

Representative subjects. Subject 1: A 21-year-old man showed the maximum thigh circumference at 4 min after exercise with a return to the pre-exercise measurement after 35 min. T2-weighted MR images revealed a marked increase in the signal intensity of the rectus femoris, semitendinosus, and gracilis at 20 min after exercise. The signal intensity decreased again by 50 min after exercise (Fig. 7-A).

Subject 2: A 22-year-old man showed the maximum thigh circumference at 6 min after exercise with a return to the pre-exercise measurement at 30 min. T2-weighted MR images revealed an increase in the signal intensity of all flexor and extensor muscles, particularly the flexor muscles. The signal intensity subsequently decreased with time (Fig. 7-B).

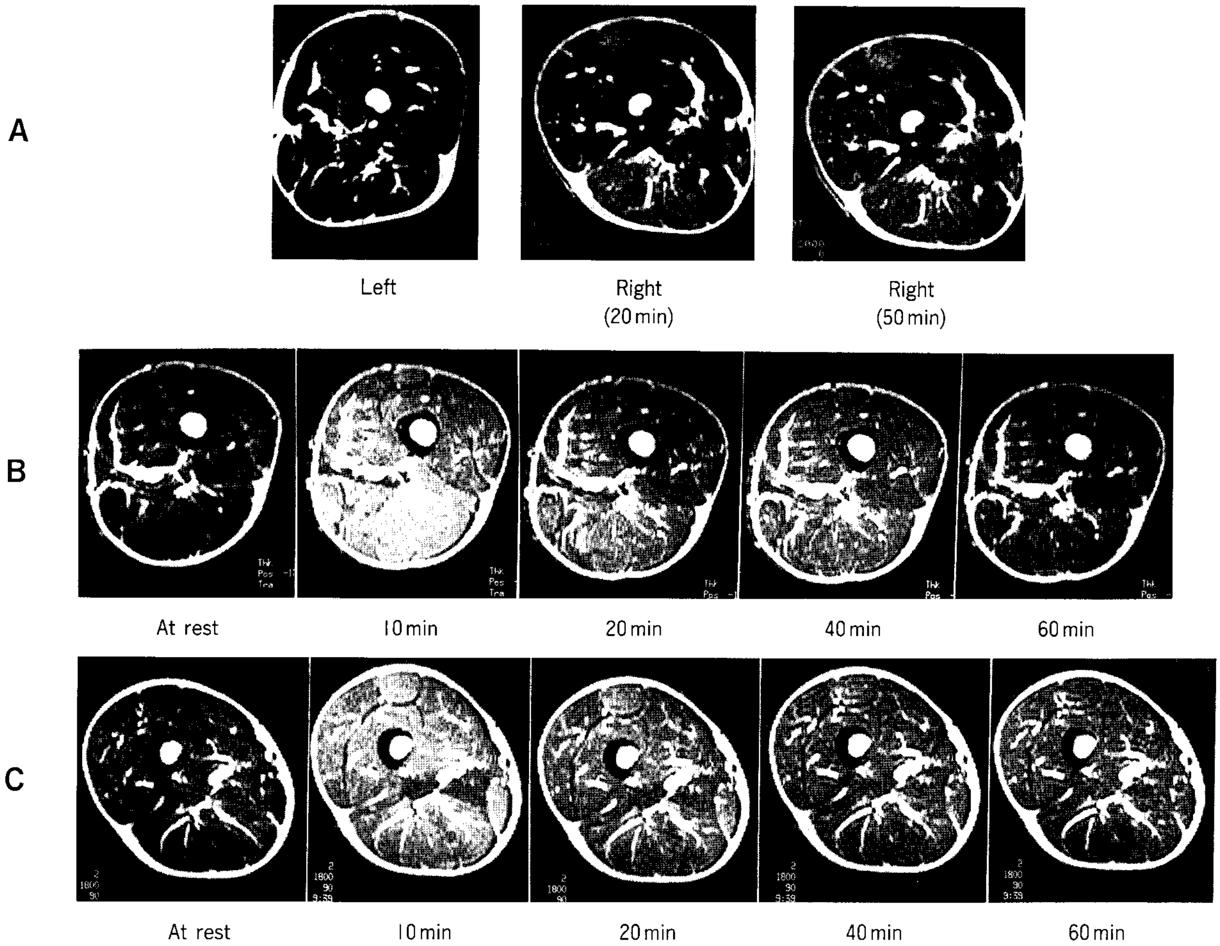

Fig. 7 A) Subject 1: A 21-year-old man. The T2-weighted images revealed a marked increase in signal intensity for the musculus rectus femoris, semitendinosus and musculus gracilis 20 min after exercise. The intensity decreased by 50 min after exercise. B) Subject 2: A 22-year-old man. The T2-weighted images revealed an increase in signal intensity for all flexor and extensor muscles, in particular the flexor muscles. The signal intensity decreased with time. C) Subject 3: A 19-year-old man. The T2-weighted images revealed an increase in signal intensity for all flexor and extensor muscles, while the intensity for the adductor muscles was unchanged. The signal intensity decreased with time.

Subject 3: A 19-year-old man showed the maximum thigh circumference at 4 min after exercise and a return to the pre-exercise measurement at 30 min. T2-weighted MR images revealed an increase in the signal intensity of all flexor and extensor muscles, while the intensity of the adductor muscles was unchanged. The signal intensity subsequently decreased with time (Fig. 7-C).

Discussion

Some investigators have reported alterations in MR signal intensity after various exercise and the origin of those alterations. In 1988, Fleckenstein *et al.* first reported that exercise altered the signal intensity of muscles on MR images (1, 2). Kuno *et al.* reported that the MR signal of the tibialis anterior muscle increased after ankle dorsiflexion exercise and returned to baseline at 30–60 min after exercise (3, 4). Yoshioka *et al.* observed serial increases in the MR signal in subjects performing alternating exercise by taking short repetition time MR images (5).

Foteder *et al.* suggested that these changes in the signal intensity of muscles on MR images after exercise depended on an increase in the muscle water content from their data obtained using MR spectroscopy (6). Sjogaard *et al.* used muscle biopsy to demonstrate that the muscle water content increased during submaximal exercise mainly due to an increase of extracellular water, whereas the largest increase occurred in intracellular water during maximal exercise (7, 8). Fisher *et al.* suggested that an increase of extracellular fluid volume was a contributing factor, while the increase of free intracellular water was the primary factor underlying the increased muscle MR signal intensity after exercise (9).

Since changes of the thigh circumference were closely correlated with changes in the MR findings on T2-weighted images in the present study (Fig. 6), they are thought to be attributable to the following similar factors. Judging from the high signal intensity on T2-weighted images, such factors may include an increase in intracellular and/or extracellular fluid (6-9), an increase in blood volume, and an accumulation of a fatigue substance. Thigh circumference may have returned to the pre-exercise level more quickly than the MR findings due to the fact that mild muscle swelling does not alter thigh circumference because of the compression of soft tissues such as fat and the nonswollen muscles such as the adductor muscles. In the present study, marked changes occurred in the findings of flexor and extensor muscles, such as the rectus femoris, gracilis and semitendinosus, while no changes occurred in the adductor muscles. Based on these observations, the muscles subjected to exercise showed striking MR alterations, while the muscles not exercised showed few or no changes, suggesting that these findings may perhaps be used as indicators for managing muscle fatigue and recovery.

Skeletal muscle is the organ with the greatest heat production in the body, and significant heat production occurs during exercise and even after the exercise ceases in order to balance the oxygen debt and ion-water imbalance. It requires a considerable time for conduction since human body components are poor heat conductors and temperature cooling reponse takes time to be generated. So the thigh temperature peaked at 10-30 min after exercise. The decline in thigh temperature may occur very slowly at ordinary ambient air temperatures via heat dissipation methods such as radiation, conduction and evaporation.

Although the changes in thigh temperature on the opposite side were considered to be mainly caused by transfer of heat produced in the exercised muscles via the systemic circulation until a balance with the exercised side was reached, the influence of local heat dissipation into the air may have contributed to the three observed patterns.

The changes in the thigh muscles after knee exercise can be visualized by using MR imaging, thigh circumference, and thigh temperature data. These parameters may provide indicators for managing muscle fatigue and recovery. In addition MR imaging demonstrating quantitative and qualitative muscle changes was correlated with thigh circumference. The thigh circumference that can be easily measured may provide indicators for managing muscle fatigue and recovery on the sports ground. The thigh temperature will be useful in investigating the changes in muscle temperature upon/due to cooling or heating in the future.

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