Evaluation of Exercise Muscle Energetics by NMR

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Magnetic resonance imaging (MRI) is superior to ultrasonography and X-CT especially in density resolution in soft tissue. ³¹P NMR provides information on metabolism, which has not been obtained in vivo by conventional methods, such as phosphocreatine (PCr), inorganic phosphate (Pi), ATP, and intracellular pH.

We used MRI and ³¹P NMR spectroscopy to study skeletal muscle metabolism of human and rat. These NMR results suggested that 1) estimation of muscle fiber composition, 2) evaluation of muscle ATP turnover and 3) imaging of local muscle fatigue are possible.

Key words: ³¹P NMR, MRI, muscle energetics, in vivo

All exercises are performed by contraction of skeletal muscle, and therefore, muscle has been an important subject for studies in sport science and medicine. However, most studies have been made in animals since muscle is not located superficially, and in humans, indirect evaluation such as measurement of muscle strength has been primarily done.

With advances in medical technology, ultrasonography and X-ray CT (X-CT) have been applied to sport medicine, allowing non-invasive morphological evaluation of cross-sections of human muscle. However, ultrasonography is limited in spatial resolution while X-CT inevitably involves a major problem of exposure to X-ray despite high density resolution. In addition, axial images are mainly obtained, but sagittal sections are not yet provided only morphological data on organs and tissues but none on tissue specificity.

On the other hand, muscle biopsy was introduced to sport medicine in the 1970s, and biochemical analysis of human muscle has been performed. Muscle biopsy has provided various data, especially many findings on fast-twitch and slow-twitch fibers. The close association between the muscle fiber

composition of the muscle primarily working during running, jumping, and throwing and types of sport. For example, more than 75% of the muscle fibers of the thigh (M. vastus lateralis) are fast-twitch fibers in many elite sprinters while more than 70% are slow-twitch fibers in many elite long distance runners. Muscle fiber composition is considered to be genetically determined and difficult to change after birth. Therefore, to produce elite sprinters or marathon runners, athletes with appropriate muscle fiber composition should be discovered at an early stage. However, this is not being done because of the difficulty in muscle biopsy, and noninvasive evaluation methods are needed.

Characteristics of MRI and ³¹P NMR

MRI is superior to ultrasonography and X-CT especially in density resolution in soft tissue but inferior in imaging time. Moreover, the time has been shortened by the high performance imaging methods recently developed. NMR provides any desired slice and also more than 10 slices simultaneously. Fig. 1 shows longitudinal and transverse images of the thigh (Kuno et al., 1988b). On the

Fig. 1. Longitudinal and transverse images of the thigh by MRI

Fig. 2. MR angiography

transverse image, each muscle group, fat, blood vessels, and nerves are clearly differentiated. In addition, MR angiography, which visualizes blood flow, is possible (Fig. 2). Contrast medium is used in conventional X-ray angiography but not necessary in MR angiography because blood flow is visualized utilizing the properties of fluid itself.

^{31}P NMR provides information on metabolism, which has not been obtained *in vivo* by conventional methods, such as phosphocreatine (PCr), inorganic phosphate (Pi), ATP, and intracellular pH. These data have been obtained by biochemical methods. However, since separation and purification inevitably cause changes in the *in vivo* state of substances, the value of noninvasive measurement is high.

Fig. 3. Relationship between longitudinal relaxation time (T1) and % area fast-twitch (FT) fibers

Application of MRI and ^{31}P NMR to sport science

- (1) Estimation of muscle fiber composition based on ^1H -relaxation time (T1) calculated by MRI (Kuno et al., 1988a)

Fig. 3 shows the muscle fiber composition (% area FT fibers) obtained by muscle biopsy and T1 obtained by MRI in 16 subjects. A very high correlation was observed between them. T1 obtained by MRI largely depends on the state of water *in vivo*, which is affected by protein conformation of the substance. Fast-twitch and slow-twitch fibers have been reported to differ in protein conformation. Therefore, a difference in T1 between these fiber types is expected. However, the reason for longer T1 in subjects with a higher percentage of fast-twitch fibers remains unclear. Despite some unclarified points, our results show the usefulness of MRI for estimating muscle fiber composition.

- (2) Relationship between muscle fiber composition and ^{31}P NMR (Kuno et al., 1989a)

^{31}P NMR was performed in 30 subjects at rest

^{31}P -MRS OF M. VASTUS LATERALIS

Fig. 4. ^{31}P NMR spectra in human muscle with high or low percentage of fast-twitch (FT) fibers

who had undergone muscle biopsy. Fig. 4 shows spectra in a subject with a high percentage of fast-twitch fibers and that with a low percentage of this type fibers. Despite apparent differences in muscle fiber composition, their spectra were similar.

(3) Effects of training of rat skeletal muscle by ^{31}P NMR

Running training for 3 months was performed in rats. The dynamic change in phosphorus metabolites was measured during and after the exercise by ^{31}P NMR. ATP turnover distinctly improved after the training. (unpublished data)

(4) Imaging of local muscle fatigue by MRI and ^{31}P NMR (Kuno et al., 1989b)

Muscle fatigue can be felt, but its visualization has been difficult. We visualized muscle fatigue by MRI and ^{31}P NMR. Fig. 5 shows transverse images of the right crus before and immediately after dorsiflexion exercise and in the recovery process. During the dorsiflexion exercise, only the musculus tibialis anterior was used. Immediately after the exercise, the image of the musculus tibialis anterior became

Fig. 5. Transverse MR image of the right crus before and after the dorsiflexion exercise

white compared with other muscles while the image of the musculus triceps surae, which was not used during the dorsiflexion showed a contrast similar to that before the exercise. Changes in the intensity of image signals are due to changes in T1. The causes

Fig. 6. ^{31}P NMR spectra of the musculus triceps surae (A) and tibialis anterior (B) during the dorsiflexion exercise 1. Pi, 2. PCr, 3.~5. ATP

Fig. 7. A 3-dimensional image of the right crus

of the changes in T1 are not clear but seem to be accumulation of fatigue substances and an increase in blood flow.

To confirm fatigue of the musculus tibialis anterior and not of the musculus triceps surae during dorsiflexion, ^{31}P NMR was performed during the exercise. The spectra of the musculus tibialis ante-

rior showed a decrease in PCr and an increase in Pi while the spectrum of musculus triceps surae was similar to that at rest (Fig. 6). These results suggest that visualization of muscle fatigue is possible by MRI and ^{31}P NMR. A 3-dimensional image of the right crus after the exercise is shown in Fig. 7. The net represents skin, and the musculus tibialis anterior alone could be isolated from other muscle groups because of the difference in the signal intensity of this muscle.

REFERENCES

- Kuno, S., S. Katsuta, T. Inouye, I. Anno, K. Matsumoto, M. Akisada 1988a: Relationship between MR relaxation time and muscle fiber composition. *Radiology*, 169:567-568.
- Kuno, S., S. Katsuta, M. Akisada, I. Anno and K. Matsumoto 1988b: Estimation of muscle fiber composition using magnetic resonance imaging (MRI). *Jpn. J. Phys. Fitness Sports Med.*, 37:376-382.
- Kuno, S., M. Niitsu, I. Anno, K. Matsumoto, M. Akisada, I. Kanbayashi, S. Katsuta, K. Kose, T. Inouye 1989a: Relationship between muscle metabolism by ^{31}P MRS and muscle fiber composition. *Jpn. J. Mag. Res. Med.*, 9 (abstract).
- Kuno, S., M. Niitsu, I. Anno, K. Matsumoto, M.

Akisada, K. Kose, T. Inouye, S. Katsuta 1989b: Res. Med., 9 (abstract).
Change of MR imaging by exercise. Jpn. J. Mag.

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