MRI assessment of Slow training effect on focal fat metabolism in skeletal muscle

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Introduction

Proton (H^1) magnetic resonance spectroscopy (H^1-MRS) performed by 3 Tesla magnetic resonance imaging (3T MRI) can measure focal intramyocellular lipid (IMCL) and extracellular lipid (EMCL) precisely and noninvasively [1]. Therefore, we supposed H^1-MRS might be also able to assess focal fat metabolic change due to various kind of exercise method for physical health.

"Slow training" is an exercise method that does not utilize oxygen, and is performed by slowly and continuously delivering stress to skeletal muscle. This very simple technique does not require any special equipment and can be performed at home. Moreover, slow training is associated with neither injury risk nor disorders of the skeletal muscle or joint, due to the very low amount of stress, and it does not need to be performed every day. Therefore, slow training can be performed regardless of age, gender, or type of job. Additionally, despite its simplicity, this training method is expected to enable acquisition of good physical health and to prevent lifestyle-related diseases. However, to the best of our knowledge, the mechanism through which slow training directly affects focal skeletal muscle metabolism is not yet known. The purpose of this study was to monitor and evaluate slow training effects on focal fat metabolism in healthy normal male skeletal muscle with H^1-MRS using 3T MRI.

Materials & Methods

Twenty-three healthy male volunteers were recruited and divided into two groups: group A (training group; n=11) and group B (control group; n=12). In group A, all volunteers performed "calf raise" training regularly for 3 months in their dominant calves. In contrast, volunteers in group B did not perform any special physical training for 3 months. All 23 calves in the two groups were followed by H^1-MRS with 3T MRI periodically, and IMCL and EMCL were monitored.

Before the start of the study, a baseline MRI scan (0M) was performed for all calves. After the study began, scans were performed every month (1M, 2M, and 3M). Calf raise training was performed in group A. While standing, volunteers repeatedly raised themselves using their dominant foot while bearing their weight on the dorsal calf. Volunteers pushed against the wall to balance their bodies during this exercise, which constantly stimulated the dorsal side of the muscles, including the soleus (SOL) muscle by their own weight-bearing (Fig.1). Training was strictly timed. Raising and lowering took 2 seconds each. One set consisted of ten raising and lowering cycles and took 1 minute. Each volunteer did three sets each using the calf of the dominant foot. Training was performed twice a week for 3 consecutive months.

A 3T clinical MRI machine (Achieva, Novadual, Philips, Best, The Netherlands) was used for scanning. IMCL and EMCL of the SOL muscle of the dominant calf were measured in both groups. All H^1-MRS studies were performed with a TORSO array coil, which has six QD-surface coils. The VOI size was 12 mm x 12 mm x 35 mm. A single voxel-localized H^1-MRS was performed using a point-resolved spectroscopy (PRESS) sequence, both with and without a water suppression pulse. Water suppression was accomplished using three preceding chemical-shift–selective (CHESS) pulses (bandwidth, 140 Hz). Before spectroscopic measurements were obtained, field homogeneity was optimized over the selected VOI by observing the H^1-MR signal of the tissue water with the spatially selective PRESS sequence by automatic shimming. The typical full width achieved in most assessments was half of the maximum 14 Hz. The following PRESS sequence parameters were used: TR = 3000 ms; TE = 40 ms; number of points sampled = 1024; spectral width = 2,000 Hz; average number of signals in metabolites = 96; and average number of signals in tissue water = 16.

LCModel version 6.2 (LA Systems) software was used in the muscle mode to assess lipid content. IMCL and EMCL obtained in each of the 23 SOL muscles in both groups were averaged for each period (0M, 1M, 2M, and 3M). Average IMCL and EMCL values were compared with two-factor fractional ANOVA between groups A and B for each period. In addition, IMCL and EMCL values for each period were compared with repeated measurement using one-way ANOVA and a post-hoc test in each group.

Fig. 1 Calf raise exercise. The volunteer must move one heel upward and downward very slowly while he pushes against the front wall to keep his body balanced and to stress appropriate weight-bearing to the dorsal side of the calf
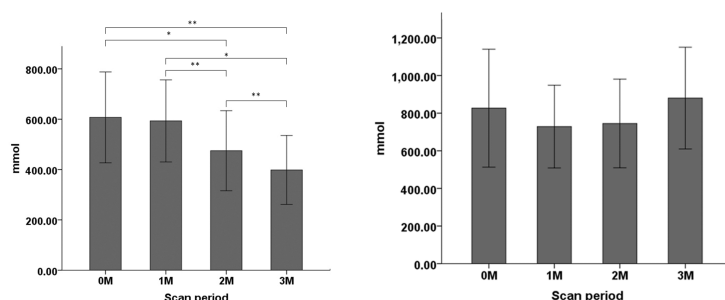
Results & Discussion

The average maximum area of group A calves was 4224 mm^2 at 0M and 4379 mm^2 at 3M; this slight increase was not statistically significant. Calf area results in group B were almost identical—4338 mm^2 and 4334 mm^2—at 0M and 3M, respectively. The change in average IMCL of the 11 SOL muscles in group A is shown in Fig.2A, and the change in average EMCL is shown in Fig.2B. While the amount of IMCL did not change until 1M, it decreased gradually thereafter. Statistically significant differences were observed between 0M and 2M ($0.01<P<0.05$), 0M and 3M ($P<0.01$), 1M and 2M ($P<0.01$), 1M and 3M ($P<0.01$), and 2M and 3M ($0.01<P<0.05$). No significant changes were observed for EMCL within group A. No significant changes were observed for either lipid on IMCL and EMCL results of group B (not shown). No statistically significant differences were observed during each period for either IMCL or EMCL between groups A and B.

It is not clear why IMCL content of the SOL muscle decreased as a result of long-term slow training. However, we hypothesize that this was primarily caused by an increase in the number of mitochondria due to chronic stimulation of skeletal muscle cells, particularly the slow-twitch fibers. Calf raise training might deliver slow and constant stress to the dorsal side of the calf, including the SOL muscle. The SOL muscle is known to have the largest number of slow-twitch fibers among calf muscles [2]. Thus, slow training could also stress these numerous slow-twitch fibers. Stimulation of skeletal muscle due to training activates AMP kinase (AMPK) in skeletal muscle cells [3], resulting in increased glutamine 4 (GLUT4) [4]. Glucose metabolism is also accelerated due to the translocation of GLUT4 from the cellular pool to the cell membrane. Moreover, a recent study clarified that AMPK regulates PGC-1α, which increases the number of mitochondria, according to several animal studies [5]. Mitochondria trigger β-oxidation of fatty acids to acetyl-coA. Therefore, we hypothesize that an increased number of mitochondria might induce constant β-oxidation, even at a resting state, resulting in a gradual focal IMCL decrease primarily within the slow-twitch fibers of the SOL muscle.

Fig. 2 Change in IMCL (2A, left) and EMCL (2B, right) values in the SOL muscle during training in group A. Among the scans from 0M to 1M, the average IMCL did not change to a statistically significant degree. However, it gradually decreased from 1M to 3M. with statistically significant differences. No statistically significant changes in average EMCL were observed, although a slight gradual increase over time was observed

Conclusion

We could successfully monitor and evaluate slow training effects on focal fat metabolism in healthy normal male skeletal muscle with H^1-MRS using 3T MRI .We could show H^1-MRS had a potential to become new assessment method for various kind of exercise for health.

References
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