Differentiation of Slow and Fast Twitch Muscles by T2*-weighted Imaging and Near Infrared Spectroscopy

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Purpose: To differentiate slow and fast-twitch muscles non-invasively, we investigated the relationship between changes inT2*-weighted MR signal intensity and hemoglobin oxygenation monitored by near-infrared spectroscopy (NIRS).

Methods and Materials: MRI and NIRS measurements of the midcalf of 5 healthy males were performed under a 10-minute disturbance of blood flow in the lower leg induced by rapid cuff inflator placed around the thigh just proximal to the knee. To obtain different blood flow conditions (graded ischemia), different cuff pressures were employed; 100, 150 and 200 mmHg. A single shot gradient EPI was used on a 1.5-Tesla scanner under the condition of TR 4s; TE 60ms; slice thickness 5 mm; matrix size 64 x 64. We measured MR signal changes of ROIs in the anterior tibialis muscle (AT), which is a slow-twitch muscle, and the gastrocnemius muscle (GM), which is a fast-twitch muscle, on an axial image. To monitor changes in oxygenated hemoglobin and deoxygenated hemoglobin (deoxyHb), NIRS measurements were performed with two single-channel spectrometers, the probes of which were located to sense the ROIs of the MR measurements.Changes in an apparent transverse relaxation rate (R2*) were calculated from changes in T2*-weighted MR signal intensity in each ROI. To monitor blood flow under different cuff pressures, we measured the blood flow of popliteal veins and arteries with Doppler ultrasonography.

Results and Discussion: The slope of R2* changes versus deoxyHb changes (ΔR2*/ΔdeoxyHb) under 100mmHg compression was significantly larger than those under 150 and 200mmHg compression in both slow and fast-twitch muscles (P<0.05) (Fig. 1). This evidence is discrepant from the blood oxygenation level dependent (BOLD) theory which claims that there is a proportional relationship between R2* and deoxyHb changes[1)]. To understand this discrepancy, we introduce the idea of contrast in magnetic susceptibility between inside and outside blood vessels. R2* is based on the difference in magnetic susceptibility ($\Delta\chi$) between blood vessel and surrounding tissue. The magnetic susceptibility outside blood vessels (surrounding muscle tissue) increases during ischemic compression because myoglobin (Mb) is deoxygenated to become paramagnetic[2)]. Therefore, decreases in $\Delta\chi$ result in reductions in R2* changes despite the existence of deoxyHb inside the blood vessels. Evidence that Doppler ultrasonography confirmed both occlusion of popliteal arteries and veins under 150 and 200 mmHg compression supports deoxygenation of Mb under severe ischemic compression. Contrary to those compressions, only veins were occluded under 100mmHg compression. Therefore, no deoxygenation of Mb occured and arterial blood supply resulted in an increase of blood volume.

The degree of decrease in ΔR2*/ΔdeoxyHb from 100 mmHg to 150 mmHg compression was greater in slow-twitch muscle than in fast-twitch muscle (Fig. 2) (P<0.05). This implies a large increase in magnetic susceptibility in tissue of slow-twitch muscle: an increase in deoxygenated Mb. This event agrees with evidence that slow-twitch muscles contain 1.4 times larger Mb than fast-twitch muscles[3)]. The value of ΔR2*/ΔdeoxyHb in slow-twitch muscle for each compression in each volunteer was smaller than that in fast-twitch muscle. The proportionality between R2* and deoxyHb changes reflects the vascularity[4)]. This proportionality increases in a large-vein rich area and decreases in a capillary rich area. Therefore, smaller ΔR2*/ΔdeoxyHb in slow-twitch muscle reflects affluent capillaries. Although changes in ΔR2*/ΔdeoxyHb at 100mmHg did not differ significantly between fast and slow-twitch muscle (P>0.05), the degree of decrease in ΔR2*/ΔdeoxyHb from 100 mmHg to higher compressions may allow differentiation between fast and slow-twitch muscles (Fig. 2).

Conclusion: We conclude that the ratio of changes between R2* and deoxyHb during graded ischemia is a good marker to represent fast and slow-twitch muscles.

References: (1) Ogawa S, et al. *Magn Reson Med* 29:205-210, 1993 (2) Lebon V, et al. *Magn Reson Med* 40:551-558, 1998 (3) Jansson E, et al. Histochemistry 78:121-124, 1983 (4) Ogawa S, et al. Biophys J 64:803-812, 1993

Fig. 1

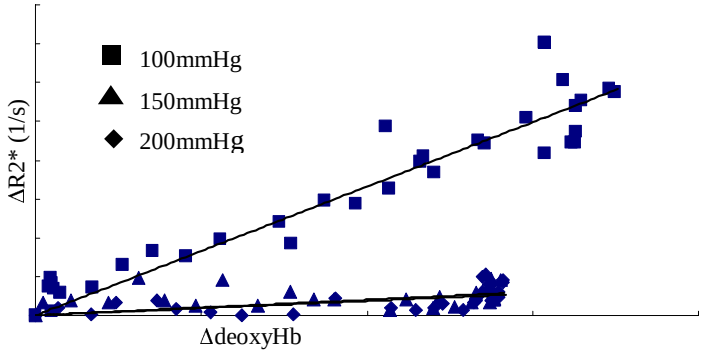

Fig. 1 R2* changes versus deoxyHb changes of AT (slow-twitch muscle) in a volumteer.

Fig. 2

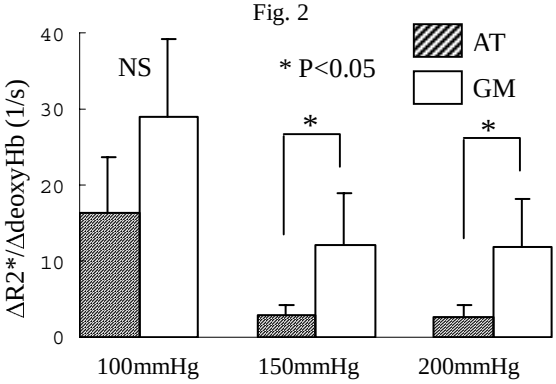

Fig. 2 Ratio of changes between R2* and deoxyHb during graded ischemia in AT and GM by 100, 150 and 200 mmHg compression (n=5).