Evaluation of the Relationship between IVIM Microvascular Blood Flow and Exercise Duration in Shoulder Muscles after Lift-off Test

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Purpose

Intravoxel Incoherent Motion (IVIM) offers the possibility to study microvascular perfusion properties of skeletal striated muscle [1-5]. The Lift-off test is used in daily clinical practice to specifically assess the integrity and functionality of the subscapularis muscle [6]. The purpose of this work was to evaluate the changes of IVIM microvascular blood flow in several shoulder muscles, after Lift-off tests of 1 min and 2 min duration, and to compare these findings to the increase in T2 signal (as measured on the b0 images), which is known to increase gradually with exercise intensity [7].

Methods

The experiment was performed in 12 shoulders of 6 healthy male volunteers (age 32±5 years). First, images were acquired at rest (8 min of lying on the scanner table). Each volunteer was then asked to hold (outside the scanner) a Lift-off test during 2 min at maximum effort. The volunteer was subsequently rescanned. The whole experiment was repeated after 2 weeks, decreasing the duration of the Lift-off test from 2 min to 1 min. 25 slices were acquired at 3T with a 16-channel receiver shoulder coil, using a standard Stejskal-Tanner diffusion-sensitizing gradients and a single-shot echo-planar imaging readout. 16 b-values ranging from 0 to 900 s/mm^2 were acquired. Averages=3, in-plane resolution=2×2 mm2, slice thickness=4 mm, TR/TE=4000/54 ms, GRAPPA acceleration factor=2, bandwidth=1302 Hz/pixel. Total acquisition time was 10 min 12 sec. Regions of interest were drawn on the b0 images in all rotator cuff muscles, as well as in the 3 distinct heads of the deltoid muscle. The signal obtained was averaged for each b-value, and IVIM perfusion parameters were obtained by fitting the IVIM bi-exponential model using a 2-step method as described elsewhere [8]. Student t-tests were used to calculate statistical significance.

Results

A statistically significant increase in IVIM blood flow fD* (**Fig.1**), diffusion coefficient D, and T2-weighted b0 signal was observed in the subscapularis muscle, as well as in the posterior and (to a lesser extent) lateral heads of the deltoid muscle, after 1 min and 2 min Lift-off tests, compared with rest (**Fig.2**). Interestingly, there was no significant difference between 1 min and 2 min Lift-off tests in fD* and D, while there was a gradual increase in T2-weighted b0 signal after 2 min Lift-off test compared with 1 min. As expected, the changes were much less marked in the supra- and infraspinatus muscles (slight decrease in fD* and D, not always statistically significant), as well as in the anterior head of the deltoid muscle.

Discussion

This study demonstrates the selective increase in IVIM perfusion parameters in subscapularis and posterior and lateral deltoid muscles after a clinical test recognized to be selective for those muscles. An increase was also observed in the diffusion coefficient, but of much lower amplitude (approximately +7% for D, compared with around +170% for fD*). This method is a promising new tool to investigate skeletal striated muscle physiology as well as perfusion-related muscular disorders, such as peripheral arteriopathies and diabetes mellitus-related microangiopathies.

References

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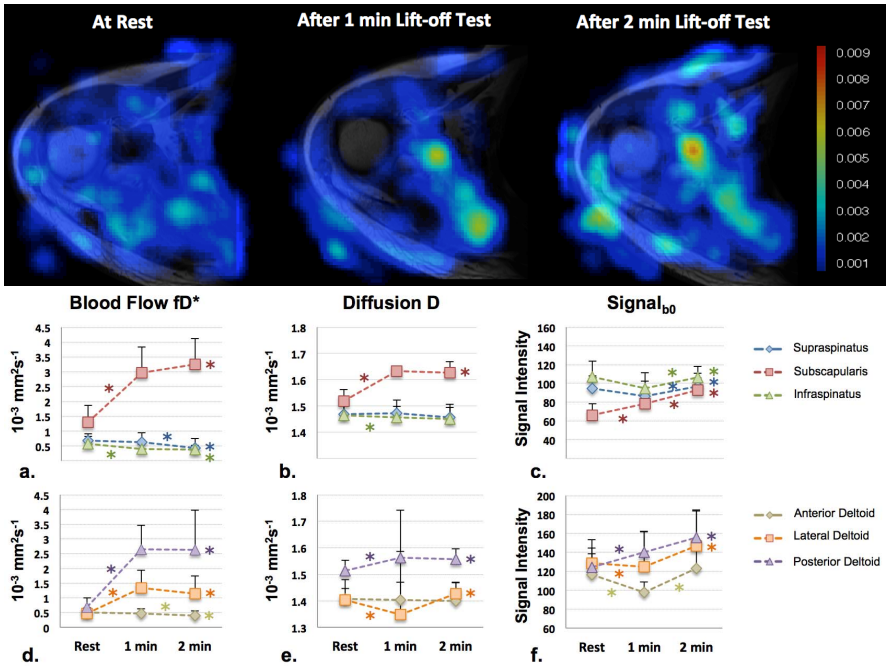

Fig. 1. Axial images of color-coded maps of blood flow-related fD*, superimposed on anatomical T1-w images, at rest, and after 1 min and 2 min Lift-off tests, showing a selective increase in fD* in the subscapularis muscle, as well as in the posterior head of the deltoid. Colorbar scale: mm^2/s

Fig. 2. Absolute changes in IVIM blood flow fD*, diffusion coefficient D, and T2-weighted b0 signal, for the rotator cuff muscles (top) and the three distinct heads of the deltoid (bottom). (∗) above a dashed line indicates a statistically significant difference ($p<0.05$) between the measurements connected by this line, while (∗) on the right side of the 2 min measurement indicates a statistically significant difference between the 2 min and the measurements at rest.