Skeletal muscle oxygen extraction fraction measurement - at rest and during ischemia

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Target Audience: Researchers and clinicians with an interest in skeletal muscle oxygenation.

Purpose:

The tissue oxygen extraction fraction (OEF) is an important physiological quantity, particularly in organs such as skeletal muscle, in which oxygen delivery and use are tightly coupled [1]. The purpose of this study was to develop a reliable method to directly quantify regional skeletal muscle OEF at rest and during ischemia.

Materials and Methods:

Study Population: This study was approved by local institutional human study committee. Eight healthy volunteers (22–27 years old) were recruited and scanned for measurements of skeletal muscle OEF.

MRI Methods: All the muscle measurements were carried out on a 3.0 Tesla Philips Intera Achieva MR scanner (Philips Medical Systems, Best, The Netherlands), using a 32 channel SENSE Torso Cardiac coil. The measurement of skeletal muscle OEF was derived from a model [2] with the magnetic susceptibility effect on deoxyhemoglobins [3,4]. A single-shot triple-echo asymmetric spin-echo sequence with 32 echo shift was implemented to acquire the source images for the model. The other imaging parameters were: repetition time = 2 s; field of view = 260×210 mm^2; matrix size = 80×80; slice thickness = 6 mm; NSA = 2; total acquisition = 2 min..

To validate the accuracy of ASE derived R2* and R2 map, multi-echo GE R2* and SE R2 were implemented.

In Vivo Experiments: An air-cuff was placed just above the right knee with an imaging plane selected 20-25 cm away from the distal side of the air-cuff. Following 10 min of rest, the cuff was rapidly inflated to 100 mmHg. The cuff maintained for 6 minutes, after which the cuff was rapidly released.

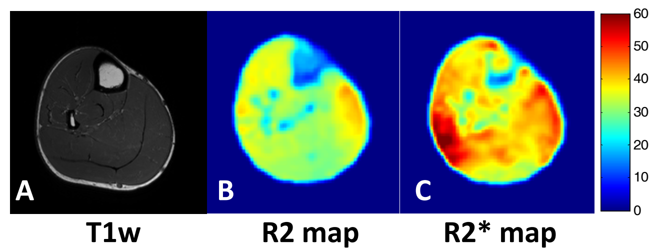

Fig.1. Anatomical T1w image (A), ASE based R2 map [s^{-1}] (B), and ASE based R2* map [s^{-1}].

Results:

A representative anatomic T1-weighted image, and the corresponding R2 and R2* maps derived from ASE were shown in Figure 1.

The ASE derived R2 is in good correlation with that of multiecho SE (r = 0.91 and 0.74 for gastrocnemius muscle (GA) and soleus muscle (SO)) and the ASE derived R2* values is aslo in good correlation with that of multiecho GE (r = 0.68 and 0.65 for GA and SO).

The scan-rescan reproducibilty is measured by coefficient of variation (CV). The CVs of R2' are 9.8% in GA and 9.7% in SO, the corresponding CVs of OEF are 8.4% in GA and 5.7% in SO.

The typical R2' and OEF maps at rest (pre), 2-4 minutes after the air-cuff pressure (post1) and 4-6 minutes after the air-cuff pressure (post2) are represented in Figure 3. It is clearly shown that the R2' and OEF increases obviously in the calf muscle in the statuses of post1 and post2, especially in GA and SO. The mean R2' and OEF in the

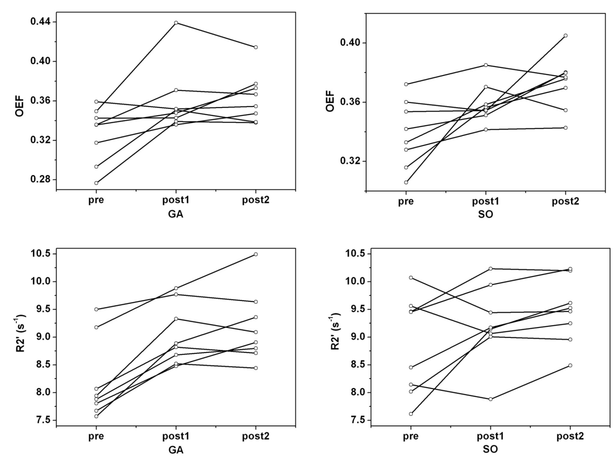

Fig.2. The mean OEF and R2' value in GA and SO of all eight volunteers at rest (pre), 2-4 minutes after the air-cuff pressure (post1) and 4-6 minutes after the air-cuff pressure (post2).

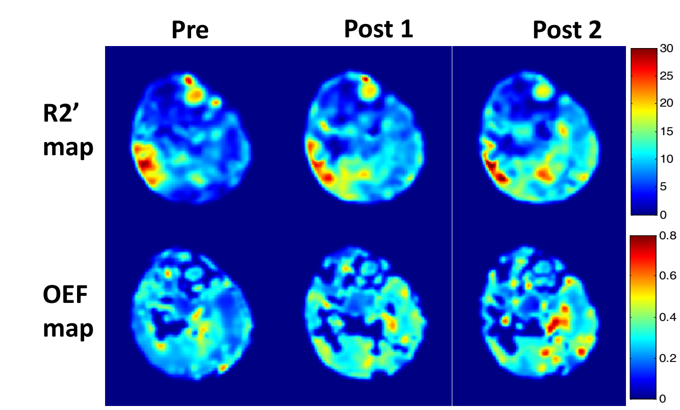

Fig.3. An example of R2' map and OEF map at rest, 2-4 min after cuff pressure, and 4-6 min after cuff pressure.

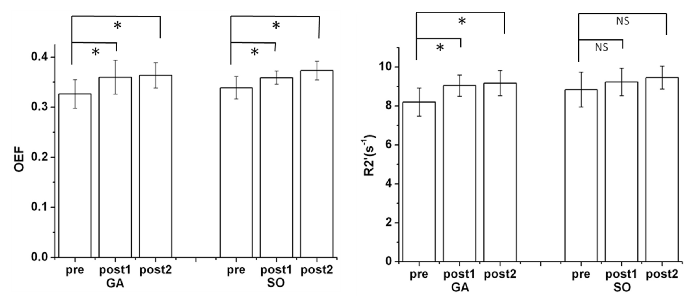

Fig.4. Comparison of the mean OEF and R2' at rest (pre), 2-4 minutes after the air-cuff pressure (post1) and 4-6 minutes after the air-cuff pressure (post2).

GA and SO of all volunteers under the conditions of pre, post1 and post2 are expressed in Figure 2. The results of R2' and OEF of all volunteers in GA and SO in three statuses of pre, post1 and post2 are shown in Figure 4. The R2' in GA increases significantly from 8.202 ± 0.722 (pre) to 9.046 ± 0.549 ($P<0.05$) (post1) and to 9.179±0.649 ($P<0.05$) (post2). Meanwhile, the R2' in SO muscle increases from 8.847 ± 0.894 (pre) to 9.234 ± 0.704 (post1) and 9.465 ± 0.586 (post2) although no statistical significance was found. The OEF rises significantly from 0.326 ± 0.028 (pre) to 0.360 ± 0.034 ($P<0.05$) (post1) and 0.364 ± 0.025 ($P<0.05$) (post2) in GA, and in SO the OEF increases from 0.339 ± 0.023 (pre) to 0.359 ± 0.013 ($P<0.05$) (post1) and 0.373 ± 0.019 ($P<0.05$) (post2). The increments of R2' and OEF in GA are higher than those in SO.

Discussion & Conclusions:

This study demonstrates the accurate and robust calculation of R2, R2* and R2'. The feasibility of noninvasive measurements of regional skeletal muscle oxygen consumption has been shown in normal volunteers. By comparison of the calculated OEF at rest and during ischemia, significantly increased OEF and R2' could be found in both GA and SO. These results hold promise for some clinical uses, for example, to study vascular function in peripheral artery disease.

References:

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