Dynamic measurement of muscle R2, R2' and R2* during ischemia and reactive hyperemia

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Target Audience: Researchers and clinicians with an interest in dynamic quantification of tissue relaxation rates and skeletal muscle oxygenation.

Purpose:

Muscle BOLD MRI has been used to infer small vessel function following arterial occlusion, the infusion of vasoactive compounds and to study vascular function in peripheral artery disease. BOLD R2* is a summation of irreversible (R2) and reversible(R2') relaxation rates (R2*=R2+R2'). It has been suggested that R2 is sensitive to many physiological perturbations, including tissue water content, inflammation and changes in tissue oxygenation [1]. However, R2' is linearly dependent on tissue oxygenation. Therefore, R2' is able to provide a more specific and direct evaluation of muscle oxygenation.

Background:

R2' is most commonly measured using the GESSE[1], GESFIDE[2] and ASE[3] sequences. ASE method is able to manipulate R2' weighting with constant R2 weighting, which allows R2' to be fitted directly. With single-shot multi-echo ASE method, R2 and R2' could be calculted simultaneously and dynamiclly.

Materials and Methods:

Subjects and MR Imaging:

Five healthy volunteers (mean age 24 ± 2 years, range 22-27) were recruited to undergo the imaging of the lower limb using a 3.0-T whole-body scanner (Achieva TX, Philips Healthcare). The study protocol was approved by the hospital's institutional review board. A multislice 2D 4-echo ASE sequence was implemented with three different R2' weighting: τ = -10, 0, 10 ms. The space between each echo was 20 ms. The other imaging parameters were: repetition time = 2 s; field of view = 260×210 mm^2; matrix size = 70×65; slice thickness = 6 mm; NSA = 1.

To verify the accuracy of R2 and R2* maps, baseline R2 and R2* maps derived from multiecho GE and SE sequences were used as golden standard.

In Vivo Experiments

To achieve ischemia and reactive hyperemia, an air-cuff was rapidly inflated to an occlusion pressure of 100 mmHg after 10 min of rest. The occlusion continued for a period of 8 min, after which the cuff was rapidly released. During ischemia, the maximum ischemic value (MIV) and time to half ischemic maximum (THIM) were determined. During reactive hyperemia, the ratio of maximum ischemic value to hyperemia bottom value (MTH) and the SLOPE describing the rate of surge at the moment of cuff release were calculated. Gastrocnemius muscle (GA) and soleus muscle (SO) were analysised seperately.

Validation:

Tissue oxygenation data were collected using a frequency domain, multidistance NIRS oximeter (model 96208; ISS, Inc., Champaign, IL), and its accompanying software.

Results:

The ASE derived R2 is in good correlation with that of multiecho SE (r = 0.81 and 0.65 for GA and SO) and R2* values is aslo in good correlation with that of multiecho GE (r = 0.70 and 0.66 for GA and SO).

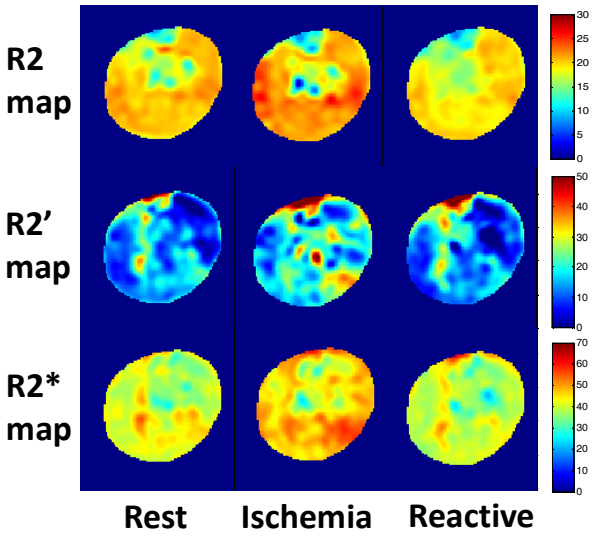

Fig.1. An example of the 4-echo ASE based R2, R2' and R2* map at rest, at the end of ischemia, and 10s after the cuff release.

The R2, R2' and R2* maps derived from ASE of one volunteer at rest, the end of the ischemic phase and 10s after the cuff release are represented in Figure 1. It is clearly shown that the R2, R2' and R2* increase obviously from rest to the end of the ischemic phase and decrease significantly at 10s after the cuff release, especially in GA and SO. The corresponding time curves of R2, R2', R2* derived from ASE and the 1-%HbO2 provided by NIRS in GA at rest, ischemia and reactive hyperemia are expressed in Figure 2. During ischemia, R2' increases steeply initially and then less notably subsequently but persists growth until the end of the ischemic phase, while R2 has relatively slow rise to the maximum ischemic value. After deflation of the compression cuff, R2 decreases rapidly to the hyperemia bottom value and then increase toward a steady-stated intensity. The characteristic of the time curve of R2' is smilar to that of 1-%HbO2, which means that R2' obtained by ASE is a valuble tool to reflect muscle oxygenation.

Table 1. The characteristics of R2 and R2' curves in different muscle groups (n = 5) *

	R2' curve (s^{-1})		R2 curve (s^{-1})	
Features	**MIV**	**THIM**	**MTH**	**SLOPE**
Gastrocnemius	59.38±26.45	80.00±31.30	5.91±2.36	0.34±0.07
Soleus	36.35±13.45	99.60±22.91	6.60±2.53	0.39±0.12

* Data are mean ± SD.

The maximum ischemic value (MIV) and time to half ischemic maximum (THIM) of R2' curve in GA and SO, and the ratio of maximum ischemic value to hyperemia bottom value (MTH) of R2 curve and the SLOPE describing the rate of R2 curve surge at the moment of cuff release of all the volunteers in GA and SO are expressed in Table 1. SO has a relatively smaller MIV of R2' and higher slope of R2 than GA, which is in line with the structures of different muscles. The main function of SO is to keep balance and largely contains slow-twitch oxidative muscle fibers which possibly have a higher capillary density and myoglobin content compared to GA, which mainly consists of fast-twitch dominant muscles[5].

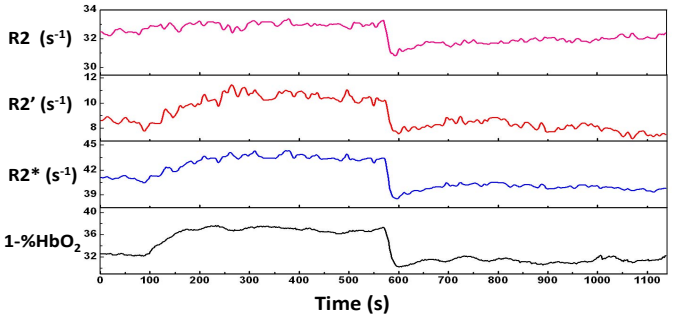

Fig.2. Typical Time courses of the ASE based R2, R2', R2* relaxation rates, and corresponding 1-%HbO_2 during baseline (110s), ischemia (480s) and recovery (550s).

Discussion & Conclusions:

The good agreements of R2 between ASE and multi-echo SE and R2* between ASE and multi-echo GE imply that this method is reliable to obtain R2, R2* and R2' besides of its quickness. Significant changes of ASE based R2 and R2' were observed in GA and SO during ischemia and reactive hyperemia process. The 1-%HbO2 obtained from NIRS has also proven its effectiveness. To our knowledge, this is the first study to demonstrate the feasibility of simultaneously measureing R2' and R2 in different muscles during ischemia process. This approach is capable of dynamically measuring microvascular blood oxygenation and can be used to capture the rapid changes that occur in the lower extremity during ischemia and exercise, which could also be applied to obtain dynamic information on vascular reactivity in patients with diabetes and peripheral artery disease.

References:

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