A BOLD effect on different calf muscle groups in elderly females

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Introduction: Lower-extremity peripheral artery disease affects roughly 1 in 20 adults aged above 55 years (1). Current methods used to measure skeletal muscle blood flow are either limited by spatial resolution (e.g. PET) or are invasive (e.g. DCE-MRI). Development of non-invasive techniques for evaluating vascular function would be highly desirable. This study examines the BOLD effect on calf muscles in elderly subjects to investigate the oxygenation characteristics in different calf muscle groups.

Methods: Thirty-four elderly females (67±4.6 yrs) were recruited to undergo BOLD imaging of the lower limb using a 3T whole-body scanner (Achieva TX, Philips Healthcare). An eight-channel SENSE knee coil was used for signal reception and a T2*-weighted sequence (TR/TE 372/40 ms; slice thickness 5 mm; NEX 1; FOV 330 mm; dynamic measurements 2400; scan time 900s) was employed. An air-cuff was placed just above the left knee with an imaging plane selected 20-25 cm away from the distal side of the air-cuff. Air-cuff pressure applied was 50mmHg above systolic pressure. The cuff was inflated at 1 min and maintained for 5 minutes. Followed cuff deflation, the scanning continued for a further 9 minutes. ROIs were drawn on the gastrocnemius muscle (lateral head), the soleus muscle and the tibialis anterior muscle on T1 images and BOLD signals in the corresponding ROIs were measured from T2* images (Fig 1). A curve fitting model was employed to analyze BOLD-MRI signals using PRISM software (ver. 5). After signal normalization, four parameters were selected to characterize the T2* time course (Fig 2): Half-life, which refers to the time interval of signal decay during ischemia; minimum ischemic value (MIV), which is the minimal BOLD signal during the ischemic phase relative to baseline; Slope, which describes the rate of T2* signal surge at the moment of cuff release; and hyperemia peak value (HPV), which refers to the maximum height of T2* signal during hyperemia relative to baseline. ANOVA analysis was performed for these key parameters for different muscle groups namely the soleus, the tibialis anterior and the gastrocnemius. All statistical analyses were performed using SPSS 16.

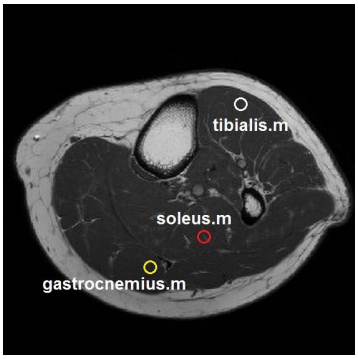

Fig 1. T1 image of the calf slice showing the location of ROIs drawn in gastrocnemius muscle (yellow circle), soleus muscle (red circle), and tibialis muscle (white circle).

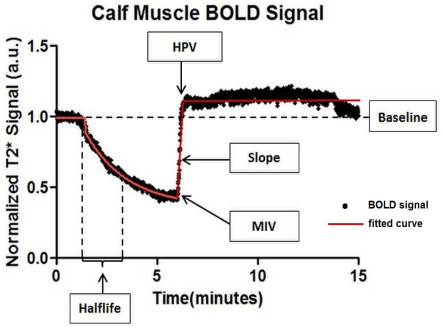

Fig 2. An example of curve fitting model for normalized T2* signal.

Results: The results obtained from the 34 subjects are shown in Table 1. Significant differences in slope and MIV parameters were observed between muscle groups ($p<0.05$).

Table 1: Muscle groups comparison by ANOVA

Muscle Groups	Slope (a.u./min)	Halflife (min)	HPV (%)	MIV (%)
Gastrocnemius (n=34)	1.5±0.5	4.0±2.6	6.1±6.2	68.0±7.8
Soleus (n=34)	2.8±1.0	4.6±4.8	6.4±7.5	61.5±10.8
Tibialis (n=34)	1.9±0.7	2.8±2.9	6.4±9.7	72.0±9.1
p value	<0.0001	0.121	0.862	<0.0001

As shown in Fig 3, the slope parameter in the soleus muscle was much steeper than that in the other two muscles. In addition, the MIV for the soleus muscle was significantly smaller compared to either the tibialis anterior or the gastrocnemius muscles.

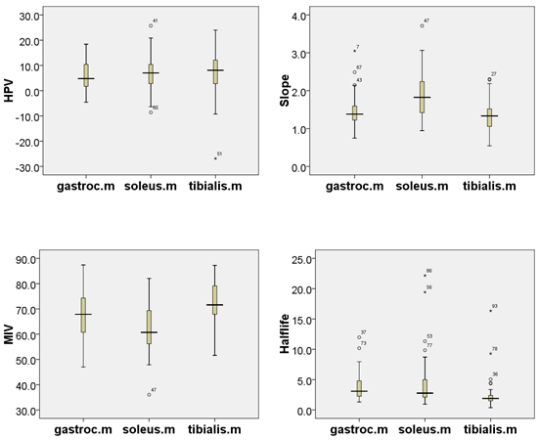

Fig 3. Comparison of the four parameters (Slope, Half-life, MIV, HPV) among 3 muscle groups.

Discussion: BOLD signal changes reflect muscle oxygenation and in particular the degree of hemoglobin oxygenation. It can be influenced by muscle blood volume, perfusion, metabolic process, vascular density, etc. MIV reflects oxygen utilization while slope reflects vascular reactivity. The soleus muscle had a lower MIV during ischemia than the other calf muscles indicating higher basal oxygen utilization. Conversely, the soleus also showed the steepest slope upon reperfusion indicating highest vascular reactivity or density. These changes are in line with expected findings. The soleus muscle mainly helps maintain balance and is mainly consists of slow-twitch oxidative muscle fibers which tend to have a higher capillary density and myoglobin content compared to fast-twitch dominant muscles, such as the gastrocnemius muscle. In this study, using a non-invasive technique, we have been able to demonstrate different oxygen requirements and re-perfusion capability in different calf muscle groups. Vascular compromise could potentially affect some muscle groups differently to others.

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