HAEMOGLOBIN-DERIVED CURVE FITTING TO POST-EXERCISE MUSCLE BOLD DATA

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Target audience: Musculoskeletal researchers interested in functional imaging of muscle.

Purpose: Blood oxygen level dependent (BOLD) imaging is promising for examining skeletal muscle [1]. Although the technique is sensitive to muscle metabolic activity [2], direct interpretation of the signal is difficult since it depends on muscle perfusion, blood volume (BV), and oxygen saturation (Y). Recently, a model has been shown to predict BOLD signals in muscle after single flexion exercise when BV and Y are measured with near-infrared spectroscopy (NIRS) [3]. Oxy- and deoxy-haemoglobin (O2Hb, HHb) concentration curves are seen to be qualitatively mono-exponential following intense exercise [4]. The purpose of the present study was to evaluate the method of fitting post-exercise BOLD data by generating curves for [O2Hb] and [HHb] and substituting them into the published model.

Muscle Group	R^2
Med. Gastroc. (MG)	0.991
Lat. Gastroc. (LG)	0.985
Soleus (SOL)	0.865
Peroneii (PER)	0.992
Extensors (EXT)	0.893
Tibialis Anterior (TA)	0.831

Table 1. R^2 values of fits.

Methods: Data was collected using a GE 3T MRI with a single receive channel flex coil. Following localization and routine T1-weighted anatomical imaging, single shot EPI datasets were acquired axially through right leg calf muscles, during and after exercise (TE/TR/flip=35/250ms/33°, 3 10mm thick slices, FOV/matrix = 16cm/64×64). The exercise protocol was 2.5 minutes of dynamic (0.5 Hz) plantar flexion at 50% of a subject's 1-repetition maximum (1RM). Regions of interest (ROIs) were drawn to assess the lower leg muscle groups (**Table 1**). Mono-exponential curves were generated for [HHb] and [O2Hb] using a custom-written Matlab script, resulting in BV and Y curves and a curve-fit to the BOLD data for each muscle group. Pre-exercise BOLD signal was assumed to represent 50% saturation and 3ml blood/100ml muscle [3].

Results: BOLD signal changes were much higher in the triceps surae muscles (MG, LG, SOL), as expected for plantar flexion exercise. Curves were generated in good agreement with post-exercise BOLD data, although some muscle groups fit better than others ($0.831 < R^2 < 0.992$). The generated fit curves were stable regardless of starting model parameters. Typical fit curves are shown in **Fig. 1**, with R^2 values shown in **Table 1**.

Discussion: The underlying parameters showed much larger changes for the muscles involved in plantar flexion, as expected. Overall the parameter values produced were physiologically plausible. The soleus fitting was notably poor, with the simple model unable to reproduce the fast components of the muscle response. This may be due to the differing fibre-type distribution and capillarization of the soleus [5]. In particular, the soleus parameters returned to baseline values more quickly than gastrocnemius, possibly due to increased oxidative potential and the nutritional advantage afforded by increased capillary tortuosity in the soleus.

Conclusion: In general the simple model with further assumptions on curve shapes performed rather well. Good fits were obtained across a range of muscles, even in dorsiflexion muscles which were not involved in the exercise. Qualitatively, [HHb] returned to baseline quickly, while [O2Hb] remained elevated, in agreement with previous literature for similar exercise [6]. One can draw tentative conclusions about physiological parameters in the muscle using this technique, although a more sophisticated model may improve accuracy. Positive verification of the procedure under known conditions would also improve confidence.

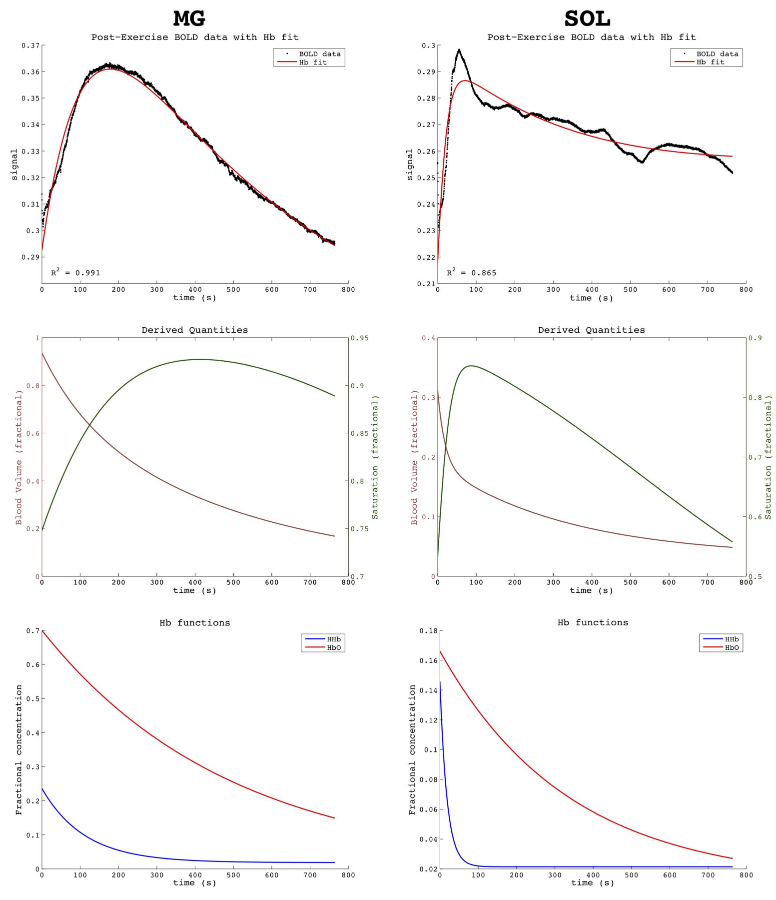

Figure 1: Post-exercise BOLD with fit curves (**top**), derived quantities BV & Y (**middle**), and generated curves for [HHb] & [O2Hb] (**bottom**) for two muscles.

References: **[1]** Carlier PG, *et al.* (2006) *NMR Biomed* 19:954–967. **[2]** Noseworthy MD, *et al.* (2010) *Semin Musculoskel Radiol* 14:257–268. **[3]** Towse TF, *et al.* (2011) *J Appl Physiol* 111:27–39. **[4]** Kek KJ, *et al.* (2010) *Adv Exp Med Biol* 662:199–204. **[5]** Andersen P, *et al.* (1978), *Eur J Physiol* 375:245–249. **[6]** Torricelli A, *et al.* (2004), *Phys Med Biol* 49:685–699.