Simultaneous Quantification of Blood Velocity and Oxygenation in Femoral Artery and Vein in Response to Cuff-induced Ischemia

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Introduction

There are numerous targeted physiological parameters for evaluating peripheral arterial disease (PAD) during post-occlusive reactive hyperemia, including changes in blood flow rate [1], flow mediated dilatation [2], T2* of muscle tissue [3] and blood oxygenation [4]. PAD is a complex disease, thus no single physiological parameter can provide a complete assessment of the vascular dysfunction. Instead, quantification of several physiological parameters may lead to more sensitive assessment to detect asymptomatic PAD. As a first step toward an integrated MRI evaluation of PAD we have combined high-speed blood velocity and oxygenation quantification to improve and extend the MR oximetric approach to evaluate vascular function. The method is demonstrated in a healthy subject during post-occlusive hyperemia.

Methods

MR susceptometry-based oximetry [5,6] quantifies the relative magnetic susceptibility between intravascular blood and surrounding muscle tissue by phase mapping. Absolute blood velocity can be quantified rapidly by removing signal contribution from the background static tissue using a reference image [7] prior to taking phase difference between velocity-encoded projections. The pulse sequences shown in **Fig. 1** allow simultaneous quantification of blood velocity and oxygen saturation (HbO_2). In both sequences, TE2 and TE4 are acquired for quantifying HbO_2 by phase mapping. The purpose of the reference image taken at TE1 (**Fig. 1a)** is to remove static tissue signal from the velocity-encoded projections that are acquired at TE1 in **Fig. 1b** to yield temporally-resolved blood velocity. In **Fig. 1b**, the phase encoding is inserted between TE1 and TE2, and the two-step velocity encoding is "toggled" by separating the flow-compensating gradient lobes appropriately. In short, the phase encoding is always stepped up for TE2 and TE4 for HbO_2 quantification and velocity is quantified with velocity-encoded projections. The latter is a two-step process where reference image (**Fig. 1a**) is used to remove tissue signal from the velocity-encoded projections as described in [7] (**Fig. 1b**). Note that TE2 and TE4 have the same first moment so that flow-induced phase accumulation does not contribute to the phase difference image for HbO_2 quantification. HbO_2 and velocity was quantified in the femoral artery and vein of a healthy subject during reactive hyperemia induced by 5-mins of cuff occlusion in the upper thigh. All experiments were performed on a 3T Siemens Trio and axial images of the femoral vessels were acquired using a phased-array eight-channel knee coil (Invivo Inc., Pewaukee, WI). The following imaging parameters were used: FOV=128 x 128 mm^2, voxel size = 1 x 1 x 5 mm^3, TE/TR = 4.8/39.1 ms, BW = 521 Hz/pix, Flip angle = 10º, VENC = 200, 100 and 60 cm/s and total scan time 6 mins. The pulse sequence was programmed using SequenceTree™ [8], a custom-designed pulse-sequence design and editing tool.

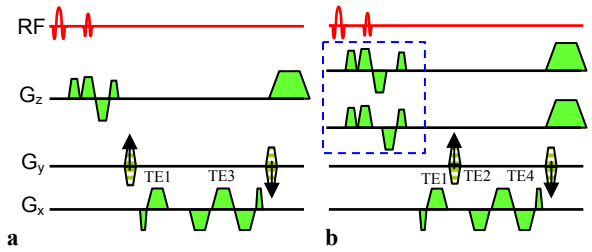

Fig. 1 a) RF-spoiled multi-echo GRE pulse sequence with fat suppression and flow compensation. In **b**) the two-step velocity-encoding is toggled between TR (dashed box).

Results

The maximum blood velocity during hyperemia is approximately four and six times that of peak systolic velocity at rest (not shown) in artery and vein, respectively. The peak blood velocity is reached under 10 s and comes to the baseline value in about 30s, consistent with Doppler ultrasound measurement [1]. The physiological parameters (washout time, upslope and the overshoot) derived from the time-course of the venous oxygenation are quantitatively consistent with that in a healthy young subject [4]. It is characterized (**Figure 2b**) by a short washout time (~ 15s, blue arrows), steep upslope (1.64 $\%HbO_2$/s, dashed red line) and high venous saturation or overshoot (85 $\%HbO_2$, black arrow).

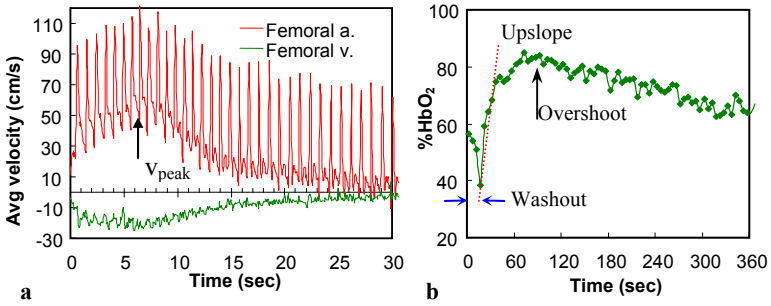

Figure 2 Time-course of **a**) blood velocity and **b**) venous oxygenation during post-occlusive reactive hyperemia. Time is set to zero at the moment of cuff deflation. Temporal resolution is 80 ms for velocity encoding and 5 s for venous HbO_2.

Conclusions

A simple modification to a spoiled multi-echo GRE pulse sequence allows simultaneous quantification of blood velocity and oxygenation in femoral artery and vein. High temporal resolution of the velocity quantification will provide a more sensitive assessment of the early phase of hyperemia, the first 10 s of cuff release. The time-course of the blood velocity and oxygenation agrees with previous studies [1,4]. Unlike Doppler ultrasound blood velocity of both artery and vein can be monitored simultaneously. A cross-sectional study involving healthy controls and patients with PAD is needed to assess the advantage of simultaneous quantification of blood velocity and oxygenation during the post-occlusive hyperemia.

References

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