Improved temporal resolution of dynamic oximetry via keyhole acquisition for quantifying reactive hyperemia

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Introduction Early detection of asymptotic PAD is critical for reducing morbidity and mortality because the progression of PAD accelerates as it becomes more severe [1] and PAD increases the relative risk of heart attack and stroke 5-fold and 2 - 3-fold, respectively [2]. Dynamic oximetry [3] is capable of characterizing microvascular reactivity in the lower limbs by "labeling" tissue blood via cuff occlusion and then following the fate of the desaturated capillary blood as it passes through the imaging slice. The current temporal resolution of dynamic oximetry is limited to 5s and thus may not be able to resolve potentially important information that could differentiate subtle differences in the vascular reactivity between, for example, healthy smokers and non-smokers, targeted in a future study. Reducing TR is not a satisfactory solution since it will lead to unacceptable SNR in reference tissue as well as a minor loss of blood signal due to saturation effect. In this work we implemented and evaluated the keyhole [4,5] acquisition scheme for improving the temporal resolution of dynamic oximetry by a factor of four without sacrificing SNR and accuracy.

Methods MR susceptometry [6,7] quantifies blood oxygen saturation level (HbO_2) in large vessels (approximated as a long cylinder) by estimating the relative magnetic susceptibility difference between the intravascular blood and surrounding muscle tissue via a field map, acquired with a spoiled multi-echo GRE pulse sequence. In order to better capture the dynamics of the blood oxygenation during the early phase of reactive hyperemia keyhole (KH) acquisition scheme is implemented, where the high spatial frequency data are filled from a reference data. The KH scheme for field mapping has been evaluated by comparing its performance against the fully-sampled k-space data in a susceptibility phantom and in a cross sectional study involving young and older healthy subjects. For in vivo studies, a blood-pressure cuff (Aspen Labs A.T.S 1500 Tourniquet System, Littleton, CO) is applied to the upper thigh with a paradigm consisting of 2 mins baseline, 5 mins occlusion and 6 mins recovery. All axial images were acquired with an 8 ch Tx/Rx knee coil (Invivo Inc., Pewaukee, WI) with the following imaging parameters: TE1/ΔTE/TR=5/2.34/39.1ms, FOV=128 x 128 mm, matrix size=128 x 128 for fully sampled k-space or 128 x 32 for KH, BW/pixel=521 Hz. For the in vivo studies the KH acquisition was implemented only during the critical period (-10 to +70 s, cuff deflation is at t = 0 s) of reactive hyperemia. The details of reducing static field inhomogeneity and HbO_2 calculation can be found in [8].

Results **Fig 1** summarizes the phantom results and the average difference in measured and calculated susceptibility was less than 3%. Difference in the SNR was not observed between the magnitude images (**Fig 2a, c**) reconstructed from keyhole and fully sampled acquisition. **Fig 3** shows the magnified view of the femoral vein from **Fig 2b**. **Figure 4** indicates that the temporal window to observe the desaturated capillary blood is less than 3s and **Fig 4b** suggests that 5s resolution may have missed the minimum venous saturation.

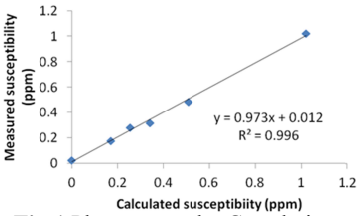

Fig 1 Phantom study. Correlation between calculated and measured susceptibility values using KH acquisition.

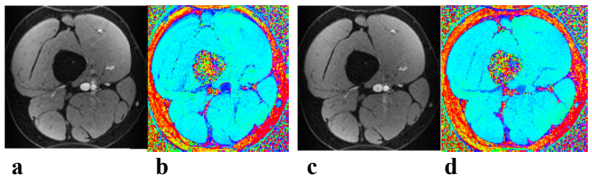

Fig 2 Magnitude and corresponding phase difference image (**a,b**) at t = 18.25s reconstructed with KH acquisition, corresponding to the time-point of minimum venous saturation. (**c,d**) Reconstruction based on first fully sampled k-space at t = 72.5 s.

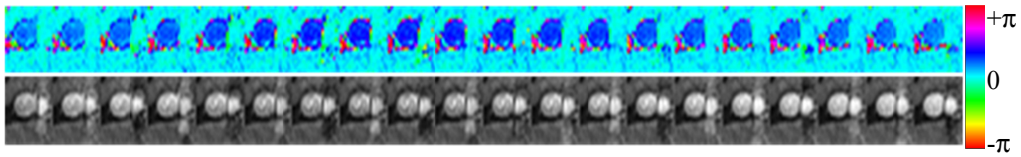

Fig 3 Magnified view of the dynamic change in the magnetic susceptibility of the femoral vein captured with KH acquisition from t=8 to 32s at a temporal resolution of 1.25s. The ninth frame corresponds to the minimum venous saturation. Note rapid change in HbO_2 during passage of desaturated blood.

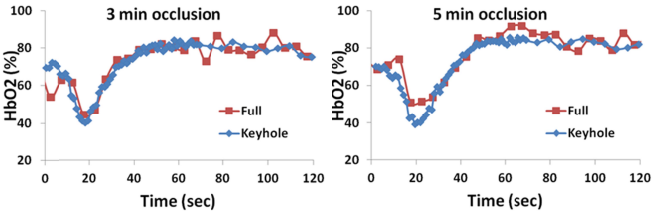

Fig 4 Time-course of HbO_2 level in the femoral vein of a healthy young female (25 yrs) after **a**) 3 min and **b**) 5 min occlusion period. Time-courses of HbO_2 for full k-space sampling (5s temporal resolution) and KH acquisition (1.25s temporal resolution) are plotted for comparison for each occlusion duration.

Conclusions Keyhole acquisition improves temporal resolution fourfold without SNR penalty. The phantom and *in vivo* data suggest that the central 32 k-space lines capture the essential phase information to accurately quantify dynamic magnetic susceptibility. The improved temporal resolution should enhance the precision in the measurement of the washout time parameter, a measure of microvascular reactivity.

References: [1] Smith et al, J Vascu Surg 2003; [2] Criqui et al, N Engl J Med 1992; [3] Langham et al, JACC 2011; [4] Jones et al, MRM 1993; [5] Van Vaals et al, JMRI 1993; [6] Haacke et al, Human Brain Mapping 1997; [7] Fernández-Seara et al, MRM 2006; [8] Langham et al, MRM 2009.

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