Quantification of cerebral arterial and venous blood T_1 during hyperoxia and hypercapnia

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Target audience: Researchers and clinicians interested in functional MRI, brain physiology, arterial spin labelling, calibrated BOLD and hypercapnia/hyperoxia inversion recovery based MRI

Purpose: In recent years several inversion recovery (IR) based magnetic resonance imaging (MRI) techniques have been introduced to study crucial physiological parameters such as cerebral blood flow (CBF) [1,2], cerebral blood volume (CBV) [3,4], cerebral metabolic rate of oxygen ($CMRO_2$) [5,6] and oxygen extraction fraction (OEF) [7]. Some of these techniques rely on hyperoxic or hypercapnic gas breathing challenges [8,9]. Their accuracy might, however, be diminished by changes in blood longitudinal relaxation times T_1 induced by increased concentrations of inhaled O_2 and CO_2. The purpose of this study is to quantify changes in cerebral arterial and venous blood T_1 resulting from the inhalation of 7 different gas-mixtures typically used in modern IR based functional MRI (fMRI) techniques such as calibrated BOLD.

Methods: Experiments were performed with 3 subjects on a 3 Tesla whole-body MRI scanner using a 32 channel head coil. A single slice IR Look-Locker echo-planar imaging (IR-LL-EPI) [10] sequence was used to acquire T_1-weighted MRI images with a temporal resolution of 250ms for the sagittal sinus and 100ms for the basilar artery. Further sequence parameters were: partial Fourier factor 6/8, TE=25ms, TR=15s, slice thickness 5mm, nominal isotropic spatial resolution 2mm. Slice positioning perpendicular to the vessels and optimised temporal resolution was used to avoid saturation effects due to multiple blood excitation. Each ROI contained 4 voxels within the vessels. The averaged data from 5 repetitions was fitted to an IR relaxation equation with M_0 and T_1 as fitting parameters. Volunteers inhaled 7 different gases during one MRI scan: 100% O_2; 5%, 7.5%, 10% CO_2 + 21% O_2 + rest N_2; 5%, 7.5%, 10% CO_2 + rest O_2 (carbogen). Fat suppression was deactivated in order not to influence T_1 decay.

Results:

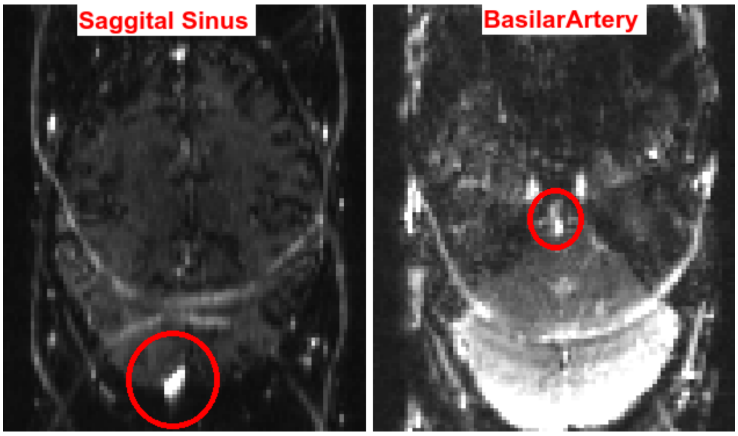

Fig. 1: Example images acquired via an IR-LL-EPI MRI sequence containing the sagittal sinus (left) and the basilar artery (right)

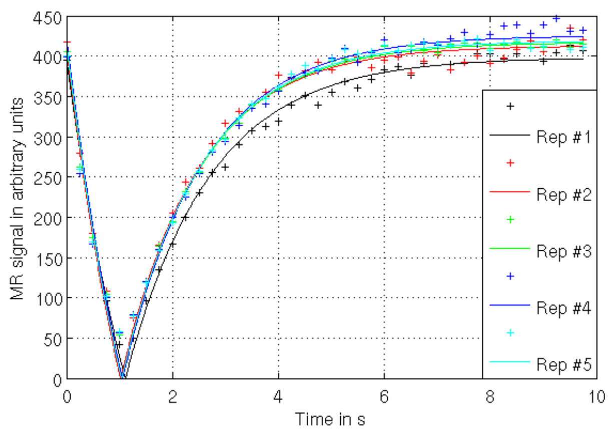

Fig. 2: Example data fits for 5 repetitions taken from the sagittal sinus ROI.

	Baseline	100% O_2	5% CO_2	7.5% CO_2	10% CO_2	Carbogen-5	Carbogen-7.5	Carbogen-10
Sagittal Sinus	1.56s	1.59s	1.61s	1.61s	1.53s	1.62s	1.53s	1.48s
Basilar Artery	0.92s	0.95s	0.84s	0.79s	0.38s	0.68s	0.76s	0.51s

Table 1: Longitudinal relaxation times T_1 of venous and arterial blood during inhalation of different gas mixtures averaged across 3 subjects.

Discussion: The estimated T_1 values of venous blood were found in the expected range [11,12]. Venous blood T_1 decreased for higher carbogen concentrations which might be related to higher blood oxygenation [13] in combination with increased blood flow. The effect of increased CO_2 at isooxia resulted in a smaller decrease in venous blood T_1. Arterial blood T_1 values obtained in this study are generally smaller compared to literature values [11]. This may be a consequence of partial volume effects due to the small diameter of the basilar artery, fresh blood inflow effects due to high arterial flow rates or arterial pulsation effects. Despite these difficuties of quantification, arterial T_1 changes due to CO_2 and carbogen inhalation showed a similar trend as changes in venous T_1 for the same gas mixtures.

Conclusion: We measured venous and arterial blood T_1 via an IR-LL-EPI MRI sequence and estimated T_1 changes due to inhalation of various gas mixtures. Relative changes in venous and arterial T_1 found in this study might provide valuable information for ASL based studies that need correction for under- or overestimation of blood flow due to gas inhalation procedures. More work remains to be done especially on arterial T_1 estimation.

References: [1] Calamante et al. JCBFM (1999), [2] Kim et al. MRM (1995), [3] Lu et al. MRM (2003), [4] Huber et al. MRM (2013), [5] Davis et al. PNAS (1998), [6] Hoge et al. MRM (1999), [7] Gauthier et al. Neuroimage (2012), [8] Chiarelli et al. Neuroimage (2007), [9] Gauthier et al. HBM (2013), [10] Gowland and Mansfield MRM (1993), [11] Lu et al. MRM (2004), [12] Zhang et al. MRM (2013), [13] Pilkinton et al. MRM (2012)