Full-brain Blood Volume, Oxygenation and Hematocrit Imaging using T1 and T2 Prepared Velocity Selective Labeling

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INTRODUCTION: Blood oxygen saturation is an important parameter in the management of diseases such as stroke or cancer. In stroke, the bloods oxygen saturation is related to the Oxygen Extraction Fraction (OEF) and Cerebrovascular Reserve (CVR), both markers for the viability of the tissue. Impaired CVR results in high OEF and low oxygen saturation which is associated with an increased risk of ischemic events. In cancer patients, the treatment benefits from high oxygen saturation as oxygen is a vital component in the generation of free radicals which eventually destroy the cell's DNA. This is in particular the case in radiation therapy but it may also play an important role during certain types of chemotherapy. Therefore the assessment of oxygen saturation is important in the clinical setting. Techniques based on modeling of T_2 and T_2* in a two-compartment model [1] have been developed for measuring oxygen saturation (Y) and regional OEF. To avoid possible sensitivity to field inhomogeneity and model assumptions, a more direct measurement of outflowing venous blood have been proposed in the form of the QUIXOTIC sequence [2]. While outflowing venous saturation Y_v is ideal for true OEF estimation, the technique suffers from low SNR. In reality, the oxygenation levels have dropped significantly before blood even reaches the capillaries and SNR improvements can be achieved by including the entire vasculature as proposed in the recent T_2-BIOS approach [3]. The sequence exploited the intravoxel incoherent motion (IVIM) in a single-slice T_2-prepared DWI sequence to obtain blood volume and T_2. Knowing the blood T_2, Y can be estimated using previous determined relationships between T_2 and Y [4,5] if the hematocrit (Hct) is known. In this work we present an improved method, which allows simultaneous full brain measurement of blood-volume, oxygenation and hematocrit using a modified version of the T_2-BIOS sequence.

METHODS: The sequence is shown in Fig. 1. It starts with a pre-saturation followed by a recovery time with options for adding a CSF suppression inversion pulse. Then the longitudinal magnetization is T_2 prepared using either a standard MLEV preparation [4] or a series of B_1-insensitive rotation pulses. Subsequently, a BIR-4 based velocity selective labeling sequence is played out right before a conventional multi-slice EPI readout. The sequence is repeated in groups of 4, each with different effective TE preparations in the range 0-160 ms. For each eTE, both a label and a control experiment is performed thereby allowing the separation of the vascular signal from the static tissue signal. In addition to this, the shortest eTE is repeated at different saturation times, allowing T_1 measurements of blood. Hematocrit is then calculated based on a previously determined T_1 vs. Hct relationship [6] using the fitted T_1 of blood from the sagittal sinus. For T2 the signal relationship follows:

$$\Delta S(eTE) = V_b \cdot M_{0b} \cdot e^{-\frac{eTE}{T_{2b}}}$$

where eTE, is the effective MLEV echo time, $V_b \cdot M_{0b}$ is blood volume fraction times bloods equilibrium magnetization. With appropriate knowledge of M_{0b}, e.g. from a partial volume free voxel in the sagittal sinus, a blood volume estimate can be obtained. Estimation of oxygen saturation from the fitted T_2 was done by the use of eq.1 in [5]. Five healthy volunteers were scanned (3T Philips Achieva) using the modified T2-BIOS sequence according to institutional guidelines. The scan parameters were: TR/TE=7600/7ms, 40x40 matrix, FOV=240x240, flip-angle=90°, 11 slices of 7mm, SENSE=2.0, eTE=0,40,80 and 160ms, $V_{enc}=\infty$ and V_{enc}=1.5cm/s. Total scan time 6:32 min. The scan was repeated with and without a hypercapnic challenge. In 2 subjects variable saturation times were included for measuring blood T_1. In 3 subjects simultaneous oxygen saturation measurements were performed using an MR-compatible Near Infrared Spectroscopy (NIRS) device (Artinis Medical Systems, Zetten, The Netherlands).

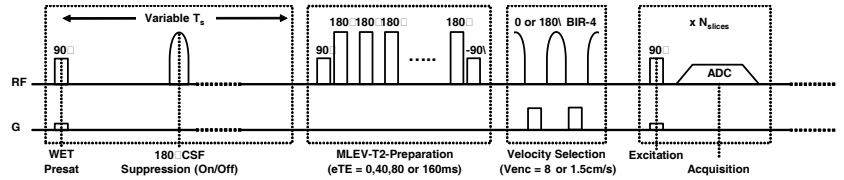

Figure 1. *Sequence for measuring blood T_1, T_2, and M_0.. The sequence is repeated 4 times, each with a different T_2-preparation for each of the velocity selective label and control conditions. This result in effective TEs of 0,40,80 and 160ms used for T_2 mapping. A variable saturation time T_s allows simultaneous T_1 mapping of the blood.*

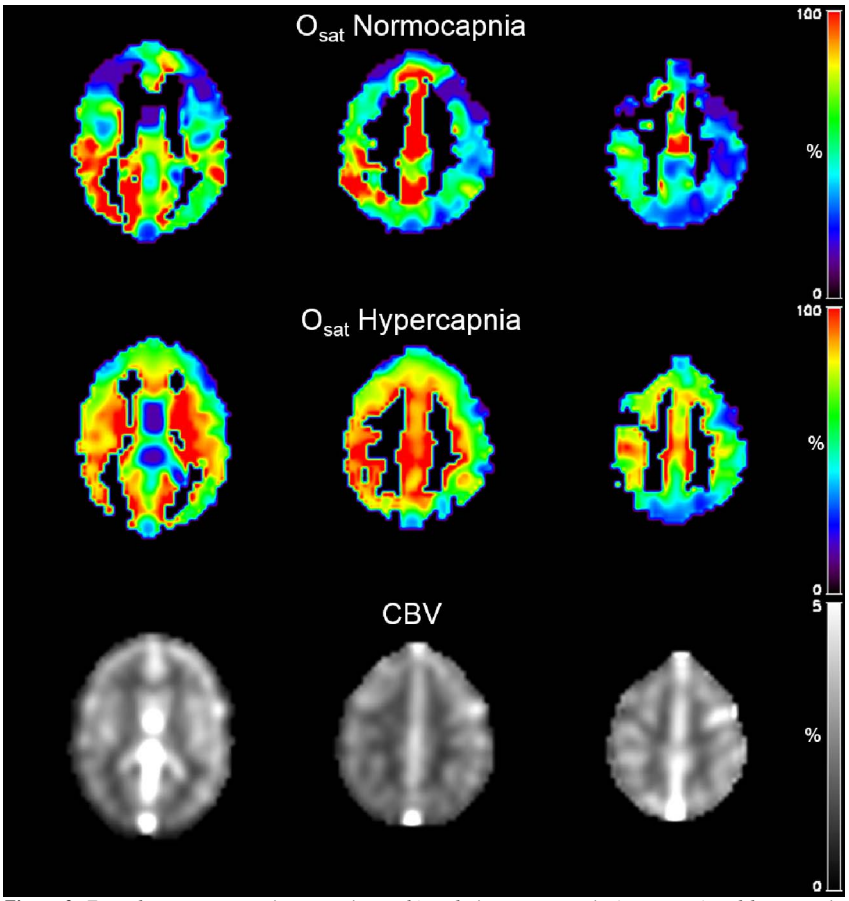

Figure 2. *Example oxygen saturation maps in a subject during normocapnia (upper row) and hypercapnia (middle row). In the bottom row the corresponding CBV map is shown. The sagittal sinus region can be clearly seen in most slices and an automatic mask extracts the sagittal sinus for blood T_1 and global venous T_2 estimation. In the current example, the T_1 of 1.73 results in a hematocrit of 0.42 and the T_2 translates into a global oxygen saturation of 49.8% and 58.6% during normo- and hypercapnia, respectively.*

RESULTS and DISCUSSION: Figure 2 show oxygen saturation maps from one volunteer. Average whole-brain normocapnia Y was 62.7±5.4% and hypercapnic Y was 75.1±6.2%. In the initial NIRS data we observed a limited increase from 66.2% to 67.6% (N=3). Global venous normocapnia Y_v was 51.2±4.6% and hypercapnic Y_v was 63.1±7.3%. Two subjects had blood T_1 measured simultaneously (1.73 and 1.68s) which correspond to hematocrits of 0.42 and 0.45 respectively. This allows for the correction of the T2-Y relationship which is Hct dependent [5].

CONCLUSION: A full brain method for simultaneous CBV, Y and Hct mapping is proposed. Although in a preliminary phase, the initial results are promising and further validation work is ongoing in healthy subjects using a reactivity challenge while simultaneously monitoring frontal Y by NIRS.

REFERENCES: [1] An H et al, JCBFM 2000;20:1225-36 [2] Bolar DS et al, MRM 2011;66:1550-62 [3] Petersen ET et al. ISMRM'13 #2906 [4] Lu H et al, MRM 2008;60:357-63 [5] Lu H et al, MRM 2012;67:42-9 [6] Varela M et al, NMR Biomed 2011;24:80-8

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