High Temporal Resolution In-Vivo Blood Oximetry via Projection Based T2 Measurement

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Introduction: Measuring oxygen saturation (S_vO_2) in large blood vessels can provide important information about oxygen delivery and its consumption in vital organs. Quantification of blood's T_2 value via MR can be utilized to determine S_vO_2 non-invasively [1]. However, current T_2 based methods for S_vO_2 quantification are limited in their application due to long acquisition times and sensitivity to partial volume effects from surrounding tissue [1, 2, 3]. We propose a fast method for in vivo blood T_2 quantification via computing the complex difference of velocity-encoded projections.

Methods: As blood flows continuously, its signal can be robustly isolated from the surrounding tissue by computing the complex difference of two central k-space lines (k_y=0) with differential velocity encodings (VENC). This resultant signal can then be measured as a function of effective echo time (TE_{eff}) for rapidly quantifying blood T_2. The magnitude of complex difference (CD) of the signal with two different velocity encodings can be denoted as, $CD = 2Z\left|Sin(\pi v / 2VENC)\right|$ where Z is weighted by spin density, sequence parameters and spin relativities and *v* represents the blood flow velocity. Assuming flow and other sequence parameters to remain constant for different TE_{eff}'s, complex difference processing can be used to estimate T_2 of the flowing spins as $Z \propto e^{-TE_{eff}/T_2}$. Signal variations due to flow can be minimized by choosing VENC close to the average velocity in the vessel (due to sinusoidal dependence of CD on velocity).

All experiments were performed on a 3T Siemens TIM Trio scanner. A flow phantom consisting of a vinyl tube placed in a cylindrical plastic container containing 1.5% agarose gel doped with 0.1mM Gd-DTPA was constructed to compare the proposed method with conventional full k-space T_2 measurement. A 0.1mM $MnCl_2$ solution was used to mimic blood with S_vO_2 ~70%. Additionally, baseline T_2 measurements were obtained in three subjects in the superior sagittal sinus (SSS) (repeated thrice to test measurement precision), straight sinus (SS) and internal jugular vein (IJV). Also changes in blood oxygenation in response to a hypercapnia challenge (5% CO_2) were evaluated in the SSS of one subject. The experimental setup was similar to that used in a previous hypercapnia study [6]. The sequence used for preparing T_2 magnetization was similar to that of Qin et al. [3]. However instead of full k-space readout, two velocity-encoded projections (k_y=0) were obtained for each TE_{eff}. Sequence parameters: FOV = 192x192mm, TE_{eff}= 20, 40, 80 and 160 ms, VENC = 20 (SSS), 40 (SS), 15 (IJV), 50 (SSS, hypercapnia) cm/s, nominal scan time=1.5s (TR) x 2 (velocity encodes) x4 (TE_{eff}) s ~12s, NEX=2 (SSS, SS), 5 (IJV). NEX was chosen using the standard error formula based on the mean and standard deviation of the complex difference of the vessel signal over several cardiac cycles (acquired using a high temporal resolution velocity mapping method [4] ~30ms/measurement point). Additionally, Monte Carlo simulations to model the effect of flow variations on T_2 values (assuming a normal distribution of flow velocities; 30% standard deviation about mean) yielded a coefficient of variation ~7 % in T_2 estimates. T_2 measurements were translated to S_vO_2 levels using calibration curves provided by Dr. van Zijl's group [3].

Results and Conclusions:

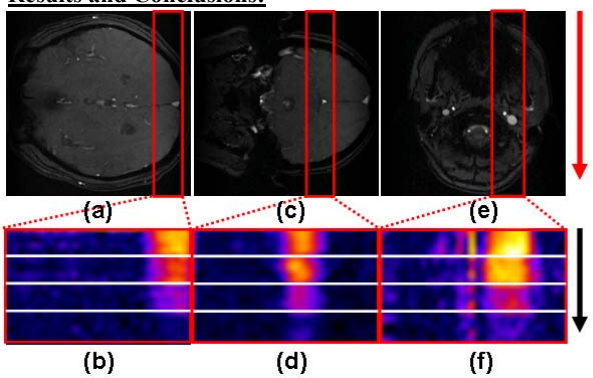

Figure 1*: Magnitude images of the slices used for imaging:* ***(a)*** *SSS;* ***(c)*** *SS;* ***(e)*** *IJV. Red arrow indicates the projection direction. Corresponding T_2-weighted projections at TE_{eff}= 20,40,80 and 160ms (zoomed in;top to bottom, panels* ***b****,* ***d*** *and* ***f****).*

Subject 1	SSS		SS		IJV (R)		IJV (L)	
Trial 1	69.8	65.4	83.3	71.6	71.6	66.3	70.2	65.6
Trial 2	65.2	63.0						
Trial 3	67.0	63.9						
Subject 2								
Trial 1	78.5	69.5	77.3	68.9	81.9	71.0	85.5	72.5
Trial 2	74.1	67.4						
Trial 3	74.4	67.6						
Subject 3								
Trial 1	66.6	63.7	80.2	70.2	72.3	66.6	75.6	68.1
Trial 2	63.4	62.0						
Trial 3	65.7	63.3						
Grand Averages	69.4	65.1	80.3	70.2	75.3	67.9	77.1	68.7

Table 1*: T_2 (ms; grey) and S_vO_2 (%; white) measurements in SSS, SS and left and right IJV. Measurements in SSS were repeated thrice to test measurement precision.*

Measured T_2 values in $MnCl_2$ phantom using conventional and the proposed T_2 mapping methods were 85.7 and 86.8 ms, respectively. **Figure 1** displays acquired T_2-weighted projection data in various veins of interest at rest. **Table 1** lists the results of the T_2 and S_vO_2 measurements in those vessels. Average S_vO_2 measurements in SSS, SS, left and right IJV in the group were 65±3 %, 70±1%, 68±3% and 69±3%, respectively. These values are in good agreement with previous results [2, 3, 5].

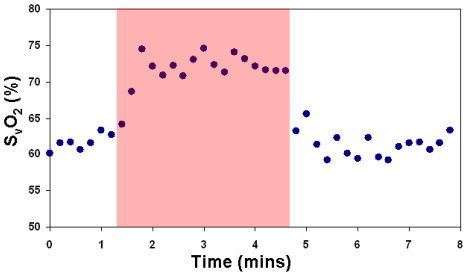

Figure 2*: Time course of SvO_2 changes in SSS in response to hypercapnia (5%CO_2; red band) obtained at a temporal resolution of 12 s. The hypercapnic episode was preceded and followed by periods of breathing normal room air.*

Figure 2 shows the result of S_vO_2 changes in the SSS in response to hypercapnia. The observed increase in S_vO_2 is in agreement with the known vasodilatory effect of hypercapnia. S_vO_2 levels during baseline, hypercapnic and recovery periods were 61±1%, 72±1 %, 61±3 %, respectively.

In summary, we introduced a fast, robust and reliable method to determine S_vO_2 with high temporal resolution in blood vessels. This method is not limited by the orientation of the blood vessel with respect to the magnetic bore nor is there a need for reference tissue as is the case with phase-based oximetry methods [5]. Additionally due to the complex difference subtraction, the method is robust against partial volume effects. However, the method requires flow with low pulsatility, a condition that is met for most cerebral veins. Potential clinical applications extend to the study of pathologic conditions affecting cerebral metabolism, for example, neurodegenerative conditions such as Alzheimer's dementia.

References: **[1]** Wright et al., JMRI 1991; 1:275-283 **[2]** Lu et al., MRM 2008; 60(2):357-363 **[3]** Qin et al., MRM 2011; 65(2): 471-479 **[4]** Langham et al., MRM 2010; 64(6):1599-1606 **[5]** Jain et al., JCBFM 2010;30(9):1598-1607 **[6]** Jain et al., JCBFM 2011;31(7)1504-12.