T_2-weighted Fourier velocity encoding: MR oximetry in small vessels

C. M. Wernik[1], V. Ramanan[2], G. A. Wright[1,2], and C. K. Macgowan[1,3]
[1]Dept. of Medical Biophysics, University of Toronto, Toronto, ON, Canada, [2]Imaging Research, Sunnybrook Health Sciences Centre, Toronto, ON, Canada, [3]Dept. of Diagnostic Imaging, Hospital for Sick Children, Toronto, ON, Canada

Introduction: MR oximetry based on quantitative T_2 measurement [1] is a noninvasive technique for measuring blood oxygen saturation. However, partial volume effects limit T_2 accuracy in narrow vessels or impose long scan times at reduced SNR [2]. To overcome these limitations, we propose an improved technique referred to as Magnetic resonance Oximetry with Velocity Encoding (MOVE). In this study, the feasibility of MOVE was tested using an apparatus that mimics constant blood flow in a vessel.

Theory: Fig. 1 shows the pulse sequence diagram for MOVE, which uses Fourier velocity encoding (FVE) [3] to control for partial volume effects while maintaining SNR. Upon scanning, a 4D dataset $S(TE,k_x,k_y,k_v)$ is acquired, where k_v is the velocity frequency variable encoded by the bipolar gradient. The application of a 3D IFFT at each TE results in $S(TE,x,y,v)$. For voxels (x,y) covering a vessel, a plot along the v-axis generates a T_2-weighted velocity distribution in which the signal from moving blood is separated from that of surrounding static tissue.

Methods: To mimic blood flowing in a vessel, water was pumped through a thin-walled (thickness = 0.5 mm) latex tube at a constant flow rate by a computer-controlled gear pump. The tube was immersed in a water bath to mimic static tissue surrounding the vessel and Gd-DTPA (Magnevist, Berlex, Canada) was used to adjust the tubing and bath T_2 values to represent arterial blood and tissue, respectively. Imaging was performed on a 1.5T MR system (GE Healthcare, USA) using the body coil.

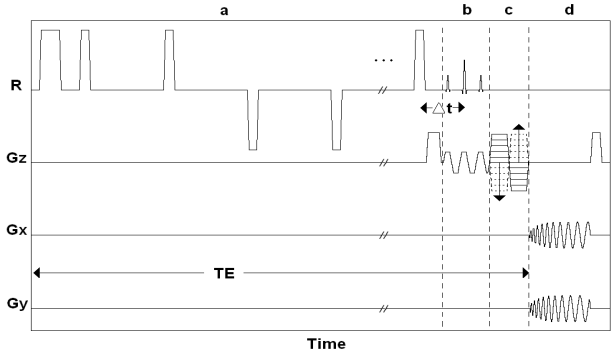

Figure 1: MOVE pulse sequence diagram showing **(a)** non-selective, flow-insensitive T_2 preparation of longitudinal magnetization; **(b)** spectral-spatial RF excitation; **(c)** bipolar flow-encoding gradient; and **(d)** interleaved spiral acquisition. The sequence concluded with a B_1-independent rotation (BIR4) excitation to reset longitudinal magnetization (not shown).

To demonstrate the feasibility of MOVE in the presence of partial volume effects, two low spatial resolution datasets were acquired: $S_1(TE,k_x,k_y)$ using conventional MR oximetry with TE = [2.9, 50.7, 98.5, 194] ms, TR = 1.5 s, $\Delta x = \Delta y = 5$ mm, scan time ≈ 18 s, and $S_2(TE,k_x,k_y,k_v)$ using MOVE with TE = [7.6, 55.4, 103.2, 198.7] ms, TR = 1.5 s, $\Delta x = \Delta y = 5$ mm, VENC = 40 cm/s, velocity resolution = 10 cm/s, scan time ≈ 2 m 24 s. The difference in TE is a result of the bipolar gradient in MOVE. The imaged slice corresponding to $S_1(2.9ms,x,y)$ is shown in Fig. 2a along with a high spatial resolution reference in Fig. 2b. At the imaged spatial resolution, partial volume effects contaminate all vessel voxels. An ROI encompassing the vessel (red box in Fig. 2a) was selected and the signal intensities averaged to produce $S_{1,ROI}(TE)$ and $S_{2,ROI}(TE,v)$. The average data was then least squares fit according to the equation in Fig. 3, where C_o accounts for T_1 relaxation during the time interval Δt shown in Fig. 1. In the case of $S_{2,ROI}$, the fit was performed at each velocity and the result for tubing T_2 taken as the weighted mean of each non-zero velocity T_2 estimate.

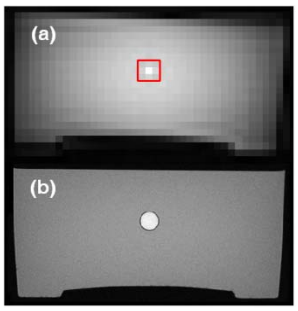

Figure 2: (a) Imaged slice at low spatial resolution; **(b)** High spatial resolution reference.

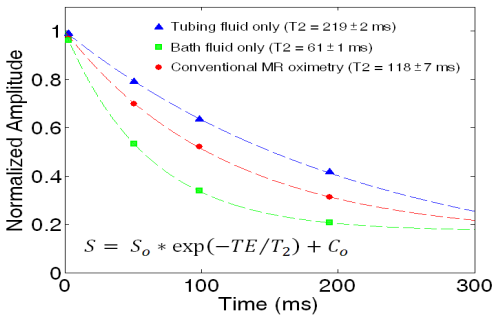

Figure 3: Reference and conventional MR oximetry T_2 relaxation curves (errors too small to plot).

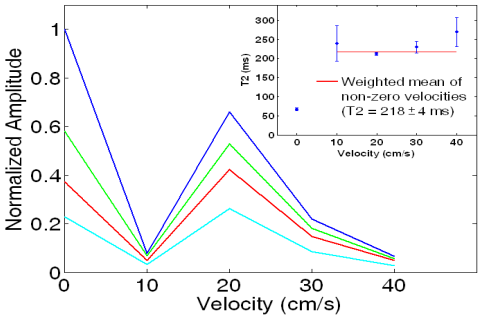

Figure 4: T_2-weighted velocity distributions from MOVE acquisition and (inset) velocity-dependent T_2 estimates.

Results & Conclusion: Reference T_2 relaxation curves measured in isolated samples of the tubing and bath fluids are shown in Fig. 3 (T_2 = 219 ± 2 ms and 61 ± 1 ms, T_1 ≈ 250 and 80 ms, respectively). Also shown is the conventional MR oximetry measurement of tubing fluid with a T_2 estimate of 118 ± 7 ms, indicating dramatic partial volume errors. Fig. 4 shows that MOVE eliminates these errors by separating the tubing and bath fluid signals using FVE, resulting in T_2 estimates of 218 ± 4 ms and 66 ± 4 ms, respectively. Although MOVE requires greater scan time, it does so in an SNR-efficient manner while also providing flow information. Conversely, increasing the spatial resolution of conventional MR oximetry would reduce partial volume effects at the expense of SNR. We plan to validate gated MOVE for *in vivo* application by investigating heart rate variability and T_2* effects during flow encoding.

References: [1] Wright *et al.* JMRI 1:275-283 (1991) [2] Stainsby *et al.* MRM 40:494-499 (1998) [3] Carvalho *et al.* MRM 57:639-646 (2007)