Improved estimation of venous saturation using simultaneous arterial and venous acquisition of T2

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Introduction: Several MRI techniques (1-3) have been recently proposed for in vivo measurement of venous oxygenation (Y_v) in the brain. Y_v provides the basis for determination of OEF and $CMRO_2$, which are important physiological markers of brain function. These parameters may also help elucidate the complex relationship between CBF, CBV, and $CMRO_2$ in the BOLD signal. One critical step *common* in these techniques is the conversion of T_2 measured from isolated venous blood to Y_v. Although several authors have published calibration data (4, 5), the conversion step based on these data is critically technique dependent which limits its universal applicability since the T_2-Y_v relationship is influenced by a large number of experimental conditions including the type of sequence used to measure T_2, as well as the property and source of the blood sample. Using a two-compartment exchange model (5), Lu et al. experimentally determined the 6 model parameters to remove the inter-echo spacing and hematocrit confounds from the T_2-Y_v relationship. Using the same model and fittings parameters as a framework, we propose a new imaging strategy that minimizes the dependence on these experimental parameters and consequently improves the accuracy in the estimated of Y_v via the **s**imultaneous **a**rterial and **v**enous **a**cquisitio**n** of **T_2** (SAVANT).

Theory: Eq. 1 describes the two-compartment exchange model (5), which establishes an analytical relationship between R_2, Y, and hematocrit (Hct).

$$R_2 = a_1 + a_2 Hct + a_3 Hct^2 + [b_1 Hct + b_2 Hct^2](1-Y) + [c_1 Hct(1-Hct)](1-Y)^2 \quad [1]$$

Using a measurement of an R2 difference between two vessels (ΔR_2) removes some of the potential systematic errors introduced if parameters a1, a2 and a3 are not accurately known. If the T_2 of arterial and T_2 of venous blood are known, a new equation (Eq. 2) can be formulated, which reduces the fitting parameters from 6 to 3.

$$\Delta R_2 = (Y_a - Y_v) + (B + 2C - CY_a - CY_v), where\ B = b_1 Hct + b_2 Hct^2\ and\ C = c_1 Hct(1-Hct) \quad [2]$$

Y_a can be readily measured with a pulse oximeter and Eq. 2 can be rearranged to analytically solve for Y_v.

Methods: SAVANT is a variant of the TRUST MRI technique (1) with several notable modifications. First, the PICORE ASL tagging module was replaced with the FAIR module to allow inflows from both proximal (arterial) and distal (venous) sides of the imaging slice to contribute to the difference image. Second, a BIR-4 (6) instead of a spin echo based T_2 preparation module was used since B1 insensitivity of the former provided more uniform measure of T_2 across the imaging slice, an important feature in this study since multiple ROIs were used to perform the T_2 fitting procedure. Third, the inversion time (TI) was adjusted to ensure sufficient signal from both the arterial and venous inflows. Fourth, a single-shot EPI readout was replaced by a spiral readout for imaging to minimize TE and maximize SNR. As a proof of principle, a healthy male volunteer was scanned on a 3T GE MR750 scanner. Imaging parameters were FOV = 240x240ms, Slice thickness = 10mm, matrix: 64x64, Effective TE (e**T**E) = 0ms, 40ms, 80ms, and 160ms, TR = 8000ms, TE = 2.9ms, TI = 800ms, repetitions = 8 at each eTE. To investigate the effect of TIs, the above experiment was repeated with TI = 400ms, 600ms, 800ms, 1000ms, and 1200ms at eTE = 0ms.

Results & Discussion: Fig. 1 shows the average control, tag, and difference image at each eTE. Signal modulation of the T_2 prep module can be seen as a function of eTEs. In addition to the venous signal in the sagittal sinus similar to the one obtained in TRUST MRI, regions with focal arterial signal are also identifiable. Using the arterial and venous ROIs shown in Fig. 2, we observed the maximum mean arterial and venous signal (normalized for the T_1 decay) at TI = 800ms, and 600ms, respectively. Averaged over all TIs, the raw venous signal was 3.2 times larger than the arterial signal. Based on these results, we chose TI = 800ms to calculate ΔR_2. Fig. 2 shows the normalized arterial and venous signal decay fitted to a mono-exponential function. Also shown are the calculated T_{2a} and T_{2v}. With the assumed Hct of 0.48 and the experimental parameters from Lu et al. (5) when τ_{CPMG} = 15ms, we calculated Y_v and OEF using Eqs. 1 and 2. For additional comparison, we also used a T_2-Y_v calibration curve described in ref. 1-3. The results are summarized in the following table. Given that the approximate Y_v for the normal resting human brain is 0.60, the results indicate that the ΔR_2 approach provides venous oxygenation estimates that are more consistent with physiology. In conclusion, we demonstrate that 1) simultaneous measurement of Y_a and Y_v is feasible with the novel SAVANT technique and 2) using the new ΔR_2 formulation reduces dependence on experimental parameters and thus potential systematic errors, which is likely to yield more accurate venous oxygenation and OEF values.

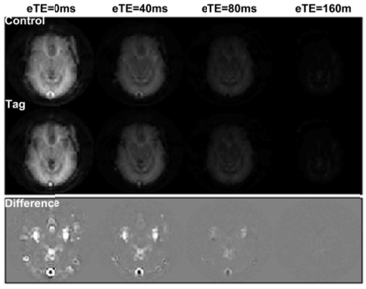


Fig 1. Tag, control and difference images weighted by T2 prep module.

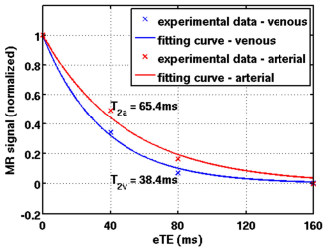
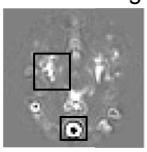


Fig. 2. T2 signal decays measured from the arterial/venous blood. Chosen ROIs are also shown.



T_2 to Y_v conversion method	**Y_v**	**Y_a**	**OEF $[(Y_a-Y_v)/Y_a]$**
Calibration curve (ref. 1-3)	0.49	0.66	0.26
Eq. 1 using 6 fitting parameters	0.46	0.66	0.30
Eq. 2 (ΔR_2 method w/ 3 fitting parameters)	0.59	Pulse oximeter (0.98)	0.40

References: 1. Lu et al. MRM 60:357 (2008). 2. Bolar et al. MRM, In Press (2011). 3. Guo et al. ISMRM, 2010 (Abstract 4057). 4. Zhao et al. MRM 58:592 (2007). 5. Lu et al. MRM, In Press (2011). 6. Nezafat et al. MRM 61:1326 (2009).