Hybrid Encoding for Quantitative Electron Paramagnetic Resonance Imaging

Hyungseok Jang[1,2], Chandramouli Gadisetti[3], Devasahayam Nallathamby[4], Murali C Krishna[4], and Alan B McMillan[1]

[1]*Radiology, University of Wisconsin, Madison, WI, United States,* [2]*Electrical and Computer Engineering, University of Wisconsin, Madison, WI, United States,* [3]*GenEpria Consulting Inc., Columbia, MD, United States,* [4]*Radiation Biology Branch, Center for Cancer Research, National Cancer Institute, Bethesda, MD, United States*

Target Audience Researchers interested in electron paramagnetic resonance oxygen imaging

Purpose Electron paramagnetic resonance imaging (EPRI) is a modality capable of quantitative oxygen imaging owing to the development of non-toxic, exogenous spin probes[1]. Unfortunately, because the transverse relaxation time of these probes is extremely short (<1 us), ultrashort TE (UTE) methods need to be employed to enable successful pulsed imaging. Single point imaging (SPI) has been explored for EPR oxygen imaging, showing good image quality and the capability of T_2^* mapping for oxygen quantitation using an FID acquisition[2]. However, SPI is still limited in temporal resolution due to pointwise k-space encoding, and several efforts to accelerate the technique have been proposed, such as single acquisition SPI-EPRI using k-space extrapolation (KSE)[3] or the application of Fourier transform conjugate symmetry and/or compressed sensing. *In this study, we explored a hybrid encoding scheme for quantitative EPR oxygen imaging, by combining SPI and frequency encoding to accelerate quantitative EPRI.*

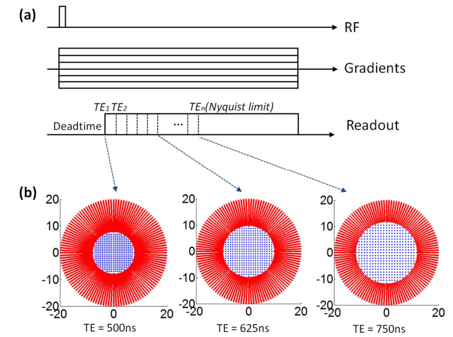

Fig 1. (a) Pulse sequence, and (b) example of sampled k-space with ME-PETRA

Methods

We implemented a new, hybrid encoding using the PETRA (Pointwise Encoding Time reduction with Radial Acquisition) scheme[4] (Figure 1-a), which we term Multi-Echo PETRA (ME-PETRA). The difference from conventional PETRA is the ability to reconstruct short TE images across a range of time delays to enable T_2^* quantification. In PETRA, central k-space is measured by SPI (blue dots in Figure 1-b), while outer k-space is covered by frequency encoding (red dots in Figure 1-b). The diameter of the SPI encoded region, N_{SPI}, can be determined by the following equation, $N_{SPI} = \lceil 2\gamma_e G_{max} FOV\ TE \rceil$, where γ_e is the gyromagnetic ratio of the electron, G_{max} denotes maximum gradient amplitude, and *FOV* denotes the desired field of view. The outer k-space is acquired using frequency encoding gradients with amplitude of G_{max}. *TE* is commonly selected to be the earliest possible encoding time after RF coil deadtime to minimize the size of SPI encoded region. For example, we propose to utilize an oversampled $N_{SPI} = 23$ (where the minimum N_{SPI} for conventional PETRA on our EPRI scanner with matrix size 41x41x41 was 16 with TE_1=500ns) to enable reconstruction across a wide range of *TE*s, as shown in Figure 1, from TE_1 (immediately following deadtime) to TE_n where images begin aliasing (Nyquist limit, due to the well-known "zoom-in" effect in SPI with increasing echo time). Thus, oversampling the SPI region enables T_2^* parameter fitting with multiple images at different *TEs* as shown in Figure 2. After combining SPI samples and frequency-encoded data across a range of TEs, convolution gridding reconstruction was performed to reconstruct images at a constant FOV and compensate for variable density k-spaces. To verify the validity of the ME-PETRA scheme, we performed a phantom experiment using three vials with 0%, 2%, or 5% dissolved oxygen. 2mM Oxo-63 agent (GE Healthcare) was used as spin probe. Data was acquired on a custom pulsed EPRI scanner with the parameters: *Gmax*=13.75mT/m, TR=25us, 13,767 TRs (5,575 SPI encodings and 8,192 frequency encodings after undersampling), and 5,000 signal averages.

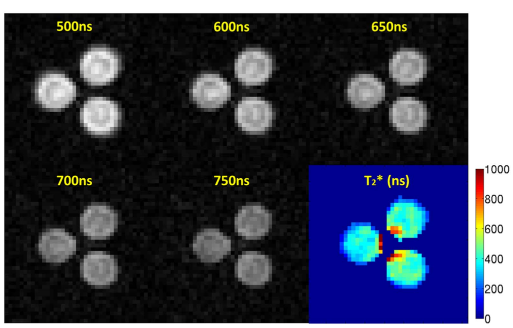

Fig 2. Reconstructed image and estimated T_2^* map (Coronal slice)

Results Figure 2 shows coronal slice in 3D images reconstructed at TE=500ns, 600ns, 650ns, 700ns, or 750ns. Using 51 consecutive images from 500ns to 750ns with sampling interval of 5ns, T_2^* parameter map was estimated.

Discussion and Conclusion We have developed a new scheme for hybrid multi-echo UTE encoding (ME-PETRA) and successfully employed it for EPR oxygen imaging. The proposed acquisition achieves *5x acceleration* to obtain 41x41x41 images across 51 different echo times. In addition, we have shown that multiple echo time images obtained using ME-PETRA can be used to estimate T_2^*, which can be used to perform quantitative oxygen imaging. Note that this method provides an additional 3x acceleration (*net 15x acceleration*) compared with conventional methods that require sequential repeated scans to obtain multiple TE images for quantitative oxygen imaging.

References 1. Ardenkjaer-Larsen JMR 1998;133:1-12. 2. Subramanian MRM 2002;48:370–379. 3. Jang MRM 2013;70(4):1173-1181. 4. Grodzki MRM 2012;67(2):510–8.