A NOVEL PULSE SEQUENCE TO MEASURE OXYGEN EXTRACTION FRACTION IN THE BRAIN USING PARAMETER ASSESSMENT USING RETRIEVAL FROM SIGNAL ENCODING (PARSE) TECHNIQUES

Rajiv G Menon[1], Bradley P Sutton[2], Donald B Twieg[3], and Timothy J Carroll[1]

[1]Department of Radiology, Feinberg School of Medicine, Northwestern University, Chicago, IL, United States, [2]Bioengineering Department, University of Illinois at Urbana-Champaign, Urbana, IL, United States, [3]Biomedical Engineering Department, University of Alabama at Birmingham, Birmingham, AL, United States

INTRODUCTION: Oxygen Extraction Fraction (OEF) gives crucial information regarding the stage of hemodynamic impairment in patients with neurovascular disease. Until an advanced stage of hemodynamic impairment is reached, OEF values remain unchanged mainly due to the auto-regulatory capacity to vasodilate small arterioles. Oxygen extraction starts increasing only when this autoregulatory capacity is exceeded, to ensure normal oxygen metabolism and brain function.

Currently, Positron Emission Tomography (PET) is the gold standard for measurement of OEF. Its adoption is setback due to drawbacks of prohibitively high cost, low availability, in-house cyclotron facility requirements, low image resolution and the usage of radiolabeled oxygen. An MRI based OEF measurement technique would be very useful, and currently there is a need for acquisition sequences that efficiently and robustly estimate the required parameters for OEF estimation. Most techniques use multiple echo, gradient echo based methods using the model by Yablonskiy and Haacke [1] (Equation 1) to measure susceptibility related frequency changes.

$$\delta\omega = \gamma \cdot \frac{4}{3} \cdot \pi \cdot \Delta\chi_0 \cdot Hct \cdot OEF \cdot B_0 \qquad (1)$$

where $\delta\omega$ is the deoxyhemoglobin induced frequency shift; $\Delta\chi_0$ is the susceptibility difference between oxyhemoglobin and deoxyhemoglobin. Hct is the hematocrit, and B_0 is the magnetic field strength in Tesla.

PARSE (Parameter Assessment by Retrieval from Signal Encoding) is an efficient acquisition and multi-parameter estimation technique proposed by Twieg, DB (2003) [2]. This method uses a more accurate MR signal model and can simultaneously estimate M_0, R_2^*, and local frequency in a single 65ms acquisition. Of particular interest here, is the feasibility to directly measure susceptibility related frequency changes from local frequency estimates. Since OEF abnormalities are focal and their location is known *a priori,* a combination of focal shimming and contralateral measurements will be used to estimate the offset frequency ($\delta\omega$). In addition, frequency changes caused due to respiratory changes will be filtered using respiratory gating.

METHODS: To implement the PARSE technique, a non-Cartesian Rosette trajectory was designed (Fig1 (a), (b)). The sequence was implemented on a Siemens 3T Tim Trio MRI scanner. Calibration studies were done to determine the realized rosette trajectory. Numerical simulations using PARSE were performed to measure and validate the estimation accuracy of local frequency under reasonable noise conditions (equivalent image SNR=186). An inverse estimation technique using a progressive length conjugate gradient (PLCG) algorithm was used. The resulting frequency estimates using the PARSE technique were then analyzed, and a sensitivity analysis was performed to assess the feasibility of using PARSE for measurement of OEF.

RESULTS: From the numerical simulations we validated that the PARSE sequence can accurately estimate offset frequencies (Figure 2). From a number of PET studies [3,4,5] it has been established that the brain extracts 40-45% of the oxygen delivered to tissue in healthy normals. From these studies, we expect that a 4-5% increase in OEF would suffice to detect mild vascular insufficiencies, so we target our approach for this scale of change. This translates to a frequency change ($\delta\omega$) of approximately 4 Hz as shown in Figure 3. The OEF increase would be much more (>20%) for severe cases. We determine from numerical simulations that PARSE, for a 3T MRI scanner, can detect a frequency-offset change of less than 4 Hz as shown in figure 3 (error-bars represent standard deviations). Thus, from the above sensitivity analysis we conclude that the PARSE technique can be used to measure oxygen extraction including changes during mild vascular insufficiencies. This study will later establish if the PARSE technique can robustly detect OEF changes in pathological situations.

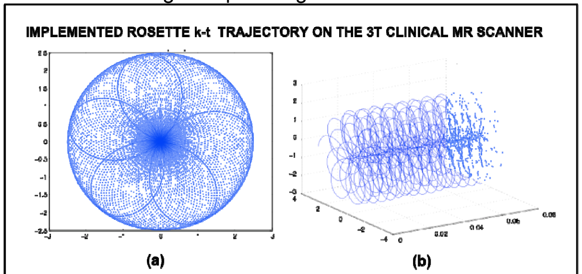

Figure 1. The Rosette k-t trajectory as designed for the 3T Clinical MRI Scanner. (a) the 2D representation showing k-coverage (b) k-t trajectory as it plays out in the scanner

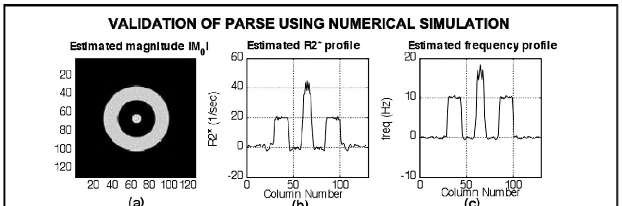

Figure 2. Parameter estimates from numerical simulations using PARSE . (a) parameter map of estimated initial transverse magnetization. (b) a profile through the center of the R_2^* map. The R_2^* for the outer annulus was set to 20 s^{-1}, and center disc set to 40 s^{-1}. (c) a profile along the center of the estimated frequency map. Here the outer annulus was set to 10 Hz, and the center disc to 15 Hz.

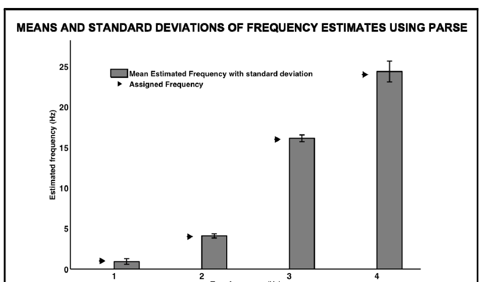

FIGURE 3. Simulations show that PARSE can detect frequency changes within 4 Hz threshold as required by the sensitivity analysis.

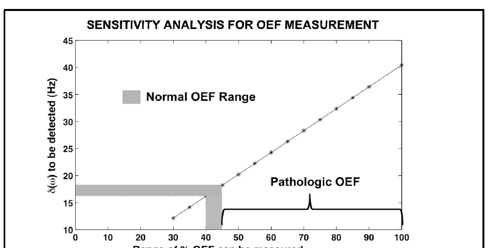

Figure 4. A Sensitivity Analysis for OEF measurement shows that to detect A OEF change of 5% the PARSE technique would need to detect a change of 4Hz or more.

References:

[1] Yablonskiy DA, Haacke EM. *Magn Reson Med.* 1994;32:749-763

[2] Twieg DB. *Magn Reson Med.* 2003;50:1043-1052

[3] Derdeyn CP, Videen TO, *et.al. Brain.* 2002;125:595-607

[4] Derdeyn CP, Yundt KD, *et.al Stroke.* 1998;29:754-758

[5] Yamauchi H, *et.al J Neurol Neurosurg Psych.* 1996;61:18-25