## R2' Mapping of the Human Kidney Using Navigator Gated, Asymmetric Spin Echo, Multi-Shot EPI

Jon Thacker<sup>1</sup>, Huan Tan<sup>2</sup>, Shivraman Giri<sup>3</sup>, and Pottumarthi Vara Prasad<sup>2</sup>

<sup>1</sup>Biomedical Engineering, Northwestern, Evanston, Illinois, United States, <sup>2</sup>Northshore University Health System, Evanston, Illinois, United States, <sup>3</sup>Siemens Healthcare, Chicago, II, United States

# INTRODUCTION

Assessment of renal oxygenation is an important factor in determining overall kidney health. Kidneys exhibit inhomogeneous oxygenation, with the medulla being poorly oxygenated in relation to the cortex. It is valuable to detect the spatial distribution of oxygenation within the kidney as opposed to at the global organ level. Renal oxygenation is typically detected by BOLD MRI through the use of R2\* maps [*Magn Reson Imaging Clin N Am.* 2008 Nov;16(4):613-25]. R2\* is thought to be comprised of two components: R2 and R2'. The dependence on R2 makes it sensitive to changes in local tissue physiology other than changes in oxygenation. R2' is related to the susceptibility induced component and has been investigated for its sensitivity to renal oxygenation.

R2' can be estimated by subtracting R2 from R2\* [*Academic radiology* 2008;15(7):912–918]. Direct estimations have also been performed by using asymmetric spin echo (ASE) sequences [*NMR Biomed.* 2012 doi: 10.1002/nbm.2823. [Epub ahead of print]]. The ASE-EPI sequence (illustrated in Figure 1) employs a spin echo EPI sequence, with the refocusing pulse shifted to give more local inhomogeneity weighting to the resulting image [*Magnetic resonance in medicine* 1998;40:432–442]. R2' can then be obtained by fitting the magnitude signal over multiple shifted echo times ( $\tau$ ). Previous implementations of the ASE-EPI sequence have been limited in spatial resolution due to their single shot nature. This limitation is due to the fact that as matrix size increases, the ADC window will too but it is limited by the effective TE/2, which is optimized to maintain a sufficient signal to noise ratio (SNR). This inherent limitation on spatial resolution can be an issue when attempting to differentiate renal anatomy. In addition, acquisitions of different  $\tau$  values were performed during a single breath-hold scan, which is limited for widespread application due to the long breath-hold interval. This interval also determines how many  $\tau$  values can be sampled. In this study, we have implemented a navigator-gated, multi-shot (segmented) ASE sequence to facilitate free-breathing scans, improved spatial resolution and allow for an arbitrary number of  $\tau$  values to be acquired.

### METHODS

A 2D navigator was employed to trigger data acquisition based on respiration. The navigator plane was positioned over the liver-lung interface to estimate kidney motion. Each 2D navigator image was reduced to a one dimensional image, with the dark band representing the diaphragmatic level. A typical time course of the navigator signal is illustrated in Figure 2.

ASE-EPI image acquisitions were triggered during expiration (apex of the navigator profile). We used  $\tau$  values ranging from 15ms to 27.75ms in steps of 0.75ms resulting in 18 images. The signal intensity was fit to the equation  $S(\tau) = S0 \exp(-2 R2' \tau)$  to estimate R2' on a voxel by voxel basis. An interleaved 2-shot EPI readout trajectory was used. Further imaging parameters are as follows: effective TE=65ms, TR=1000ms, FOV=250mm x 250mm, Matrix=128 x 112, Slice

Thickness=6mm, Bandwidth =1149 Hz/Pixel. Images were reconstructed to 256 x 224 by interpolation. All experiments were performed on a 3T MRI system (MAGNETOM Verio, Siemens

Healthcare, Erlangen, Germany) using the body and spine phased array coil Regions of interest were drawn around the cortex and medulla to extract

## averaged R2' values.

#### RESULTS

Average values from 5 volunteers for R2' in the cortex and medulla were found to be  $10.09 \pm 5.41 \text{ s}^{-1}$  and  $17.38 \pm 8.49 \text{ s}^{-1}$ , respectively. These values are consistent with the previous report [*NMR Biomed.* 2012 doi: 10.1002/nbm.2823. [Epub ahead of print]].

Representative plots of signal vs.  $\tau$  are illustrated in Figures 3 (cortex) and 4 (medulla) where the blue dots are the acquired data points and the red line is the fitted curve.

Figure 5 shows the images from the same subject at both the smaller matrix size of 64x56 and the segmented version of 128x112. Improved delineation of the renal cortex and medulla was observed with the segmented ASE sequence.

#### DISCUSSION AND CONCLUSION

Navigator gated, segmented EPI based ASE-EPI sequences provide several benefits over previously demonstrated methods. Navigator gating allows for data to be acquired while subjects are freely breathing, increasing their comfort and potentially allow multi-slice imaging. A navigator gated scan further allows for an unconstrained number of different  $\tau$  values to be acquired which should increase the quality of the R2' curve fitting. By segmenting the EPI readout train, higher resolutions are achievable and allow for better differentiation between the anatomical structures of the kidney without increasing the effective TE and hence compromising SNR. Parallel imaging and partial Fourier encoding are two other techniques that can be used to improve resolution, though at the cost of SNR and phase encode resolution, respectively.



Figure 1: ASE-EPI sequence diagram.



*Figure* 2: Example navigator profile image. The x-axis is time and the yaxis is the motion of the diaphragm. The yellow boxes indicate actual data acquisition.



Figure 4: Representative medulla ASE-EPI data and fit with increasing  $\tau$ 

Figure 5: Representative R2' map for segmented vs. single-shot EPI readout. (A) Standard readout,  $\tau = 15$ ms. (B) Standard readout, R2' map. (C) Segmented readout,  $\tau = 15$ ms. (D) Segmented readout, R2' map.



Figure 3: Representative cortex ASE-EPI data and fit with increasing  $\tau$ 

