Accelerated Quantitative Single Point EPR Imaging Using Model-based Compressed Sensing

Hyungseok Jang[1], Sankaran Subramanian[2], Nallathamby Devasahayam[2], Shingo Matsumoto[2], Keita Saito[2], Jiachen Zhuo[3], Murali C. Krishna[2], and Alan B. McMillan[1]
[1]Radiology, University of Wisconsin, Madison, WI, United States, [2]Radiation Biology Branch, Center for Cancer Research, NCI, National Institutes of Health, Bethesda, MD, United States, [3]Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine, Baltimore, MD, United States

Target Audience Researchers interested in applications of accelerated quantitative T_2* imaging using single–point imaging techniques.

Purpose Electron Paramagnetic Resonance Imaging (EPRI) has emerged as a promising non-invasive imaging modality that is capable of imaging *in vivo* tissue oxygenation. Due to extremely short spin-spin relaxation time, EPRI benefits from single point (SP) imaging[1] that inherently suffers from low spatial and temporal resolution owing to purely phase-encoded acquisitions. Recently, single acquisition EPRI using gridding and k-space extrapolation (KSE) has been proposed[2] to enable calculation of T_2* from a single acquisition and improve temporal resolution by 3x. However, SP-EPRI is still limited in temporal and spatial resolution, preventing localization of small hypoxic tissues and differentiation of hypoxia dynamics, making accelerated imaging a crucial issue. In this work we have developed new methods for accelerated SP imaging by combining a new, bilateral KSE technique with the implementation of model-based compressed sensing that benefits from dense data in the parameter domain (measurement of the T_2* decay of the FID).

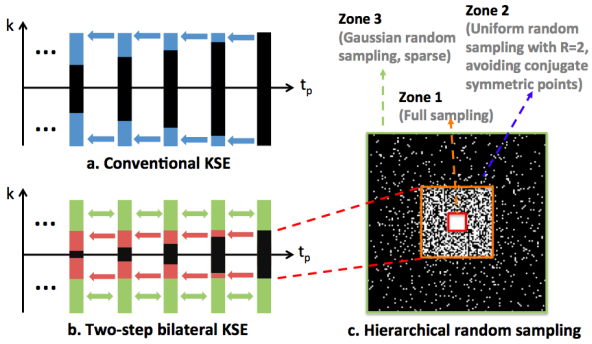

Figure 1. 1-dimensional concept of (a) KSE and (b) two-step bilateral KSE, (b) 2D hierarchical random sampling, and (c) images reconstructed with KSE or two-step bilateral KSE.

Methods Previously described KSE techniques extrapolate peripheral k-space samples into adjacent samples in a reversely cascading manner (blue arrows in Figure 1-a) to reduce time varying Gibb's ringing what occurs when images are reconstructed at a constant FOV across phase-encoding time delays[2]. Unfortunately, this technique is not amenable to k-space undersampling and compressed sensing, and thus we have developed a new technique (two-step bilateral KSE) that can secure more k-space samples by bilaterally extrapolating k-space samples from the neighboring samples (green arrows in Figure 1-b), using a hierarchical random sampling strategy. Here k-space is segmented into 3 sections with different sampling criteria as shown in Figure 1-c. Segment 1 and 2 are processed using standard KSE methods (red arrows in Figure 1-b), while segment 3 is processed by bilateral KSE. Although two-step bilateral KSE significantly improves image quality (Figure 2), T_2* estimation can still be affected by undersampling. Because abundant parameter domain data is available in SP imaging, we implemented PCA-based compressed sensing[3] to exploit the abundant parameter domain data due to long readout times.

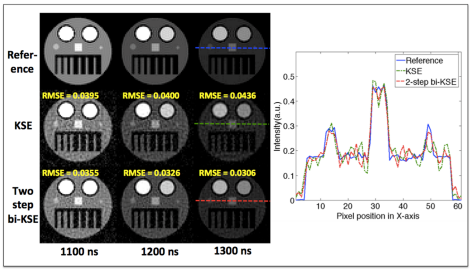

Figure 2. Simulated 2D images reconstructed with KSE or two-step bilateral KSE, and 1D profiles. N=127x127, R=8, input SNR=30

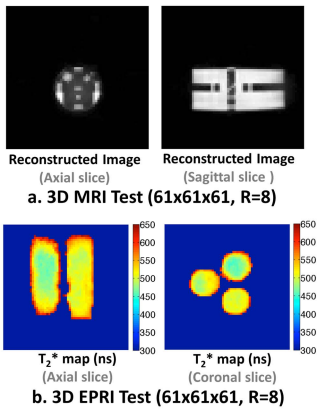

Figure 4. Accelerated compressed sensing single point imaging with prospective under-sampling. (a) MR phantom image, and (b) 3-tube phantom of Oxo63 bubbled with 0%, 2%, and 5% oxygen.

In PCA-based compressed sensing, an overcomplete dictionary matrix whose columns consist of training data, which consists of time series for all possible FID signals, are used with compressed sensing reconstruction to suppress noise and fluctuations related to k-space undersampling.

Results The use of bilateral KSE improves image reconstruction quality in undersampled SP imaging (Figure 2). Simulation results (Figure 3) show good performance for accelerated single-acquisition T_2* imaging using combined KSE and PCA-based compressed sensing. Performance of these methods improves with higher matrix size. Figure 4 shows the result of prospective testing performed on a 1.5T MR (GE Signa HDxt) and a 10 mT EPR scanner[1]. Accelerated single acquisition parameter estimation was possible using the proposed method for both SP-MRI and SP-EPRI.

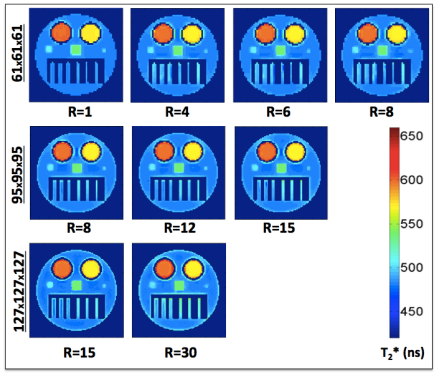

Figure 3. Simulated T2* quantification using 3D bi-lateral KSE with PCA-based compressed sensing (center slice shown).

Discussion and Conclusion The proposed reconstruction method will allow high resolution imaging with realistic imaging times on existing hardware. For example, if we acquire data with 61x61x61 gradient steps, the full sampling scheme will require a scan time of approximately 37.8 min (226,981 phase encoding points), whereas 8x under-sampling will enable imaging within approximately 4.7 min (28,373 phase encoding points). In future work, we will further speed up SP imaging in dynamic imaging by applying and developing time interleaved k-space acceleration techniques and .

References **1.** Subramanian et al. (2002). MRM. 48: 370–379. **2.** Jang et al. (2013). MRM. 00: 1–9. **3.** Huang et al. (2012). MRM. 67(5): 1355–66.