

3D Renal BOLD Imaging with a Prospectively Navigated Free Breathing Pulse Sequence

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Target Audience: Investigators and researchers using BOLD imaging to study renal function and disease

Introduction: We have previously demonstrated a free-breathing prospectively navigated pulse sequence for improved renal BOLD imaging (1). By extending the possible imaging time beyond a single breath hold, this sequence allows flexible tradeoff of imaging time with signal to noise ratio (SNR), spatial resolution, and extent of coverage of the kidneys. Here we demonstrate that this sequence can perform renal BOLD imaging over the entire 3D volume of the kidney in a reasonable imaging time and < 2mm voxels.

Methods: The prospectively navigated sequence uses navigators to define "bins" corresponding to different points in the respiratory cycle. A separate k-space is accumulated for each navigator bin. Navigators are analyzed in real-time and the corresponding bin is examined to see what k-space line should be acquired next for centric k-space ordering. This information is fed back in real-time to the running sequence, which then acquires that phase-encode step. The sequence finishes when one bin has a full k-space. Desired navigation efficiency (i.e. fraction of acquired data that appears in the final image) is set by the user, and the sequence dynamically calibrates the discrimination threshold for bin assignment throughout the duration of the scan to meet this desired efficiency. A set of motion-free images corresponding to six different echo times is reconstructed from the full k-space bin. For full 3D coverage of the kidney, the following sequence parameters were used: 256 x 256 x 32 matrix size, 1.1 x 1.1 x 2.0 mm resolution, TE 5, 11, 17, 23, 29, 35 msec, TR = 95 msec, parallel imaging with GRAPPA reduction factor = 4, navigation efficiency = 25%, fat saturation.

Results: Figure 1 shows six sagittal slices from a full 3D renal BOLD T2* map obtained in about 10 minutes.

Discussion: Full 3D coverage of the kidneys has several advantages.

SNR: Signal to noise ratio of 3D acquisition is higher than that of multi-slice 2D acquisition.

B0 inhomogeneity: Typical B0 inhomogeneity of one or two parts per million causes large variations in the T2* map. This effect can be seen in Figure 1, where the kidney rapidly loses signal with longer echo times because of air-filled bowel anterior to the kidney (to the right on the images). This effect can be corrected if a B0 map is constructed from two of the echoes from the renal BOLD acquisition. With 2D renal BOLD imaging, only the in-plane component of B0 is measured. Through-plane variations of B0 will cause T2* errors that are not detectable or correctable unless a separate 3D B0 map acquisition is performed.

Error and bias in renal BOLD data analysis: Published renal BOLD results have been mostly based on manual segmentation of the kidney into cortex and medulla. Such analysis is susceptible to bias. This has motivated the development of methods to analyze renal BOLD data over

Figure 1: Six successive sagittal slices from a 32-slice full 3D renal BOLD kidney study. Three of the six acquired echo times are shown. Image resolution is 1.1 x 1.1 x 2.0 mm, total imaging time 10 min.

an entire imaging slice without manually defined ROIs (2,3). However, Saad *et al.* recently showed that even with a whole-slice method of renal BOLD analysis, results varied widely for different slices spaced closely in the kidney. Full 3D coverage of the kidney with our renal BOLD sequence removes the variability of 2D BOLD results caused by selection of a particular slice.

Conclusion: Our sequence makes full 3D renal BOLD possible in reasonable imaging time. Future refinements include segmented echo-planar readout with reduced number of echo times and 2D selective excitation to limit the imaging field of view to further reduce the required imaging time and to eliminate motion artifacts from structures outside the kidney.

References: 1). Morrell G *et al.*, Prospectively navigated multi-echo GRE sequence for improved 2D BOLD imaging of the kidneys. 21st Meeting ISMRM. Salt Lake City 2013. p 1569. 2). Ebrahimi B *et al.*, Compartmental analysis of renal BOLD MRI data: introduction and validation. Invest Radiol 2012;47(3):175-182. 3). Saad A *et al.*, Human Renovascular Disease: Estimating Fractional Tissue Hypoxia to Analyze Blood Oxygen Level-dependent MR. Radiology 2013;268(3):770-778.

Advantages of full kidney 3D renal BOLD acquisition:

- Improved SNR relative to 2D.
- Elimination of bias and error in BOLD data analysis caused by selection of slice or regions of interest
- Correction of T2* for B0 inhomogeneity