THEORETICAL AND EXPERIMENTAL COMPARISONS OF SINGLE BREATH-HOLD RENAL PERFUSION IMAGING BETWEEN 3T AND 7T

Xiufeng Li[1], Edward J. Auerbach[1], Pierre-Francois Van de Moortele[1], Kamil Ugurbil[1], and Gregory J. Metzger[1]
[1]*Radiology-CMRR, University of Minnesota, Minneapolis, MN, United States*

Target audience: Arterial spin labeling researchers, renal imaging scientists

Purpose

Recently, arterial spin labeling (ASL) has been demonstrated and applied for renal perfusion imaging at 7T[1-3]. It has been shown that there are no specific absorption rate (SAR) issues when using respiratory triggering as a motion control strategy in FAIR imaging with an EPI readout [1]. Theoretical simulations using typical parameters on 3T and 7T for FAIR EPI indicate that 7T can benefit renal perfusion imaging in term of signal-to-noise ratio (SNR) efficiency due to prolonged tissue/blood T_1 and elevated imaging SNR[2]. To overcome the susceptibility-based distortions present with EPI, single-shot fast spin echo imaging (ss-FSE) was used as an alternative imaging readout for non-contrast perfusion imaging on 7T [3].

By using FAIR ss-FSE, single breath-hold renal perfusion imaging has been demonstrated and shows promise [3]. In contrast to EPI, using an ss-FSE readout had short-term SAR issues even when high parallel imaging acceleration factors and hyper echoes were applied. To avoid short-term SAR, long repetition times had to be used, thus decreasing perfusion SNR efficiency. Using a shorter TR and acquiring a larger number of label and control images at 3T within a single breath-hold may provide similar perfusion imaging quality as that obtained at 7T. To test such a hypothesis, both theoretical and experimental evaluations were performed for renal ASL imaging on 3T and 7T.

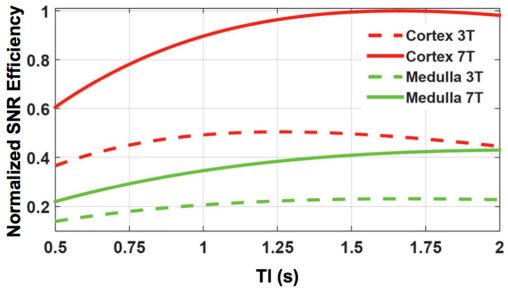

Figure 1. Renal perfusion SNR efficiencies from theoretical simulations for single breath-hold FAIR ss-FSE imaging at 3T and 7T. TI represents post-labeling delay.

Methods

3T studies were performed on a TIM Trio scanner (Siemens Healthcare, Erlangen, Germany), transmitting with the whole body coil and receiving with combined surface array (two rows of 3 elements) anteriorly and the spine array (two rows of 3 elements) posteriorly. 7T studies were performed on a Siemens whole body MRI scanner with an external 16-channel transceiver TEM stripline array driven by a series of 16, 1 kW amplifiers (CPC, Pittsburgh, PA). All studies were performed under an IRB approved protocol with informed written consent.

Theoretical simulations were performed using the same approach as reported previously[2], and the same imaging parameters as in *in vivo* studies and the recently reported renal tissue T_1 and T_2 were applied[4]. Perfusion data were acquired within a single breath-hold using the FAIR ss-FSE with one M_0 image proceeding ASL acquisition[3]. Local B_0 shimming was achieved by using volumetric phase maps acquired within a single breath-hold[5]. On 7T, a dynamic B_1 shimming strategy[6] was applied using 2 solutions: **1)** one solution for the arterial spin labeling inversions covering the descending aorta; **2)** a second solution for pre-saturation and imaging slice[3]. B_1 shims were all based on tradeoff solutions between RF efficiency and B_1 field homogeneity[7]. To reduce the specific absorption rate (SAR), an optimized GOIA pulse[8] was utilized for FAIR inversions. The use of GOIA RF pulse reduced TR $\leq$ 3.5 s that is needed to overcome the short-term SAR issue on 7T. The common FAIR ss-FSE imaging parameters for a single oblique coronal imaging slice were: resolution = 2 x 2 x 5 mm^3, phase encoding direction = left to right with 50-80% oversampling, partial Fourier = 5/8, and post-labeling delay = 1.5 s, and selective/spatially-confined selective inversion slab size = 25/160 mm. The major parameters specific for 7T were: TR/TE = 3500/16 ms, parallel imaging factor = 4 with 24 separately acquired reference lines, hyper echo flip angle = 90°, and 4 pairs of label and control images. The major parameters specific for 3T were: TR/TE =2500/29 ms, parallel imaging factor = 2 with 24 separately acquired reference lines, and 6 pairs of label and control images. Total acquisition times were 30 and 31 s for 7T and 3T, respectively. Two hundred noise images were also acquired by using the same imaging protocol with RF pulses turned off to estimate thermal noise levels.

Post-imaging processing, including motion correction for small drifts, was performed within Matlab and SPM. For SNR comparisons between 3T and 7T, thermal noise maps were measured by using the temporal standard deviations of the 200 noise images. Voxel-wise spatial SNR maps were generated by taking the ratio of normalized perfusion-weighted images (PWI) and noise maps. Temporal SNR was evaluated as the ratio between the mean and standard deviation of the PWI series. SNR efficiency was calculated as SNR per unit time for both the renal cortex and medulla.

Results and Discussions

Simulation results show that perfusion SNR efficiency at 7T can be about 1.5 and 1.9 times higher than those at 3T in the cortex, and 1.7 and 1.8 times for the medulla for 1.2 and 1.5 s post-labeling delays, respectively (Fig. 1). One representative subject's normalized perfusion SNR maps from 3T and 7T are presented in Fig. 2. Measured spatial and temporal SNR efficiency ratios between 7T and 3T for renal cortex and medulla are showed in Fig. 3.

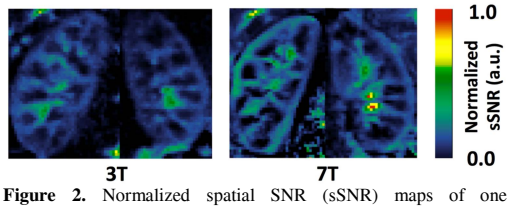

Figure 2. Normalized spatial SNR (sSNR) maps of one representative subject from single breath-hold FAIR ss-FSE imaging at 3T (left) and 7T (right).

The study results disapproved the initial hypothesis that 3T could provide similar perfusion imaging quality as 7T by using a shorter TR and acquiring a larger number of label and control images within a single breath-hold. This hypothesis was originally proposed based on the fact that there is no SAR issue at 3T, making it possible to acquire a larger number of label and control images within a breath hold using a shorter TR. However, our studies indicate that there exist physiological constraints at 3T, in contrast to SAR constraints at 7T, limiting the shortest possible TR at 3T. Although a TR as short as 2 s is possible at 3T, to allow sufficient refreshment of labeled blood within the descending aorta, a TR of 2.5 s was required to avoid the loss of labeling efficiency (data not shown). To allow for shorter TRs at 3T, spatially confined inversion slab (160 mm), instead of non-selective inversion, had to be used. The 160 mm inversion slab used provides a temporal bolus width equivalent to that achieved at 7T. Further analysis indicated that measurement errors at 3T are lower than 10% overall for the cortex and medulla, but perfusion imaging quality at 3T was poorer than that at 7T, indicating that single breath-hold renal perfusion imaging at 3T would be better performed using lower imaging resolution, e.g. 2 x 2 x 10 mm^3, and that to reduce the contamination for renal tissue perfusion signals due to hyperintense intravascular artifacts, 1.5 s or longer post-labeling delays had to be used for both 3T and 7T.

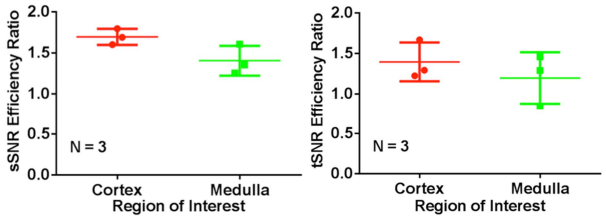

Figure 3. Spatial and temporal signal-to-noise efficiency ratios between 7T and 3T for single breath-hold renal perfusion imaging using FAIR ss-FSE. sSNR represents spatial SNR and tSNR temporal SNR.

Conclusions: Even after attempting to optimize perfusion imaging acquisition parameters for 3T to take advantage of shorter TRs and lower power deposition, the perfusion imaging quality was still superior at 7T.

Acknowledgements: P41 EB015894, WM Keck Foundation and S10 RR026783. Research reported here was also supported by the National Center for Advancing Translational Sciences of the National Institutes of Health Award Number UL1TR000114. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

References: **1**. Li. et al. ISMRM 2012: 1310. **2.** Li. et al. ISMRM 2013: 1540. **3.** Li. et al. ISMRM 2013: 0030. **4.** Li. et al. NMR Biomed 2014. **5.** Shah et al. Proc. ISMRM, 2009:42-2. **6.** Li et al. ISMRM 2011: 593. **7.** Metzger et al. MRM 2012. **8.** Tannús et al. NMR Biomed 1997.