THEORETICAL EVALUATION OF ULTRAHIGH FIELD BENEFITS TO NON-CONTRAST ENHANCED RENAL PERFUSION IMAGING USING FAIR-EPI

Xiufeng Li[1], Kamil Ugurbil[1], and Gregory J. Metzger[1]

[1]*Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN, United States*

Introduction: Renal perfusion imaging using arterial spin labeling (ASL) is an attractive approach in assessing renal diseases (1) and a well-suited imaging modality for longitudinal evaluation of renal function after transplantation (2). Unfortunately, the intrinsically low signal noise ratio (SNR) nature of ASL imaging can result in poor imaging quality thus reducing diagnostic accuracy and sensitivity, and the necessity of lengthy signal averaging and correspondingly long imaging acquisition times impose critical limitations on its application in patients (2). In addition, the short half-life of labeled blood spins at lower fields also limits the coverage and resolution of renal ASL perfusion imaging. Performing ASL studies at ultra high field (UHF) has the potential to overcome these limitations due to increased SNR, prolonged longitudinal relaxation times, and improved parallel imaging performance (3). However, renal ASL perfusion imaging at UHF also faces new challenges: increased B1+ and B0 inhomogeneity, more constrained specific absorption rate (SAR) as well as reduced T_2 and T_2*. Although FAIR ASL renal perfusion imaging has been shown at UHF in healthy volunteers (4), an analysis of the potential benefits of increasing field strength, taking into account multiple parameters including acquisition details and relaxation times, has not been undertaken to date. Therefore, theoretical simulations of perfusion signal SNR and SNR efficiency were performed for all currently available MRI fields. Particularly, renal ASL perfusion imaging SNR efficiency at 7T was compared to that at 3T by using typical imaging settings of each field including an echo planar imaging (EPI) readout, which is still the best way to achieve rapid full kidney coverage.

Table 1. Model and Parameters for Theoretical Renal ASL Imaging Simulation

Single-tissue compartment model: $\Delta M / M_0(TI) = 2 \cdot \alpha \cdot TI \cdot RBF_t \cdot \lambda^{-1} \cdot \exp(-TI / T_1^t)$

	Denotation	Assumed Values
ΔM	ASL difference signal	------
M_0	Proton density	------
α	Labeling efficiency	1.0
TI	Inversion time (s)	Varied
RBF	Renal blood flow (mL/100 g/min)	------
t	Renal tissue	Cortex or medulla
RBF_{cortex}	Cortical blood flow (mL/100 g/min)	300
$RBF_{medulla}$	Medullary blood flow (mL/100 g/min)	100
λ	Blood-tissue partition coefficient (mL/100 g)	80
T_1^t	T_1 of renal tissue	$\propto \omega^{0.3}$ (7)
T_2^{*t}	T_2^* of renal tissue	$\propto \omega^{-1}$ (8)
ω	Larmor frequency	Varied
SNR	Signal noise ratio	$\propto B_0$
B_0	Field Strength (Tesla)	Varied
Used renal relaxation times at 1.5 T		
	Cortex	Medulla
T_1 (ms) (5)	966	1412
T_2^*(ms) (6)	70.9	59.5

Materials and Methods: The widely used single-tissue compartment model was employed for all performed theoretical simulations with assumed parameters listed in Table 1, and EPI imaging parameters in Table 2.

<u>B_0 Dependent Perfusion SNR:</u> Simulations were performed for five MRI field strengths: 1.5, 3.0, 4.0, 7.0, and 9.4 Tesla. Renal T_1 and T_2* values as a function of field strength were estimated by using renal relaxation times at 1.5T (5-6) and extrapolated based on theoretical models (7-8, Table 1). The voxel size of T_2* measurements at 1.5T was 1.64 mm x 1.64 mm x 7 mm (= 18.8 mm^3), which is close to the voxel size of EPI used in theoretical simulations. Three different TEs were selected: 26 ms TE without using parallel imaging (Reduction factor, R=1), 15 ms TE with R=2, and 9 ms with R= 4. With assumed constant geometry factors (g-factors) across field strengths, imaging SNRs under parallel imaging conditions were normalized to that with R=1. The simulations utilized three steps similar to the approach used previously (8).

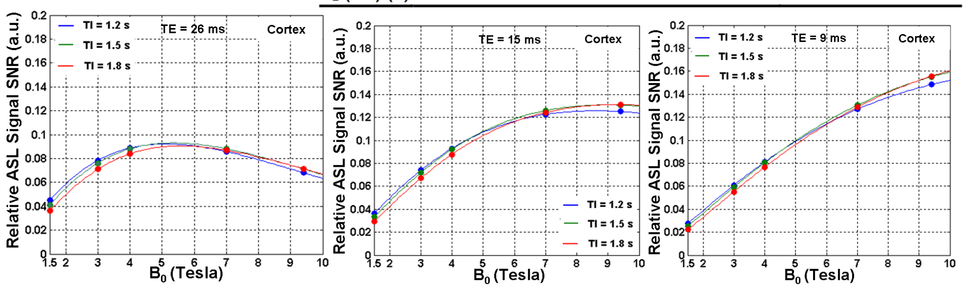

Figure 1. Simulation results for renal FAIR-EPI imaging SNR.

<u>Perfusion SNR Efficiency:</u> In Table 3, parameters for the theoretical comparisons of renal perfusion SNR efficiency between 3T and 7T are provided. Simulations were performed over a range of inversion times (TIs). Renal T_1s at 7T were experimentally measured by using single breath-hold single-shot fast spin echo imaging method (5). In addition, the SNR efficiency at 7T is shown at several different repetition times (TRs) relative to the TR used for the 3T simulations. Unlike in the field strength dependent simulations, parallel imaging reduction factors were appropriately chosen for 3T and 7T (3T R=2, 7T R=4) at which point the g-factors are nearly the same (3). Longer TRs are probable at UHF as longer labeling TIs are possible due to the increased T_1 and because of limitations resulting from local power deposition (SAR).

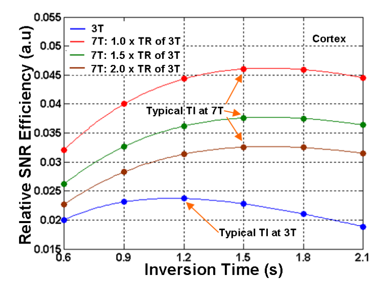

Figure 2. Renal ASL SNR efficiency comparisons between 3T and 7T.

Results and Discussion: Perfusion SNR as a function of field strength is presented in Figure 1 for the renal cortex. These results indicate that decreasing TE, which can be accomplished with increasing R, is crucial to achieve the potential SNR gains for UHF renal perfusion imaging using FAIR-EPI. In reality, the simulation in Figure 1 is quite conservative as the higher reduction factors are only reasonable to use at UHF since the geometry factor (g-factor) would be much larger at lower field thus appreciably decreasing the SNR ($SNR \propto 1/(g \cdot \sqrt{R})$) (9). The renal medulla, by comparison, has similar consistently lower SNR due to intrinsically lower medullary perfusion (data not shown). Figure 2 shows the SNR comparison for a range of TIs. Even with increased TR, there is still significant gain in SNR efficiency at 7T. In fact, with moderate respiration rates, e.g. 12~16 breaths/min, FAIR-EPI has proven not have SAR issues at 7T (4). When longer TIs are used, further SNR efficiency can be achieved at 7T compared to 3T. Using longer TIs (ideal in terms of SNR efficier at 7T) can reduce the sensitivity of ASL perfusion imaging (8) to variable arterial transit times and minimize intravascular artifacts, thus increasing renal blood flow quantification reliability and accuracy, and will improve the application of these methods in patients with slow arterial blood flow, e.g. patients with renal artery stenosis. One subject's renal perfusion imaging results using FAIR-EPI at 7T are presented in Figure 3.

Table 2. EPI parameters for Simulation

FOV (mm)	220
Matrix	110
Slice thickness (mm)	5
Phase oversampling	50%
Partial Fourier	6/8
TE (ms):	26, R = 1 and SNR = 1.0 15, R = 2 and SNR = 0.69 9, R = 4 and SNR = 0.48

Conclusion: Performing renal perfusion studies at UHF will increase perfusion signal SNR, and improve quantification reliability as well as SNR efficiency even when increased repetition times are required.

Table 3. Parameters for the comparison of ASL SNR Efficiency between 3T and 7T

	3T		7T
Parallel Imaging R	2		4
Relative TR	1		1, 1.5 and 2
Cortical T_1 (ms)	1142	(5)	1639
Medullary T_1 (ms)	1545	(5)	2086

ASL SNR Efficiency = $SNR / \sqrt{TR}$

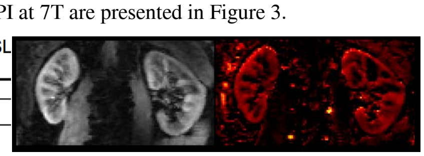

Figure 3. One subject's proton and perfusion weighted images from perfusion study using FAIR-EPI at 7T (resolution: 2 x 2 x 5 mm^3).

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References: **1.**Fenchel et al. Radiology 2006;238(3):1013–21. **2.** Nathan et al. MRI 2011;29:74-82. **3.** Snyder et al. MRM 2012;67(4):954-64. **4.** Li et al. Proc. ISMRM 2012;1310. **5.** de Bazelaire et al. Radiology 2004;230(3):652-659. **6.** Zhang et al. ISMRM 2011, 2954. **7.** Bottomley et al., Med Phys 1987;14:1–37. **8.** Wang et al. MRM 2002;48(2):242-254. **9.** Adriany et al., MRM 2008;59(3):590-7.