NON-CONTRAST ENHANCED HUMAN RENAL PERFUSION IMAGING USING ARTERIAL SPIN LABELING AT 7T: INITIAL EXPERIENCE

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Introduction: Arterial spin labeling (ASL) imaging, as a non-invasive and non-contrast enhanced approach, is very suitable for longitudinal evaluation of kidney function after transplantation, and can significantly benefit patients with renal dysfunction or other contraindications to the use of MR contrast-agent. Previously, ASL has been used for renal perfusion investigations at 1.5 T and 3.0 T with promising results (1-2). Potential advantage can be achieved by performing such studies at ultrahigh field (UHF) due to the prolonged longitudinal relaxation times and increased SNR. In this work, the challenges and potential benefits of performing renal ASL perfusion at UHF are investigated and our initial experiences reported. To our knowledge, these are the first attempts at performing ASL perfusion studies in human kidney at 7T.

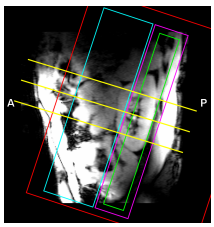

Fig. 1. Imaging (green), selective inversion (pink), spatially confined inversion (red) and intravascular spin suppression saturation (cyan) slabs used in renal perfusion studies with FAIR. The sagittial anatomic image was acquired by using GRE. Three yellow lines represent oblique transverse imaging slices used for defining ROIs for B1 optimization.

Materials and Methods: Renal perfusion imaging studies were performed on a Magnex 7T magnet using Siemens console with whole body gradients, and an external 16-channel transceiver TEM stripline array driven by a series of 16, 1 kW amplifiers (CPC, Pittsburgh, PA). Flow-sensitive alternating inversion recovery (FAIR) (3) technique was used with HS4 RF pulses (4), and vascular spin suppression (VS) was achieved by using four saturation RF pulses (Figures 1, 2). B1+ shimming was performed on a three-slice, small flip angle, calibration scan (5) optimizing over a user-defined ROIs covering both kidneys and the feeding arteries (Figure 1). Based on our simulation and imaging test results, a tradeoff B1+ shimming solution was selected for renal ASL perfusion imaging. Single breath hold local B0 shimming was performed in the imaging region by using volumetric phase maps (6). All healthy adults recruited for ASL renal perfusion studies were imaged under an IRB approved protocol.

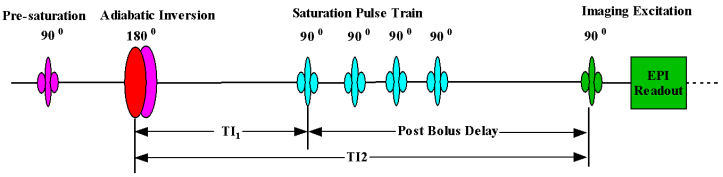

Fig. 2. Diagram for used FAIR sequence in renal perfusion studies.

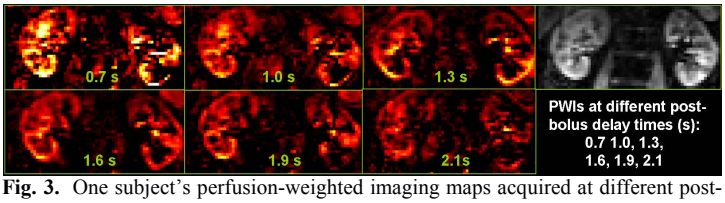

Fig. 3. One subject's perfusion-weighted imaging maps acquired at different post-bolus delay times and corresponding EPI proton density image.

Two major ASL renal perfusion imaging studies were performed using: 1) low resolution with varied post-bolus delay times and 2) high resolution with single post-bolus delay time for renal blood flow (RBF) quantification. In study one, the following imaging parameters were used: TE = 6.7 ms, FOV = 240 x 240 mm^2, matrix size = 64 x 64, in-plane resolution = 3.75 x 3.75 mm^2, slice thickness/gap = 5/1 mm, number of slices = 5, phase encoding direction = left to right with 50% oversampling, acquisition order = anterior to posterior, GRAPPA iPAT factor = 3 with 36 reference lines, partial Fourier = 6/8, number of measurements = 80, selective/spatially-confined inversion slab = 50/230 mm, labeling time (TI_1) = 0.6 s, post-bolus delay times ={0.7, 1.0, 1.3, 1.6, 1.9, 2.1} s, VS saturation RF pulse size/interval/number = 80 cm/ 50 ms/4, HS4 RF pulse R value/duration = 20/ 20 ms. Study two was the same with the exception of the following: TE = 13 ms, matrix size = 120 x 120, in-plane resolution = 2 x 2 mm^2, number of measurements = 140~160, post-bolus delay = 1.6 s. Proton density (PD) images (M_0) were acquired with the same EPI imaging parameters but with a 10 s TR. Respiration gating was performed on inspiration for the free-breathing ASL imaging acquisition with adjusted trigger delays according to the respiration rate of different subjects and different post-bolus delay times in study one. Images with poor quality, such as blurring due to large motions, were excluded in a pre-processing within Matlab and SPM prior to RBF quantification. RBF was estimated with a single blood compartment model (7) with assumed blood-tissue water partition coefficient, 80 ml/100 g (8) and T1 of the blood, T_{1b}, equal to 2.6 s (9) (see the formula in Fig. 5).

Results and Discussion: Renal perfusion imaging studies performed at lower fields typically use selective and non-selective inversions without the application of intravascular suppression pulses. Due to short blood T_1 and limited SNR at lower fields, this strategy along with short inversion times results in significant intravascular contributions to the apparent perfusion signal which gives higher than expected perfusion levels especially in the medulla. Therefore, to get reasonable perfusion estimates, these hyper-intense signals had to be excluded by using a threshold. Our multiple post-bolus delay imaging results (Fig. 3) showed that short delay times (e.g. 0.7 s, giving 1.3 s inversion time, close to those inversion times typically used at lower fields), resulted in a significant amount of intravascular signal, as observed at low fields, despite the use of VS saturation RF pulses. This indicates that longer post-bolus delay times are advisable to greatly reduce intravascular artifacts and associated RBF estimation errors as in this study. UHF can directly benefit these studies by making feasible these longer delay times due to increased blood T_1 and SNR, thus reducing intravascular contamination and potentially resulting in higher resolution and more accurate renal perfusion maps. Study two imaging results from a single subject are presented in figure 4, and RBF measurements using the middle imaging slice of four subjects are represented in figure 5. Our RBF measurements are comparable to those reported in the literature (1-2). Our initial studies used a single shot EPI readout. With optimized imaging parameters, proper planning and subject coaching, high quality EPI images were obtained. Rapid acquisition with EPI allowed improved coverage compared to standard gradient echo or True-FISP readouts, making it possible to perform whole kidney RBF imaging with sagittal imaging slices (data not shown). Comparisons of the current techniques with different imaging readout strategies and respiratory triggering/tracking strategies are under investigation.

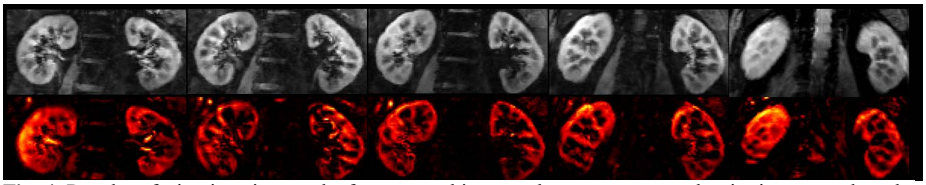

Fig. 4. Renal perfusion imaging results from one subject: on the top are proton density images and on the bottom perfusion-weighted imaging maps.

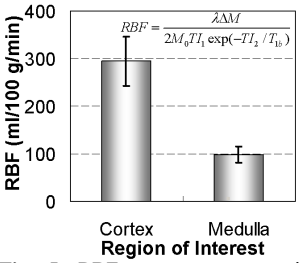

Fig. 5. RBF measurements in middle slice from 4 subjects. Error bars represent standard deviation.

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