MULTI-PARAMETRIC RENAL MRI AT 7T

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Target audience: Arterial spin labeling researchers, renal imaging scientists

Purpose

Motivated by the promise of higher signal noise ratio (SNR), increased resolution and/or reduced imaging time, new or better tissue contrast and improved parallel imaging performance, human MRI at ultrahigh magnetic fields (UHF, ≥ 7T) has been a major research focus[1-4] despite the numerous challenges[5]. Recently, with advances in RF coil engineering, RF shimming strategies and acquisition methods, UHF MRI technical development and translational research has been expanded from the human brain to the abdominal and pelvic organs [6-13]. Particularly, we have recently demonstrated that UHF can benefit non-contrast enhanced renal perfusion imaging using arterial spin labeling (ASL) [11-12]. To facilitate MRI research on renal physiology and clinical studies of kidney diseases, we are developing multi-parametric renal MRI at 7T, combining the ASL based renal perfusion imaging with T_1 and T_2 imaging to measure tissue MRI properties and T_2* imaging to evaluate oxygen level or bioavailability. Our efforts towards this multi-parametric protocol for assessing the kidneys at 7T are presented.

Methods and Results

We have developed, optimized and evaluated multiple renal MRI methods in healthy volunteers at 7T. These methods comprise a multi-parametric renal MRI protocol which was evaluated 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). These studies were performed under an IRB approved protocol with informed written consent.

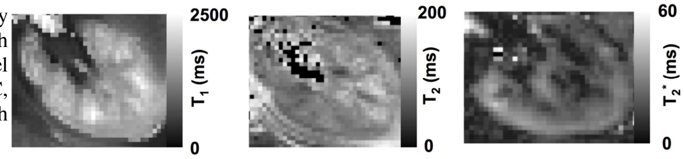

Figure 1. T_1, T_2 and T_2* maps from one volunteer using inversion recovery prepared ss-FSE, CPMG-T_2 prepared ss-FSE and multi-contrast GRE imaging methods.

***B_0 and B_1 Management*:** Local B_0 shimming was achieved by using volumetric phase maps acquired within a single breath hold[14]. For T_1, T_2 and T_2* imaging, a static B_1 shim solution based on the trade-off between RF efficiency and B_1 homogeneity[15] has been applied within an ROI covering one kidney in an oblique transverse plane. For renal perfusion imaging with an oblique coronal imaging slice, a dynamic B_1 shimming strategy[9] was applied using two solutions: **1)** one solution for the arterial spin labeling inversions covering the descending aorta; **2)** a second solution for pre-saturation and the imaging slice[12].

Single Breath-Hold T_1, T_2 and T_2* imaging: We have developed single breath-hold T_1 and T_2 imaging by using magnetization-prepared single-shot fast spin echo (ss-FSE) methods [13]. To minimize short-term specific absorption rate (SAR) at 7T, short, long inversion times and CPMG T_2 contrast preparation echo trains were applied in an interleaved fashion to distribute RF power depositions over time. To further minimize short-term SAR, parallel imaging, hyper echoes and GOIA inversion RF pulse were applied. Renal T_2* mapping using multi-contrast gradient recalled echo (mc-GRE) imaging was also successfully achieved. T_1, T_2 and T_2* imaging maps from one volunteer are presented in Figure 1.

Renal Perfusion Imaging Using ASL: We have evaluated different methods for renal ASL perfusion imaging at 7T. Renal perfusion imaging using FAIR EPI has been demonstrated both theoretically and experimentally, indicating that compared to 3T, 7T can provide superior SNR efficiency with no specific absorption rate (SAR) issues when using respiratory triggering as a motion control strategy[10]. To avoid the susceptibility-based distortions present with EPI, single-shot fast spin echo imaging (ss-FSE) has been applied as an alternative imaging readout, and the feasibility of single breath-hold renal perfusion imaging has been further demonstrated[12]. To overcome the increased short-term SAR due to the use of ss-FSE, high parallel imaging acceleration factors (R= 4), hyper-echoes and GOIA inversion RF pulse have been applied, which have reduced the repetition time ≤ 3.5 s across subjects. Based on the estimated temporal bolus width from multi-inversion FAIR ss-FSE studies and using a single compartment model, quantitative RBF has been measured. Figure 2 shows the RBF map from one volunteer.

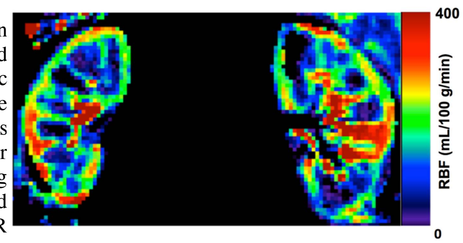

Figure 2. Renal blood flow (RBF) map using single breath-hold FAIR ss-FSE perfusion imaging.

Multi-Parametric Renal MRI Protocol: The developed multi-parametric renal MRI protocol is presented in Table 1. In this protocol, two sets of calibration scans are included for three sets of B_1 shimming solutions with two for renal perfusion imaging and one for T_1, T_2, and T_2* mapping, and three sets of B_1 mapping scans to assess B_1 shimming solutions.

Table 1. 7T Multi-Parametric Renal MRI Protocol. *

Scan	Sequence	Time
Scout (axial, sagittal and coronal)	Turbo-FLASH	3 BH, < 16 s each
Two B_1 shimming calibration acquisitions	GRE	2 BH, ≤ 25 s each
Three B_1 mapping acquisitions	Calibrated 2D AFI	3 BH, ≤ 28 s each
B_0 mapping	Dual-echo 3D GRE	1 BH, ≤ 23 s
Anatomic imaging (axial, sagittal and coronal)	T_1-weighted Turbo-FLASH	3 BH, < 21 s each
T_1	IR ss-FSE	1 BH, ≤ 27 s
T_2	CPMG-T_2 ss-FSE	1 BH, ≤ 25 s
T_2*	Multi-contrast GRE	1 BH, ≤ 16 s
RBF	FAIR ss-FSE	1 BH, ≤ 30 s RT, ~ 120 s

* BH represents breath-hold, RT respiratory triggering, AFI actual flip angle imaging, IR inversion recovery, and RBF renal blood flow.

Discussion

With proper management of B_0 and B_1 inhomogeneity and SAR, multi-parametric renal imaging can be achieved at 7T. Multi-parametric renal MRI will potentially provide comprehensive insights into renal pathophysiology in clinical research studies of diverse kidney diseases. For example, using patient-specific renal tissue properties may improve RBF quantification since RBF quantification requires knowing renal T_1 and the pathologic state can result in renal T_1 changes.

We also developed a similar multi-parametric renal MRI protocol at 3T. Compared to 3T, 7T has several limitations that need to be overcome, including 1) minimizing B_1 inhomogeneity effects on the accuracy of T_1, T_2 and T_2* mapping, for which we found it is preferable to image one kidney a time at the expense of effectively doubled imaging time and 2) the mandatory B_1 calibration which sometimes requires more time than the multi-parametric acquisitions themselves. At last, we have to acknowledge that breath-hold duration as long as 30 s, though well achievable in our healthy volunteers, will become impractical for ill patients. This can be potentially addressed by further technical developments and RF optimization, and will be well resolved by performing free-breathing acquisitions as shown previously [11]. Performing free-breathing perfusion studies will also benefit from 7T due to the increased perfusion SNR thus decreasing overall scan duration [12].

Conclusions: Although challenging, with proper management of B_0, B_1 and SAR, multi-parametric renal MRI has been successfully applied at 7T with healthy volunteers, potentially becoming a viable tool for clinical research studies of renal diseases.

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References: **1**. Ugurbil et al. 2012 Neuroimage. **2.** Kerchner et al. J Alzheimers Dis 2011. **3.** Nakada et al. Brain Dev 2007. **4.** Beisteiner et al. Neuroimage 2011. **5.** Vaughan et al. MRM 2001. **6.** Vaughan et al. MRM 2009. **7.** Suttie et al. NMR Biomed 2012. **8.** Metzger et al. MRM 201. **9.** Li et al. ISMRM 2011: 593. **10.** Li. et al. ISMRM 2012: 1310. **11.** Li. et al. ISMRM 2013:1540: 1540. **12.** Li. et al. ISMRM 2013: 0030. **13.** Li. et al. NMR Biomed 2014. **14.** Shah et al. Proc. ISMRM, 2009:42-2. **15.** Metzger et al. MRM 2012.