Quantitative Mouse Renal Perfusion Imaging using Arterial Spin Labeling

R. Rajendran[1], C-X. Yong[1], J. Tan[1], J. Wang[2], and K-H. Chaung[1]
[1]Lab of Molecular Imaging, Singapore Bioimaging Consortium, Singapore, Singapore, Singapore, [2]University of Pennsylvania, United States

Introduction

The kidneys, which receive 20% of the cardiac output, are the most highly perfused organs in the body. Quantitation of changes in renal perfusion can provide valuable information about many diseases including hypertension, acute renal failure and diabetic nephropathy[1]. Unfortunately, clinically available Gd-chelates for measuring blood flow are easily filtrated by renal glomeruli and hence difficult to apply to quantify the renal perfusion. Another promising technique for perfusion quantitation is the arterial spin labeling (ASL) MRI. However, the technique has low sensitivity, and especially, it suffers from motion and susceptibility artifacts in the abdomen[2]. So far, only a few studies have been done in humans and rats [3-6]. Here we present ASL perfusion imaging in the mouse kidney.

Methods

The animal study was approved by the local Institutional Animal Care and Use Committee. The experiments were carried out in C57BL/6 mice under differing physiological conditions with ~1% isoflurane mixed with 1) air: oxygen = 10:3, 2) 100% oxygen, and 3) 95% oxygen and 5% carbon dioxide. Artifact was checked in some animals after euthanasia with CO_2. We used the FAIR (Flow-sensitive Alternating Inversion Recovery) to obtain the ASL where images were alternated with selective and nonselective inversion. The inversion time (TI) was varied from 0.2 s to 4 s to allow estimation of arterial transit time. A coronal slice covering both kidneys was acquired by a single-shot spin-echo EPI on a Bruker 7T ClinScan with TR = 10 s to ensure a complete relaxation of the spins between measurement, and TE was kept to a minimum. The imaging slice thickness was 1.5 mm with an inversion slice thickness of 4 mm to avoid artifacts from not fully inverted spins at the margins of the readout slice[3]. Water excitation was used to minimize the fat artifact. Motion artifact due to respiration was minimized by triggering with the respiration. T1 measurement was done with inversion recovery SE-EPI with TI changing from 0.2 s to 8 s. Using Matlab, the perfusion and the arterial transit time maps were generated based on the pair-wise subtracted FAIR images and the T1 maps.

Results

The image of the kidneys and the corresponding perfusion image are shown in Fig 1. With proper 3D shim and water excitation, good quality of SE-EPI can be obtained at 7T. High perfusion signal can be observed in the renal cortex but not medulla, probably due to very low perfusion in that region. Absence of signal obtained post mortem indicates that the signal is indeed due to renal perfusion (Fig.2). When 5% CO_2 was administered together with 95% oxygen, the dilation of the blood vessels led to decreased transit time and increased perfusion (Table1).

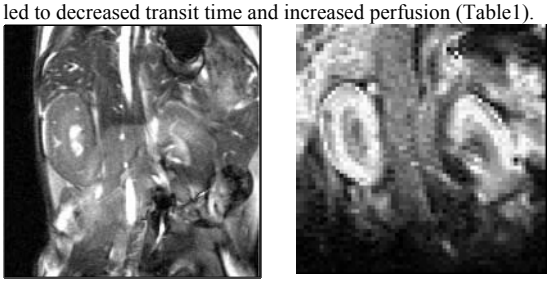

Fig 1: A TrueFISP image (left), the corresponding SE-EPI image (middle) and the quantified perfusion map (right).

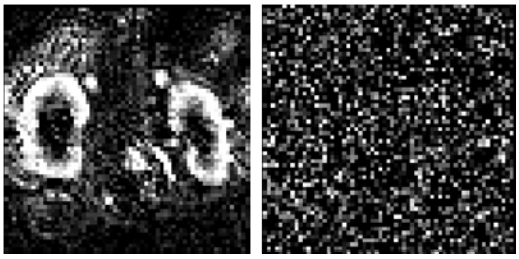

Fig 2: ASL difference signal in a live mouse (left) compared to post mortem (right), which is at 5x the intensity of the one on the left.

Table 1: Blood flow, transit time and T1 in the renal cortex under different physiological conditions

Subject	Gas composition	Blood Flow (mL/100 g/min)	Transit time (ms)	T1 (ms)
Mouse 1	100% Oxygen	477	571	1429
	95% Oxygen + 5% CO2	516	484	n/a
Mouse 2	100% Oxygen	637	549	1495
	95% Oxygen + 5% CO2	798	519	1358
Mouse 3	100% Oxygen	660	475	n/a
	Air: Oxygen = 10 : 3	637	445	1425

Discussion

We demonstrated quantitative renal perfusion in mice using ASL MRI. The change in the signal with FAIR ASL indicates the sensitivity to renal perfusion. The estimated cortical blood flow corresponded well with the literature[7]. About 10-20% perfusion increase was observed with vessel dilation by 5% carbon dioxide. This is much less than what was observed in the mouse brain under similar conditions. With single-shot SE-EPI and triggering, respiratory motion artifact was minimized. Although single-shot SE-EPI provides good quality in the kidney, higher resolution would require either multi-shot or other fast imaging techniques like TrueFISP. With the non-invasive ASL technique, further studies can be carried out repeatedly in the same subject over time. Development and validation of this quantitative method opens up the possibility for translational studies.

References:

1. Prasad, P.V. *Am J Physiol Renal Physiol* **2006**, 290, F958.
2. Robson, P.M.; Madhuranthakam, A.J.; Dai, W.; Pedrosa, I.; Rofsky, N.M. and Alsop, D.C. *Magnetic Resonance in Medicine* **2009**, 61,1374.
3. Karger, N.; Bierdere, J.; Lusse, S.; Grimm, J.; Steffens, J-C.; Heller, M. and Gluer, C-C. *Magnetic Resonance Imaging* **2000**, 18, 641.
4. Williams D.S.; Zhang, W.; Koretsky, A.P. and Adler, S. *Radiology* **1994**,190, 813.
5. Martirosian, P.; Klose, U.; Mader,I. and Schick, F. *Magnetic Resonance in Medicine*, **2004**, 51, 353.
6. Wang, J.J. et al. *Kidney Intl* 1**998**, 53, 1783.
7. Steinhausen, M. *Kidney Intl* **1990**, 38, 769.