Reproducibility of R2* and R2 measurements in human kidneys

J. L. Zhang[1], P. Storey[1], H. Rusinek[1], H. Chandarana[1], M. Wauchope[1], R. Bhatta[1], D. Stoffel[1], E. E. Sigmund[1], Q. Chen[1], and V. S. Lee[1]
[1]Department of Radiology, New York University, New York, NY, United States

Introduction

Blood oxygenation level-dependent (BOLD) MRI is a promising approach for monitoring kidney tissue pO_2 (1). Deoxyhemoglobin (dHb) is paramagnetic, and increases the spin-spin relaxation rate (R_2*) of neighboring water. Thus, if other conditions stay the same, a high R_2* value could be interpreted as a high consumption rate of oxygen (2). Changes in medullary R_2* induced by diuretics (e.g. furosemide) can indicate the functional state of a kidney, because the active transport in the loops of Henle of a normally functioning kidney can be blocked by diuretics, thus lowering the consumption rate of oxygen (3,4).

R_2* consists of two components: R_2 due to spin-spin interactions, and R_2' due to local B_0 inhomogeneity (mainly induced by dHb). There is evidence (1) that R_2' is a more direct indicator of tissue oxygenation than R_2*, as R_2* also reflects water content through the R_2 contribution.

One limiting factor in BOLD MRI for diuretic studies of the kidney is the low reproducibility of relaxation rates measured in abdominal area (3,4). To our knowledge, reproducibility of R_2 and R_2' has not been reported. We examined the day-to-day reproducibility of R_2*, R_2, and R_2' estimates in human renal cortex and medulla obtained in four healthy volunteers.

Methods

Four subjects (2 females and 2 males, age 43.8±14.5 yrs) without known renal disease consented to participate in this IRB-approved study. Each subject was examined on two days (gap 5±8 days) on the same 1.5T MRI unit (Avanto, Siemens Medical Systems, Erlangen, Germany). On each day, following standard automatic 3D shimming,BOLD and T_2-weighted imaging were performed with the following parameters: BOLD: 2D gradient-echo, 25 echoes with monopolar gradient echo readout and echo time (TE) from 1.78 to 58.42 ms with equal interval of 2.36 ms; voxel size 1.64 mm×1.64mm; matrix 256×208; repetition time (TR) 80 ms; flip angle 25; bandwidth 700 Hz/pixel; 1 average. T_2-weighted imaging: 2D turbo-spin-echo (TSE) sequence, eight echoes with TE from 18 to 142 ms with equal intervals of 18 ms; turbo factor 4; voxel size 0.88×0.88; matrix 480×400; TR 800 ms; bandwidth 495 Hz/pixel; number of averages 1. Each was performed using a coronal slice of thickness 7 mm and was completed in one breath hold.

The multiple-echo data for each pixel was fitted by an exponential decay to produce parametric maps of R_2 or R_2*, signal magnitude at TE of 0 (S_0), and the relative root mean squared error (RMSE) for the fit, σ. Regions of interest (ROI) were manually drawn on the S_0 map, where cortico-medullary differentiation was best appreciated. For each kidney, one cortical and one medullary ROI were drawn at the upper, middle and lower pole, respectively. ROI drawing was first done for T_2 data, and then with the result displayed, for BOLD data. This helped to make sure that the location and the size of the corresponding ROIs of T_2 and BOLD data were similar. The same method was used to make sure that ROIs for the two different days were similar. With the ROIs copied to R_2 or R_2* maps, we obtained the R_2 or R_2* values for the intra-ROI voxels. The average of all R_2 or R_2* values for the same tissue type in each kidney (involving 3 ROIs) were computed and recorded.

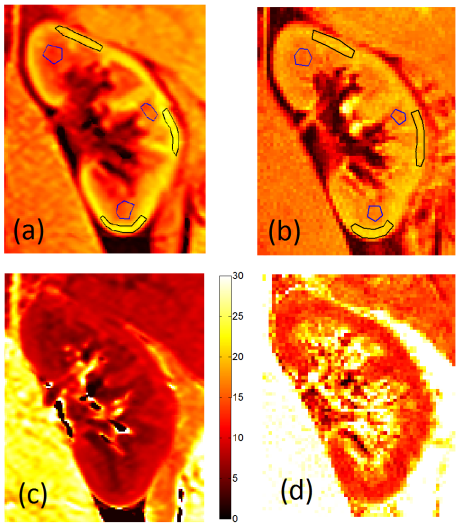

Fig 1. (a) and (c) S_0 and R_2 maps for T_2 data; (b) and (d) S_0 and R_2* maps for BOLD data. ROI contours are shown on S_0 images

To evaluate the repeatability, we computed the absolute difference between the relaxation rates (R_2* and R_2') measured on the two days, and divided it by the average of the two values. The computation was done for cortex and medulla of each kidney separately.

Results and Discussion

The relative RMSE σ was 3%-5% for R_2* fitting, and 1%-2% for R_2 fitting, indicating excellent monoexponential behavior. Representative S_0, R_2, and R_2* maps are shown in Fig. 1.

Table 1. Day-to-day reproducibility of R_2, R_2* and R_2'.

	R_2 (1/s)			R_2* (1/s)			R_2' (1/s)		
	Day-1	Day-2	Relative difference	Day-1	Day-2	Relative difference	Day-1	Day-2	Relative difference
Cortex	8.9±0.6	8.9±0.6	3.4%±1.7%	14.1±1.8	14.2±1.6	7.9%±5.3%	5.1±1.7	5.4±1.1	22.1%±15.4%
Medulla	7.3±0.7	7.0±0.7	3.9%±3.5%	16.8±2.2	15.9±3.1	7.5%±5.6%	9.5±1.9	8.9±2.7	13.0%±10.3%

Table 1 shows the relative difference between day-to-day measurments for R_2, R_2* and R_2'. The difference for R_2 was less than 4% for both cortex and medulla, and for R_2*, ~7%-8%. Our R_2* difference is smaller than 12% reported in Li et al (3). The reason could be improvements in shimming technology or the much longer day-to-day gap in their study (3-9 months versus 5±8 days in our study). The error in R_2' was about 1 s^{-1}, which resulted in the relative error, 13.0% for medulla and 22.1% for cortex.

Cortex-medulla R_2* contrast was 2.2 s^{-1}, with medulla R2* being 16% larger than cortex R_2*, whereas for R_2', the cortico-medullary difference was 4 s^{-1}, or 77%. The R_2' difference between cortex and medulla agrees with their expected pO_2 difference (5).

In conclusion, R_2 and R_2* measurement are highly reproducible, but the reproducibility of their difference, R_2', was not as good. Improved SNR may be necessary to detect changes in R_2' with interventions such as diuretics, possibly using more averages with co-registration.

Reference

1. Prasad et al Circulation 1996;94:3271
2. Ogawa et al PNAS 1990; 87:9868
3. Li et al JMRI 2004;19: 610
4. Simon-Zoula et al NMR Biomed. 2006;19:84
5. Epstein. Kidney Int 1997;51:381