Reproducibility of R2* and R2 measurements in human kidneys

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Introduction

Blood oxygenation level-dependent (BOLD) MRI is a promising approach for monitoring kidney tissue pO2 (1). Deoxyhemoglobin (dHB) is paramagnetic, and increases the spin-spin relaxation rate (R2*) of neighboring water. Thus, if other conditions stay the same, a high R2* value could be interpreted as a high consumption rate of oxygen (2). Changes in medullary R2* 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).

R2* consists of two components: R2 due to spin-spin interactions, and R2′ due to local B0 inhomogeneity (mainly induced by dHB). There is evidence (1) that R2* is a more direct indicator of tissue oxygenation than R2*, as R2* also reflects water content through the R2 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 R2 and R2′ has not been reported. We examined the day-to-day reproducibility of R2*, R2, and R2′ 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 T2-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. T2-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 R2 or R2*, signal magnitude at TE of 0 (Sn), and the relative root mean squared error (RMSE) for the fit, s. Regions of interest (ROI) were manually drawn on the Sn 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 T2 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 T2 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 R2 or R2* maps, we obtained the R2 or R2* values for the intra-ROI voxels. The average of all R2 or R2* values for the same tissue type in each kidney (involving 3 ROIs) were computed and recorded.

To evaluate the repeatability, we computed the absolute difference between the relaxation rates (R2* and R2′) 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 s was 3%-5% for R2* fitting, and 1%-2% for R2 fitting, indicating excellent monoexponential behavior. Representative Sn, R2, and R2* maps are shown in Fig. 1.

Table 1. Day-to-day reproducibility of R2, R2*, and R2′.

<table>
<thead>
<tr>
<th></th>
<th>R2 (1/s)</th>
<th>R2* (1/s)</th>
<th>R2′ (1/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex</td>
<td>Day-1</td>
<td>Day-2</td>
<td>Relative difference</td>
</tr>
<tr>
<td>8.9±0.6</td>
<td>8.9±0.6</td>
<td>3.4%±1.7%</td>
<td>14.1±1.8</td>
</tr>
<tr>
<td>7.3±0.7</td>
<td>7.0±0.7</td>
<td>3.9%±3.5%</td>
<td>16.8±2.2</td>
</tr>
</tbody>
</table>

Table 1 shows the relative difference between day-to-day measurements for R2, R2*, and R2′. The difference for R2 was less than 4% for both cortex and medulla, and for R2*, ~7%-8%. Our R2* 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 R2′ was about 1 s−1, which resulted in the relative error, 13.0% for medulla and 22.1% for cortex.

Cortex-medulla R2* contrast was 2.2 s−1, with medulla R2* being 16% larger than cortex R2*, whereas for R2′, the cortico-medullary difference was 4 s−1, or 77%. The R2′ difference between cortex and medulla agrees with their expected pO2 difference (5).

In conclusion, R2 and R2* measurement are highly reproducible, but the reproducibility of their difference, R2′, was not as good. Improved SNR may be necessary to detect changes in R2′ 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