Optimizing dose and imaging parameters in MR renography for quantitative measurement of renal function

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Target audience: Physicians and MR scientists who want to use MR to measure kidney function noninvasively

Introduction: Conventional measures of renal function, such as serum Cr, are insensitive to renal disease, particularly when only a single kidney is affected. Many have advocated low-dose Gd MR, or MR renography, to measure renal function noninvasively (1-4). To estimate functional parameters accurately, Gd enhancement in renal tissue needs to be measured accurately. Multiple factors can influence the measurement error in Gd concentrations, including renal function, injection dose (D), and how the concentrations are measured. For example, with T1-weighed saturation recovery (SR), signal noise affects estimates of tissue Gd concentration depending on inversion time (TI). In this study we systematically analyzed how the accuracy of tracer kinetic models to analyze MR renography data depends on injected Gd dose and on image acquisition parameters, such as TI in SR sequence. Following a Monte Carlo simulation, we compared renal function estimates using different protocols in 22 patients.

Methods: Monte Carlo simulation started with generating arterial input function (AIF) using different Gd doses (D, 0.5mmol/ml), from 1 ml to 10 ml. Gd concentration vs. time curves for kidney tissue were constructed by convolving the AIFs with impulse retention functions (IRF) that reflect different renal status: healthy, dysfunctional and obstructed, based on published literature (4). From Gd curves, we simulated the corresponding saturation recovery (SR) signals with different TI values: 100 ms to 1000 ms with intervals of 100 ms. Random noise of Rician distribution was added to the signals. Using methods presented in previous studies (5), we processed the signals simulated with each combination of D and TI, to obtain estimates of three renal parameters: GFR, RPF and kidney MTT.

With informed consent, 22 patients underwent SR turbo-FLASH at 3T (TIM Trio, Siemens) with slice thickness 7 mm, TR 519 ms, TE 1.15 ms, FA 15°, matrix 176×160, FOV 500×455 mm, acquisition time 1.5s, three slices. The coronal slice through the aorta used a TI of 100 ms, and axial and coronal kidney slices used a TI of 300 ms. After 5 acquisitions, 4 ml gadoteridol was administered iv. Imaging continued for 5 min. Arterial input functions (AIF) were sampled from the coronal slice of TI 100ms and from the axial slice of TI 300ms. We compared the parameters estimated using the two different AIFs.

Results: In *simulations*, except for GFR and MTT_K of the dysfunctional kidney, all three parameters for the three kidney scenarios showed large errors at D>5ml and TI>500ms (Fig. 1a). These errors were caused by the underestimation of Gd concentration with high dose and/or high TI (Fig. 2). GFR of both healthy and dysfunctional cases (Fig. 1, the first column) were overestimated with TI 100 ms, presumably due to the bias caused by Rician noise. Mean deviation of all parameter estimates indicate that for parameter accuracy, the optimal combination of D and TI is around 3-5ml and 300-500 ms.

For patients, paired t tests show that all parameters estimated from AIF of TI 100ms were significantly higher than those from TI 300 ms: RPF 157.2±51.7 vs 143.4±48.8 ml/min (P value 0.0006), GFR 33.3±11.6 vs 30.2±11.5 ml/min (P value 0.0015), and MTT_K 246.1±65.7 vs 222.1±54.2s (P value 0.0001). This agrees with our finding in simulation. Bland-Altman plot showed that for both GFR and RPF, the estimated difference between TI 100 ms and 300 ms increases as the average of the two estimates increases (the plot for GFR shown in Fig. 3). This indicates that the TI-induced variability in RPF and GFR is more severe for healthy kidneys than in dysfunctional ones. The result agrees with our simulation results too (see Fig. 1).

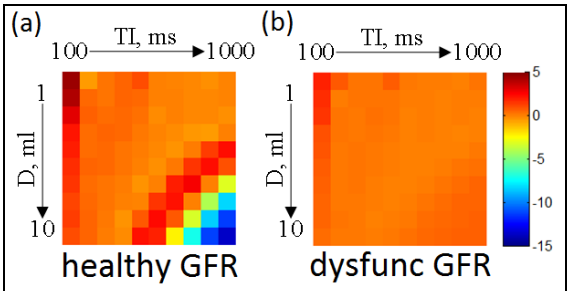

Fig. 1. Mean deviation of healthy (a) and dysfunctional (b) GFR estimates.

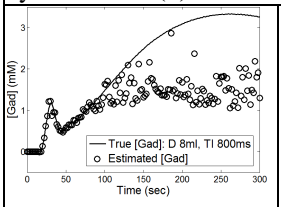

Fig. 2 Underestimation of high [Gad] at high TI and D values.

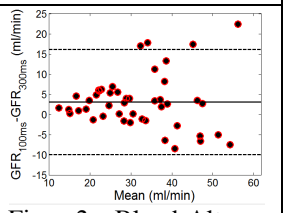

Fig. 3 Bland-Altman plot for **patients GFR** of TI 100 vs. 300 ms.

Discussion and conclusion: Lower dose and/or lower TI may result in low MR signals with Rician bias (6), while at high dose and/or high TI, sampled signals become saturated. Our simulations indicate that to perform MR renography, the injection dose should be around 3-5 ml and TI for SR sequence should be around 300-500 ms. For patients with low eGFR, the injection dose and TI can be higher, but should not exceed 8 ml and 800 ms according to our simulation.

References: 1. Lee et al AJP-renal. 292(5):F1548-59, 2007. 2. Buckley et al JMRI. 24(5):1117-23, 2006. 3. Tofts et al Eur Radiol. 22(6):1320-30, 2012. 4. Zhang et al MRM. 59(2):278, 2008. 5. Vivier et al Radiology 259(2):462-70, 2011. 6. Gudbjartsson et al. MRM 34(6):910, 1995