Measurement Precision of Gadolinium Enhanced Magnetic Resonance Nephro-Urography using Rapid 3D Imaging and a Multi-Compartment Kinetic Model

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INTRODUCTION

It is currently known that an estimation of glomerular filtration rate (GFR) can be determined non-invasively using MRI perfusion techniques. Specifically, a fast, volumetric gradient echo technique can capture time-sensitive perfusion, filtration and excretion of a gadolinium-chelated contrast agent. Since there is a direct linear relationship between contrast agent concentration and signal intensity, perfusion data can be analyzed using compartmental kinetic analysis, whereby specific features of kinetic distribution can be extracted. Apart from accuracy, the utility of such techniques depend highly on repeatability and robustness of the acquisition and kinetic modeling steps, to ensure the physiological parameters are comparable and applicable clinically. Precision measures are also important from a quality-control vantage point, since the error in repeated measures of the same sample can be analyzed for particular biases in the acquisition and modeling steps.

PURPOSE

The purpose of this investigation was to determine precision of defined physiological parameters of the kidney, subject to an accelerated volumetric acquisition technique and semi-automated kinetic modeling steps.

METHODS

This investigation was HIPPA compliant and approved by our institution's Internal Review Board, and all participants provided informed consent. The study group included 5 subjects (4 male, 1 female), with no prior history of impaired renal function or contraindications to MRI. Each subject was imaged 3 times, on 3 different days (no more than 2 days apart). Imaging was consistently performed in the morning, and the subjects' hydration level was controlled with 1 liter of water intake 1 hour prior to examination. ***MRI Acquisition***. Kidney perfusion experiments were performed with 0.1mmol/kg of a non-albumin binding gadolinium-chelated contrast agent (Prohance, Berlex, NJ), diluted to 60ml total volume with saline. Contrast infusion rate was set to 0.6cc/s. Dynamic image acquisition was performed with a 3D spoiled gradient echo technique on a 1.5T Philips Intera system, using 30 coronal slices of 3mm thickness, TR/TE/flip = 3.7/1.7ms/30, 430mm field-of-view, 96 matrix (interpolated to 256), and fat suppression. A dynamic acquisition time of 0.9sec per volume was achieved with SENSE=3, and a scan percentage=70%. A total of 250 dynamics were acquired with the subject free breathing. ***MRI Analysis.*** Volumetric data sets were exported off-line and processed using Analyze 6.0 (Mayo Clinic MN). Normalized signal curves were generated for blood, and right and left kidneys with regions- and volumes-of-interest. These, along with measured kidney volumes, were input into an in-house kidney perfusion modeling program, which optimally fits 4 physiological variables (among which are GFR and renal blood flow-RBF-) to each kidney using a 3-compartment kinetic model: vascular, trapped, and interstitial space. The model assumes uniform Gd distribution in the plasma, unidirectional kinetics into the tubules, and free diffusion in/out of the interstitial space. The processes are represented by a series of partial differential equations. ***Statistics.*** Data from each subject were reported as the mean (M) and standard deviation (SD). A coefficient of precision (CP%) was determined by computing SD/M for GFR, RBF, and kidney volume.

RESULTS

Figure 1 shows an example of functional data from one kidney and the curve fit from the kinetic model. All fits produced an r-squared value >0.90, with minimal user configuration of unknown variables. Table 1 summarizes the reproducibility data from all subjects, along with an average score of CP% for each measured variable. The data was found to be very precise for GFR and kidney volume (CP%<5.0); however, the RBF was subject to greater relative variability, partly due to limited data in the early perfusion phase for the curve fit (~10secs). The SD remained low for all measurement variables.

CONCLUSIONS

This investigation shows that the series of steps involved in non-invasively measuring functional kidney physiology was reproducible. These steps include image acquisition, image segmentation and signal curve generation, and curve fitting with a specific multi-compartment kinetic model. Since there is a high degree of user involvement in the analysis process, these initial results lend themselves to further investigations of repeatability (inter-observer analysis) and technical robustness (limiting user inputs). Moreover, there is an impetus to extend the study clinically to describe sensitivity and accuracy.

Table 1. Summary of Precision Measures for GFR, RBF, and Volume

Subj	MR-GFR* (ml/min)				RBF (ml/s)				Volume (ml)			
	Right	CP%	Left	CP%	Right	CP%	Left	CP%	Right	CP%	Left	CP%
1	54.4±2.3	4.2	54.1±2.7	5.0	6.2±1.0	16.6	6.5±1.4	21.0	121.3±8.9	7.3	126.1±8.2	6.5
2	43.9±1.6	3.8	45.4±2.5	5.5	5.8±1.2	21.5	6.0±1.9	32.3	147.2±8.0	5.4	156.6±10.5	6.7
3	57.5±4.3	7.5	59.3±4.9	8.2	8.2±1.4	17.8	8.5±0.7	8.2	159.4±4.9	3.1	169.5±2.4	1.4
4	56.6±0.8	1.5	55.4±0.6	1.0	7.4±1.7	22.7	6.6±1.1	16.3	183.5±9.8	5.3	182.1±6.3	3.5
5	60.4±2.8	4.6	60.5± .5	4.1	12.2±1.4	11.3	13.4±2.6	19.1	172.9±7.1	4.1	179.4±4.1	2.2
AVG		4.3		4.8		15.0		16.1		5.0		4.1

**MR-GFR: GFR measured by MR Nephro-Urography*

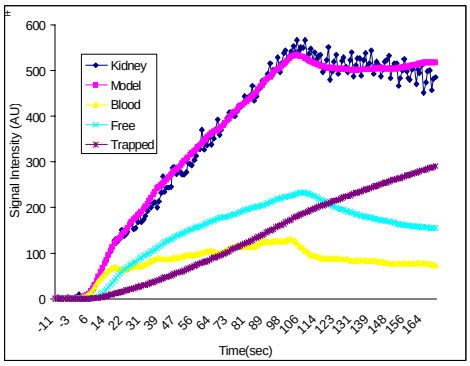

Figure 1. Plot of curve fit with model constituents in one subject.