Single Kidney Glomerular Filtration Rate Measurement using a High Spatiotemporal Resolution View Sharing Technique and 2-Compartment Model

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PURPOSE: Glomerular filtration rate (GFR) is an indicator of kidney function and can be measured by dynamic MR Urography (MRU) [1]. In dynamic MRU, a Gadolinium (Gd) based contrast agent is administered intravenously and a series of images with high spatiotemporal resolution is acquired to track the uptake and clearance of contrast in the urinary system. Here, we assess the GFR estimation based on a high spatiotemporal resolution DCE method called DISCO (Differential Subsampling with Cartesian Ordering) [2]. We optimized the acquisition strategy to reduce errors in pharmacokinetic modeling and presented a clinical case to demonstrate DISCO-MRU.

METHODS: In DISCO, for each time point, the center of k-space (A region) is fully sampled and outer k-space (B region) is pseudo-randomly subsampled. The N non-overlapping sub-regions (B_1, B_2, … B_N) are acquired progressively (AB_1, AB_2, … AB_N). In each time frame, missing k-space data is filled in using nearest-neighbor view sharing. Hence, the temporal resolution and the temporal footprint are determined by the size of the A region and the number of B regions. To determine optimal DISCO parameters for MRU, we created a 4D digital phantom (Fig. 1) in MATLAB based on a 3D dataset from a pediatric subject. The enhancement curves of the aorta and the kidneys were modeled with a 2-compartment model [3] at a high temporal resolution (0.1s) and inserted into the phantom on a voxel by voxel basis to create a high spatiotemporal resolution 4D dataset. The phantom retains the structural details of a real kidney because the enhancement curves are calculated using the initial signal intensities of the voxels and the concentration curves that are derived from the model. Table 1 shows the parameters used in the model. Two slices from the digital phantom were selected for analysis: one with the kidneys and one with the aorta. Each slice was converted into k-space, sampled with DISCO and then reconstructed. The reconstructed slices were analyzed using the 2-compartment model curve fitting technique [3] and the average K_{trans} values (i.e. GFR per unit volume of kidney tissue) were extracted from the enhancement curves using a parenchymal ROI of the kidneys. This process was repeated with different DISCO parameters (i.e. A region size & number of B regions). For each parameter set, the estimated K_{trans} was compared with the model K_{trans} and the estimation error was recorded. A pediatric patient with suspected hydronephrosis was scanned using DISCO (A fraction: 0.1, 3 B regions, blue box in Fig. 2) after informed consent on a GE 3T scanner using a 32-channel torso array. Imaging parameters were: 12° flip angle, ± 167 kHz bandwidth, TR~3.9ms, matrix 256x200, FOV 28-28 cm, slice thickness 2.6 mm, 34 slices and 2x2 parallel imaging acceleration. The sequence was respiratory gated to acquire each A region and sub-partitions of B in each end-expiratory period. Following the injection of Gd contrast, 50 phases covering 10 minutes were acquired. The images were analyzed with the curve fitting method and the average K_{trans} values were extracted for both kidneys using parenchymal ROIs.

Table 1 – Model Parameters

Ktrans(min^{-1})	0.28
Vb	0.35
T1 Blood/Kidney (s)	1.4/1.2
r1 (s^{-1}mM^{-1})	4.5
Htc Large/Small	0.41/0.24

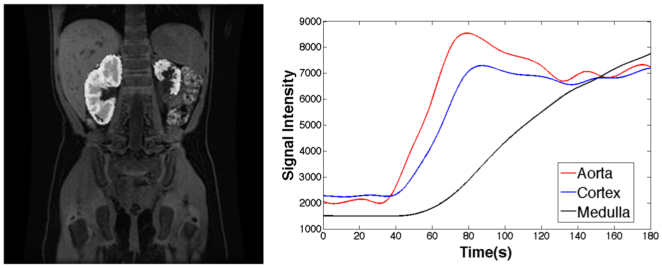

Figure 1 – Digital phantom (left) and enhancement curves (right). Digital phantom uses only the pre-contrast image and the AIF of the real MRU data. Signal intensities are predicted using 2-compartment model.

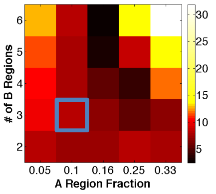

Figure 2 – Ktrans error for various DISCO parameters (b). For each parameter set (i.e. A region size and number of B region combinations) the maximum Ktrans estimation error percentage is shown. For A region sizes 0.1 and 0.16 the Ktrans estimation error is

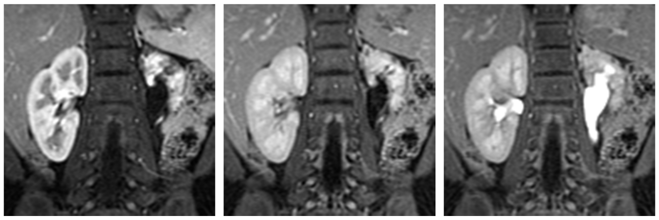

Figure 3 – Cortical, medullary, collecting system phases from a patient.

RESULTS/DISCUSSION: Simulation results from the digital phantom are shown in Fig. 2. The temporal resolution is the best when the A region is small and the number of B regions is high but when the A region is too small we lose most of the energy in the central region of k-space. In Fig. 2, the error increases as we move to the upper right corner (due to high temporal footprint), as we move to the lower right corner (due to low temporal resolution) and as we move to the left side (due to low central k-space coverage). The error for the parameters used for our clinical case is marked by the blue box (12s temporal resolution). Different MRU phases of the clinical scan are shown in Fig 3. High spatial resolution in the images allows us to generate regional K_{trans} maps (Fig. 4). The results of the 2-compartment analysis for this subject are shown in Table 2. The K_{trans} values found in the clinical case are consistent with the normal K_{trans} values found in literature (0.28min^{-1}) [3].

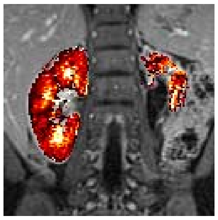

Figure 4 – Regional Ktrans map from a the same patient. Bright regions indicate high K_{trans} values.

Table 2 – Clinical MRU Results

Kidney	**K_{trans} (min^{-1})**	**GFR (ml/min)**
Right	0.2691	16.87
Left	0.2530	4.73

CONCLUSION: We have presented a free-breathing method for regional/spatially-resolved GFR estimation, and we have validated it using digital phantom simulations, and demonstrated the clinical feasibility of DISCO-MRU.

REFERENCES: [1]H. Chandarana et al. American Journal of Roentgenology, vol. 192, no. 6, pp. 1550 -1557, 2009. [2]M. Saranathan et al. Journal of Magnetic Resonance Imaging, vol. 35, no. 6, pp.