Renal perfusion and single-kidney GFR at 3.0 T using a 3-compartment filtration model with reabsorption correction

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Introduction.
There has been growing interest over the last few years in using dynamic contrast-enhanced (DCE) MRI to assess renal perfusion and function (glomerular filtration rate, GFR). However, the technique suffers from a number of problems that have restricted its development [1,2]. Principal amongst these are the problems of breathing motion, requiring gated acquisitions or temporal registration of the data, and the selection of appropriate tracer kinetic models [2]. If the model is too simple the data may not be properly described but a good fit to the data doesn't necessarily produce accurate estimates of function [3]. The aims of this study were to assess the effect of temporal registration on 3D DCE-MRI data acquired at 3.0 T and to compare single kidney (SK) GFR estimates made using a conventional Rutland-Patlak approach with those using a 3-compartment filtration model (3CFM) with reabsorption correction [4].

Methods.
Nine imaging investigations were assessed in this preliminary study. Six patients (62 to 75 years old) with atherosclerotic renovascular disease were examined, 3 of whom underwent repeat imaging following revascularization. Quantitative data were acquired on a Philips Achieva 3.0 T MR system using torso phased-array coils. Baseline T_1 was measured using a 3D multiple shot IR-turboFLASH sequence (intershot delay 4 s; TI 80, 500, 1250, 2250, 3850 ms; SENSE factor 2). Low dose (0.025 mmol/kg Gd-DTPA-BMA) DCE-MRI was performed using a 3D FLASH sequence (17° flip, TR/TE 5.05/0.87 ms, SENSE factor 2) with volumes acquired every 2.1 s for 4.5 minutes. Acquisitions were performed in an oblique coronal plane encompassing both kidneys and the descending aorta.

Temporal registration of the DCE data was performed using a modification of general-groupwise registration [5] in which the 3D boundary of the kidney was registered non-rigidly over time but the renal tissue subsequently underwent affine transformations only. Data were extracted from regions of interest in the descending aorta and encompassing the entire parenchyma of each kidney. Following T_1 correction, the dynamic data were analysed according to two methods. The first employs a Rutland-Patlak plot and data acquired between 40 and 110 s after aortic signal rise [3]. The second uses a non-linear fit of the 3CFM to the entire time course [4]. In each case estimates of extraction-flow product (EF_p) were multiplied by parenchymal volume to obtain MR-estimates of split renal function that were compared with radioisotope estimates of SK-GFR obtained using ^{51}Cr-EDTA and ^{99m}Tc-DMSA.

Results.
Data were successfully analyzed from all 18 kidneys. Baseline estimates of parenchymal T_1 ranged from 1200 to 1900 ms (mean, 1600 ms) and baseline SK-GFR ranged from 0 to 58 ml/min (median 11 ml/min). There were good correlations between Rutland-Patlak estimates of SK-GFR and the reference standard (Spearman's rho = 0.77, p < 0.001) and 3CFM estimates of SK-GFR and the reference standard (rho = 0.72, p < 0.001). The slopes of the regression lines were 0.45 and 0.67, respectively. The 3CFM provided both excellent fits to all data sets (e.g. Fig. 1) and estimates of renal parenchymal perfusion (mean 1.3 ml/min/ml, range 0.5 to 2.4 ml/min/ml). Registration of the data improved the strength of the correlation (from 0.76 to 0.77 - Rutland-Patlak and from 0.64 to 0.72 - 3CFM, Fig. 2). Only 1 revascularized patient showed a significant improvement in renal function (seen in both kidneys). Two other kidneys showed no change in function despite much enhanced parenchymal perfusion.

Figure 1. Tracer concentration against time and excellent 3CFM fit to the data from one kidney.

Figure 2. MR estimates of renal function plotted against the radioisotope determined reference standard. There are good correlations using both methods but the 3CFM data lie closer to the line of identity (shown).

Discussion.
There was no systematic effect of motion on MR estimates of renal function but registration of the data reduced scatter and improved the strength of the correlation with the reference standard. Use of a reabsorption-corrected 3CFM had the desired effect of describing the time-course data extremely well (Fig. 1) while maintaining a good correlation between MR estimates of renal function and definitive SK-GFR (Fig. 2) [3]. These data suggest that fluid reabsorption has a significant influence on the measurement of renal function by DCE-MRI but further data is required to estimate its magnitude (e.g. a measured venous output function) [4]. Combined measures of renal perfusion and function in a single MR study may help in the selection of patients who might benefit from revascularization.

References.
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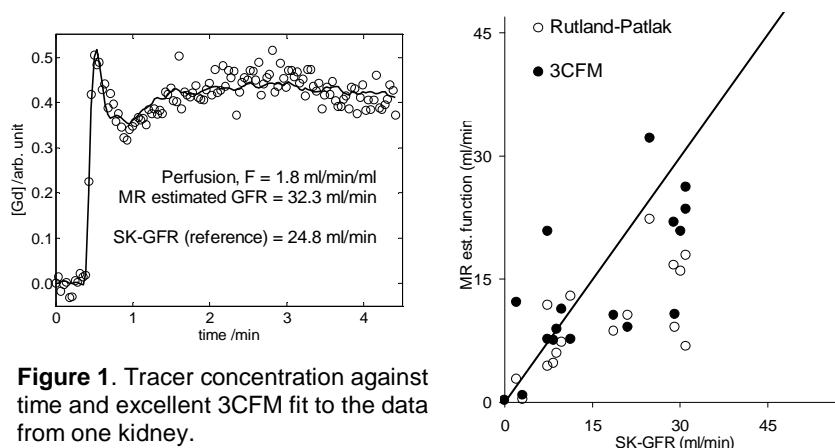[5] Cootes TF et al. *Proc. 16th British Machine Vision Conference,* Oxford, 2005:879.