Accurate and precise measurement of renal filtration and vascular parameters using DCE-MRI and a 3-compartment model.

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Hypothesis: A recent compartmental model of DCE-MRI can provide precise and accurate measurements of renal filtration, blood flow and blood volume, and hence be reliable enough for clinical studies. Precision would be estimated from repeated measurements; accuracy by comparison with published normal values.

Introduction: A 3-compartment model fits DCE data with small residuals. Two modes have been described: uptake mode (for data up to 90s, when efflux is ignored), and complete mode (for longer time-series, when efflux is allowed). Cortical and parenchymal ROI’s have been studied.

Methods: MRI: 15 normal subjects were imaged before and after injection of 0.05 mmole/kg of Gd-DTPA, on a Siemens 1.5T Avanto imager, using a TIM 32 channel body phased array coil. A spoilt gradient echo 3D sequence had TR=1.4ms, TE=0.6ms, FA=17°. 18 contiguous 7.5mm slices were collected every 2.5s, with in-plane resolution 3.1 x 3.1mm, covering both kidneys. Subjects were imaged a week later, giving a total of 60 normal kidney curves.

Compartimental Modelling: The 3-compartment model of DCE-MRI was simplified to exclude efflux:

\[ C_p^{glomer}(t) = C_p^{aorta}(t) \otimes g(t) = \int_0^t C_p^{aorta}(t-\tau)g(\tau)d\tau \]

\[ C_i(t) = V_p (1-Hct) C_p^{glomer} + K^{trans} \int_0^t C_p^{glomer}(\tau)d\tau \]

\[ C_p, C_i, C_p^{glomer}, C_i^{glomer} \] are the time-dependent concentrations in \( V_p \), aortic plasma, glomerular plasma, and kidney tissue respectively. \( V_p, V_s \) and \( V_d \) are the fractional volumes of glomerular plasma, glomerular blood and the distribution space for tracer extracted from the blood (principally the tubules). The delay and dispersion for plasma-borne tracer travelling from the aorta to the glomeruli are described by the Glomerular Impulse Response Function (GIRF) \( g(t) \). \( F \) is the transfer constant \text{from} glomerular plasma to kidney (GFR per unit volume of tissue).

MRI modelling: There were 4 free parameters: \( V_p, K^{trans}, \) and 2 delay and dispersion parameters which defined the GIRF. Three GIRF shapes were investigated: instant exponential decay; delayed exponential decay; and delayed gaussian. Blood flow \( F \) was estimated from the peak, and also using \( F \times V_p/MTT \) (MTT=mean transit time). Filtration Fraction \( FF= K^{trans}/F \). Perfusion mode gave better fits that uptake mode (residuals \( p \) lower); however reproducibility and perfusion parameters were the same.

Results: Delayed exponential and gaussian GIRF’s fitted better (residuals \( p < 0.05 \)) than instant exponential; gaussian values are shown in the table. Cortical ROI’s gave higher values of filtration, and lower MTT’s, than parenchyma, as expected. However parenchymal \( V_b \) (44%) and \( F \) were unexpectedly higher than cortical \( V_b \) (35%) and \( F \). Perfusion mode gave better fits that uptake mode (residuals \( p < 0.05 \)); however reproducibility and perfusion parameters were the same.

Discussion and Conclusions:

Figure: uptake mode fit to parenchymal ROI for 90s

Table: analysis of renal parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Mean ± SD</th>
<th>Instrumental Mean ± SD</th>
<th>Literature Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Kidney Volume</td>
<td>150 ± 30 mL</td>
<td>160 ± 30 mL</td>
<td>150 ± 30 mL</td>
</tr>
<tr>
<td>Blood Flow (mL/min)</td>
<td>1 L/min</td>
<td>1 L/min</td>
<td>1 L/min</td>
</tr>
<tr>
<td>Filtration Fraction</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Glomerular Inflow Rate</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Glomerular Volume (mL)</td>
<td>150 ± 30 mL</td>
<td>160 ± 30 mL</td>
<td>150 ± 30 mL</td>
</tr>
<tr>
<td>Mean Transit Time (s)</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>% Error of Measurement</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

References:
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2. Tofts ISMRM 2009; 408
3. Tofts JMRI 1999;223
5. Tsushima Am J Kid Dis 1999;33:754
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