# Modelling for MR renography: accurate and precise GFR using a two-compartment model

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**INTRODUCTION** It has been known for over a decade that single-kidney glomerular filtration rate (SK-GFR) can be estimated with MR renography [1]. Despite this, confidence in the results remains low, in part due to the large number of tracer-kinetic models that have been used [2]. Recent comparative studies failed to produce a clear recommendation, as they revealed that the most accurate models did not fit the data [3,4]. The aim of this study was to identify the reason for the SK-GFR bias in the simplest model that does fit the data, the two-compartment filtration model (2CFM) [5]. A correction is proposed on the basis of the findings.

**METHODS** Three possible explanations for the bias were evaluated: (I) water reabsorption is modelled incorrectly; (II) the model is not suitable for whole-kidney curves; (III) the indicator is not well-mixed in the tubuli. The assumptions were replaced by alternatives with the same number of free parameters: (I) water reabsorption was included by separating glomerular and peritubular plasma [6]; (II) the model was applied to cortical curves; (III) the tubulus was modelled as a plug-flow system. Accuracy & precision in SK-GFR were determined for the 2CFM and each of the alternatives by linear regression with respect to a gold-standard SK-GFR in 64 kidneys.

16 patients with renal artery stenosis underwent MR renography and radio-isotope SK-GFR measurements before and 4 months after revascularization. Isotope SK-GFR covered a large range from 2 to 54 ml/min (normal), with mean 22 and stdev 14 ml/min. DCE-MRI was acquired under free breathing at 3T (Philips Achieva) with 0.025mmol/kg Gd-DTPA-BMA injected at 3 ml/s, and a 3D spoiled gradient-echo sequence (matrix 128x128x20, voxel size 3.1x3.1x5mm, 2.1 s temporal resolution, 4.4 min acquisition time) [7]. An AIF was measured in the aorta. Maps of blood flow and distribution volume were calculated by deconvolution [8]. Cortex and whole-kidney ROIs were selected semi-automatically by thresholding these maps. No motion correction was applied.

**RESULTS** Figure 1 (top row) shows that the MR SK-GFR of the 2CFM correlates well with isotope SK-GFR (R=0.88), but values are overestimated by a factor 2.02 (intercept -2.2 ml/min). The three alternatives fitted the data equally well. Incorporating water reabsorption lowered renal blood flow (RBF) from 281 to 235 ml/min/100ml ($p<0.001$) but did not reduce the bias in SK-GFR (slope 2.01, intercept +1.8 ml/min) and reduced the precision (R=0.85). Fitting to a cortical curve increased RBF (315 ml/min/100 ml, $p<0.001$), and eliminated the bias (slope 0.99, intercept 5.7 ml/min) at the cost of a loss in precision (R=0.65). A plug-flow model of the tubulus (figure 1, bottom row) lowered RBF (247 ml/min/100ml, p=0.002), and eliminated bias in SK-GFR (slope 1.06, intercept -1.4 ml/min) at higher precision (R=0.91).

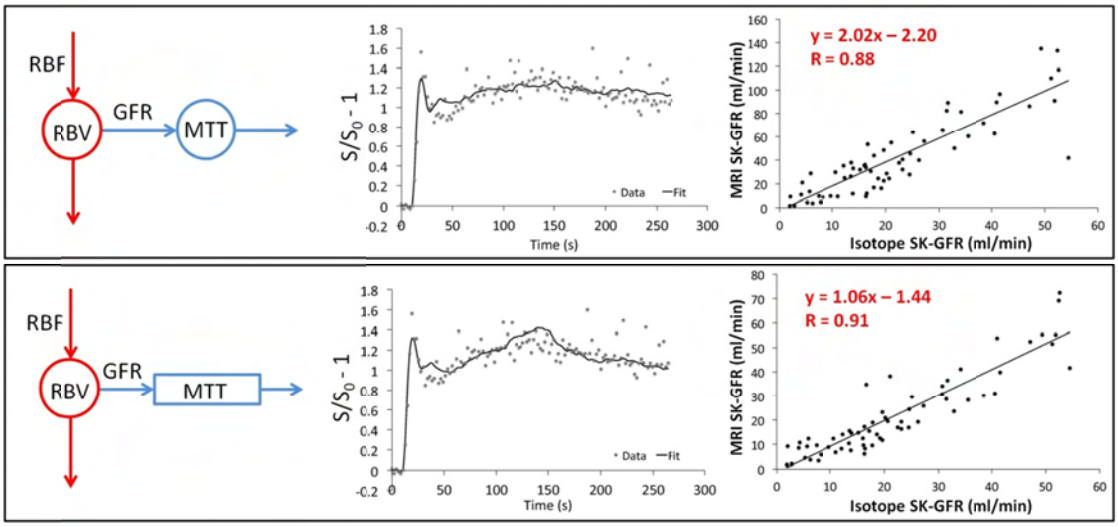


**Figure 1**. The top row shows a diagram of the 2CFM (left), a typical single kidney curve with model fit (middle) and the correlation with isotope GFR (right). The bottom row is the equivalent for a model where the well-mixed tubulus (blue circle) is replaced by a plug-flow tubulus (blue rectangle). Both models have the same architecture and the same four free parameters: renal blood flow (RBF), renal blood volume (RBV), GFR and tubular mean transit time (MTT). They both provide a good fit to the data (middle), but the well-mixed tubulus leads to a systematic overestimation in GFR (slope 2.02). The plug-flow tubulus eliminates this bias (slope 1.06) and improves the correlation (R=0.91).

**CONCLUSION** The assumption that the tubuli form a plug-flow system rather than a well-mixed space eliminates the bias in SK-GFR without compromising precision or individual fit quality, and without increasing the complexity of the model. With this approach, accuracy and precision are higher than all other results found in the literature [3,4]. If the precision can be improved further by including motion correction, MR renography may become a reliable technique for measuring SK-GFR.

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