Hepatic perfusion quantification using a dual-input kinetic model with a novel portal venous estimation method: Evaluation against other model- and slope-based perfusion quantification approaches

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Introduction: The development of metastatic liver disease is an adverse prognostic factor in patients with cancer. The normal liver has a dual vascular supply mainly derived from the portal vein, with a smaller contribution from the hepatic artery. The relative vascular contribution is altered in the presence of disease. Perfusion quantification can be performed via kinetic modelling of dynamic contrast enhanced (DCE-) MR data using a dual-input single compartment model. Due to difficulties in measuring accurate individual input functions, population-averaged input functions are often employed. A methodology which estimates portal dispersion from liver tissue DCE-MR data has been developed and submitted to this conference [1]. The advantage of this method is that the portal-venous input function is patient-specific, and its estimation does not require any additional imaging. Other approaches taken to quantify perfusion are the slope-based methods which have been more widely studied using dynamic CT [2, 3]. These methods are simple to compute and require shorter dynamic imaging periods to quantify perfusion. In this study, we have quantified hepatic perfusion in clinical patient data using the novel model-based approach with a population-averaged arterial input function and a portal dispersion estimate (referred as *'model with AIF and dispersion'*). These were compared with perfusion values quantified using a dual-input single compartment model with population-averaged arterial and portal input functions and a slope-based, modified Blomley method (referred as *'model with AIF and PIF'* and *'modified Blomley'* respectively).

Method: 20 DCE-MR datasets (iv. Magnevist® 0.1mmol/kg body weight) of neuroendocrine cancer patients with liver metastases were acquired coronally on a Siemens Avanto 1.5T using a phased array body coil and a 3D FFE sequence. Dynamic data were acquired in pairs during breath-holds on expiration with 5s gap between successive breath-holds. 40 volumes were acquired over a 4 minute period. The imaging parameters were TR/TE = 3.28/1.10 ms, FA = 18°, 12×5 mm slices, NSA = 1, iPAT = 2, FOV = 350 mm^2, 256×256 matrix. The dynamic scan was preceded by a calibration scan with the same parameters except FA = 2° to allow conversion of dynamic signal intensities to gadolinium concentration. Data analysis was performed using in-house software, MRIW [4]. Dynamic images were registered using a simple rigid body algorithm.

Model-based approaches: The dual-input is modelled using $c_P(t) = \gamma c_A(t) + (1-\gamma)c_V(t-t_P)$, where $c_A(t)$ and $c_V(t)$ are the arterial and portal-venous curves, γ is a partitioning term with $0<\gamma<1$, t_P is the portal delay time and $c_P(t)$ is the overall input function curve [5, 6]. For both model-based approaches, K^{trans} and γ are estimated on a pixel-by-pixel basis. Arterial and portal perfusions are calculated using the following expressions respectively: $\gamma.K^{trans}$ and $(1-\gamma).K^{trans}$.

Slope-based approach: In the *modified Blomley* method, the time of peak splenic concentration, t_{peak} is used as a surrogate to distinguish the arterial and the portal phases in the liver. To calculate arterial and portal perfusions, the maximum gradients of the liver curve before and after t_{peak} are divided by the measured population-averaged peak aortic and portal-venous concentrations respectively. The hepatic perfusion index, HPI (which is equivalent to model-derived γ) is calculated by dividing the arterial perfusion by the sum of the arterial and the portal perfusion. The modified Blomley method differs from the original [3] in that the portal component was derived without deconvolving the arterial curve from the liver curve.

Regions-of-interest (ROIs) analysis: ROIs were drawn encompassing the whole liver (WL), the lesion (L) and the surrounding liver (SL). The median arterial and portal perfusions and HPI values were derived from the ROIs and compared to literature values [7].

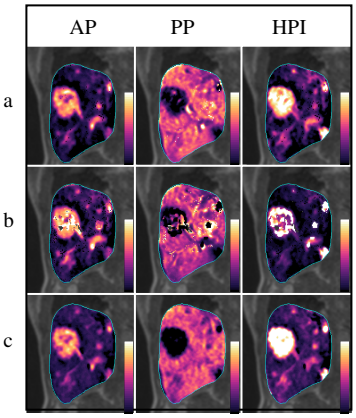

Figure 1: Parametric maps of arterial and portal perfusions and HPI calculated using a) *model with AIF and dispersion*, b) *model with AIF and PIF* and c) *modified Blomley*.

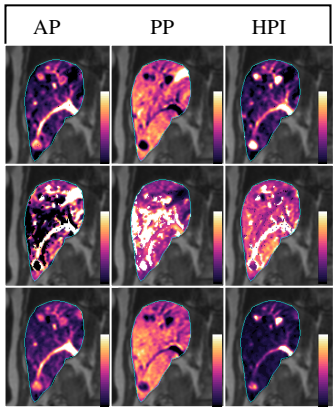

Figure 2: Parametric perfusion maps calculated using a) *model with AIF and dispersion*, b) *model with AIF and PIF* (which did not work well) and c) *modified Blomley* method.

Results & Discussion: Parametric perfusion maps calculated using the three different methods of a representative data are shown in figure 1. A colour scale where black represents low metric value and white represents high metric value is used to display the images. It is evident that the metastatic regions have markedly different perfusion values compared to the surrounding liver tissue. Visually, there is good spatial correlation between the parametric maps derived using the three different methods. Figure 2 shows parametric perfusion maps where the *model with AIF and PIF* failed to produce realistic results (row b) whilst the *model with AIF and dispersion* and the *modified Blomley* methods produced realistic perfusion maps (rows a and c). Using a population-averaged portal-venous input function is clearly non-ideal in this particular case. The AP, PP and HPI distributions from the ROI analysis using the three different methods are displayed in the form of box-and-whisker plots in figure 3 (boxes show median and inter-quartile ranges). Large variations are observed in the perfusion metrics derived using the *model with AIF and VIF*. With all three methods, arterial perfusion is largest in the lesion ROI and smallest in the surrounding liver ROI and the HPI values follow a similar pattern. Portal perfusion is largest in the surrounding liver ROI and smallest in the lesion ROI. The mean of the median perfusion metrics from all 20 patients are tabulated below, together with those from the literature which are based on three patients. There is good agreement between the HPI and AP derived using all three methods and the literature values. The portal perfusion values derived from the WL and SL using the *model with AIF and PIF*, however, are larger than those in the literature.

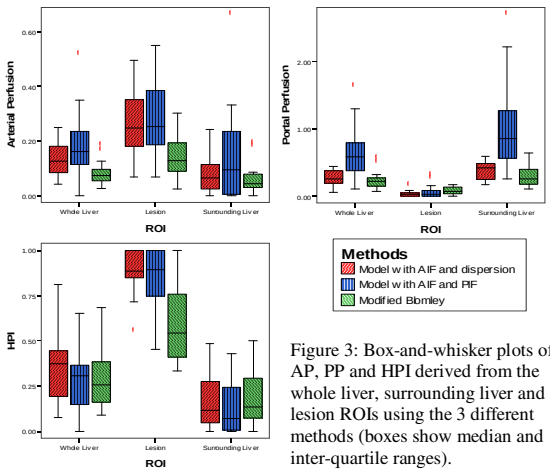

Figure 3: Box-and-whisker plots of AP, PP and HPI derived from the whole liver, surrounding liver and lesion ROIs using the 3 different methods (boxes show median and inter-quartile ranges).

	AP (ml.min^{-1}.ml^{-1})			PP (ml.min^{-1}.ml^{-1})			HPI		
Methods	**WL**	**L**	**SL**	**WL**	**L**	**SL**	**WL**	**L**	**SL**
Model with AIF and dispersion	0.133	0.266	0.083	0.270	0.036	0.382	0.363	0.883	0.169
Model with AIF and PIF	0.184	0.280	0.136	0.621	0.067	1.018	0.278	0.840	0.135
Modified Blomley	0.078	0.140	0.061	0.230	0.078	0.303	0.281	0.621	0.190
Literature[7]	0.18	0.188	0.256	0.228	0.067	0.271	0.49	0.73	0.48

Conclusion: Parametric perfusion maps were generated from quantified DCE-MR data using three different approaches. The novel model-based approach which generates patient-specific portal-venous input functions is more robust than one that employs measured population-averaged arterial and portal-venous input functions. The perfusion metrics derived using the *model with AIF and dispersion* and *modified Blomley* methods agree well with those from the literature. The agreement we observed using the latter is especially encouraging as it is quick and simple to employ in a clinical setting. The ability to accurately quantify hepatic perfusion is desirable, and may be of clinical value for disease evaluation and assessment of treatment response. It is therefore, important to further explore the novel model-based [1] and the slope-based, *modified Blomley* methods.

References: [1] Orton MR, *et al.* 'Novel method of portal delay and dispersion estimation for dual-input kinetic modelling of DCE-MRI liver data', ISMRM (2009) - submitted, [2] Miles K, *et al.* Radiology (1993), [3] Blomley MJK, *et al.* J Comput Assist Tomo (1995), [4] d'Arcy JA, *et al.* Radiographics (2006), [5] Materne R, *et al.* MRM (2002), [6] Orton MR, *et al.* In Proc ISMRM, 1709 (2008), [7] Koh TS, *et al* Radiology (2008).

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