Evaluation of slope-based hepatic perfusion index quantification methods against dual-input kinetic model based approach

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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 hepatic perfusion index (HPI), which is the ratio of the arterial perfusion to the total hepatic perfusion, is elevated in the presence of liver metastases. HPI can be quantified using slope-based methods [1, 2] which are simpler to compute and easier to implement in clinical settings compared with dual-input kinetic modelling methods. In this study, HPI was evaluated in clinical patients with liver metastases using two slope-based methods – the Miles method [1] and a modified Blomley method [2]. These were compared with parameters derived using a dual-input single compartment model with population-averaged arterial and portal input functions. The ability to accurately quantify hepatic perfusion is desirable, and may be of clinical value for disease evaluation and assessment of treatment response.

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 [3]. Dynamic images were registered using a simple rigid body algorithm. The HPI is calculated by dividing the arterial perfusion by the sum of the arterial and the portal perfusion. The two slope-based methods are summarised in figure 1. In both methods, the time of peak splenic concentration, t_{peak} is used as a surrogate to distinguish the arterial and the portal phases in the liver (see figure 1). The modified Blomley method differs from the original [2] in that the portal component was derived without deconvolving the arterial curve from the liver curve. Peak concentrations from the aorta and the portal vein were measured where available, and the population-averaged values (which were 10.7mM and 3.8mM respectively) were used in the HPI calculation. A dual-input single compartment model was used to analyse HPI using measured population-averaged arterial and portal input functions [4, 5]. ROIs were drawn encompassing the whole liver, the lesion and the surrounding liver. The median HPI values derived from the ROIs were compared using a paired t-test (p-value<0.05 taken to be significant).

Hepatic perfusion index

• $HPI = \frac{\text{Arterial perfusion}}{\text{Arterial perfusion} + \text{Portal perfusion}}$

	Slope 1 (Miles)	Slope 2 (modified Blomley)
Arterial Perfusion	$\frac{g_{arterial}}{I_{arterial}}$	$\frac{g_{arterial}}{I_{arterial}}$
Portal Perfusion	$\frac{g_{portal}}{I_{arterial}}$	$\frac{g_{portal}}{I_{portal}}$

where
$g_{arterial}$ = Max. gradient of liver curve before t_{peak}
g_{portal} = Max. gradient of liver curve after t_{peak}
$I_{arterial}$ = Peak aortic concentration
I_{portal} = Peak portal concentration

Schematic tissue [Gd]-time curves

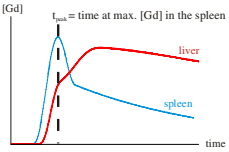

Figure 1: HPI quantification using the slope methods

Results: Parametric HPI maps derived using the three different methods of analysis are shown for two example patients (figure 2). All maps are colour scaled from HPI of 0 (black) to 1 (white). Histogram plots of HPI from the whole liver ROI derived using all three methods were overlaid on top of each other for every dataset. Example plots from 3 datasets (different from those shown in figure 2) are shown in figure 3. HPI distributions from the ROI analysis using the 3 different methods are displayed in the form of box-and-whisker plots in figure 4.

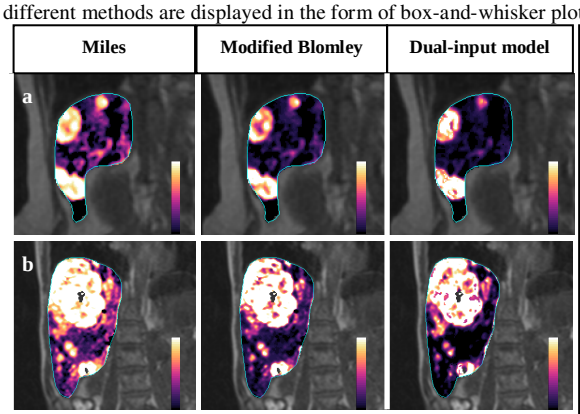

Figure 2: Parametric maps of HPI, colour scaled from 0 (black) to 1 (white), derived using the 3 methods (arranged from left to right). 2 different patient examples are shown in separate rows.

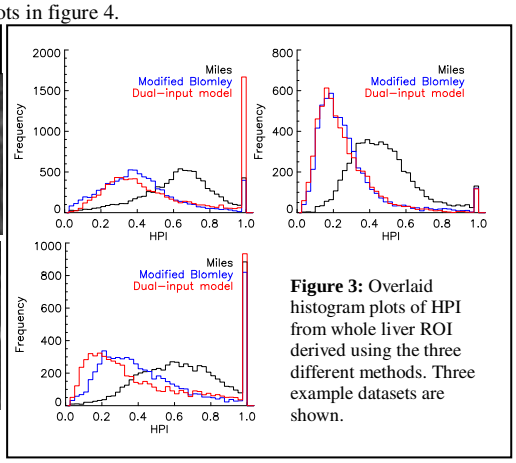

Figure 3: Overlaid histogram plots of HPI from whole liver ROI derived using the three different methods. Three example datasets are shown.

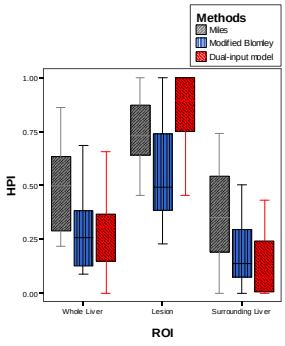

Figure 4: Box-and-whisker plots of HPI derived from the ROIs using the 3 different methods (boxes show median and inter-quartile ranges)

Discussion: From figure 2, it can be seen that all three methods produced parametric HPI maps which depict increased HPI in the metastases compared to the surrounding liver tissue. A bi-modal HPI distribution is clearly seen in the histograms in figure 3. A clear peak is observed at an HPI of 1 which corresponds to highly arterialised regions of metastases. A second peak is observed at a lower HPI, corresponding to the surrounding liver tissue which has different proportions of arterial and portal supply which would differ in individuals. Visually, there is good spatial correlation between the parametric maps derived using the three different methods. The absolute HPI of the surrounding liver tissue derived using the Miles method, however, appear greater compared with parameters derived using the modified Blomley method and the dual-input model. This is confirmed by the histogram analysis where histogram plots of HPI derived using the two methods agree well and exhibit similar distributions whilst the histogram plot derived using the Miles method is generally shifted towards higher HPI. In the ROI analysis, the HPI values derived from the whole liver and the surrounding liver ROIs using the modified Blomley and dual-input model agree well with each other (and with those previously reported in the literature which range from 0.16 to 0.49 [1, 2, 6, 7]) whilst parameters derived using the Miles method do not. In the lesion ROI, however, there is good agreement between HPI derived using the Miles and the dual-input model methods. This agreement was not observed in the lesion HPI values obtained using the Miles and the dual-input model. These observations suggest that when employing a slope-based method to quantify HPI in a non-metastatic liver region, it is inappropriate to calculate the portal perfusion by dividing g_{portal} by the peak aortic concentration.

Conclusion: Parametric maps of HPI using two slope-based methods and a dual-input single compartment model were generated from quantified DCE-MR data. Results show that the absolute values of HPI in the surrounding liver using the Miles method are overestimated compared to the modified Blomley and the dual-input model methods. This study shows that in non-metastatic liver regions, the modified Blomley method which requires the quantification of peak portal concentration allows HPI quantification which agree better with the dual-input single-compartment model derived HPI values than the simple Miles method.

References: [1] Miles K, *et al*. Radiology (1993), [2] Blomley MJK, *et al*. J Comput Assist Tomo (1995), [3] d'Arcy JA, *et al*. Radiographics (2006), [4] Materne R, *et al*. MRM (2002), [5] Orton MR, *et al*. In Proc ISMRM, 1709 (2008), [6] Kissel A, *et al*. J Radiol (2001), [7] Fowler RC, *et al*. Radiology (1998).
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