ESTIMATION OF HEPATIC PERFUSION USING AN OPTIMISED DUAL-SECTION SATURATION RECOVERY SEQUENCE

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Introduction Hepatic perfusion is known to alter in several disease states and changes have been correlated with cirrhosis, malignant disease and post liver transplant graft failure [1]. Although it is possible to estimate overall perfusion and arterial-portal ratios using gradient methods these are limited by the difficulty of reliably defining the start and end of the different component contributions and the majority of recent perfusion work has relied on a dual input pharmacokinetic model. This requires accurate measurement of the timing and gadolinium concentrations in the artery (aorta), portal vein and liver parenchyma [2]. Given the non-linearity of the relationship between gadolinium concentration and signal on T_1-weighted imaging it is difficult to use a single set of MR parameters that will accurately cover this wide concentration range and provide adequate SNR. A solution to this problem is to use two temporally adjacent axial sat-prep acquisitions with differing parameters targeting higher concentrations on one acquisition and lower on the other [3]. This approach generated robust data for analysis but gave consistently high perfusion estimates [4]. Reanalysis of that data indicated that the portal vein concentration data was being underestimated. Two problems were identified, firstly the problem of trying to sample on a single axial image two non-aligned vessels (aorta and portal vein) one of which moves with respiration - potentially creating partial volume problems. Secondly the portal vein concentrations were more accurately estimated by the higher concentration range acquisition – not the lower as used.

Method Informed consent was obtained from the volunteers (3 male, 2 female, age 30-55) who were fasted overnight to ensure good portal vein diameters. A 1.5T whole body MRI scanner (Excite HD, GEHC, Milwaukee) with an eight channel torso array coil was used for the study. To determine the initial T_1 values, a saturation-prepared fast gradient echo imaging sequence (flip 10°, TR/TE/NEX = 4.6ms/1.2ms/1) was modified to acquire extra images with exponentially increasing saturation times. Pre-contrast T_1 maps were calculated using points from 10 images with saturation times between 28-14336ms. For the dynamic contrast acquisition, a modified fast gradient echo imaging sequence was used to obtain two independently oriented images per heartbeat, for 200 heartbeats. Each image pair shared most parameters (matrix 256x128, ASSET factor 2, thickness 10mm, TR/TE/NEX = 4.8ms/1.3ms/1, flip 12°, BW 31.2 kHz, centric phase ordering) but had individually specified saturation times and prescription geometry. The first image of the pair sampled the two vascular input functions (VIFs): a short saturation time (50ms) was used to avoid saturation of the vascular signals [4]; the sagittal-oblique slice prescription allowed perpendicular and oblique intersection of both the portal vein and the aorta respectively. The second image sampled the liver parenchyma: a longer saturation time (150ms) was used to obtain a greater signal to noise ratio for the lower concentration of contrast agent; an axial slice was prescribed to show the liver parenchyma above the portal vein. The oblique VIF image was localised by navigating to the view using a custom-developed real-time FIESTA sequence. By moving the acquisition to the coronal plane, the location of the slice was briefly tagged by saturated spins that provided a visual guide for the VIF slice prescription. A bolus injection of Gd-DTPA was given after 20s of baseline imaging: 0.1 mmol/kg followed by 25ml saline at 3ml/s. The initial T_1 map and the region of interest (ROI) time series for the aorta, the portal vein and liver were extracted using CineTools 5.4.1 (GEHC). The time series were converted to gadolinium concentrations using the T_1 map. Perfusion parameters were calculated using a dual-input model:

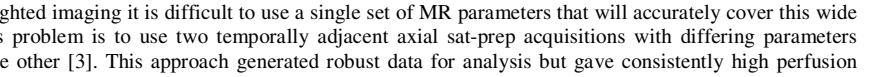

Fig 1. Example images showing (l-r): rtFIESTA prescription image, the VIF slice with (i) enhancing aorta (ii) enhancing portal vein, liver slice

$$\frac{dc_L}{dt} = k_{1a}c_a(t-\delta) + k_{1p}c_p(t-\delta) - k_2 c_L(t)$$

Where c_L, c_P, c_A are the liver, portal vein and aorta Gd concentrations; k_{1a}, k_{1p} and k_2 are the aortic plasma to liver, portal plasma to liver and liver to hepatic veins transfer constants; δ is the aorta to parenchyma uptake delay.

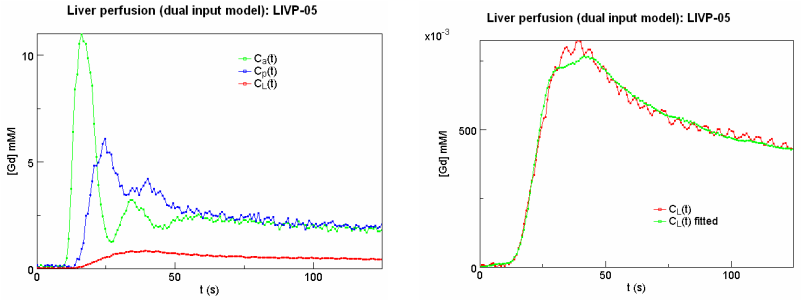

Fig 2. *(l)* Input for aorta, portal vein and liver, *(r)* dual-input model fitted to liver uptake

Results The extracted inputs and fitted model output are shown in Figure 2. The results are summarised in Table 1. They show group mean values for total perfusion (TP) and distribution volume (DV) that are closer than earlier estimates [4] to other published values for normal liver perfusion from CT/MRI [5,6] by factors of 102%/17% for TP and 180/197% for DV, having differences of 3%/35% (TP) and 60%/40% (DV). However, group mean differences in mean transit time (MTT) increased by 10% compared with previous results but are still 25%/40% lower than the literature. Compared with earlier estimates [4], the percentage error of the mean for total liver perfusion and distribution volume decreased by a factor of 2 (and MTT by a factor of 3) indicating lower intra-subject variability.

Table 1. Results of hepatic liver modelling for 5 healthy volunteers *(ml min^{-1} 100ml^{-1})

Subject	*Arterial fraction (%)*	*Arterial perfusion**	*Portal perfusion**	*Total perfusion**	*Mean transit time (s)*	*Distribution volume (%)*
LIVP-01	11.1	13.3	106.3	119.6	7.2	14.4
LIVP-02	6.0	6.3	97.5	103.8	8.6	14.4
LIVP-03	22.6	21.9	74.9	96.8	11.1	17.9
LIVP-04	5.2	4.5	81.8	86.3	9.6	13.8
LIVP-05	9.7	11.3	105.0	116.3	11.1	21.6
Mean±SD	**10.9±6.98**	**11.5±6.85**	**93.1±14.09**	**104.6±13.77**	**9.5±1.68**	**16.4±3.32**

Conclusion This work demonstrates that the use of independently optimised images (for T1w saturation, resolution and position) acquired within a single heartbeat provides improved hepatic perfusion estimates in healthy volunteers, comparable with other techniques [5,6]. The improved demonstration and tracking of the portal vein during respiration is likely to be important in patient studies where both alterations of portal vein size and flow rates are common.

References [1] Pandharipande *et al., Radiology* 234:661–673, 2005, [2] Materne *et al.,* Magn Reson Med 47:135–142, 2002, [3] Gatehouse *et al.*, *JMRI* **20**, 39 (2004), [4] Hollingsworth *et al., Proc. Intl. Soc. Mag. Reson. Med.* 14 (2006) 397, [5] Van Beers *et al.,* AJR 2001; 176:667–673, [6] Annet *et al.*, *Radiology* 229, 409 (2003)

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