IVIM-DTI of Healthy Human Liver

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Target Audience: Research scientists who are interested in body diffusion, perfusion and diffusion tensor analysis.

Purpose: Diffusion weighted imaging (DWI) based on intravoxel incoherent motion (IVIM) theory is useful in quantifying the diffusion and perfusion effects in tissue[1]. One variant, diffusion tensor imaging (DTI) provide more quantitative information, such as fractional anisotropy (FA), eigenvalues (λ_1, λ_2, λ_3) and eigenvectors (v_1,v_2,v_3), using 6 or more non-coplanar gradient encoding directions. Combined IVIM-DTI has recently been applied in human kidney, showing the combination of the two methods being feasible[2]. Both DT metrics and IVIM metrics may provide useful information in categorizing diseased liver tissue. In this study, we demonstrate the feasibility of our modified IVIM-DTI technique in human liver.

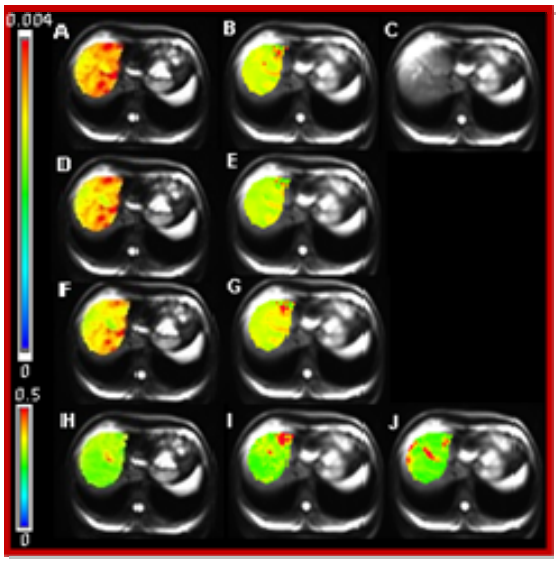

Figure 1*: The eigenvalue and FA maps calculated using DTI and IVIM. A, D, F and H correspond to λ1, λ2, λ3 and FA maps calculated using conventional DTI. The equivalent λ1, λ2, λ3 and FA maps calculated using IVIM-DTI were shown in B, E, G and I, respectively. C corresponds to the b-value = 0 s/mm² image. J corresponds to the FA_f map obtained from IVIM-DTI calculation.*

Methods: In a study approved by our local institutional review board, 4 healthy volunteers were recruited and liver images were collected using a 3T GE MRI scanner and a 32 channel torso array coil (Discovery MR750, General Electric Healthcare, Milwaukee, USA). Sixteen axial images were acquired with a single shot dual-spin echo DTI EPI sequences (TE/TR = 77/1600ms, 20 gradient directions, slice thickness = 10mm, 35cm FOV, 110x110 matrix, 3 NEX, 35s per b-value setting per NEX) with varying b-value settings (10, 15, 20, 25, 30, 35, 40, 50, 100, 200, 300, 400, 500 s/mm^2). Respiratory motion compensation was done by breath holding and linear motion correction was done offline with mcflirt[2] (FSL, FMRIB, Oxford, UK). IVIM-DTI analysis was performed based on the method of Notohamiprojo[3]. DT metrics at b = 300 mm^2/s were calculated using FSL while the IVIM-DT metrics were calculated using a custom matlab script (Matlab 2010a, Mathworks, Natick MA). The calculation of the IVIM-DTI involved the following steps. (1) IVIM fit was performed for each diffusion gradient directions. (2) The eigenvalues of D*, D and f (indicated in the subscript) were estimated using singular value decomposition (SVD), assuming the eigenvectors remained the same using both techniques. FA values (FA_f and FA), mean eigenvalues (M_f, MD and M_{D*}) and eigenvalues ($\lambda1$, $\lambda2$, $\lambda3$, λ_f1, λ_f2, λ_f3) of each IVIM matrix were calculated. Where relevant, a Wilcoxon-ranksum test was performed to compare the results using IVIM-DTI to those obtained using conventional DTI. Comparison between the ROI in liver parenchyma and hepatic blood vessels was also performed using Wilcoxon-ranksum test, to assess the effect confounding of major blood vessels on the results.

Results: FA calculated by both DTI and IVIM-DTI were similar (***Table 1***). Significantly smaller MD and eigenvalues were obtained using IVIM-DTI. When a small circular ROI was selection instead of the whole liver, significantly higher FA was obtained in highly vascular areas using IVIM-DTI (***Table 2***).

Parameters	DTI	IVIM-DTI
MD [x 10^{-3} mm^2/s]	2.6 ± 2	1.5 ± 0.2 *
M_{D*} [x 10^{-3} mm^2/s]		55 ± 2
M_f		0.28 ± 0.01
FA	0.16 ± 0.01	0.16 ± 0.04
FA_f		0.17 ± 0.05
λ1 [x 10^{-3} mm^2/s]	3.0 ± 0.3	1.7 ± 0.7 *
λ2 [x 10^{-3} mm^2/s]	2.5 ± 0.1	1.5 ± 0.2 *
λ3 [x 10^{-3} mm^2/s]	2.2 ± 0.2	1.5 ± 0.1 *
λ_f1		0.29 ± 0.05
λ_f2		0.28 ± 0.03
λ_f3		0.28 ± 0.03

Table 1: *The calculated DTI and IVIM-DTI metrics of the whole liver averaged over 4 healthy volunteers (mean ± SD). * denotes statistical significant at p<0.05).*

Discussion: As shown in ***Figure 1***, elevation in the FA (***I***) and FA_f (***J***) were observed in the blood vessels region, showing IVIM-DTI is able to differentiate blood vessels from normal liver tissue. More importantly, significantly smaller liver FA compared to blood vessel FA was obtained using IVIM-DTI (p<0.05). The obtained FA was, in fact, closer to the expectation that liver tissue has isotropic diffusion. Previous work has shown non-linear liver motion, due to cardiac contractility, results in elevated FA, hypothesized to be flow related[4]. The IVIM –DTI approach, however, involves separation of flow and diffusion components.

	Liver tissue		Blood vessel	
Parameters	**DTI**	**IVIM-DTI**	**DTI**	**IVIM-DTI**
MD [x 10^{-3} mm^2/s]	1.9 ± 0.3	1.3 ± 0.2 #	2.8 ± 0.5 *	1.6 ± 0.2 #
FA	0.11 ± 0.05	0.05 ± 0.02	0.13 ± 0.04	0.21 ± 0.07 *
λ1 [x 10^{-3} mm^2/s]	2.2 ± 0.1	1.3 ± 0.02 #	3.4 ± 0.6	1.7 ± 0.3
λ2 [x 10^{-3} mm^2/s]	1.9 ± 0.1	1.22 ± 0.03 #	2.9 ± 0.4	1.5 ± 0.2 #
λ3 [x 10^{-3} mm^2/s]	1.8 ± 0.3	1.3 ± 0.2 #	2.6 ± 0.5	1.7 ± 0.4 #

Table 2: The DTI and IVIM metric were calculated over a small circular ROI, which cover liver tissue and mostly blood vessels (mean ± SD). * denotes statistically significant between ROIs (p<0.05). # denotes statistically significant between choice of calculation techniques (p<0.05)

Conclusion: The IVIM-DTI technique is feasible in the liver when using multiple breath holds and subsequent retrospective motion compensation and image registration. The approach minimized pseudo-hepatic anisotropy artifact to the measured metrics in the liver. This technique is potentially useful in assessing diffusive liver disease.

References: [1] Le Bihan D, et al. Radiology. 1988; 168(2):497-505; [2] Jenkinson M, et al. NeuroImage. 2002, 17 :825-841; [3] Notohamiprojo M, et al. Proc. ISMRM. 2012; 20:110; [4] Nasu K, Kuroki Y, Sekiguchi R, et al. Radiat Med 2006; 24:438-444.