Effect of Diffusion Time on Intravoxel Incoherent Motion Parameters in Abdominal Organs

Yeeliang Thian[1], Matthew R. Orton[2,3], David J. Collins[2,3], James A. d'Arcy[2,3], Martin O. Leach[2,3], Thorsten Feiweier[4], and Dow-Mu Koh[1]

[1]Department of Radiology, Royal Marsden Hospital, Sutton, Surrey, United Kingdom, [2]CR-UK and EPSRC Cancer Imaging Centre,Institute of Cancer Research UK, Surrey, United Kingdom, [3]Royal Marsden Hospital, Surrey, United Kingdom, [4]Siemens AG, Healthcare Sector, Erlangen, Germany

Purpose : Intravoxel-incoherent motion (IVIM) analysis relates the observed signal attenuation of mobile water molecules in tissues on diffusion-weighted MR imaging (DWI) to intrinsic tissue characteristics of perfusion (pseudo-diffusion) and tissue diffusivity [1]. A recent study demonstrated that the observed water diffusion in rat brain cortex is dependent on the diffusion time [2]. The effects of altering the diffusion time on IVIM perfusion-related and diffusion parameters have not been previously studied in abdominal parenchyma in vivo. In this study, we explore the diffusion time dependency of IVIM parameters in abdominal organs in healthy human volunteers.

Methods : *Image acquisition*: 15 healthy volunteers (10 males, 5 females) underwent multi b-value axial DWI of the upper abdomen on a 1.5 T MR system (MAGNETOM Avanto, Siemens AG, Erlangen, Germany). Each volunteer underwent 2 consecutive DWI acquisitions, performed at diffusion times of 24.1 ms and 54.1 ms, with a work-in-progress sequence. The other acquisition parameters were held constant : free breathing, Stejskal and Tanner MPG, single-shot echo-planar imaging technique, three-scan trace, 9 b values (0, 20, 40, 60, 80, 100, 250, 500, 750 s/mm^2), TR/TE = 4000/93.6 ms, 128 x 128 matrix, FOV : 380mm, bandwidth = 1628 Hz/voxel, GRAPPA = 2, slice thickness = 5mm, NEX = 4. *Analysis* : Three representative regions of interest (ROIs) were drawn in each of the following organs : liver, spleen, right kidney and pancreas; with exact positional concordance between ROIs drawn on the 2 DWI sequences. IVIM bi-exponential fitting was performed with the Markov chain Monte Carlo (MCMC) approach, using proprietary software (ADEPT, Institute of Cancer Research, UK). The mean f, D and D* for each organ were calculated at each diffusion time. Pairwise comparisons were made with the Wilcoxon signed-rank test.

Results : The results are summarized in Table 1. The perfusion fraction (f) was significantly higher with a higher diffusion time of 54.1 ms for all organs. The diffusion coefficient (D) value showed no significant difference for the spleen and liver but was significantly higher in the kidney and pancreas at the higher diffusion time. The pseudo-diffusion (D*) parameter showed no significant difference for the spleen, kidney and pancreas; but was higher in the liver at the diffusion time interval of 54.1 ms. Under our measurement conditions, water diffusion in the tissue compartment occurred over mean distances of 11.3 – 17.0 μm at the diffusion time of 24.1 ms, and 16.9 – 26.1 μm at the diffusion time of 54.1 ms.

Table 1. Mean values of f, D and D* in abdominal viscera of healthy individuals calculated using the IVIM bi-exponential model at 2 diffusion time intervals. Units for D and D* are 10^{-3} mm^2/s. f is in %.

	24.1 ms	54.1 ms	mean difference	p
f				
spleen	8.4	10.9	-2.5	0.047
liver	29.6	30.9	-1.3	0.031
kidney	19.7	23.0	-3.3	0.020
pancreas	29.5	33.4	-3.9	0.005
D				
spleen	0.878	0.880	-0.002	0.776
liver	1.246	1.216	0.030	0.191
kidney	2.004	2.104	-0.100	0.031
pancreas	1.546	1.720	-0.174	0.027
D*				
spleen	39.790	43.410	-3.627	0.496
liver	68.364	74.440	-6.073	0.015
kidney	53.040	48.427	4.613	0.281
pancreas	60.662	60.631	0.031	0.670

Discussion : Our results show that measured IVIM parameters using the bi-exponential fitting model can be dependent on the diffusion time, at diffusion times of 24.1 and 54.1 ms which are common on clinical MR scanners. An increase in the f parameter, which relates to the fraction of spins within the vascular compartment was uniformly seen with a longer diffusion time. A significant effect on D* and D parameters which reflect tissue perfusion and diffusivity were variably seen, depending on the organ under study. At the diffusion distances in our study, the measured tissue diffusivity for the liver and spleen appear to reach a limiting value. The main limitations of our study are the relatively small cohort included, and the limited range of diffusion timings.

Conclusion : The diffusion time has a significant impact on measured IVIM parameters in abdominal organs. Diffusion measurement parameters require reporting when employing the IVIM model. Further work to elucidate the sensitivity of IVIM to diffusion time is warranted.

References :

1. Koh DM, Collins DJ, Orton MR. Intravoxel incoherent motion in body diffusion-weighted MRI: reality and challenges. American Journal of Roentgenology. 2011 Jun;196(6):1351–61.
2. Pyatigorskaya N, Le Bihan D, Reynaud O, Ciobanu L. Relationship between the diffusion time and the diffusion MRI signal observed at 17.2 tesla in the healthy rat brain cortex. Magn Reson Med. 2013 Sep 10. doi : 10.1002/mrm.24921. [Epub ahead of print]

Acknowledgements : We acknowledge CR-UK and EPSRC for Cancer Imaging Centre, NIHR funding of Biomedical Research Centre and Clinical Research Facility.