

Quantitative Diffusion-Weighted MR Imaging of Crohn's Disease using a Spatially-Constrained Probability Distribution Model of Incoherent Motion (SPIM)

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Purpose: Crohn's disease (CD) is a chronic inflammatory bowel disease, which has relapsing, and remitting clinical course. Long-standing inflammation can result in bowel obstruction, stricture, fistula, abscess and an increased risk for small and large bowel malignancy. Identifying disease stage is crucial for determining the correct treatment options. Magnetic resonance imaging (MRI) allows accurate assessment of Crohn's disease (CD), but requires gadolinium injection, which poses risks. Diffusion-weighted (DW-MRI) yields comparable performances in small bowel CD without requiring gadolinium injection¹. However, there are challenges associated with parameter estimation using current diffusion signal decay models, such as the bi-exponential signal decay model of Intra-voxel incoherent motion (IVIM)²⁻⁴. IVIM has one decay rate parameter for the slow diffusion associated primarily with the Brownian motion of water molecules, and a second decay rate parameter for the fast diffusion component associated primarily with the bulk motion of intravascular molecules in the micro-capillaries. However, in biological systems diffusion can occur over a large range of length and time scales due to widely varying vessel sizes and flow rates⁴, and the point estimate of a single parameter as in the IVIM model cannot represent this heterogeneity in diffusion components. We recently introduced the Spatially-constrained Probability distribution model of Incoherent Motion (SPIM)⁵ to represent the heterogeneity of the diffusion scales with a two-component probability distribution mixture model of incoherent motion and spatial homogeneity of the diffusion parameters with a spatially smoothing prior⁷. The SPIM model allows for the precise characterization of the diffusion components even from relatively low SNR DW-MRI images. In this work, we compare the performance of quantitative DW-MRI parameters computed using SPIM model with parameters computed using the IVIM model to differentiate normal looking small bowel regions and regions with CD in DW-MR images of 20 CD patients that were acquired within last year in our hospital. The magnetic resonance index of activity (MaRIA)¹ is also computed for the same bowel regions using gadolinium enhanced MR images. The bowel regions with a MaRIA score larger than 30 are selected as regions with CD.

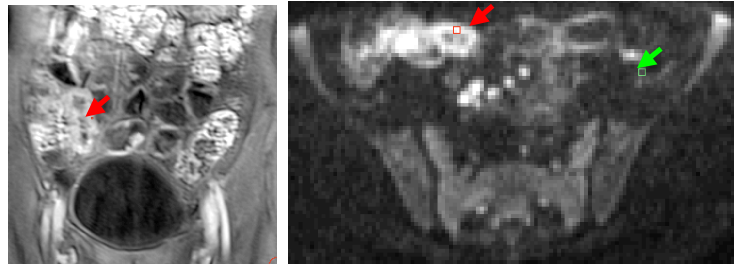


Fig. 1: **Left:** Post-contrast image. Red arrow shows abnormal bowel region with enhancement in bowel wall signal. **Right:** DW-MRI image (b-value=600). Red arrow shows abnormal bowel loop with restricted diffusion and high signal value and green arrow shows a normal bowel loop with normal diffusion and low signal value.

Methods: DW-MRI data of 20 CD patients were acquired using a 1.5-T scanner (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) with free-breathing single-shot echo-planar imaging using the following parameters: repetition/echo time (TR/TE) = 7500/77ms; matrix size=192x156; field of view=300x260 mm; slice thickness/gap = 5mm/0mm; 40 axial slices; 7 b-values = 0,50,100, 200,400,600,800 s/mm² with 1 excitation; acquisition time = 5.5 min.

We obtained diffusion parameter estimates with two different models; the IVIM model, and the recently proposed spatially-constrained probability distribution mixture model (SPIM)⁵. We fitted each model to b-value images and computed three parameters for each voxel: slow (D) and fast diffusion coefficient (D*) and fast diffusion fraction coefficient (f). Parameters of the two-component probability density mixture model in SPIM were converted to IVIM parameters. The means of two components corresponded to fast (D*) and slow (D) diffusion decay rate parameters in IVIM. The area under the curve for fast diffusion component corresponded to the f parameter.

We compared the performance of the parameter estimates from the 2 models as follows. The radiologist in our team placed a region of interest (ROI) in normal looking areas and areas with CD (Fig. 1 right). We then calculated the mean value of each parameter over the ROI. Finally, the mean and standard deviation of D, D* and f parameters were computed over all normal-looking and abnormal bowel ROIs.

To compute MaRIA score, pre- and post-contrast wall signal intensity (WSI) was quantitatively analyzed (see Fig 1 left). Relative contrast enhancement (RCE) of the intestinal wall was calculated according to the following formula: $RCE = ((WSI_{\text{postgadolinium}} - WSI_{\text{pregadolinium}}) / (WSI_{\text{pregadolinium}})) \times 100 \times (s.d. \text{ noise}_{\text{pregadolinium}} / s.d. \text{ noise}_{\text{postgadolinium}})$. The MaRIA was calculated with the following formula¹: $MaRIA = 1.5 \times \text{wall thickening (mm)} + 0.02 \times RCE + 5 \times \text{edema} + 10 \times \text{ulceration}$.

Results: Table 1 shows the mean and standard deviation (SD) of slow (D), fast diffusion (D*) and fast diffusion fraction (f) parameters estimated using SPIM and IVIM models in normal-looking and abnormal areas with CD. Abnormal areas are regions with a MaRIA score larger than 30. D and f parameters estimated using SPIM model were significantly lower in abnormal areas compared to normal looking areas.

	IVIM			SPIM		
	Mean±SD Normal- looking bowel	Mean±SD Abnormal bowel	p-value	Mean±SD Normal- looking bowel	Mean±SD Abnormal bowel	p-value
D	1.88 ± 0.72	1.39 ± 0.55	0.035	1.78 ± 0.56	1.21 ± 0.55	0.007
D*	32.49 ± 27.23	45.45 ± 51.29	0.41	32.29 ± 16.87	34.31 ± 26.59	0.81
f	0.44 ± 0.27	0.29 ± 0.21	0.071	0.53 ± 0.19	0.34 ± 0.16	0.006

Table 1. The mean and SD of slow (D), fast diffusion (D*) and fast diffusion fraction (f) parameters estimated using SPIM and IVIM models are compared in normal-looking and abnormal areas with CD (MaRIA score>30). D and f parameters estimated using SPIM model were significantly lower in abnormal areas compared to normal looking areas (p-value < 0.01). IVIM results were not statistically significant.

Discussion and Conclusion: The Magnetic Resonance Index of Activity (MaRIA) score has recently been validated for assessing inflammation in ileocolonic CD⁸. The performance of ADC parameter in DW-MRI was assessed and correlated with the MaRIA score with good results. Here we showed that both slow diffusion parameter (D) and fraction of fast diffusion parameter (f) were significantly lower in regions with Crohn's disease compared to normal-looking small bowel regions. These results for parameters f and D agree with the findings shown in previous work⁵ on a different cohort of CD patients. These results show that the SPIM model improves parameter estimation accuracy and precision compared to the IVIM model.

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