LONGITUDINAL REPRODUCIBILITY OF QUANTITATIVE DIFFUSION WEIGHTED MRI IMPROVED BY SPATIALLY CONSTRAINED PROBABILITY DISTRIBUTION MODEL OF INCOHERENT MOTION (SPIM)

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Purpose: Diffusion-weighted MRI (DW-MRI) of the body is a non-invasive imaging technique that enables characterization of tissue microenvironments through measurement of variations in the mobility of water molecules due to cellularity, cell membrane integrity, and compartment they are located. Quantitative DW-MRI has a well-established role in the detection, characterization and follow-up of a variety of abdominal abnormalities including liver fibrosis, tumors and active inflammation[1-3]. Several quantitative DW-MRI techniques have been proposed to model water molecule motion and quantify diffusion changes associated with abnormalities. The Intra-voxel incoherent motion (IVIM)[1-3] model represents the diffusion signal decay with a bi-exponential function that 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 fast diffusion can occur over a large range of length and time scales due to widely varying vessel sizes and flow rates[4], and the IVIM model cannot represent this heterogeneity in diffusion components. We recently introduced the Spatially-constrained Probability distribution model of Incoherent Motion (SPIM)[5]. The SPIM model represents 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 prior[6]. The SPIM model allows for the precise characterization of the diffusion components even from relatively low SNR DW-MRI images. In this work, we evaluate the effect of the incoherent motion model used on longitudinal reproducibility of parameters estimation in data collected from both healthy volunteers and Crohn's disease patients.

Methods: We acquired DW-MRI data of five healthy volunteers using a 1.5-T scanner (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany). We performed free-breathing single-shot echo-planar imaging using the following parameters: repetition/echo time (TR/TE) = 7500/77 ms; matrix size = 192x156; field of view = 300x260 mm; slice thickness/gap = 5 mm/0 mm; 40 axial slices; 7 b-values = 0,50,100,200,400,600,800 s/mm^2 with 1 excitation. The acquisition time was 5.5 min. For intra-scan reproducibility analysis, we repeated the acquisitions [6,4,4,3,3] times for volunteer one to five respectively. For inter-scan longitudinal reproducibility analysis, we retrospectively analyzed longitudinal clinical DW-MRI data sets of Crohn's disease patients acquired between 01/2011 and 06/2014. We selected 25 patients (10 female/15 male, ages from 9 to 19) with at least two scans, where the second scan was acquired 6 months to 2 years apart from the first scan. One patient had an incomplete acquisition and was removed from the analysis. Radiological findings of liver and spleen were normal for these Crohn's Disease patients.

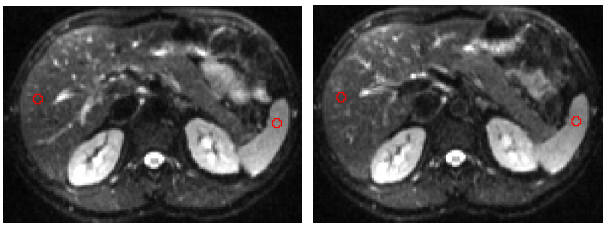

Fig. 1: Two b-value=0 images from a healthy volunteer scanned in the same session. For each voxels in the ROIs circled in red, we compute CV% of parameters obtained using IVIM, SCIM and SPIM models of.

We obtained diffusion parameter estimates with three different models; the IVIM model, the spatially-constrained IVIM model (SCIM)[6], 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 longitudinal reproducibility of the parameter estimates from the 3 models as follows. We first placed a region of interest (ROI) in corresponding areas of the liver on each longitudinal scan, with the help of anatomical landmarks (Fig. 1). We then calculated the percentage of coefficient of variation (CV%=standard deviation/mean x100) of each parameter over time for each voxel in the ROI. Finally, a mean CV% was computed. This measure indicates how much parameter estimates vary over different scans acquired at different time points, either within the same session or in different sessions.

Results: Fig. 2 shows the bar plot of intra-session CV% with error bars showing the variations over five subjects. IVIM parameters had intra-session mean CV% of 22±11, 76±33 and 34±19 while SPIM parameters had lower mean CV% values of 14±7, 29±12 and 23±12 for D, D* and f respectively over five subjects in liver. Fig. 3 shows the bar plot of inter-session CV%'s for both liver and spleen computed over 24 patients. IVIM parameters had inter-scan mean CV% of 23±25, 75±43 and 46±37 while SPIM parameters had lower mean CV% values of 16±14, 45±34 and 32±21 for D, D* and f respectively over 24 subjects in liver.

Discussion and Conclusion: The longitudinal reproducibility analysis results show that the CV% of the diffusion parameters estimates obtained using the SPIM model were significantly lower in both liver and spleen regions compared to the IVIM model. D* had the largest CV% among three parameters. The CV% of D* decreased 47% for intra-session and 30% for inter-session estimations when using SPIM instead of IVIM in liver. SPIM model also improved CV% compared to SCIM especially in liver, which might be related to using a model that better represents the heterogeneity of fast diffusion.

Unlike previous work[3], we characterize the CV% for each voxel rather than the mean CV% of the parameter estimate over a region because the latter approach is less sensitive to local heterogeneity. Future work aims at evaluation of CV% of parameters estimated using SPIM model in diseased regions such as heterogeneous malignant liver tumors.

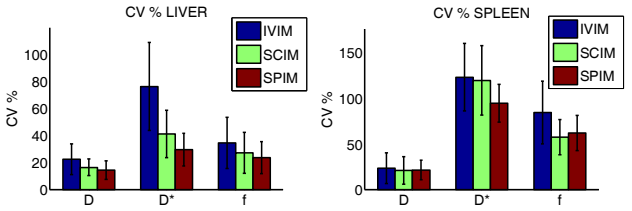

Fig. 2: Intra-session coefficient of variation percent (CV%) of D, D* and f parameters computed using IVIM, SCIM and SPIM models in liver (left) and spleen regions (right) of five healthy volunteers.

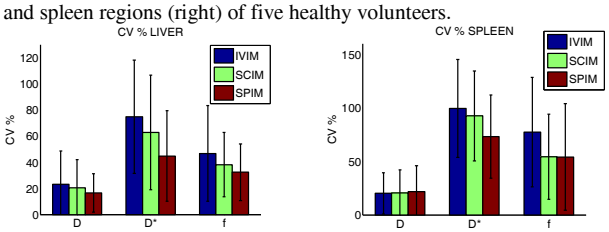

Fig. 3: Inter-session coefficient of variation percent (CV%) of D, D* and f parameters computed using IVIM, SCIM and SPIM models in liver (left) and spleen regions (right) of 24 subjects with bowel disease.

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