Intra-voxel incoherent motion modelling of diffusion weighted MRI data is feasible in 5 minutes scan time

Oliver Gurney-Champion[1,2], Martijn Froeling[3], Remy Klaassen[4,5], Hanneke W.M. van Laarhoven[4], Jaap Stoker[1], Arjan Bel[2], and Aart J. Nederveen[1]

[1]Radiology, Academic Medical Center, Amsterdam, Netherlands, [2]Radiation Oncology, Academic Medical Center, Amsterdam, Netherlands, [3]Radiology, University Medical Center Utrecht, Utrecht, Netherlands, [4]Department of Medical Oncology, Academic Medical Center, Amsterdam, Netherlands, [5]Laboratory for Experimental Oncology and Radiobiology, Academic Medical Center, Amsterdam, Netherlands

Target audience: Clinical physicists and clinicians involved in optimizing diffusion weighted imaging

Purpose: The intra-voxel incoherent motion (IVIM) model for diffusion weighted (DW) MRI takes into account the effects of perfusion in addition to diffusion. The model is promising as its parameters *f* (perfusion fraction), *D* (diffusion coefficient) and *D** (pseudo diffusion coefficient) can be used for lesion characterization, for example in the liver and pancreas, and can possibly enable treatment response monitoring.[1,2] However, IVIM-measurements take long (≥10 minutes) as images from multiple diffusion weightings (b-values) are required to fit the IVIM-model and often multiple images per b-value (averages) are required to increase signal to noise ratio. Due to this long acquisition time, the IVIM-model is not widely used in clinical practice. Therefore, our aim was to minimize the acquisition time, by determining the minimum number of b-values and averages per b-value needed for precise and accurate IVIM-measurements of the pancreas and liver.

Methods: We implemented an abdominal IVIM-imaging sequence and developed an in-house post-processing toolkit. We scanned 16 healthy volunteers (8 male, mean age 28 years) twice in two sessions, using a 3T MRI scanner (Philips Ingenia). Scans were obtained under respiratory triggering using a single-shot echo-planar sequence: voxel size 3x3x3.7 mm^3, 0.3 mm slice gap, FOV=432x108x72 mm^3, TE/TR=44/2300 ms, BW=62.5 Hz/voxel. We obtained 9 averages (3×3 directions) per b-value for 14 b-values (0, 10, 20, 30, 40, 50, 65, 80, 100, 125, 175, 275, 375 and 500 s/mm^2). In our postprocessing toolkit (Fig 1) all DW images were denoised using a Rician adaptive non-local means filter.[3] Then, slices with signal drop-out due to cardiac motion were removed. Finally, the elastix package was used to perform a mutual information based non-rigid registration to deal with the potential limited performance of respiratory triggers, peristaltic motion and eddy currents.[4] After post-processing we selected regions of interest (ROIs) on the resulting images, containing the entire pancreas, the entire liver, part of the pancreas (12×12×12 mm^3) or part of the liver (12×12×12 mm^3). We averaged all data within each ROI and fitted the IVIM-model to the data. In these fits, we fixed *D** to values obtained from fits of all pancreatic and liver data (D^*_p=0.0453 mm^2/s and D^*_l=0.0659 mm^2/s respectively). To study the accuracy of the IVIM model parameters as function of number of averages and b-values taken along, we calculate the deviation of the mean value of *D* and *f* from the mean *D* and *f* determined from the full data set. To study the precision we also do this for the within subject coefficient of variation (CV) of *D* and *f*. We also determine the total acquisition time. In this analysis, b-values exclusion was done according to the following scheme: 175, 375, 65, 125, 80, 40, 250, 30, 10, 20 and 50 s/mm^2. Finally, we select the optimal combination of b-values and averages by minimizing acquisition time, without compromising in systematic errors and the CVs, and generated *D* and *f* maps from this limited set. We compared these maps to *D* and *f* maps generated using all b-values and averages.

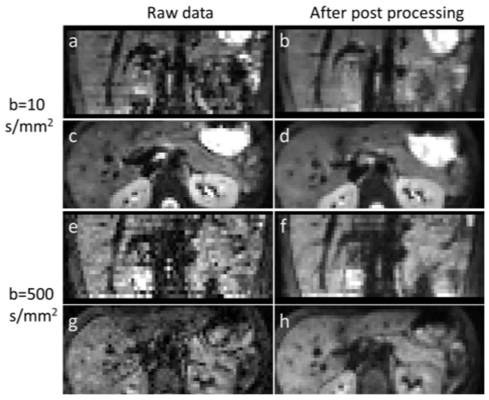

Fig 1: Example images from a slice **(c,d,g,h)** and through slice **(a,b,e,f)** of the data as acquired **(a,c,e,g)** and after post processing **(b,d,f,h)** for images from b=10 s/mm^2 **(a–d)** and b=500s/mm^2 **(e–h)**.

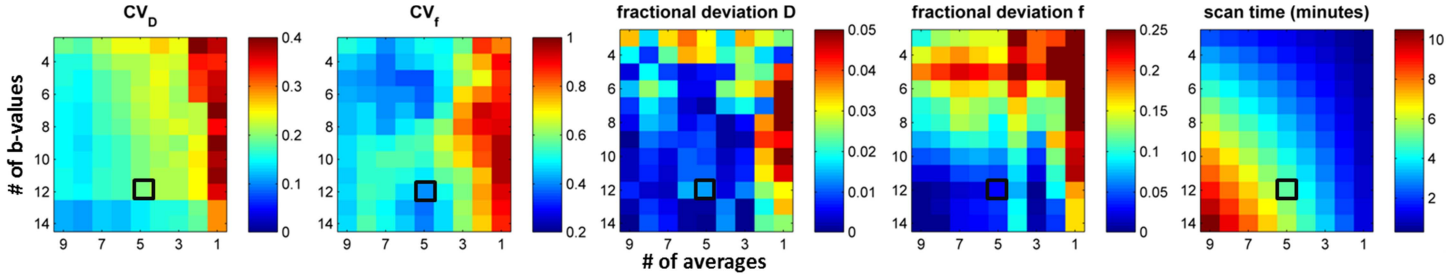

Fig 2: Plots of the fractional difference in D and f compared to the full measurement as well as CVs of D (CV_D) and f (CV_f) and the total scan time, as function of the # of b-values (vertical axes) and # of averages (horizontal axes) for the small ROI (12×12×12 mm^3) in the pancreas. Similar results were found for the small ROI in the liver. The black square indicates the setting we selected as optimal.

Results: Taking all b-values and averages into account and fitting the model to the entire pancreas, we found CVs of CV_f=0.25 and CV_D=0.05 for *f* and *D*, respectively. For data from the entire liver these values were CV_f=0.41 and CV_D=0.09. For data from the smaller ROIs, CVs increased to CV_f=0.47 and CV_D=0.12 for the pancreas and CV_f=0.51 and CV_D=0.14 for the liver. We found a mean *D* of 0.0013 mm^2/s and *f* of 0.075 for the small ROI in the pancreas and a mean *D* of 0.0010 mm^2/s and *f* of 0.062 in the liver. The CVs, and thus the precision, improved mainly by increasing the number of averages (Fig 2). The fractional deviations depended also on the number of b-values taken along (Fig 2). We believe that decreasing the number of b-values leads to underdetermining the IVIM model, which introduced systematic errors; this decreased the accuracy and thus increased the fractional deviations. The plots provided here facilitate visualisation of the trade-off between acquisition time and robustness for different acquisition strategies. The optimal settings will depend on the users goal. We believed that the combination of 5 averages and 12 b-values should give robust IVIM-measurements. Fitting to such a limited set of measurements yielded similar *D* and *f* maps when compared to fits to the full set of measurements (Fig 3). It has been shown in simulations that a different choice of b-values may improve the robustness of IVIM measurements. Therefore our choice on how to delete the b-values could influence the results. However, we looked into 3 different schemes of deleting b-values and found no major differences.

Conclusion: In this work we show that obtaining 12 b-values with 5 averages yields the best compromise between scan time and data quality for IVIM-measurements in the liver and pancreas. Using our approach we have decreased measurement time from 10 minutes to 5 minutes without losing robustness.

References: [1] A. Lemke et al., Invest. Radiol. **44**, 769–75 2009. [2] D.M. Koh, Radiology **272**, 307–8 2014. [3] J. V Manj ón et al., JMRI **31**, 192–203 2010. [4] S. Klein et al., IEEE Trans. Med. Imaging **29**, 196–205 2010.

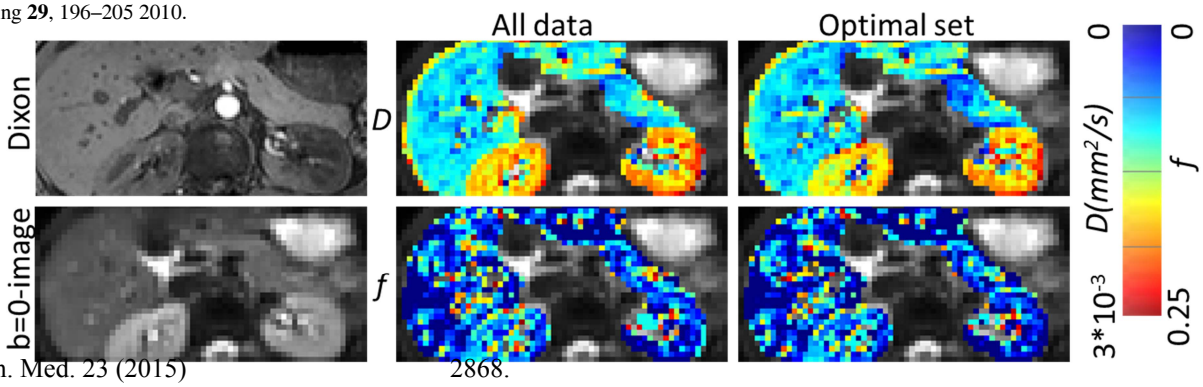

Fig 3: Reconstructed parameter maps of *f* and *D* using all data (middle) or our selected optimal set (5 averages, 12 b-values) (right) for a healthy volunteer. Note that maps look similar, indicating that measuring 5 averages and 12 b-values is sufficient for IVIM in the pancreas and liver.