

# ROBUST DATA FITTING FOR IVIM IMAGING OF THORACIC LESIONS

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## Purpose

Intravoxel incoherent motion (IVIM) imaging<sup>1</sup> can be used to quantify the influence of microscopic perfusion-related motion on diffusion-weighted images (DWI) and differentiate it from pure molecular diffusion. IVIM has the potential to provide valuable clinical information about the microcirculation in the capillary network of malignant body tumors. This information holds great value for the determination of tumor viability as well as the prediction of therapy outcome.

In order to determine the diffusion and perfusion parameters, a sequence of DWI acquisitions with increasing diffusion-sensitizing gradient magnitude is acquired. A model of the influence of diffusion and perfusion on the signal intensity is then fitted to this sequence. The quality of the final result is, therefore, very sensitive to deviations from the model, such as those caused by patient motion between the acquisitions.

We study here the use of robust regression techniques to enable IVIM analysis in the presence of outliers, like those caused by physiological motion, when imaging lesions in the thorax and upper abdomen.

## Methods

Data was acquired from ten oncology patients using a tri-modality setup consisting of a GE Discovery 690 PET/CT in an adjacent room to a Discovery 750w MR. The MR table can be undocked and moved to the PET/CT room, where a special device is used to transfer the patient without altering his position. The PET/CT acquisition followed the standard clinical protocol for an oncological whole-body study. The MR acquisition consisted of a series of 25 respiratory-gated DWI acquisitions covering 10-15 slices centered on the lesion of interest ( $b = \{0, 15, 30, 45, 60, 75, 90, 110, 130, 150, 170, 185, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 1000\}$ , TE 69, BW 250, ST 8, matrix 128x96). The acquisition time oscillated between 4 and 5 minutes.

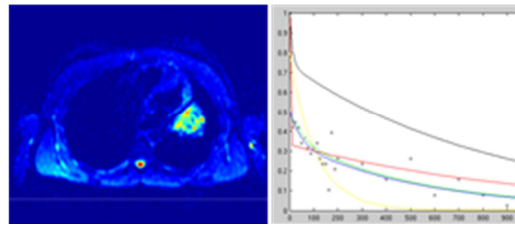


Figure 2 – DWI samples of a voxel in a lung tumor, fitted with standard (red) and robust (blue) methods.

The acquired data were retrospectively fitted with a bi-exponential model:  $F = (1 - f)e^{-bD} + fe^{-b(D+D^*)}$ , where  $f$  is the perfusion fraction,  $D$  is the diffusion coefficient and  $D^*$  is the pseudo-diffusion (perfusion) coefficient. The data fitting problem was first solved in the least squares sense using a trust region algorithm. Secondly, the fitting problem was solved again using a robust method, the iteratively reweighted least squares algorithm<sup>2</sup>. This algorithm solves objective functions of the form:  $\arg \min_p \sum_{i=0}^{n-1} w_i(p) |y_i - f_i(p)|^2$ , where  $y_i$  are the measured data,  $f(p)$  is a parametric model being fitted to the data and  $w(p)$  is a weighting function that mitigates the influence of outliers. In our tests, a bisquare weighting of the residuals was used.

## Results

From a qualitative point of view, the robust fitting consistently achieved an improved fit of the DWI samples, leading to better uniformity of the resulting diffusion and perfusion fraction maps. It was noticed that this improvement in uniformity led to easier correlation of the results with the corresponding morphological images and interpretation. Localized errors in the data fitting, previously perceived as hot or cold spots in the images, were noticeably reduced, especially in the  $D^*$  map.

A quantitative estimation of the data fitting improvement was obtained by comparing, for each voxel, the median of the squared residuals obtained with each algorithm. Using this measure, the robust fit was shown to increase the accuracy of the fit in 84% of the voxels. From the clinical point of view, the use of robust fitting led to a noticeable change in the estimated metabolic parameters over the entire image. This effect was particularly noticeable in the perfusion fraction, which showed an average increase of 16% with respect to the standard least squares fit.

## Discussion

The use of well-known robust data fitting on IVIM datasets leads to an objective improvement of the model fit. The resulting parametric maps, and in particular those of perfusion fraction and pseudo-diffusion coefficient, are significantly different from those obtained using standard processing. The validation of these results, however, poses a considerable challenge due to the lack of ground truth data. Ongoing work is being carried out to compare IVIM results with concurrent PET, T2-weighted STIR and (when available) CE-MR. A database of oncology patients with large lesions in the liver, pancreas, spleen and lung is being gathered for this purpose.

The model seems particularly sensitive to normalization errors due to outliers in the low-gradient images ( $b < 100$ ). These often lead to an overestimation of the pseudo-diffusion parameter. Robust fitting did not suffice to compensate this issue in our tests. We are currently re-designing our acquisition protocol in an attempt to minimize the problem.

## Conclusion

The results show that robust data fitting techniques may enable the use of intravoxel incoherent motion models on diffusion series of thoracic regions affected by movement artifacts. Ongoing work is aimed at comparing the obtained results with those of concurrent PET and CE-MR acquisitions.

## References

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2. Holland PW, Welsch RE. Robust Regression Using Iteratively Reweighted Least-Squares. *Communications in Statistics: Theory and Methods*. 1977;A6:813-827.

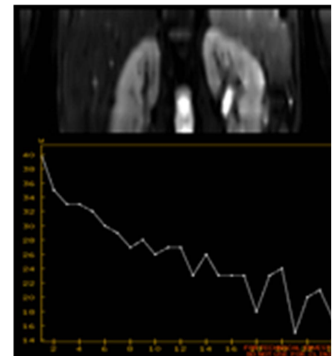


Figure 1 – Coronal view of a DWI frame and profile from a liver voxel.

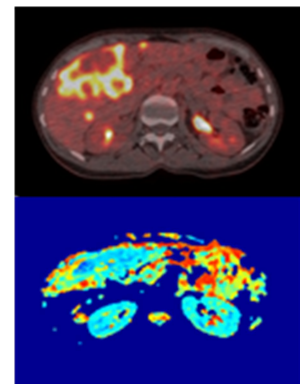


Figure 3 – Axial PET/CT view of a liver lesion and corresponding  $D^*$  map.