THE INFLUENCE OF PERFUSION REGIME AND T2 RELAXATION ON IVIM IMAGING PARAMETER ESTIMATION

Sonia Isabel Goncalves[1,2], Filipe Caseiro Alves[1,2], and Miguel Castelo Branco[1,3]

[1]*Medical Faculty, University Coimbra, Coimbra, Coimbra, Portugal,* [2]*Radiology, University Hospital Coimbra, Coimbra, Coimbra, Portugal,* [3]*Biomedical Institute for Research in Light and Image, University of Coimbra, Coimbra, Coimbra, Portugal*

Purpose

Intra-voxel incoherent motion (IVIM) imaging differentiates between true molecular diffusion or slow diffusion (*D*), diffusion due to perfusion or fast diffusion (*D**), and quantifies perfusion fraction (*f*). IVIM imaging has been applied to characterize and stage, in a non-invasive way, several pathological changes of the liver [1-3]. Results from its clinical application have been ambiguous. For instance, the results of the magnitude of change of parameters *D*, *D** and *fp* in the setting of diffuse liver diseases such as cirrhosis or steatosis [1,2] have been quite different. Although its applicability has been demonstrated, the b-value range is normally chosen heuristically and the effect of T2 relaxation on diffusion parameter estimation using the IVIM concept is often neglected. In [4] and [5] methods have been proposed to optimize b-value distribution so that the errors associated with *D*, *D** and *f* are minimized. In [4] an approach based on Monte Carlo simulations is used whereas in [5] the optimal b-value combination is chosen through the minimization of an error propagation factor. In this paper, we hypothesize that different perfusion regimes will have different error behavior associated with *D*, *D** and *f* and that T2 relaxation effects will have an impact on the error behavior of the optimal b-value distribution. In order to investigate this, we will apply the method proposed in [5].

Methods

The IVIM signal follows a bi-exponential model combining the effects of slow and fast diffusion:

$$S = S_0\left((1-f)e^{-bD} + fe^{-b(D^*+D)}\right) \quad (1)$$

where S_0 is the nominal signal intensity for b=0. In order to estimate the error propagated into the IVIM parameters of different perfusion regimes, the error propagation factor as defined in [5] was implemented and the total error propagated into S_0, *D*, *D** and *f* by the optimal b-value distribution was computed for different combinations of (*D**, *f*), where *D** ranged from 0.01 to 0.15 mm^2/s and *f* ranged from 0.1 to 0.4, whereas S_0 and *D* were kept fixed at 100 and 0.00123 mm^2/s respectively. The total propagated error was computed considering equal weights for the individual errors of S_0, *D*, *D** and *f*. The optimization was performed for combinations of 5, 8, 10 and 16 b-values and the maximum b-value was constrained to 800. To test T2 relaxation effects on the error behavior associated with IVIM parameter estimation using the optimized b-value distribution with 8 b-values under different perfusion regimes, IVIM signal including T2 relaxation effects was simulated using the signal model in [1] affected by the $e^{-TE/T2}$ multiplication factor, where TE is the echo time. Rician noise with SNR equal to 50 was added to the simulated data. The relative error associated with the estimation of *D**, *D* and *f* were calculated for TE values ranging from 50 to 100 ms and for T2=34 ms (liver T2 relaxation value at 3T [6]). A comparison was made with the results obtained with conventional equidistant b-value sampling with 8 b-values (0, 20, 40, 80, 100, 200, 400, 800) and 16 b-values (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 200, 400, 800).

Results

In figure 1, representative results of the error propagated into IVIM estimations is shown for different perfusion rate (PR) regimes, defined as *D**× *f* [5]. In lower perfusion rates (A) the error propagated into S_0, *D*, *D** and *f* is larger than for higher perfusion rates (B). Furthermore, for the same perfusion rate conditions, the propagated error is larger for very low or very high *D** values. Finally and depending on the perfusion rate regime, the use of a larger number of b-values either decreases (A, D*=0.03), only marginally decreases (B, D*=0.08) or does not have an appreciable effect ((A, D*=0.01), (B, D*=0.15)) on the propagated error. In figure 2A, the effect of intrinsic decrease in SNR due to TE increase is shown for *D**. Further simulation parameters were *D* and *D** equal to 0.00123 and 0.08 respectively, f equal to 0.2 and background rician noise amplitude corresponding to SNR=50. It shows that the optimal parameter distribution with 8-b values (0, 11, 11, 80, 80, 80, 177, 800) performs better than its equidistant counterpart either with 8 or 16 b-values. A similar behavior was observed in the error of *f* (results not show), with the optimal distribution performing better than its equidistant counterpart but less well than the equidistant 16 b-value distribution. Parameter D showed the smallest relative error (results not shown) and also here, the optimum parameter distribution performed best. The effects of T2 relaxation in the error performance for high *D**=0.15 mm^2/s and low *f*=0.1 show (fig. 2B) that the optimum b-value distribution yields better estimations of D* than its equidistant counterpart. However, for TE>80 ms, the error increases well above (points not shown in the depicted scale) that of the other 2 non-optimal distributions. Similar results (not shown) were found for *D* but not for *f*. Here, the optimum b-value distribution performed better that the equidistant distribution with 8 b-values but less well than the equidistant distribution with 16 b-values.

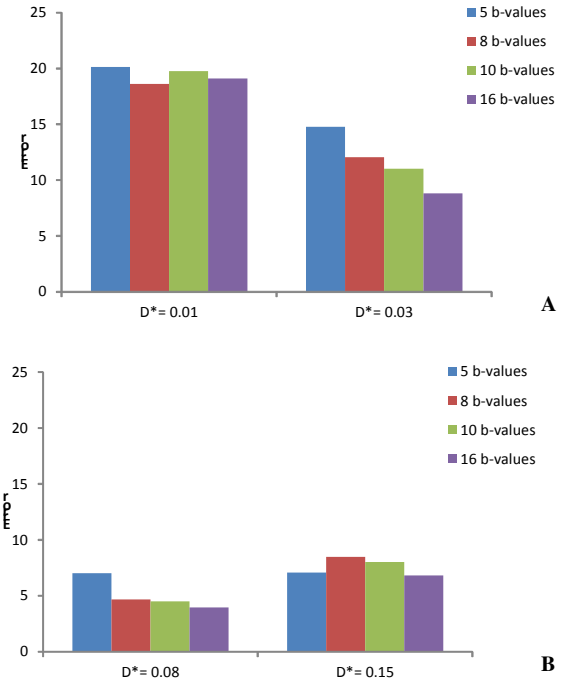

Figure 1. A) PR = 0.003 mm^2/s b) PR = 0.016 mm^2/s

Discussion

IVIM diffusion parameter estimation, and in particular, the error in *D** and *f* estimation increase rapidly with SNR decrease, whether by larger noise amplitude or lower signal amplitude due to T2 relaxation effect. Approaches have been proposed to optimize the b-value distribution so that the error associated with IVIM parameter estimation is minimized. In this simulation study we show that the error minimization obtained by the optimal b-value distribution is highly dependent on the perfusion regime (Fig. 1), and within each perfusion regime, it depends on the relative magnitudes of *D** and *f*. Additionally, the error magnitude for the optimal b-value distribution with increasing TE also depends on the perfusion regime, being that for large D* and long TEs, the optimal b-value distribution can even underperform other non-optimal b-value distributions.

Conclusions

Most of the liver clinical IVIM applications [1,4] are based on and heuristic choice of b-value distribution and thus largely overlook the possible effects on the error propagated into IVIM parameters. This might become more relevant when targeting e.g. pure liver inflammation or inflammation with steatosis that potentially represent different perfusion regimes. The calculation of optimal b-value distribution should take into account not only T2 relaxation effects, that may become especially important in the presence of iron deposition, but also differentiated error weights for *D*, *D** and *f*, depending on the expected perfusion regime.

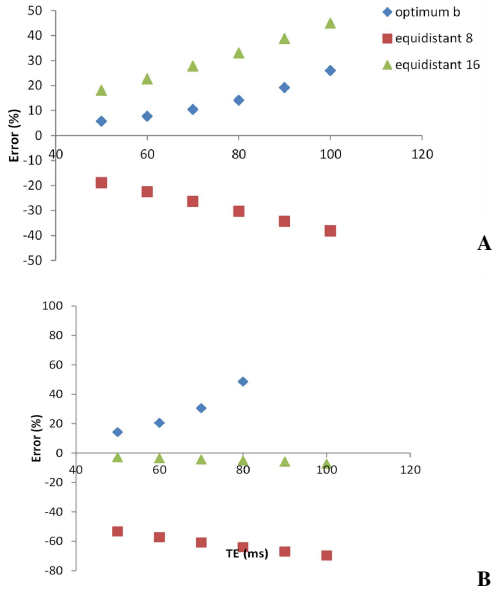

Figure 2. Error in D* estimation.

References

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