A comparison of the full and segmented IVIM models in the liver

Alexander D Cohen[1], Moira F Schieke[2], and Kathleen M Schmainda[2]
[1]Biophysics, Medical College of Wisconsin, Milwaukee, WI, United States, [2]Radiology, Medical College of Wisconsin, Milwaukee, WI, United States

Target Audience

Body imaging researchers and clinicians

Purpose

Intravoxel Incoherent Motion (IVIM) imaging has been increasingly used in body MRI to assess liver cirrhosis[1,2] and to evaluate renal lesions[3], however, the best way to collect and analyze this data remains unknown. The IVIM technique involves the collection of multiple b-values to extract perfusion-related diffusion parameters. Data can be collected in a breath hold (BH), during free breathing (FB), or respiratory triggered (RT) and with different diffusion directions and diffusion weightings (b-values). The 3dir method acquires three orthogonal directions and averages them while the 3in1 method applies three gradient directions simultaneously. Furthermore, there are multiple ways to calculate IVIM parameters. The segmented technique involves using only high b-values to calculate a perfusion insensitive diffusion parameter and fractional perfusion. The full technique involves fitting the entire equation. This study examines the parameter values and repeatability of the two fitting techniques for various combinations of triggering technique and diffusion direction in the liver of healthy control subjects.

$$\frac{S_b}{S_0} = \left(1 - f_p\right) \cdot e^{-b \cdot D_t} + f_p \cdot e^{-b \cdot D_p} \quad (1)$$

$$S_b = S_{\text{int}} \cdot e^{b \cdot D_t} \quad (2)$$

$$f_p = \frac{\left(S_0 - S_{\text{int}}\right)}{S_0} \quad (3)$$

Methods

Imaging Eight subjects with no known history of abdominal disease participated in this study. Each subject underwent two consecutive imaging sessions on a GE 1.5T scanner. Each session consisted of four DWI scans with various combinations of triggering technique and diffusion directions. FOV ranged from 36-50cm with a slice thickness of 8mm and skip of 2mm. These scans are summarized in Table 1. ***Data Analysis*** IVIM modeling was performed using both the full and segmented models. All curve-fitting analyses were accomplished using Matlab and a Levenberg-Marquardt algorithm. For the full model, the multiple b-value data was fit to Equation 1, where f_p is the fractional perfusion, D_t represents the pure molecular diffusion, and D_p is the pseudodiffusion, or perfusion related diffusion. The segmented approach takes advantage of the fact that since $D_p >> D_t$, it's effect can be neglected when b > 200 s/mm^2. Thus, D_t can be estimated by linearly fitting the natural log of Equation 2, and f_p by evaluating Equation 3. D_p can then be calculated by fitting Equation 1 with f_p and D_t already known. To compare full and segmented IVIM parameters, 20mm radius circular ROIs were drawn in segments 5/6 in the lower right lobe of the liver. Median values of each parameter were extracted on a voxelwise basis within the ROI. The DWI signal was also averaged within the ROI and the averaged signal was then fitted with each model. Repeatability was assessed the within subject coefficient of variation (CV).

Table 1. DWI Scan Parameters

#	b-values (s/mm^2) NEX	Triggering	Diffusion Directions	TE(ms) TR(ms)
1	0 50 100 150 200 400 800 1 1 2 2 2 6 6	FB	3dir	70.6 3000
2	0 50 100 150 200 400 800 1 1 2 2 2 6 6	FB	3in1	63.4 3000
3	0 50 100 150 200 400 800 1 1 2 2 2 6 6	RT	3dir	70.6 Var
4	0 50 100 150 200 400 800 1 1 2 2 2 6 6	RT	3in1	63.4 Var

FB=Free Breathing; RT = Respiratory Triggered; Var = Variable

Table 2. Within subject coefficient of variation (CV)

	fp seg		fp full		Dt seg		Dt full		Dp seg		Dp full		Avg	Avg
	Voxel	ROI	Voxel	ROI	Voxel	ROI	Voxel	ROI	Voxel	ROI	Voxel	ROI	Voxel	ROI
FB 3dir	0.23	0.29	0.14	0.49	0.12	0.11	0.08	0.20	1.48	0.90	1.69	0.74	0.62	0.45
FB 3in1	0.22	0.22	0.25	0.18	0.06	0.07	0.08	0.06	1.48	0.56	1.93	0.45	0.67	0.26
RT 3dir	0.11	0.08	0.09	0.06	0.05	0.05	0.04	0.04	0.91	0.51	0.33	0.48	0.25	0.20
RT 3in1	0.12	0.09	0.12	0.04	0.10	0.12	0.07	0.10	0.26	0.59	0.96	0.50	0.27	0.24
Avg	0.17	0.17	0.15	0.19	0.08	0.09	0.07	0.10	1.03	0.64	1.23	0.54		

FB=Free Breathing; RT = Respiratory Triggered; seg = segmented model; full = full model

Results

Example parametric maps are shown in Figure 1. Maps produced using the segmented model were qualitatively better than the maps produced with the full model as they had fewer outlier values caused by non-linear fitting errors. Statistical results are shown in Table 2 and Table 3. The CV was comparable between the segmented and full models. The results were mixed when comparing the voxelwise and ROI-based analysis methods. The ROI method tended to have lower CV values than the voxelwise method. This seemed to be driven by the psuedodiffusion term, which had a markedly lower CV for the ROI-based method compared to the voxelwise method. Finally, in terms of scan type, the RT scans tended to have lower CV values compared to the FB scans. The average values of all parameters were not significantly different between the full and segmented model except for the fractional perfusion calculated with the voxelwise method, where the full model gave significantly higher values compared to the segmented model (p=0.003).

Table 3. Average Values

		Voxel	ROI
f_p	Seg	0.256	0.259
	Full	0.312	0.253
D_t (mm2/s)	Seg	0.00104	0.00103
	Full	0.00103	0.00106
D_p (mm2/s)	Seg	0.041	0.042
	Full	0.039	0.050

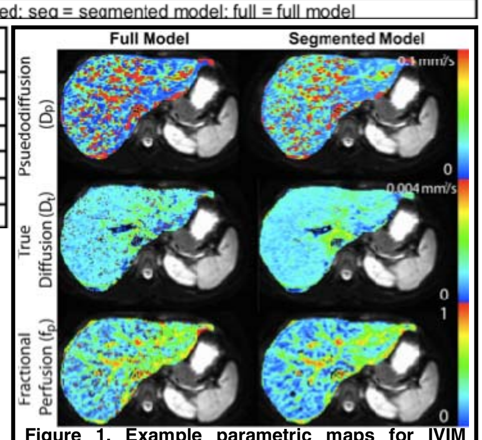

Figure 1. Example parametric maps for IVIM parameters for the full and segmented models.

Discussion

The segmented method for calculating IVIM parameters tends to be more robust than the full method leading to parameter maps that are qualitatively better. With the segmented method, the calculation of f_p and D_t amounts to a linear fitting of the signal from the high b-value data and a subsequent non-linear fit to extract D_p. With the full model, the calculation of all parameters results from a non-linear fit of three variables and leads to more fitting errors. Another advantage of the segmented method is it is computationally faster. The linear fit of Equation 2 can be accomplished almost instantaneously.

Conclusion

The segmented and full IVIM models had comparable repeatability metrics. Due to lower CV values compared to FB scans, RT scans are recommended for IVIM liver studies. The segmented model can be used when generating parametric maps and performing a voxelwise analysis to speed up computation time without compromising repeatability.

References

1. Luciani A et al. Radiology. 249(3):891-9, 2008. 2. Patel J et al. JMRI. 31:589-600, 2010. 3. Chandarana H et al. Invest Radiol. 46(5):285-91, 2011.