The repeatability of ADC and IVIM metrics in the liver: A comparison of free breathing, respiratory triggered, and breathhold techniques

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Target Audience
Researchers and clinicians interested in body/liver imaging and disease, with a particular interest in diffusion imaging

Purpose Diffusion weighted imaging (DWI) in the body poses problems not seen with DWI in the brain. Organs in the body, including the liver, are sensitive to artifacts from breathing and and/or cardiac-induced motion. As a result, most body images are collected within a single breath hold or are respiratory and/or cardiac gated. In addition, DWI images can be acquired with different diffusion directions. The most common methods are to acquire three orthogonal directions (3dir), apply three gradient directions simultaneously (3in1), or acquire only one direction (1dir). The best method for each organ is still unknown. The IVIM DWI technique involves the collection of multiple b-values and fitting the data with a biexponential model. This model assumes a voxel can be divided into intravascular and extravascular components and allows for the extraction of perfusion related components. IVIM parameters have been shown to be different in cirrhotic livers compared to normal livers[1,2]. However, the addition of extra b-values also lead to scans that are too long to be accomplished in a single breath hold. While IVIM DWI has the potential to provide clinically relevant information, above and beyond what is provided with anatomical imaging, little is known about the optimal imaging settings to use when collecting these types of images. In this study, a comprehensive analysis is done to determine the optimal imaging parameters for DWI and IVIM parameter repeatability.

Methods 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 six 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. Additional imaging parameters are summarized in Table 1. IVIM modeling was accomplished using Equation 1 where f_p is the fractional perfusion, D_t represents the pure molecular diffusion value (ie without perfusion effects), and D_p is the pseudodiffusion, or perfusion related diffusion. For this analysis, a segmented approach was conducted using methods previously published[2]. The segmented method involves using only high b-values to estimate D_t and f_p. D_p can then be calculated by fitting Equation 1 with D_t and f_p known. All curve-fitting analyses were performed in Matlab using a Levenberg-Marquardt algorithm. ADC was calculated using all b-values (ADC All), b=0,800 s/mm^2 (ADC 0,800) and b=50,800 s/mm^2 (ADC 50,800). ROIs with 20mm circular radii were drawn in segments 5/6 in the lower right lobe of the liver. Median values were extracted voxelwise within the ROI for each parameter. Repeatability was then assessed for IVIM and ADC parameters using the within subject coefficient of variation (CV) defined as the standard deviation divided by the mean. For BH scans only ADC was compared since not enough b-values were collected to perform an IVIM analysis.

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
5	0 50 400 800 1 1 1 1	BH	3dir	70.6 3000
6	0 50 400 800 1 1 2 3	BH	3in1	63.4 3000

FB=Free Breathing; RT = Respiratory Triggered; BH = Breath Hold

Table 2. IVIM CV

	f_p	D_t	D_p	Avg
FB 3dir	0.23	0.12	1.48	0.61
FB 3in1	0.22	0.064	1.48	0.59
RT 3dir	0.11	0.049	0.91	0.35
RT 3in1	0.12	0.096	0.26	0.16
Avg	0.17	0.083	1.03	0.43

FB=Free Breathing; RT=Respiratory Triggered; CV = Coefficient of Variation

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

Table 3. ADC CV

	ADC	ADC 0,800	ADC 50,800	Avg
FB 3dir	0.049	0.047	0.062	0.053
FB 3in1	0.144	0.082	0.080	0.102
RT 3dir	0.041	0.037	0.055	0.044
RT 3in1	0.065	0.060	0.079	0.068
BH 3dir	0.032	0.041	0.065	0.046
BH 3in1	0.060	0.052	0.070	0.061
Avg	0.065	0.053	0.069	0.062

FB=Free Breathing; RT=Respiratory Triggered; CV=Coefficient of Variation

Results Example parametric maps for fractional perfusion are shown in Figure 1. Repeatability results are shown in Table 2 and Table 3. For ADC the CV results were comparable for all scans. The average CV was highest for FB 3in1 scans and lowest for RT 3dir scans. For IVIM parameters, the CV results were significantly higher than for ADC. This was driven by D_p, which was extremely variable and much less repeatable. The RT 3in1 scans had the lowest CV. The f_p and D_t parameters were more repeatable with CV ranging from 0.049 to 0.231. Overall, D_t was the most repeatable IVIM metric and ADC 0,800 was the most repeatable ADC metric.

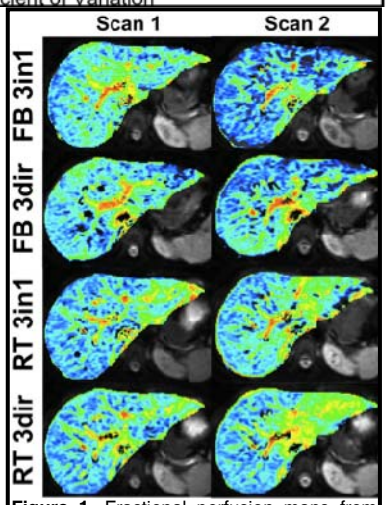

Figure 1. Fractional perfusion maps from one representative subject

Discussion One issue with multiple b-value DWI in the liver is respiratory motion and subsequent misregistration between b-values. In FB DWI this can be somewhat alleviated by performing multiple averages. In theory, RT DWI should provide better registration between b-values. RT scans tended to have lower CV values. Qualitatively, RT scans provided better coregistration between b-values. DWI with the 3in1 diffusion direction has shorter TE than 3dir scans leading to higher SNR in the short T2 liver environment. The 3dir DWI technique takes ~3 times longer to acquire than 3in1 due to three separate images being acquired, one for each of the x, y, and z directions. This also leads to increased SNR as each diffusion direction is essentially an additional average. D_p results were extremely variable and not repeatable. Low b-values drive the calculation of D_p. Different low b-values or more averages for low b-values may lead to better D_p repeatability. Overall, RT 3in1 gave the best repeatability for with all IVIM parameters having an coefficient of variation less than 26%. For the same approach the variability in ADC was less than 8% for all combinations of b-values. This suggests that differences of greater than 30% for IVIM parameters, and differences of greater than 8% for ADC parameters are necessary in order to detect true differences that might occur with pathology or treatment.

Conclusion
ADC values were repeatable regardless of scan type. IVIM parameters were more variable with CV being lower for RT scans.

References
1. Luciani A et al. Radiology. 249(3):891-9, 2008. 2. Patel J et al. JMRI. 31:589-600, 2010.