Abdominal diffusion imaging parameters from free-breathing multiple-averaged and finely-sampled decay curves compared to acquisition using active breathing control

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Introduction: Diffusion-weighted MRI (DWI) in the abdomen is confounded by blurring arising from respiratory motion; while respiratory motion can be effectively excluded by breath-holding or use of an Active Breathing Coordinator (ABC) [1], free-breathing strategy can still yield useful DWI parameters while retaining patient comfort [2]. Optimal choice of diffusion model, and thus corresponding b-values, is still the subject of much discussion [3]. The number of images acquired for a clinical DWI protocol with 4 averages and 9 b-values might equally be used to acquire a single average (with 3 orthogonal diffusion directions) at a larger number of b-values, in order to better characterise tissue diffusion signal attenuation. We evaluate the DWI statistics for normal tissues acquired with 32 and 9 b-value free breathing diffusion protocols (FB32 and FB9), in reference to a similar 32 b-value protocol acquired with an active breathing control device as a 'gold standard' where the respiratory volume is fixed during acquisition.

Method: Imaging: Six consented volunteers underwent DWI on a 1.5 T Aera clinical scanner (Siemens AG, Healthcare, Erlangen, Germany) using three strategies: ABC with 16 sequential breath-hold of 24 seconds (2 volumes) to obtain 32 separate single-average b-values; free-breathing with single-average at the same b-values ('FB32'); free-breathing with 9 b-values with 4 averages recorded separately ('FB9'). In all cases values for diffusion gradients were approximately logarithmic from 5 to 1000 $mm^{-2}s$, with minimum separation 5 $mm^{-2}s$. Common acquisition parameters for all DWI were: 2D EPI sequence (non-product), TR 4000 ms, TE 72 ms, 20 contiguous 5 mm slices, FoV 380 x 344mm, matrix 128 x 116 interpolated, voxel size 3x3mm^2, iPAT factor 2, partial Fourier 7/8, diffusion time 32.9 ms, diffusion gradient duration 18.7 ms, and orthogonal diffusion gradients. **Image Analysis:** Images from a suitable slice were analysed using the bi-exponential IVIM model, as well as some alternative models, using a Markov Chain Monte Carlo algorithm to return values and standard error estimates. Regions of interest (ROIs, approximately 50 to 150 voxels) were placed in regions of tissue that did not overlap moving boundaries, and the median of the ROI diffusion parameters taken. Here we report and discuss the IVIM parameter values, quoted as mean ± standard deviation for the cohort. A paired t-test was used for comparison of acquisition strategies.

Results: The ABC protocol was well-tolerated in volunteers, and controlled motion to an acceptable degree as expected, whereas both free-breathing strategies exhibited respiratory motion blurring (**Figure 1**). The IVIM parameters for the cohort in a selection of abdominal organs are given in **Table 1**, and show the variation between the free-breathing strategies and the motion-controlled ABC acquisitions. In general, IVIM parameters display a variation across the cohort for the ABC acquisition that is not dramatically increased by the presence of motion where the two acquisition strategies are otherwise equivalent (FB32), and no significant differences were found in the parameters (f, D, D*) themselves. Comparison of ABC and FB32 with FB9 gave the following significances: liver vascular fraction f (ABC-FB9, p=0.007), renal cortex pseudodiffusion coefficient D* (FB32-FB9, p=0.037), and spleen diffusion coefficient D (FB32-FB9, p=0.02). Standard error estimates for these parameters (not shown) similarly showed little systematic differences between the acquisition strategies, with no correction performed for multiple comparisons.

Figure 1: IVIM-D maps and corresponding diffusion curve samples for (top) active breathing control, and free-breathing with (middle) matched 32 b-values, and (bottom) 9 b-values with 4 averages.

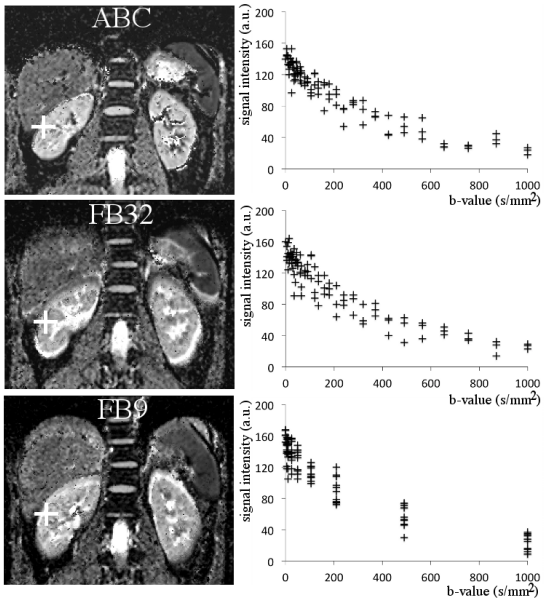

Table 1: Cohort IVIM parameters from different tissue ROIs, acquired under different acquisition strategies. Bold indicates p<0.05, paired t-test.

		ABC	FB32	FB9
Liver	f	26.7 ± 6.5	**28.2 ± 4.8**	**21.5 ± 7.6**
	D	91.7 ± 9.5	102.2 ± 5.8	97.3 ± 12.8
	D*	122.1 ± 72.7	105.5 ± 111.2	63.1 ± 20.8
Paraspinal Muscle	f	22.2 ± 9.5	20.8 ± 7.7	20.0 ± 6.1
	D	111.6 ± 23.7	110.1 ± 15.8	106.3 ± 15.1
	D*	267.4 ± 122.1	258.6 ± 187.4	200.1 ± 89.9
Renal Cortex	f	22.7 ± 6.2	21.1 ± 6.4	18.9 ± 4.8
	D	194.9 ± 27.2	195.0 ± 20.2	185.7 ± 20.6
	D*	**33.2 ± 20.8**	14.8 ± 1.7	**14.5 ± 6.6**
Spleen	f	8.4 ± 4.7	12.4 ± 7.0	9.5 ± 5.8
	D	**65.3 ± 5.1**	77.7 ± 17.3	**75.9 ± 8.8**
	D*	250.9 ± 301.0	202.1 ± 194.4	158.5 ± 150.4
Verterbral Body	f	20.9 ± 7.1	21.4 ± 10.6	20.6 ± 6.9
	D	38.0 ± 8.5	40.5 ± 9.5	40.4 ± 9.6
	D*	236.4 ± 159.0	262.6 ± 272.9	219.6 ± 154.6

Discussion: While the optimal strategy for acquiring DWI in the body must depend on the type and location of the tissue being examined, the exact acquisition scheme used will depend on the question being asked. Respiratory motion is a potential confounding factor in abdominal DWI, but does not necessarily lead to compromised DWI metrics where the patient is allowed to breathe freely; this may be a result of the large number of b-value samples. For the IVIM model applied to two different free-breathing strategies, significant differences were not found in non-moving tissues (paraspinal muscle and vertebral body) and were largely absent even in moving tissues when ROIs were drawn away from boundaries, although the presence of blurring in the free-breathing diffusion maps indicates that caution must be taken near tissue boundaries and anatomical features. These results suggest that development of an optimal DWI scheme may depend not only on the tissue perfusion/diffusion characteristics, but also on whether the intended data processing path requires multiple samples [4], robustness against diffusion model choice, or processing schemes that require maximized sampling of the diffusion decay curve [5]. Increased data support, either from an increased number of individually acquired b-values or multiple averaging over motion, appear to mitigate the effects of motion.

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