Accuracy of liver tumour apparent diffusion coefficients (ADC) can be improved by selecting optimised b-values

M. Blackledge[1], M. Orton[1], D-M. Koh[1,2], B. Wilton[1], T. Wallace[2], M. O. Leach[1], and D. J. Collins[1]

[1]CR UK Clinical Magnetic Resonance Research Group, Institute of Cancer Research and Royal Marsden Hospital, Sutton, Surrey, United Kingdom, [2]Department of Radiology, Royal Marsden Hospital, Sutton, Surrey, United Kingdom

Introduction: When conducting clinical trials employing quantitative diffusion weighted imaging (DWI) it is necessary to choose optimum b-values so that subsequent ADC calculations are accurate and anatomical contrast is maximized between tumour and the surrounding tissue. To our knowledge optimizations have not yet been applied to liver metastases and so the aim of this research was to utilise recent data from liver studies [1] to calculate the ideal b-values to be used in future trials.

Methods: Images of the entire volume of a sample liver tumour (longest diameter > 2cm) in each of seven patients diagnosed with hepatic metastases were acquired using b = 0 (single acquisition) and b = 50, 100, 250, 500 and 750 s mm^{-2} (x, y, z orthogonal trace) which were used to calculate ADC values. The scanning parameters were; TR = 3500ms, TE = 72 ms, 340 mm FOV, 112x256 matrix with interpolation to 256x256, 6 mm thickness, Grappa factor 2, Averages = 5, free-breathing single-shot fat-suppressed EPI acquisition. In each case ADC maps were calculated for the entire tumour volume using the in-house software 'DiffusionView'. Normalised population histograms were plotted using all ADC data, both pre and post treatment (see figure 1), and the median and quartile values were calculated. Calculations of the optimum b-values for maximum ADC accuracy were performed using a recently reported method [2], which optimises the dimensionless parameter bADC using both the measured SNR_{total} and T2 values of the lesions. T2 values were taken from Funicelli *et al.* [3] who reported that the median T2 value of colorectal hepatic metastasis was in the range 66.5 ± 11.2ms. The data were also used to calculate the b-values that provide optimum image contrast using equation 1 [4] where D_m is the ADC of the metastatic tissue whilst D_b is the ADC of the background liver tissue, quoted at 87 ± 26 mm^2 s^{-1} in [5]. In a follow-up study designed to demonstrate the improvement of ADC accuracy, two patients with liver disease were scanned using the b-values obtained from the analysis to observe improvements. Six lesions in total were identified on b = 1050 s mm^{-2} images which had longest diameter > 2cm and spanned across at least three slices (see figure 2). The improvement in ADC accuracy was shown by calculating normalized cohort ADC histograms where values were calculated using pairs of b = 0 s mm^{-2} with b = 100, 250, 750, 900 and 1050 s mm^{-2} respectively over three contiguous slices for each lesion. Although the correct distribution of ADC values is not known *a priori*, a narrowing in the observed distribution is considered to represent improvement in ADC accuracy under the assumption that the variance of the underlying Gaussian noise distribution is smaller and that the final result may be considered as the convolution of the noise distribution with the real distribution of ADC values.

Results: Both pre and post treatment histograms are shown in figure 1. A value of bADC = 1.1 was estimated for optimal ADC accuracy using methods in [2] giving the following optimum b-values for the histogram parameters.

Table 1 – Results

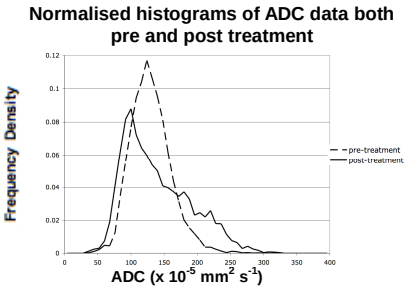
		25th percentile	Median	75th percentile
Pre-treatment	ADC (10^{-5} mm^2 s^{-1})	106.3	124.5	144.5
	Optimum b-values* (s mm^{-2})	**1038.9** *1038.1*	**886.8** *955.7*	**764.0** *882.4*
Post-treatment	ADC (10^{-5} mm^2 s^{-1})	96.5	123.6	167.8
	Optimum b-values* (s mm^{-2})	**1144.3** *1090.8*	**893.5** *959.4*	**658.1** *813.0*

*numbers quoted in **bold** refer to optimization of ADC accuracy whilst those in *italics* refer to contrast optimization

Discussion: From the above results, a range of b-values between 650-1100 s mm^{-2} appears appropriate when investigating the ADC of hepatic metastases and the optimum ratio of images to be averaged between the higher b-value and b = 0 s mm^{-2} is estimated as $r_{21} = e^{bADC} = 3.0$ [2]. Considering that many clinical scanners do not allow an arbitrary choice of b-value, we believe that a single acquisition for b = 0 and a three scan trace for b = 900 s mm^{-2} should be sufficient if only one diffusion weighting is used. For optimal contrast between diseased and normal tissues the median b-value is calculated to be approximately 950 s mm^{-2}. However, taking account of the generally wide distribution of ADC values we confirm that b = 900 s mm^{-2} would also be sufficient for obtaining good anatomical information in the liver. In the follow-up study the distribution of ADC values calculated is indeed observed to be narrowest when using b = 0 with 900 and 1050 s mm^{-2} (figure 3) although in some cases where the tumour is necrotic (red ROI in figure 2) lower b-values would be more suitable.

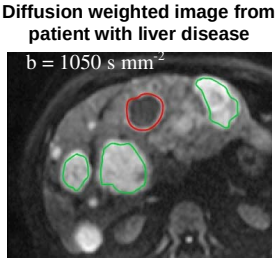
Conclusion: We propose that for DWI studies of liver metastases, b-values of 900 and 0 s mm^{-2} on a 3:1 ratio should be adopted.

Fig. 1



Normalised histograms of the population ADC data. It can be seen that although the median values are similar, the range of ADC values post treatment is larger than that for pre treatment.

Fig. 2



Example b = 1050 s mm^{-2} image from the follow-up study showing 4/6 ROIs from which ADC statistics were calculated. The red ROI displays a lesion that is necrotic.

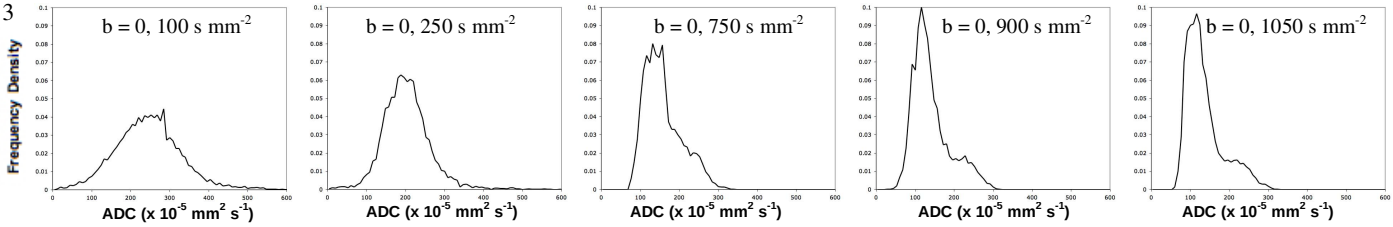
Eq. 1

$$b_C = \frac{\ln(D_m/D_b)}{D_m - D_b}$$

b_C = *b-value for max. contrast*
D_m = ADC of metastases
D_b = ADC of background tissue

Equation used to calculate the b-value that maximises tumour contrast in the liver

Fig. 3



Normalised cohort ADC histograms for the lesions in the follow-up study. The distribution is observed to be narrowest when b values of 0 and 900 s mm^{-2} are used. The high ADC shoulder in the distributions is believed to represent the necrotic tumour regions and is more clearly defined in the higher b-value histograms.

References: [1] Koh *et al.*, Proc 16th Annual Meeting ISMRM 2008 (775). [2] Saritas *et al.*, Proc 16th Annual Meeting ISMRM 2008 (1798). [3] Funicelli *et al.*, Proc 14th Annual Meeting ISMRM 2006 (2265), [4] Kingsley *et al.*, Concepts Mag. Res., 28A (2):155-179, 2005, [5] Yamada *et al.*, Radiol., 210(3):617-623, 1999.

Acknowledgement: This work was supported by Cancer Research UK grant number C1060/A5117 and also NHS funding to the NIHR Biomedical Research Centre.