Optimisation of b-values for Diffusion-Weighted Imaging of the Breast

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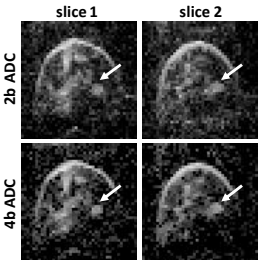
Introduction: Breast DWI has been used in cancer diagnostic and monitoring of treatment response [1]. Accurate calculation of Apparent Diffusion Coefficient (ADC) is essential for those applications, and depends on the choice of b-values employed. From a methodological point of view the problem is known [2-5], but in clinical imaging the choice of b-values is often made without reference to the target ADC range. In this work we utilise ADC data from large untreated breast lesions to calculate optimal b-values tailored to breast DWI, and compare protocols using different numbers of b-values covering the same b-value range.

Methods: All subjects were scanned at 1.5T with approval of the Local Ethics Committee. Large untreated lesions were selected in 8 patients and DWI was performed with b-values b = 0(1), 200(1), 450(1), 900(2) s/mm2 (number of averages in brackets). An experienced radiologist contoured the whole lesion on the slice with the largest cross-section, with reference to the dynamic contrast-enhanced and the T2-weighted images. The cumulative distribution of ADC pixel values was used to calculate the optimal difference between two b-values [2], on the assumption that two b-values adequately averaged could provide a more accurate estimation of the ADC parameter [3]. The influence of the spread of the breast lesion ADC values was taken into account using the fitted histogram distribution as a Probability Density Function [2, 4], assuming that the T2 of breast lesions is sufficiently long compared to the TE values used in the DWI protocol (5mm slice thickness, 340mm FOV, TE = 97ms, SPAIR fat suppression; Philips Intera, Best, Netherlands).



In order to determine the best data acquisition strategy, the clinical protocol was modified to use 4 b-values covering the range of b-values predicted by the simulation. Six sets of DW images with single averages were acquired and combined afterwards to produce two datasets covering the same range of b-values and sharing the same total number of averages (8), thus corresponding to the same total acquisition time. ADC maps were calculated for each dataset and compared within a region of interest comprising the breast lesion (Siemens Avanto, TE = 91ms, FOV= 350mm, 5mm slice thickness, fat suppression by inversion recovery). In addition, one subject with a large lesion had DWI with two different protocols of the same duration: the 2 b-values predicted by the simulation and also with a range of 4 b-values (Philips Intera, TE = 92ms, FOV= 230mm, 5mm slice thickness, SPAIR fat suppression).

Results: Eight large untreated breast lesions comprised 143 to 1236 pixels (352 ± 296 pixels, mean ± standard deviation). Combining the ADC values of all lesions studied, the following distribution was obtained: average ADC 0.99 ± 0.25 10^{-3} mm^2/s (mean ± standard deviation), 1st quartile = 0.79 10^{-3} mm^2/s, median = 0.97 10^{-3} mm^2/s, 3rd quartile = 1.2 10^{-3} mm^2/s. The average ADC value for individual patients ranged from 0.83 ± 0.15 to 1.1 ± 0.22 10^{-3} mm^2/s (mean ± standard deviation). Using the cohort normalized ADC histogram as a Probability Density Function, the optimal difference between the two b-values was calculated to be 1150 s/mm^2, with a ratio of averages 1:3 derived from the density function.

Using b = 0 and b = 1150 s/mm^2 is the most practical implementation of the optimal calculated b-value difference, as larger b-values lead to either excessive eddy-current related distortion or an increase in TE. Therefore six sets of single average DW images were acquired with the following b-values: 0, 350, 700, 1150 s/mm^2, and combined to produce 2b and 4b datasets: b=0(2) and b=1150(6) for the 2b protocol and b = 0(1), 350(2), 700(2) and 1150(3) for the 4b protocol (number of averages in brackets). DW images acquired with b=1150s/mm^2 have values above the noise floor over the lesion only. The ADC map was calculated separately for each dataset and analyzed over the breast lesions.

Subject	Protocol	Average ADC	Standard Deviation	1st Quartile	Median	3rd Quartile	Number of pixels
Subject 1	**2b**	1.19	0.51	0.77	1.31	1.68	50
	4b	1.18	0.49	0.82	1.31	1.58	
Subject 2	**2b**	0.64	0.18	0.52	0.62	0.75	171
	4b	0.61	0.18	0.53	0.63	0.72	

Figure 1 shows ADC maps calculated with the 2b and 4b protocols, covering the same range of b-values up to the ideal b separation predicted in simulations. The correlation between the ADC values calculated with both protocols within the lesion of Figure 1 is 0.86. Table 1 details the results for two different patients examined in different scanners; a small reduction of the standard deviation over the lesion was found with the 4b protocol for one patient. There are however differences elsewhere, as the 4b protocol tends to provide more information on the breast parenchyma, and is less disturbed by artifacts.

Discussion and Conclusions: Large untreated breast lesions are heterogeneous and were shown to contain a wide range of ADC values. The calculated ideal separation between the b-values (1150 s/mm2) is larger than the range of b-values used in many published clinical studies. Using high b-values increases the risk of acquiring data close to or within the noise floor. Considering the range of ADC values measured in breast lesions, the risk of achieving poor or incorrect ADC estimates due to high noise levels is significant. Our data did not show any significant advantage in the use of 2 b-values only, and therefore it may be preferable to use a larger number of b-values to minimize artifacts and to ensure a larger range of ADC values is correctly sampled. Further work is required to consider the typical noise levels in breast DWI and other confounding aspects of the problem such as intra-voxel incoherent motion.

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