Quantification accuracy of ADC measurements from Whole-Body DWIBS

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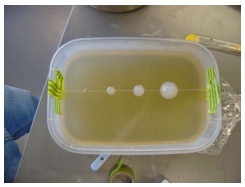
INTRODUCTION: The diffusion-weighted whole-body imaging with background body signal subtraction (DWIBS) technique was introduced in [1] as a qualitative technique for performing clinical diffusion-weighted imaging in the whole body with reasonable spatial resolution and with realistic acquisition times. To deal with motion artefacts, particularly in the torso and abdomen regions, DWIBS uses a signal-averaging approach (typically 4-6 signal averages are acquired), and the resulting PET-like images acquired with high b-factors (typically 1000 s/mm^2) have been used to detect metastases of common tumours [2]. With the growing interest in categorising tumour malignancy according to ADC values, several recent papers have attempted to quantify ADC values using the DWIBS technique [3]. The aim of this work was to assess whether accurate ADC measurements could be made with the DWIBS technique.

METHODS: To investigate the motion-averaging effect on the ADC quantification accuracy of DWIBS, a motion-phantom was developed and imaged using both a standard DWIBS protocol and an accurate gold-standard ADC measurement protocol. The phantom was designed to mimic the liver with several embedded tumours of varying sizes, and could be moved up to 15mm with a motion which mimicked the movement of the liver during the normal respiratory cycle. The background liver tissue was mimicked using 3 wt% agar dissolved in water and doped with 1x10^{-4} M $MnCl_2$ to achieve T_1 and T_2 values typical of liver tissue. 20 wt% PVA-cryogel was processed through four freeze-thaw cycles in order to create a tumour mimicking material. The healthy and tumourous tissue mimics achieved ADC values of 1.9 and 1.2 x10^{-3} mm^2/s respectively. Four tumour targets were produced (5.5, 11.5, 16.5 and 25.5 mm in diameter). The phantom was moved by connecting it via a bellows to the output of a portable ventilator (Oxylog® 3000, Drager Medical, Germany), which produced a physiological respiratory waveform capable of moving the phantom by 15mm in the z-direction (i.e. along the bore, which is the direction of motion of the liver during respiration). All imaging was performed on a 3T Achieva system (Philips Medical Systems, the Netherlands) using a 6-channel SENSE torso array coil. The DWIBS protocol used a standard SE-EPI technique with: TR/TE = 7200/41, voxel size = 3.6 x 3.8 x 4 mm, b-values = 0, 1000 mm^2/s, NSA =6, scan time = 5 min 8 s. The accurate ADC measurement protocol used: TR/TE = 2400/73ms, voxel size = 2.5 x 2.4 x 3 mm, b-values = 0, 200, 400, 600, 800 and 1000 mm^2/s, NSA = 4 for b < 500 mm^2/s and 8 for b > 500 mm^2/s, scan time = 11 min 24 s. The ADC values of the tumour targets calculated with the phantom both static and moving by 15mm, were assessed in two ways: firstly, a region of interest (ROI) was placed in the b = 1000 s/mm^2 image slice which best demonstrated the tumour and then copied to the ADC maps, to replicate a standard radiology approach. Secondly, the tumour target was automatically segmented from all slices using a program developed in Matlab (The Mathworks, USA) and histograms generated of the ADC values in both static and moving situations.



RESULTS: The single ROI analysis revealed no significant change in the mean value of ADC between the different acquisition protocols with the phantom static or moving by 15mm. The results of the segmentation analysis are shown in Figure 1, which compares the ADC values measured for the different-sized targets using the accurate ADC protocol and the DWIBS technique (static and moving by 15 mm). Although the mean ADC values did not change significantly, the standard deviation of the measurements did increase significantly ($p < 0.01$) for all but the 5.5mm target, for which all three ADC measurements were significantly greater than what can be considered to be the true ADC value measured in the 25.5mm target. The increased spread in the measured ADC values is illustrated in Figure 2, which compares the ADC histograms of the 25.5 mm target measured using the DWIBS protocol when static and moving.

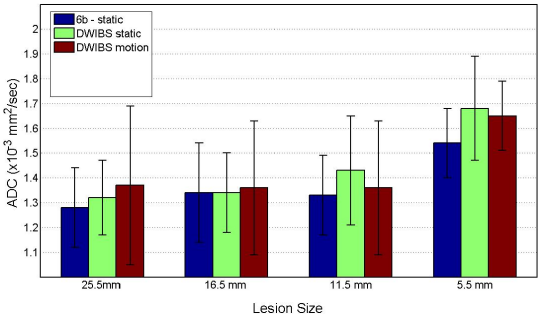


Fig 1: ADC values for targets measured using an accurate ADC protocol and DWIBS for static and moving phantom

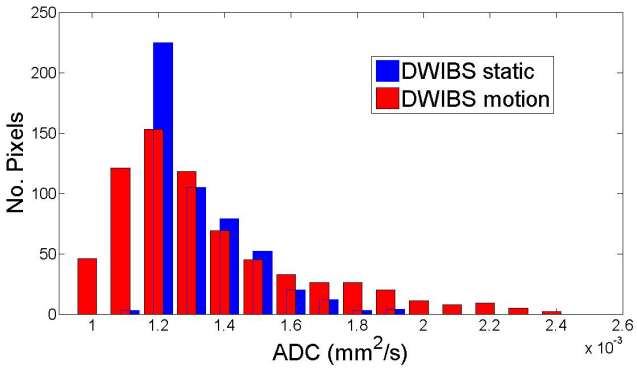


Fig 2: DWIBS-measured ADC histogram of the 25.5mm target when static and moving.

DISCUSSION: The effect of the motion of the liver during data acquisition for a DWIBS scan on the accuracy of ADC measurements made using this technique has not been previously investigated. The current study found that, although the mean ADC values were not affected, a significant increase in the spread of ADC values was measured in an otherwise uniform target tumour. This may be attributed to increased partial volume effects caused by the motion, although motion-induced EPI-related ghosting artefacts are also likely to play an important role. The higher ADC values consistently measured for the 5.5mm target likewise reflects a significant partial volume effect, due to the target having dimensions comparable to the spatial resolution of the DWI scans.

CONCLUSIONS: ADC values measured using the DWIBS technique in a moving phantom were found to be comparable to those measured using an accurate ADC measurement protocol. However, the standard deviation of the measurements increased due to the motion, with many pixels showing ADC values significantly lower and higher than their true values. These findings may be of significance in cancer therapy monitoring experiments where slight changes in tumour heterogeneity may be inferred from subtle changes in ADC histograms.

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