Measuring Quantitative ADCs with the Caliber MRI Diffusion Phantom

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Introduction

Quantification of MRI apparent diffusion coefficient (ADC) has a promising role in the staging and monitoring of prostate cancer. For ADC values to be meaningful clinically, they must first be shown to be accurate and reproducible. This work aimed to:

1. **Compare ADC measurement accuracy in prostate MRI across all clinical MRI Scanners in NHS Grampian**
2. **Measure ADC measurement reproducibility for a single scanner**
3. **Examine how the choice of b-values affects ADC accuracy**

Method

The CaliberMRI diffusion phantom was used to measure accuracy and reproducibility. The phantom consists of 13 vials of different concentrations of water and PVP solution and features built-in MR-readable thermometers. NIST Traceable calibrated ADC values in the range 250 to 2100 s/mm² are provided by CaliberMRI as expected ADC values.

Accuracy: The Aberdeen clinical prostate diffusion protocol (b = 0, 600, 1100 s/mm²) was run on each of the scanners in clinical use: two 1.5T Siemens Avanto, 1.5T GE 450W Optima, 3.0T Philips Acheiva dSTREAM). ADC values for regions of interest (ROIs) of consistent size covering each vial were compared with those provided by Caliber MRI. The calculated percentage errors are shown in Figure 2.

Reproducibility: A diffusion sequence provided by CaliberMRI (using 4 b-values ranging from 0 to 2000 s/mm²) was run on one 1.5T Siemens Avanto. The sequence was repeated 10 times to investigate the reproducibility of the average ADC values of ROIs (size 400 mm²). The reproducibility was quantified by calculating the coefficients of variation across runs for the same ROI and ROIs at different slice heights with within the same vial in the same run.

ADC variation with sequence/b value choice: To investigate how the measured ADC is affected by choice of b values used in the reconstruction of the ADC map, diffusion-weighted images were acquired for 9 b values ranging from 0 to 1100 s/mm². MATLAB was used to calculate ADC values using 84 combinations of 3 b values in the reconstruction.

Results

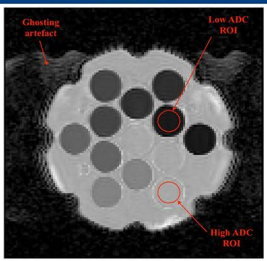

Figure 1: ADC map from a 1.5T Siemens Avanto.

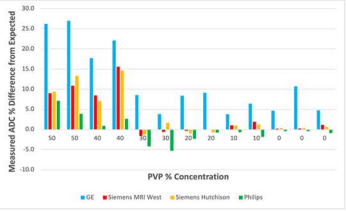

Figure 2: Comparison of measured ADCs for each vial of the Caliber phantom. Low ADCs (high PVP concentration) were measured less accurately than high ADCs by all of the scanners.

The average coefficient of variation for the Caliber sequence for 5 slices of each vial across 10 runs was 3.0%. Some vials had particularly large CoVs resulting from ghosting artefacts, but this effect was reduced by increasing the parallel imaging factor from 2 to 3, achieving an average CoV across all vials of 1.1%. The variations between the same region of interest over runs and spatially over different slices of the same vial were apparently random, both with CoVs of 1%.

In general, the measured ADCs were highly dependent on the choice of b values. A sample of the results are shown in Figure 3. Several trends were observed in this analysis:

- Using b = 0 s/mm² in the reconstruction significantly reduced the accuracy of small ADCs. The choice of b values affects the accuracy of large and small ADCs differently.
- Choosing well-spaced b values (e.g. 50, 200, 1100 s/mm² vs 50, 100, 200 s/mm²) increased the ADC accuracy and minimised the standard deviation across the ROI.

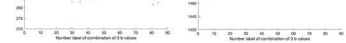

Figure 3: Comparison of calculated ADC for 84 combinations of 3 b values for expected ADC 267 s/mm² (left) and 1551 s/mm² (right).

Conclusions

Using the Aberdeen prostate protocol, ADCs were measured to within 10% with Philips Acheiva dSTREAM, 20% with Siemens Avanto and 30% with GE Optima compared with the expected values. ADC measurements were more accurate for higher ADCs. The achieved accuracy should be satisfactory to distinguish between tumour and healthy tissue, but quantification of treatment response may be more difficult. ADCs were highly dependent on the chosen scanning sequence and artefacts must be eliminated for good quantification. The average variation across repeated executions of the same pulse sequence was 1.1% using a Siemens Avanto scanner, indicating good reproducibility within scanning sessions.