Mapping of T2 and ADC in Articular Cartilage with B1 Corrected DESS

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INTRODUCTION

Measurements of T2 and the apparent diffusion coefficient (ADC) have proven useful for detecting damage or disease in articular cartilage [1,2]. Further, 3D steady-state methods are well suited for this due to their high SNR, short scan time, and good spatial resolution. Double Echo in Steady State (DESS) has recently been shown to effectively quantify ADC [3,4]. However, ADC estimation with DESS is affected by errors due to B1 variations. In this work, we demonstrate a B1 correction that improves the accuracy of the ADC estimate.

METHODS

DESS is a 3D steady-state method, acquiring two echoes separated by a spoiler gradient within one TR. The second echo experiences decay from both T2 effects and diffusion. The diffusion sensitivity depends primarily on the flip angle and spoiler gradient area. Two DESS acquisitions are performed, one with high diffusion sensitivity and one with low diffusion sensitivity. T1, T2, and ADC can be determined by relating the relative echo signals, flip angle, spoiler gradient, and scan sequence timing, to theoretical signal models [5,6]. Method 1, proposed by Staroswiecki et al., fits T1, T2, and ADC to the measurements using a precomputed solution table [3]. Method 2, proposed by Bieri et al., eliminates dependency on T1 and T2 to quickly determine ADC [4]. Both ADC estimates are sensitive to errors in flip angle.

A post-processing approach was developed to correct for such deviations in flip angle by acquiring a B1 map to estimate the actual flip angle at each pixel of the DESS image, then fitting either method on a pixel-by-pixel basis using the measured flip angles. This was implemented in a plugin for the freely available OsiriX DICOM Viewer [7], making the method publicly accessible and easy to use.

The correction method was tested in phantom scans and *in vivo*. An agar phantom was imaged on a 3T GE Discovery whole-body scanner (GE Healthcare, Waukesha, WI). Axial 3D DESS images were obtained with the following settings: TR = 26 msec; TE = 9 msec; FOV = 16x16 cm^2; resolution = 256x128; readout bandwidth = ±62.5 kHz; slice thickness = 5 mm; 36 slices; spoiler gradient duration 2 msec; and flip angle and spoiler gradient area 18º and 80 msec×mT/m along each axis for the scan with high diffusion sensitivity and 35º and 10 msec×mT/m along each axis for the scan with low diffusion sensitivity. The scan time was 2 minutes for each scan. B1 maps were generated using the double-angle method with a scan time of 10 minutes [8]. Solutions were computed with a resolution of 1% relative deviation in flip angle. The resulting values of T2 and ADC were compared to values obtained using standard spin echo methods. The *in vivo* knee scan was done on a healthy 24 year old volunteer, with a slice thickness of 3mm, resolution 256x256, bandwidth ±31.25 kHz and 46 slices with all other parameters the same as for the phantom scan. The scan time was 5 minutes for each scan. For the *in vivo* scan, the echo images were low-pass filtered to reduce the effect of noise.

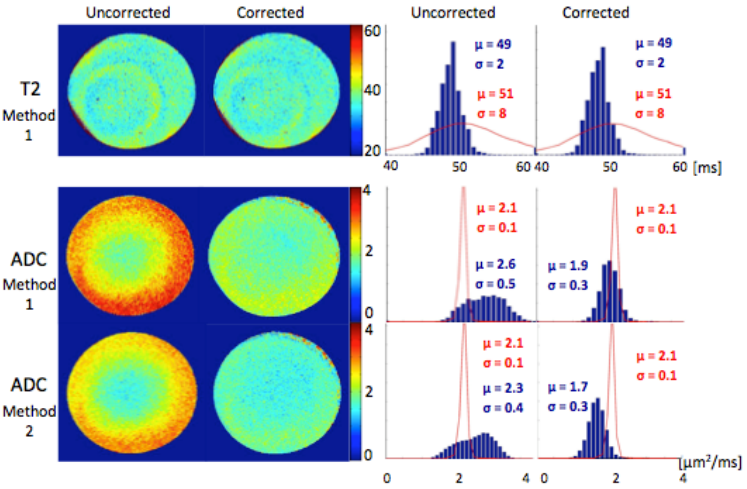

Figure 1: Comparison of results with and without B1 correction effects for Methods 1 and 2. The red line shows values from spin echo measurements. The histograms show estimates from DESS.

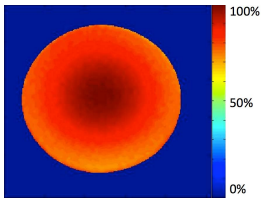

Figure 2: B1 map showing ratio of actual to desired flip angle.

RESULTS

The resulting T2 map for Method 1 and ADC maps for both methods for the agar phantom are shown in Fig. 1. The ADC map is considerably more uniform when corrected for B1 variation, with a decrease in standard deviation from 0.5 μm^2/ms to 0.3 μm^2/ms for Method 1 and from 0.4 μm^2/ms to 0.3 μm^2/ms for Method 2. The T2 map is largely unaffected due to the low flip angle sensitivity of the T2 estimate, with a mean of 49 msec slightly below the spin echo mean of 51 msec. The DESS T2 estimate has less variance than the spin echo measurements, indicating greater noise in the latter. The mean corrected ADC for Method 1 is 1.9 μm^2/ms, better than the uncorrected mean of 2.6 μm^2/ms compared to the spin echo mean of 2.1 μm^2/ms. The ADC estimate for Method 2 decreases from 2.3 μm^2/ms to 1.7 μm^2/ms, indicating less benefit from B1 correction than for Method 1. The B1 map is shown in Fig. 2. An ADC map of an *in vivo* patellar image of a healthy volunteer, with and without B1 correction, is shown in Fig. 3. An ROI covering the patellar cartilage had an average ADC value of 2.4 μm^2/ms for the uncorrected image, which is abnormally high, but 1.7 μm^2/ms after the correction with method 1, which agrees better with the previously established value of 1.5 μm^2/ms [9].

DISCUSSION

We have presented a method for correcting for B1 when calculating ADC maps using DESS imaging. We have shown that such a correction can significantly increase the accuracy and precision of the ADC map. T2 maps acquired with the same method show relatively little sensitivity to B1 errors. The acquisition of the B1 map increases total scan time. This method provides increased accuracy of DESS for clinical and research studies.

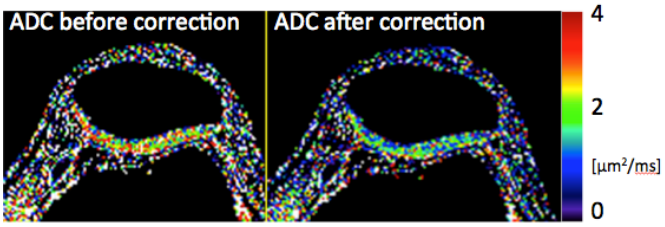

Figure 3: ADC map of knee without (left) and with (right) B1 correction.

ACKNOWLEDGEMENTS

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