Quantitative ADC Mapping using DESS with Decreased T1 and Noise Sensitivity

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PURPOSE: Early detection of osteoarthritis using MRI is critical for study of the disease process and treatment development. Double Echo Steady State (DESS) can provide high-resolution, distortion-free morphologic and quantitative images of T2 and the Apparent Diffusion Coefficient (ADC) in articular cartilage[1,2]. In this work, we demonstrate a method to calculate ADC from DESS scans, and demonstrate the ADC sensitivity to spoiler strength.

THEORY: In DESS, two echoes are acquired, separated by a spoiler gradient. By acquiring two DESS scans, one with a strong spoiler and one with a weak spoiler, the difference between the two later echoes will primarily be due to diffusion, while the difference between the first and second echo of the weakly diffusion weighted scan will primarily be due to T2 decay[3]. By keeping the flip angle the same between the two scans and assuming the T1 does not deviate greatly from an expected value (such as about 1 sec for articular cartilage), differences due to T1 between the two scans are minimized. T2 and ADC can then be determined by comparing the ratio between the two later echoes and the ratio between the two echoes of the weakly diffusion weighted scan to pre-computed values. Due to the flip angle sensitivity of the ADC estimate, a B1 map must be collected as well for use in post-processing.

METHODS: To estimate the dependency of the ADC estimate on spoiler strength, Monte Carlo simulations were run to generate DESS signals with values typical of cartilage with spoiler areas ranging from 2 to 20 cycles of dephasing across a voxel dimension of 3mm (a b-value of 250 in a DWI sequence would give comparable signal decay to the 20 cycle DESS scan). Gaussian noise was added such that the SNR of the first echo of the strongly diffusion weighted scan was 200, which was estimated to be feasible for in vivo scans. Two agar phantoms (T1, T2, ADC reference values measured as 1.7 s, 67 ms, 0.0018 mm^2/s and 1.4 s, 34 ms, 0.00172 mm^2/s) were then scanned with the DESS sequence using spoiler values corresponding to 10, 15, and 20 cycles of dephasing per pixel in the slice direction, with double-angle B1 scans acquired for flip-angle correction. The signal database to use in postprocessing was computed using Extended Phase Graph (EPG) modeling[4].The procedure was repeated on a single knee of five healthy volunteers. All scans were perfomed at 3T (TR = 26.6 ms, TE = 9.5 ms, flip angle 35°).

RESULTS: Figure 1 shows the how the simulated mean and standard deviation of the ADC estimate change depending on spoiler strength. The variation in the estimate increases with smaller spoiler, as diffusion sensitivity is lowered. At spoiler strengths less than 10 cycles, the mean also tends to be biased upwards. Figure 2 shows a similar plot for the phantom scans. A similar behavior to the simulations can be seen for the phantom with the lower T2 value, while the other phantom is more robust to noise due to the longer T2 giving higher SNR. The five in vivo scans in figure 3 also show less variation as the spoiler gets stronger. At a spoiler strength of 20 cycles, all scans give an ADC value close to a value of 0.0016 mm^2/s previously reported[5].

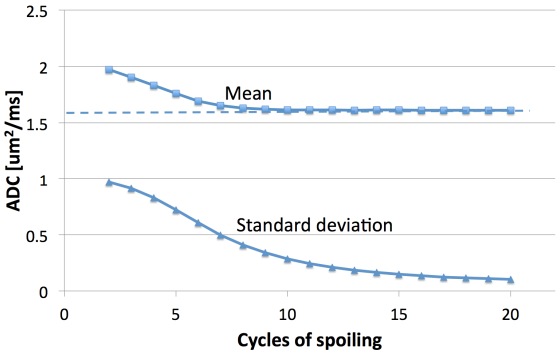

Figure 1: Mean and standard deviation of simulated ADC estimates as a function of spoiler strength. The dashed line shows the true ADC value.

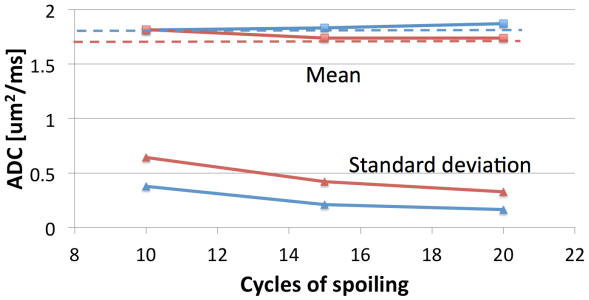

Figure 2: The mean and standard deviation of the ADC estimates of two agar phantoms. The dashed lines show DWI estimates.

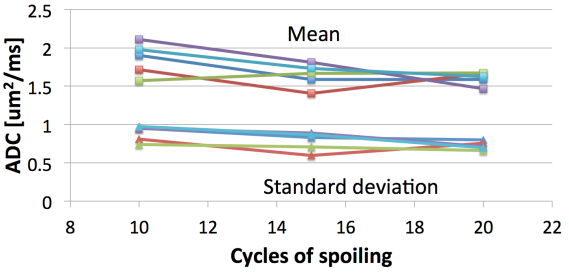

Figure 3: The mean and standard deviation of the ADC estimates of articular cartilage in five healthy volunteers.

DISCUSSION: Our results in simulations and human subjects show the same trends regarding selection of spoiler gradient size. The phantom result varies due to the difference in T2. While the this analysis demonstrates how a stronger spoiler makes the estimation method presented more robust to noise, it should be noted that all DESS-based ADC estimation methods are inherently sensitive to noise due to the low amplitude of the diffusion-weighted echo. Care must be taken to account for noise as well as B1 deviations when using DESS for ADC estimation. While this work focuses on ADC estimation, the method can also be used to produce T2 maps.

CONCLUSION: We have presented a method for estimating ADC from two DESS scans, basing the diffusion contrast on the two later echoes. We have demonstrated how this method can be used to achieve good ADC sensitivity in articular cartilage with low effects from noise and B1 deviations.

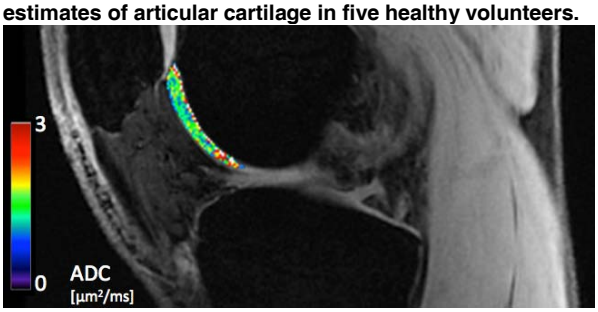

Figure 4: A sample ADC map from a scan with 20 cycles of spoiling.

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