Factors Affecting Accuracy of T1 Estimates in vivo by Variable Flip Angle Approach for dGEMRIC

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INTRODUCTION

Delayed gadolinium enhanced MRI of cartilage (dGEMRIC) is a technique for detecting the loss of glycosaminoglycans (GAGs). This technique requires quantitative T1 mapping to determine GAG level within joint cartilage. Most of the reported work on dGEMRIC has been using standard two-dimensional inversion recovery turbo spin-echo (2D IR-TSE) or three-dimensional (3D) sequences (such as inversion recovery spoiled gradient echo [JMRI 2006 24: 928] or look locker [Invest Radio. 2006; 41:198; 4] to acquire quantitative T1 mapping. Previous experience with the variable flip angle (VFA) method using two flip angles (FA) provided adequate accuracy of T1 measurements compared with the standard 2D IR-TSE technique in phantoms but not *in vivo* [Proc. ISMRM 2008, page 328]. We hypothesized that the probable causes for this to be one or more of the following: (1) the use of only two flip angles may be limiting, (2) fitting routines (e.g. the vendor implemented *in vivo* analysis uses linearized version of signal intensity *vs.* FA) and/or (3) B1 inhomogeneity. The objective of this study was to investigate the potential contributions of each of these factors.

MATERIALS AND METHOD

MR Scanner and Sequences: The study was performed on a 32-channel 1.5 T MR system (Magnetom Avanto, Siemens, Erlangen, Germany) using a commercial transmit/receive extremity knee coil. 2D IR-TSE and 3D VFA sequences were applied in both phantom and human subjects. The slice position of 2D IR-TSE was matched with the corresponding image of 3D volume in VFA method. The parameters of 2D IR-TSE were TR/TE=2200/13ms, TI=1680, 650, 350, 150, 50 ms, matrix size=384x384, slice thickness=3mm, FOV = 16cm. The total acquisition time for five T1s was 10'25"(2'5" for each TI). For offline analysis, gradient echo (GRE) acquisitions were acquired with six different flip angles (6º, 14º, 20º, 26º, 33º, 42º). Additionally, a vendor implemented two FA acquisition with inline T1 mapping were obtained. The protocol includes an inline calculation of optimal flip angle combination based on an estimated T1 (ET1) value. The parameters for the sequence included TR/TE = 15/3 ms, matrix size = 384x384, slice thickness = 3mm, bandwidth = 210 Hz/pixel. The total acquisition time for six flip angles was 16'2" (2'7" for each flip angle) and 4'7" for the two GRE acquisitions with in-line T1 mapping.

Phantom Study: To test our hypothesis, two different phantoms were used. The first phantom consisted of 9 tubes containing agar gel doped with different concentrations of nickel chloride. It was used to find out if using more than two flip angles would improve the T1 values obtained. This was done by calculating the T1s offline using MRI Mapper (with permission from Beth Israel Deaconess Medical Center, Boston, MA) with different combinations of flip angles – six, five, four and three. The phantom was also used to compare the inline fitting routines *vs.* offline calculations. For this, VFA sequences was run with ET1 values of 500 (FL=5.8, 32.8), 700 (FL=4.9, 27.9), and 900ms (FL=4.4, 24.7) respectively. The second phantom consisted of 9 tubes with 2% agar gel doped with varying concentrations of $Gd(DTPA)^{2-}$ (Magnevist, Bayer Healthcare, NJ). The tubes were longer to allow adequate coverage comparable to *in vivo* acquisitions. It was used to study slice to slice variations due to B1 inhomogeneity.

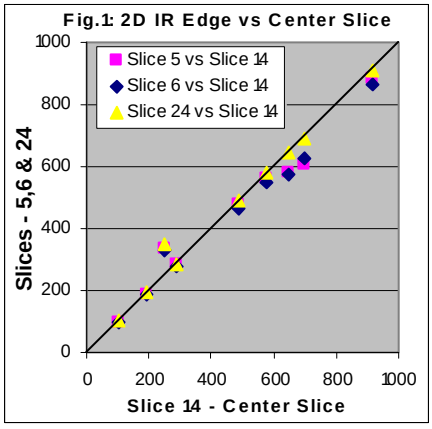
Patient Study: Eighteen subjects with osteoarthritis (OA) were imaged sagittally using 2D IR-TSE and 3D VFA sequences on one knee for each subject; the VFA sequences was applied with the six different flip angles. MR imaging was performed with contrast (90-120 minutes after 0.2mmol/kg Magnevist administration). The T1 values obtained with the 3D VFA method were compared against the T1 values of the standard 2D IR-TSE technique.

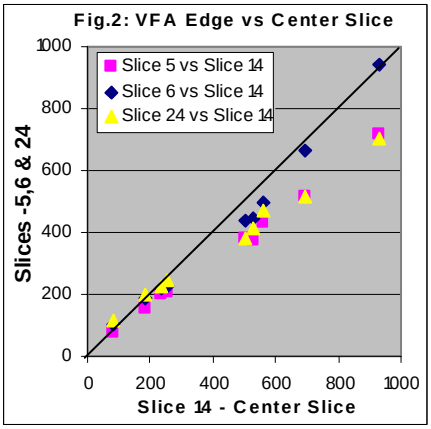
Data Analysis: ROIs (square ROI– 16x16 pixels) for phantom tests were placed at the center of each tube. For each human subject, ROIs were defined in the anterior (medial condyle only), central and posterior regions of the femoral cartilage (cF, pF) and tibial cartilage (T) in both medial (M) and lateral (L) condyles. For 2D IR-TSE, T1 mapping was performed off-line using MATLAB. For 3D VFA method, both automatic in-line T1 mapping on the scanner and off-line T1 mapping using MATLAB were done. Linear correlation was used for statistical evaluation of the agreement between the two techniques.

RESULTS

We found minimal to no difference between measurements using different number of flip angles both in phantoms and *in vivo*. Consistent with previous experience, the R^2 value *in vivo* (0.52) was much smaller compared to phantoms (0.96). Similarly, we failed to observe any differences between the vendor implemented inline T1 mapping and offline analysis.

Using the gel phantom, we did observe a significant drop off in T1 values in 6 slices (out of 28 acquired) on each edge consistent with the expected B1 profiles with standard RF pulses. Figures 1, 2 shows the level of agreement between T1 measurements obtained at the center of the phantom to those obtained at the edge. While 2D IR-FSE shows good agreement at all locations (Figure 1), one can observe significant deviations at the edge slices with 3D VFA.





DISCUSSION

Given that *in vivo* measurements are usually made at off center locations in the medial and lateral condyles, the deviation in T1 estimates may be related to the B1 profile effects. Owing to the inherent structural inhomogeneities *in vivo*, it is not easy to estimate B1 profiles *in vivo*. Approaches to include RF pulses with better B1 profiles, or efficient B1 correction methods may be needed to minimize this limitation.