Fast 3D T1 Mapping with Variable Flip Angle Method for dGEMRIC: Preliminary Validation

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INTRODUCTION

Delayed gadolinium enhanced MRI of cartilage (dGEMRIC) requires quantitative T_1 mapping to determine glyconsaminoglycan (GAG) level within joint cartilage [AJR 2004; 182:167]. 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 data for quantitative T1 mapping. The 2D technique is limited in single slice coverage. Both 2D and 3D techniques require long time for data acquisition (~10-~18 minutes) and image off-line post-processing. Recently, a fast 3D T1 mapping method based on variable flip angle (VFA) approach [MRM 2004 51:194] has been shown to be accurate when an estimate of T1 is available, with potential advantage of shorter acquisition times The objective for this study was to validate the accuracy of a vendor implemented VFA method for dGEMRIC in phantoms and perform preliminary comparison *in vivo* against standard 2D IR-TSE technique.

MATERIALS AND METHODS

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 coil. 2D IR-TSE and 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. The parameters of 2D IR-TSE were TR / TE = 2200 / 13 ms, TI=1680, 650, 350, 150, 50 ms, matrix = 384x384, slice thickness = 3 mm, FOV = 16 cm. The total acquisition time for five TIs was 10'25" (2'5" for each TI). For the 3D VFA method, two spoiled gradient echo acquisitions were made with different flip angles. The flip angle combination can be calculated using in-built macros by choosing an estimated T1 (ET1) value. The parameters for the sequence included TR/TE = 15 / 3 ms, matrix = 384x384, slice thickness = 3mm, bandwidth = 210 Hz / pixel. The total acquisition time for the 2 acquisitions is 4' 7", 4' 46" or 5' 12" for 28, 32 or 36 slices prescribed, respectively.

Phantom tests: Two phantom tests were performed separately. The first was to find optimal flip-angle combination for the range of T1s relevant for dGEMRIC of the knee cartilage. A phantom consisting of 9 tubes (each 1.4cm diameter and 5cm long) with 2% agarose gel filled and doped with different concentrations of nickel chloride, was scanned with 2D IR-FSE and 3D VFA sequences. Since the T1 values observed in dGEMRIC and pre-contrast images of the knee cartilage are usually in the range of 200 to 1000 ms, the VFA sequence was run four times with ET1 values of 200 (FL= 9.2°, 49.8°), 500 (FL= 5.8°, 32.8°), 700 (FL= 4.9°, 27.9°), and 900 ms (FL= 4.4°, 24.7°) respectively. Six of the 9 tubes, which had T1s ranged from 181 to 949ms (based on 2D IR-FSE results) were used for comparison of the two T1 measurements obtained in the center slice. The second test applied used a large uniform phantom containing nickel sulfate (15 cm diameter, 37 cm long,) to observe any distribution in T1 values across slices within the 3D volume when using VFA method. ET1 of 500 was selected with 28, 32 and 36 slices prescribed respectively. The T1 values at different slice location were compared to the averaged T1 value of the two central slices in the 3D volume.

Human subjects: Eight subjects, including 4 with osteoarthritis (OA) and 4 subjects with no known joint abnormalities (HS) were imaged sagittally using 2D IR-TSE and 3D VFA sequences on one knee for each subject. ET1 of 500 (flip-angle combination of 5.8º and 32.8º) was applied based on the results of the phantom test. Full joint coverage with 28, or 36 slices was prescribed. MR imaging was performed without (for HS), or with contrast (for OA subjects, 90-120 minute after 0.2 mmol/kg Magnevist administration). The T1 values obtained with of 2D IR-FSE method were compared with the corresponding slices of 3D VFA method.

Data analysis: ROIs for phantom tests were placed at center of each target tube. For each human subject, ROIs were defined in the anterior (medial condyle only), central and posterior regions of the femoral cartilage (aF, cF, pF) and tibial cartilage (T) in both medial (M) and lateral (L) condyles. For 2D IR-FSE**,** T1 mapping was performed off-line using MATLAB (Mathworks, Natick, MA). For 3D VFA method, automatic in-line T1 mapping was available on the scanner (Figure 1). Cartilage segmentation was performed using Syngo Fusion (Siemens, Erlangen, Germany). Linear correlation and Student's t-test were used for statistical analysis.

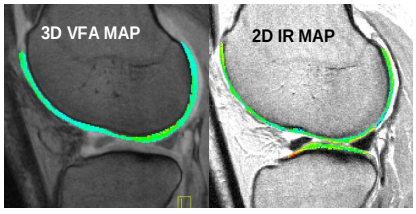
RESULTS

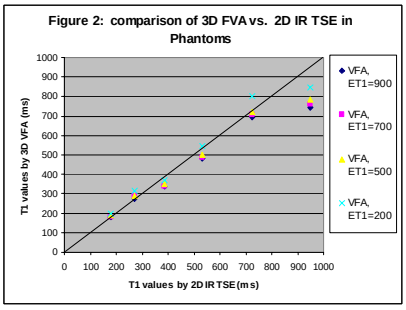
In phantoms, T1 values estimated by VFA method for all four ET1 (900, 700, 500, and 200 ms) had good agreements when compared to 2D IR-TSE results (Figure 2), with R^2 values of 0.966, 0.966, 0.970 and 0.958, respectively. Highest R^2 value (0.970) was observed when selecting ET1 of 500ms. Spread in T1 across slices within the 3D volume of VFA is shown in Figure 3. The T1 values obtained in the central part (~60% of coverage in slice direction) are relatively constant. The T1 values in the edge slices were significantly decreased. *In vivo*, the average T1 values obtained with 3D VFA and 2D IR-TSE techniques were statistically indistinguishable by Student's t-test ($p = 0.34$).

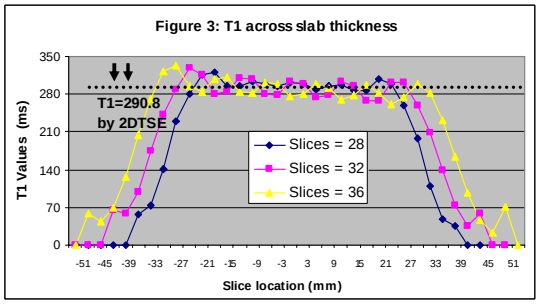
DISCUSSION AND CONCLUSION

Our preliminary results indicate that the vendor implemented VFA method is able to provide adequate accuracy of T1 measurements for dGEMRIC of femoral cartilage. Figure 3 indicates the limitation due to poor slab profiles of the standard RF pulses used. Caution is needed in the choice of slab thickness to cover the volume of interest to be within the central 60% of the slab. Future implementations could use RF pulses with optimized slab profiles. Major advantages of this implementation for dGEMRIC include entire joint coverage, shorter acquisition time (compared to even single slice 2D IR-TSE acquisition), and automated in-line T1 mapping. Since majority of OA patients have a significant disparity in T1 distributions between the medial and lateral condyles, full joint coverage allows comparing regions within the joint. Considering the wash-in and wash-out kinetics of the contrast agent, especially in the diseased cartilage, faster acquisitions are essential. The convenience of automated in-line T1 mapping should benefit widespread clinical utility of dGEMRIC.

Figure 1: T1 MAP (shown lateral only)







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