Comparison of delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) using Inversion Recovery and Fast T1 Mapping Sequences

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INTRODUCTION: The delayed Gadolinium Enhanced MRI of Cartilage (dGEMERIC) is a functional MRI technique that is able to detect the loss of the charged extracellular matrix in cartilage in early OA. This technique has been validated in vitro and in vivo and has been demonstrated to be useful in clinical studies. In hip dysplasia, dGEMRIC has been shown to correlate with patient symptoms and the severity of dysplasia(1). Additionally, dGEMRIC has been shown to be a good predictor of outcome after pelvic osteotomy for hip dysplasia(2). Despite the usefulness of this technique in clinical research, the current implementation of this technique is limited by the long scan times and post-processing necessary to obtain the T1 map. In this paper, we introduce a fast 3D sequence for dGEMRIC based on a T1 mapping technique utilizing 3D gradient echo (GRE) sequence with two different flip angles. Our objective was to validate this technique against the standard 2 D IR-sequence and to characterise the accuracy of the 2 flip angle technique when applied to a range of T1 values.

METHODS: Firstly, a phantom study was performed to experimentally determine the optimal flip angles for the Fast 2 angle T1 mapping (F2T1) technique for the range of T1 values relevant for clinical studies. Secondly, patient scans were obtained using both the F2T1 technique and Inversion Recovery T1 (IRT1) mapping technique and the results compared. Both the phantom and clinical studies were performed on the same 1.5T scanner (Magnetom Avanto, Siemens Erlangen).

Phantom study

For the phantom study, a dedicated 8 channel knee coil was used. Eight different phantoms were used consisting of water with varying concentrations of Gd (Magnevist 1, 0.5, 0.3, 0.26, 0.22, 0.18, 0.16, 0.14 mM) so as to deliver a range of T1 values. A T1 map of the phantom was then measured using (i) the IRT1 technique and (ii) The F2T1 technique using different flip angle combinations. The mean squared error (MSE) of the differences between T1 values measured using the IRT1 and F2T1 techniques were calculated. The center T1 is the optimized single target T1 value for each flip angle calculation. Student's t-test was used to determine if different center T1 values significantly changed the MSE. Based on this analysis, the center T1 value of 756 msec was chosen as an acceptable flip angle combination for patient scanning.

Patient study

Patients with hip pain due to developmental dysplasia of the hip or femoroacetabular impingement were imaged using delayed Gadolinium Enhanced MRI of Cartilage. Twenty six hips in 16 patients were scanned (14 left hips, 12 right hips). MR examinations were performed on a Siemens 1.5 T system (Magnetom Avanto, Siemens, Erlangen,Germany) and a body matrix phased array coil. The dGEMRIC scans were obtained after a double dose (0.4 mL/kg) intravenous injection of FDA approved contrast agent Magnevist (Gd-DTPA^{2-}; Berlex Laboratories, Wayne, New Jersey). Patients were required to walk 15 min prior to scan. After a 30 minute delay dGEMRIC scans(14) were obtained using both inversion recovery and fast T1 mapping sequences. The optimized center T1 value for the F2T1 technique was 756 msec. Total imaging time was approximately 30 minutes, thus, we were able to minimize the effect of contrast washout cartilage(3).

Inversion Recovery Sequence: 2-dimensional (2-D) fast spin-echo inversion recovery sequence parameters are: inversion times of 25, 75, 180, 350, 650, 1100, 1680 msec, TR 2000 msec and TE of 8.6 msec. Matrix size was 256x256 with a 16 cm field of view and slice thickness of 4 mm. T1 maps were calculated using custom software written in Matlab (Version7.0.0.19920.R14, The MathWorks, Inc., Natick,MA, USA).

Fast 2 angle T1 mapping Sequence: The 3D Fast T1 mapping sequence consists of two separate spoiled GRE measurements with different excitation pulse flip angles. The scan parameters are: TR 20, TE 4,76. Matrix 256/256. Same FoV (16cm) and same slice thickness (4mm) were chosen in order to correlate the T1 measurements with the results of the IR sequence. Based on the 2 measurements with 2 different contrasts, the T1 map can be calculated on a pixel-by-pixel basis (using inline software supplied by Siemens Medical Solutions, Erlangen, Germany) according to the following formulae(4).

$$T1c_{j,k} = \frac{TR}{\ln\left[\frac{\sin(\alpha_1)*\cos(\alpha_2) - Q_{j,k}\sin(\alpha_2)*\cos(\alpha_1)}{\sin(\alpha_1) - Q_{j,k}*\sin(\alpha_2)}\right]} \qquad Q_{j,k} = \frac{mess\_1_{j,k}}{mess\_2_{j,k}}$$

where $T1c_{j,k}$ = T1-value and $Q_{j,k}$ = quotient of the 2 signal intensities for the pixel (j,k). Correlations between two continuous variables were assessed using Pearson's linear regression.

RESULTS:

Phantom Study

Figure 1 illustrate the correlation between the T1 values measured using the F2T1 and IRT1 techniques. Good correlation between the two techniques for center frequencies ranging from 756 to 955 msec was seen. The mean squared error (MSE) was calculated for each center T1 and there were no significant differences in the MSE for center T1 ranging from 756 to 955 msec. Based on this analysis, decision was made to perform the patient F2T1 scans with center T1 set at 756 msec.

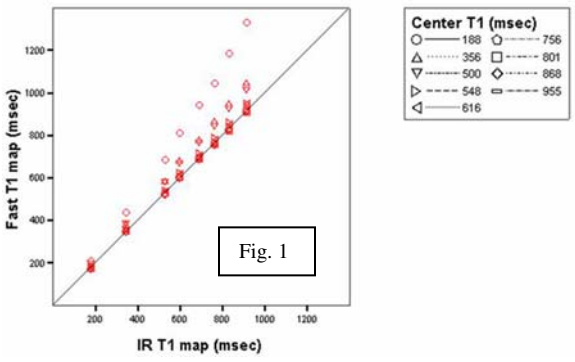

Fig. 1

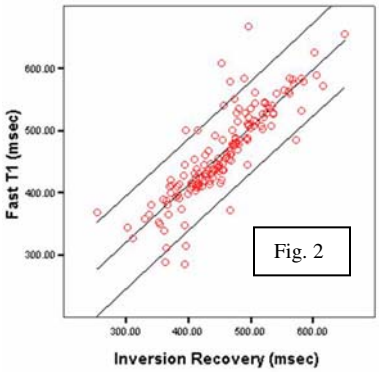

Fig. 2

Patient Study

The imaging time for the IRT1 sequence was 17 minutes compared to ~3 minutes for the F2T1 technique. The average of the patient cohort was 28 years. The radiographic osteoarthritis grade distribution was 5 grade 0, 16 grade 1, and 4 grade 2 on the Tönnis scale. Figure 2 illustrates the correlation between the F2T1 and IRT1 values obtained for each ROI. The offset is 43 msec and the slope of the regression line is 0.92. The Pearson regression coefficient R^2 is 0.74.

DISCUSSION: 1) For T1 values in the range of 200 to 1000 msec, the phantom data suggest that center T1 of 756 to 955 msec appears to provide equally accurate measurement of T1 values. For a broader T1 range of interest, additional flip angles would provide a more consistent result over the broader range. 2) In contrast to the phantom data, the actual patient data showed excellent but less than perfect correlation between the F2T1 and IRT1 data. This is not unexpected given that comparable ROI were visually selected for comparison between the F2T1 and IRT1 images. Additionally, unlike phantoms motion between IR images in the patient scans can create error in the IR T1 maps. From this respects, the F2T1 technique may less susceptible to errors introduced by slight pixel mis-registration when performing the T1 fit.

REFERENCES: (1) JBJS 2003;85-A(10):1987-1992, (2) JBJS 2006; 88(7):1540-1548. (3) MRM 2007;57(4):803-805. (4) MRM 1987;5(5):399-416.