Three-dimensional delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) at 1.5 T and 3.0 T

C. McKenzie[1,2], A. Williams[1,2], P. Prasad[3], D. Burstein[1,2]

[1]Radiology, Beth Israel Deaconess Medical Center, Boston, MA, United States, [2]Harvard Medical School, Boston, MA, United States, [3]Evanston Northwestern Healthcare, Evanston, IL, United States

Introduction: The delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) technique uses quantitative T1 mapping of articular cartilage subsequent to injection and penetration of Gd(DTPA)2- (Magnevist; Berlex, NJ) to assess the distribution of glycosaminoglycan (GAG) in articular cartilage (1). Previous implementations have used two-dimensional (2D) imaging to obtain the data necessary for the T1 map. Therefore, full-joint assessment of the GAG distribution has not been possible. Furthermore, with 2D imaging, difficulties associated with obtaining the same section in subsequent imaging sessions makes interpretation of follow-up scans unclear. The objective of this study was to develop 1.5 T and 3.0 T 3D dGEMRIC protocols to assess the entire knee.

Methods: 1.5 T Signa Excite and 3.0 T VH/I magnets (GE Healthcare, Milwaukee, WI, USA) were used in these studies. Phantoms consisted of saline doped with $Gd(DTPA)^{2-}$ (Magnevist, Berlex Imaging, Wayne, NJ) in concentrations ranging from 0.125-1.0 mM. Data were acquired with a transmit-receive extremity coil (GE Healthcare, Milwaukee, WI, USA). To ensure proper loading of the coils during phantom studies, the phantom tubes were placed on top of a 500 mL saline bag.

T1 mapping was done with a 2D inversion recovery prepared fast spin echo (IR-FSE) sequence with the following parameters: 1.5T TR/TE = 1.8s/14ms, TI= 1.68, 0.65,0.35,0.18,0.05 s; 3.0T TR/TE=2.2s/14ms, TI = 2.1,0.8,0.5,0.3,0.1,0.05 s. 3D T1 measurements used an inversion prepared spoiled gradient echo (IR-SPGR) sequence with: 1.5T TS/TE/flip=7.3ms/3.1ms/20°; 3.0T TS/TE/flip=6.5s/2/4ms/15°. The TIs were the same as 2D. 3D data acquisition required 18 minutes, versus 8 min for one 2D slice. Both 2D and 3D were acquired with 3 mm thick slices, 256x256 matrix, and 16 cm FOV for 0.63 mm resolution. For 3D, 36 slices were acquired.

In the 3D IR-SPGR sequence, one inversion pulse was applied with each iteration of the phase encode loop. After each inversion pulse was applied, a delay of TI ms was inserted prior to data acquisition in order to achieve the desired T1 weighting of the data. As a time saving measure, all of the phase encodes in the slice direction of the IR-SPGR sequence were acquired in succession after the inversion pulse. To prevent the RF pulses from disturbing the recovery of the longitudinal magnetization, the slice encoding was performed starting with the center slice encode and working outward (centric k-space ordering). Since the center of k-space dominates the overall image signal intensity, centric encoding ensured that the signal intensities of the image were determined by the selected TI. To minimize scanning time, the time between inversion pulses (TR) was set to the minimum necessitated by the inversion time and slice loop; hence TR was not constant when TI was changed. Thus TR for a given acquisition is TR=TSxNs+TI where TS was the time between RF pulses while slice encoding, and Ns was the number of slice encodes.

Data were acquired from adult volunteers (one asymptomatic and three with clinically diagnosed osteoarthritis). Each volunteer was IV injected with 0.2 mM/kg Magnevist and asked to walk for 10 minutes to facilitate transport of Gd(DTPA)2- into cartilage (2). Imaging started 90 minutes after injection. Because the cartilage-synovium / meniscus contrast was poor in the IR-SPGR images, T2 weighted images were also acquired and used as guides for segmenting the cartilage.

The metric of dGEMRIC used to report in vivo data in this study is a bulk T1(Gd) value found by averaging T1(Gd) across 4 central slices of each of the medial and lateral compartments. Separate T1(Gd) values were calculated for the 4 surfaces of each knee: medial femoral condyle, medial tibial plateau, lateral femoral condyle and lateral tibial plateau (i.e. 4 indices per knee). T1 maps were generated using a standard 3-parameter fit. In the in vivo images, areas of cartilage were determined by hand-segmentation. The calculated T1(Gd) maps were then superimposed on one of the inversion recovery images for display purposes.

Phantom [Gd-DTPA]	1.5 T T1 (ms)		3.0 T T1 (ms)	
	2D	3D	2D	3D
1 mM	208±5	203±14	199±5	196±11
0.75 mM	268±7	267±13	264±6	263±13
0.5 mM	388±10	383±21	383±10	382±16
0.375 mM	498±14	489±29	500±13	501±22
0.25 mM	677±24	673±38	672±24	673±31
0.188 mM	845±45	861±96	846±51	798±142
0.125 mM	1128±100	1259±191	1069±45	1091±106

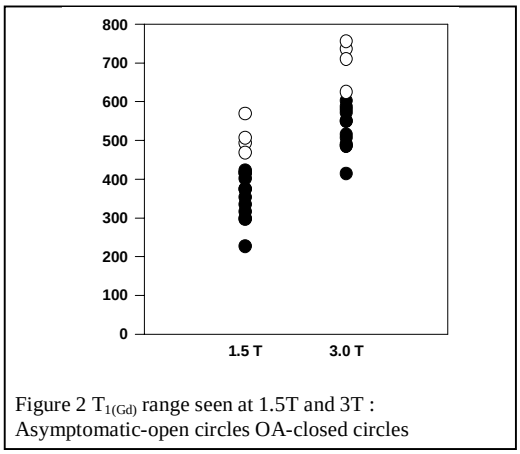

Figure 2 $T_{1(Gd)}$ range seen at 1.5T and 3T : Asymptomatic-open circles OA-closed circles

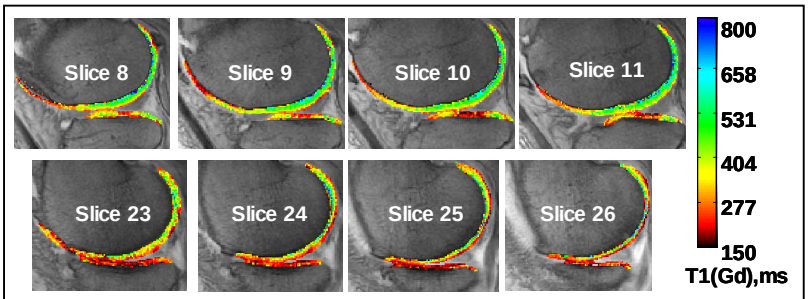

Figure 1: Sample slices from a 3D data showing the medial and lateral condyle of a volunteer with OA. The dGEMRIC index variation across condyles is apparent.

Results: 2D and 3D phantom T1 measurements are summarized in the table. A two-tailed paired sample t-test showed no significant difference between the 2D and 3D measurements at either 1.5T or 3T (p=0.4, p=0.6, respectively). Figure 1 shows representative in vivo 3D T1(Gd) maps. Good quality images were obtained across the knee with this 3D sequence in less than 20 minutes imaging time. As expected (3), the T1(Gd) values of normal and degraded cartilage measured at 3.0 T (range: 400-800 ms) were higher than the values measured at 1.5 T (range: 200-600) (Figure 2).

Discussion: Using the inversion prepared 3D SPGR sequence described in this study, it is possible to measure T1(Gd) across an entire knee with adequate resolution and in a reasonable amount of time, even with the increased TIs and TRs necessary for accurate T1 measurement at 3.0T. It is difficult to assess the "sensitivity" of dGEMRIC to disease at the two field strengths with a small number of data sets. The ultimate choice of field will probably be dominated by magnet availability and by considerations for other concurrent scans (e.g. cartilage volume). 3D dGEMRIC allows assessment of GAG distribution through the entire volume of the knee, instead of the limited set of slices that is practical using the 2D T1 sequence, and allows for more reliable follow-up scans for the evaluation of dGEMRIC changes over time. Larger clinical studies will be needed to determine what index might best represent the disease status of the cartilage in the joint, and what level of analysis is needed in these 3D data sets.

Acknowledgements: This work was funded by NIH and a grant from Pfizer.

References: 1) Bashir et al, MRM 1999;41:857-865. 2) Burstein et al, MRM 2001;45:36-41. 3) Gold et al, AJR 2004;183:343-351