Multi-Exponential T2 Mapping of Human Patellar Cartilage Using mcDESPOT

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Introduction: Water signal within articular cartilage is generally considered to consist of two components: 1) water tightly bound to macromolecules such as proteoglycan and type II collagen termed W_m and 2) bulk water loosely bound to the macromolecular matrix termed W_b (1, 2). The multiple water components are effectively averaged when performing mono-exponential cartilage T2 mapping (3, 4). Multi-exponential cartilage T2 mapping has been previously performed but only on ex-vivo bovine cartilage specimens using nuclear magnetic resonance (NMR) spectroscopy with long scan times (1, 2). Multi-component Driven Equilibrium Single Pulse Observation of T1 and T2 (mcDESPOT) is a newly developed technique that can evaluate two-component relaxometry using steady-state MR imaging (5-7). This study was performed to determine the feasibility of using mcDESPOT to perform multi-exponential T2 mapping of human patellar cartilage at 3.0T in a 20 minute scan time.

Methods: An MR examination of the knee was performed on 3 asymptomatic volunteers using a 3.0T scanner (Discovery MR750, GE Healthcare; Waukesha, WI) and 8-channel phased-array extremity coil (InVivo, Orlando, FL). Spoiled gradient echo (SPGR) scans were acquired with TR/TE=4.6/2.2ms over a range of flip angles (α =3, 4, 5, 6, 7, 9, 13, 18°). Fully-balanced steady-state free precession (bSSFP) scans were acquired with TR/TE=5.0/2.4ms over a range of flip angles (α=2, 5, 10, 15, 20, 30, 40, 50°). An additional inversion recovery IR-SPGR scan with TR/TE=4.6/2.2ms, TI=450ms, and α=5° was acquired to estimate the transmit B1 field (5). Two bSSFP scans were acquired with radiofrequency (RF) phase cycling φ=0° and 180° respectively at each flip angle to remove the effects of bSSFP banding artifacts and to provide an estimate of the B0 field (4). All scans were performed in the axial plane through the patellofemoral joint using an 18cm field of view, 256 x 256 matrix, 4mm slice thickness, and one excitation. Total scan time was 20 minutes. The images were analyzed using an in-house MATLAB program. Mono-exponential T2 relaxation time maps of cartilage were created using DESPOT2-FM (6), while multi-exponential T2 relaxation time maps and water fraction maps for the W_m and W_b components of cartilage were created using mcDESPOT (7). During image analysis, patellar cartilage was divided equally into superficial and deep halves to investigate depth dependent variations in T2 relaxation time and water fraction.

Results: mcDESPOT was able to create T2 relaxation time and water fraction maps for the tightly bound W_m and loosely bound W_b components of human patellar cartilage at 3.0T in a 20 minute scan time (Figure 1). The T2 relaxation time and water fraction values for the W_m and W_b components in the superficial and deep layers of patellar cartilage were consistent for all three volunteers (Table 1). The T2 relaxation time for the W_b component was higher in the superficial than the deep layers of cartilage, while the T2 relaxation time for the W_m component was similar in the superficial and deep layers. The W_m fraction was higher in the deep than superficial layers of cartilage, while the W_b fraction was higher in the superficial than deep layer.

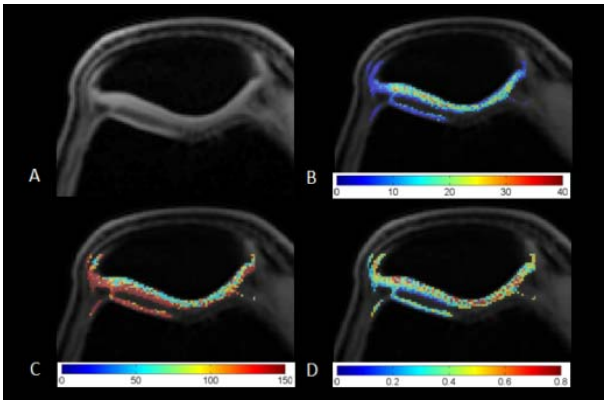

Figure 1: IDEAL-SPGR source image (A), T2 relaxation time map for the W_m component (B), T2 relaxation time map for the W_b component (C), and water fraction map for the W_m component (D) of patellar cartilage in a volunteer.

Table 1: Mono-exponential and multi-exponential T2 relaxation time and water fraction analysis for human patellar cartilage in vivo at 3.0T.

Subject	Mono-Exponential Analysis		Multi-Exponential Analysis							
			Tightly Bound Macromolecular Water (W_m)				Loosely Bound Bulk Water (W_b)			
	T2 Relaxation Time (ms)		T2 Relaxation Time (ms)		Fraction (%)		T2 Relaxation Time (ms)		Fraction (%)	
	Superficial	Deep	Superficial	Deep	Superficial	Deep	Superficial	Deep	Superficial	Deep
1	63.1	27.1	12.3	15.8	29.6	40.1	122.5	76.0	71.4	59.9
2	56.0	31.4	12.9	14.1	31.6	42.1	111.3	85.2	68.4	57.9
3	61.4	28.5	13.1	15.4	30.1	50.8	110.5	87.4	69.9	49.2

Discussion: mcDESPOT was used to perform multi-exponential T2 mapping of human patellar cartilage at 3.0T in a 20 minute scan time. The T2 relaxation time and water fraction values for the W_m and W_b components of human patellar cartilage in vivo were similar to those reported for ex-vivo bovine cartilage specimens using NMR spectroscopy (1,2). The W_m component was felt to represent water tightly bound to proteoglycan since the collagen-associated water component has been shown to exhibit extremely short T2 relaxation times of less than 100 μs (8). The greater W_m fraction in the deep layer of cartilage corresponds with the greater concentration of proteoglycan in this region (8). A depth-dependent variation in the W_b component of cartilage was present with greater values in the superficial than deep layers which was likely responsible for the depth dependent variations noted in mono-exponential cartilage T2 values (8). The higher W_b fraction in the superficial layers of cartilage may allow free exchange of loosely bound water between the macromolecular matrix and synovial fluid during articular surface compression. Additional studies are needed to determine the potential applications of mcDESPOT for evaluating articular cartilage in clinical practice and osteoarthritis research studies.

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