Numerical simulations

Numerical simulations were conducted to choose appropriate pulse sequence parameters for the in vivo study. Nominal T_1 and $T_{1\rho}$ values were set at 1200 ms and 100 ms, respectively. First, the flip angle (FA) was fixed at 6° and the repetition time (TR) at 2000 ms, and then data was acquired with 12 different number of spokes (i.e., Nsp). Values of Nsp ranged from 1 to 56 with an interval of 5 between. Simulation results showed that 41 was the optimal Nsp. Second, with the Nsp fixed at 41 as well as FA, T_1 and $T_{1\rho}$ values unchanged, TRs were set at 1600 to 3600 ms with an interval of 400 ms between them. With each simulation, $T_{1\rho}$ weighted signals were generated with four different spin lock times (TSLs) (i.e., 0, 24, 48, 72 ms).

Under different parameter combinations, magnetic resonance (MR) signals were generated by Bloch equation simulation. $T_{1\rho}$ values were calculated by fitting the simulated signals with the following equation:

$$S(TSL) = S_0 e^{-\frac{TSL}{T_{1\rho}}} + C \quad [1]$$

where S_0 is the initial signal intensity, and the constant C is included to accommodate non-$T_{1\rho}$ related signals, such as the background noise and artifacts generated during data acquisition and image reconstruction.

Simulation results are shown in *Figure S1*, where we found that Nsp=41 and TR = 2000 ms are the optimal parameters showing the smallest $T_{1\rho}$ errors.

To reduce the scan time for the in vivo study, a relatively large value of Nsp (i.e., 41) together with a relatively short TR (i.e., 2000ms) were used in this study. Both multispoke data acquisition and reduced TR (less than five times the tissue T_1) will lead to T_1 weighting. In our simulation, we found that the $T_{1\rho}$ fitting error due to T_1 contamination could be partially compensated for by adjustment of Nsp. Multispoke data acquisition and reduced TR affect the $T_{1\rho}$ fitting in opposite ways. An optimized Nsp could potentially be obtained to minimize the $T_{1\rho}$ quantification error for a particular tissue.
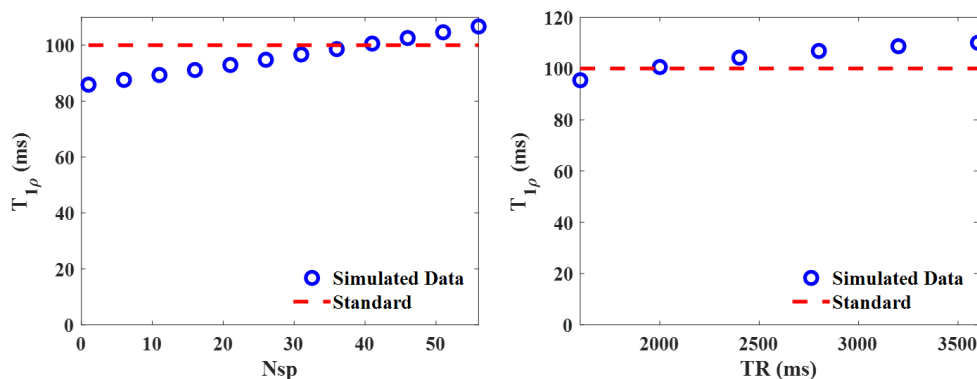

Figure S1 $T_{1\rho}$ values simulated with different Nsps (left) and different TRs (right). The red dashed line is the nominal $T_{1\rho}$ value (100 ms) and the blue circles are the simulated $T_{1\rho}$ values. Nsp: number of spokes; TR: repetition time.
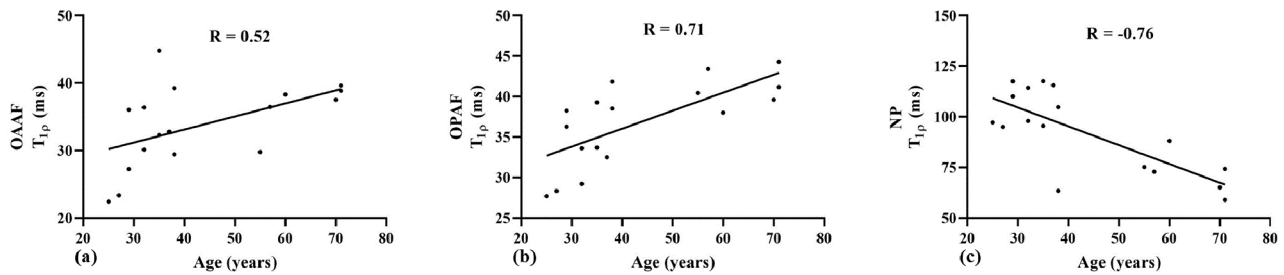
Figure S2 Scatter plots for the $T_{1\rho}$ values of OAAF, OPAF, and NP as a function of age. (a) is the correlation between $T_{1\rho}$ of OAAF and age; (b) is the correlation between $T_{1\rho}$ of OPAF and age; (c) is the correlation between $T_{1\rho}$ of the NP and age. OAAF: outer anterior annulus fibrosus (AF); OPAF: outer posterior AF; NP: nucleus pulposus.

Table S1 $T_{1\rho}$ value (mean and standard deviation) of each intervertebral disc sub-region for each modified Pfirrmann grade group. The grades increase from group 1 to group 4

Group	Grade	Disc Counts	$T_{1\rho}$ (ms)						
			OAAF	IAAF	OPAF	IPAF	SCEP	ICEP	NP
Group 1	2	31 (36.5%)	33.2±7.8	44.9±7.7	34.0±5.0	45.4±6.5	36.0±5.0	36.9±3.9	118.7±10.9
Group 2	3	21 (24.7%)	32.8±6.6	44.4±6.8	34.7±4.5	46.0±7.5	38.6±6.3	39.1±5.2	94.7±12.2
	4								
Group 3	5	18 (21.2%)	34.6±6.7	44.9±4.6	40.8±7.2	47.5±6.3	38.8±3.8	39.9±3.3	71.2±5.1
	6								
Group 4	7	15 (17.6%)	35.8 ±5 8	42.8±5.8	41.0±5.1	47.3±7.0	42.7±4.6	42.1±4.9	57.9±8.1
	8								

OAAF: outer anterior annulus fibrosus (AF); IAAF: inner anterior AF; OPAF: outer posterior AF; IPAF: inner posterior AF, SCEP: superior cartilaginous endplate (CEP); ICEP: inferior CEP; NP: nucleus pulposus.

Table S2 P values of $T_{1\rho}$ value differences between every pair of groups analyzed with the ANOVA method in each sub-region. P<0.05, significant difference

Group OAAF		P						
		OAAF	IAAF	OPAF	IPAF	SCEP	ICEP	NP
Group 1	Group 2	0.846	0.816	0.648	0.763	0.077	0.073	0.000
	Group 3	0.497	0.973	0.000	0.312	0.068	0.020	0.000
	Group 4	0.235	0.329	0.000	0.391	0.000	0.000	0.000
Group 2	Group 1	0.846	0.816	0.648	0.763	0.077	0.073	0.000
	Group 3	0.425	0.813	0.001	0.503	0.898	0.560	0.000
	Group 4	0.205	0.474	0.001	0.584	0.020	0.046	0.000
Group 3	Group 1	0.497	0.973	0.000	0.312	0.068	0.020	0.000
	Group 2	0.425	0.813	0.001	0.503	0.898	0.560	0.000
	Group 4	0.619	0.364	0.888	0.931	0.033	0.158	0.000
Group 4	Group 1	0.235	0.329	0.000	0.391	0.000	0.000	0.000
	Group 2	0.205	0.474	0.001	0.584	0.020	0.046	0.000
	Group 3	0.619	0.364	0.888	0.931	0.033	0.158	0.000

OAAF: outer anterior annulus fibrosus (AF); IAAF: inner anterior AF; OPAF: outer posterior AF; IPAF: inner posterior AF, SCEP: superior cartilaginous endplate (CEP); ICEP: inferior CEP; NP: nucleus pulposus.