EX VIVO MAPPING OF SODIUM T_1 AND T_2* RELAXATION TIMES IN HUMAN LUMBAR INTERVERTEBRAL DISCS AT 7 TESLA

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TARGET AUDIENCE: Musculoskeletal radiologists, physicists interested in mapping of sodium T1 and T2* relaxation times in spinal discs.

PURPOSE: Degeneration of intervertebral discs (IVD) is associated with loss of glycosaminoglycans (GAG). Previous studies proved that sodium (^{23}Na) concentration correlate well with GAG concentration in IVDs.[1] For absolute quantification of ^{23}Na content and for sequence optimization, it is essential to know the T1 and T_2* relaxation times of human IVDs. Previous studies on ^{23}Na relaxation times in IVDs reported different T1 and T_2* values.[1-3] Therefore the aim of this study was to map ^{23}Na T1 values as well as fast (T_2*_F) and slow component (T_2*_S) of T_2* relaxation in lumbar IVDs, and to compare the relaxation times between discs with different grades of degeneration.

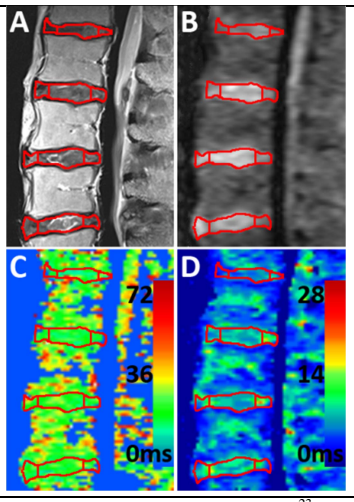

Fig.1: A. proton T_2-weighted, **B.** ^{23}Na vTE-GRE image acquired with TE= 0.95 ms, **C.** color-coded ^{23}Na T_1 map and **D.** corresponding T_2* map.

METHODS: This study was approved by local ethics commission. Three human cadaver lumbar spine samples were obtained from a local anatomy department. The samples were acquired from two females (85 and 87 years) and one male (80 years) and stored in the deep-freezer. The speciments were brought to room temperature before MR measurements. Morphological images were acquired at 3T (Tim Trio, Siemens Healthcare, Erlangen, Germany) using eight-channel knee coil (In vivo, Gainesville, FL, USA). ^{23}Na MRI was performed on a 7T whole body system (Magnetom, Siemens Healthcare, Erlangen, Germany) with a 15-channel ^{23}Na-only knee coil (Quality Electrodynamics, Mayfield Village, Ohio, USA). For morphological evaluations, sagittal T_2-weighted 2D-TSE sequence was recorded with following parameters: TR/TE= 3790/104 ms, in-plane resolution of 0.56×0.56 mm^2, 3 mm slice thickness, 15 slices, 3 averages, 151 Hz/pixel bandwidth and acquisition time of 4:18 min. To map ^{23}Na T1 relaxation times, progressive saturation method using spoiled 3D gradient-echo sequence with variable echo time scheme (vTE-GRE) [4] was employed. Seven measurements with different TR were acquired using vTE-GRE with following parameters: TRs= 10, 16, 24, 37, 60, 120, 250 ms; TE= 1.67 ms, resolution of 1.6×3.2×6.0 mm^3, 20 slices, 24 averages, bandwidth of 320 Hz/pix and acquisition time of ~4:20 hours. To enable the biexponential evaluation of ^{23}Na T2* relaxation, multiecho vTE-GRE sequence with eighteen TEs was recorded with following parameters: TEs= 0.95, 2.0, 2.9,…,54.4 ms; TR= 60 ms, resolution of 1.6×3.2×6.0 mm^3, bandwidth of 300 Hz/pix and acquisition time of ~1:24 hours. The echo times were sequentially shifted, thus in each TR only 6 TEs were acquired (during first TR, TEs number 1, 4, 7,…, 16 were recorded). The degree of IVD degeneration was evaluated on the proton T_2-weighted images using Pfirrmann grading, where the most degenerated IVD is of grade 5 (Fig.1A). The T_1 and T_2* maps (Fig.1C,D) were calculated by fitting the ^{23}Na signal evolution mono-exponentially on a pixel-by-pixel basis using a least squares fitting routine with three parameters written in IDL (Research Systems Inc, Boulder, CO, USA). To create T_2*_F and T_2*_S maps, the bi-exponential decay of ^{23}Na signal was fitted using the same IDL routine but with five parameters. To assess the fitting precision, a corresponding measure of goodness-of-fit (R^2) map was calculated for all relaxation maps in IDL. In each spine sample, only maps corresponding to one central sagittal slice were evaluated using in-house written IDL program. The ROIs drawn on the proton T_2-weighted images were subsequently transferred to all relaxation and R^2 maps and all pixel values were obtained. Eleven IVDs were evaluated, totaling to 11 region-of-interest (ROI) evaluations for nucleus (~60% of IVD area), annulus anterior (~20% of IVD area) and annulus posterior (~20% of IVD area), respectively. All statistical analyses were performed in SPSS (SPSS Institute, Chicago, IL, USA). An independent samples t-test was used to compare the relaxation times between the IVDs with different Pfirrmann grades.

RESULTS: All IVDs were divided into three groups according to Pfirrmann grades. Two IVDs had Pfirrmann score of 2, three IVDs had score 3 and three IVDs had score 4. Approximately 18% of voxels from nucleus and 47% from annulus revealed difference lower than 4 ms between T_2*_F and T_2*_S values. Such values were excluded from further evaluations. The means, standard deviations, corresponding R^2 values and pixel count for each relaxation parameter are summarized in Table 1. Significant differences were found between all three groups when comparing T_1, T_2*, T_2*_F and T_2*_S values from nucleus. The only significant differences in annulus were found in T_2* values (between all Pfirrmann grades) and in T_2*_S (between grade 3 and 4).

Tissue	Pffirmann Grade	T1				T2*				T2*fast			T2*slow			Biexponential	
		Mean (ms)	S. D. (ms)	R2 (a.u.)	Count	Mean (ms)	S. D. (ms)	R2 (a.u.)	Count	Mean (ms)	S. D. (ms)	Part (%)	Mean (ms)	S. D. (ms)	Part (%)	R2 (a.u.)	Count
Nucleus	2	22.6	5.9	0.97	132	7.1	2.1	0.97	132	1.4	1.0	57	13.4	8.2	43	0.96	105
	3	19.6	5.9	0.96	235	7.5	1.2	0.97	235	1.1	1.0	57	11.9	4.8	43	0.96	222
	4	17.3	4.9	0.94	146	6.1	1.7	0.97	146	1.0	1.2	56	9.0	5.9	44	0.98	107
Anulus	2	22.9	7.2	0.94	65	7.5	3.6	0.97	65	1.3	1.1	58	11.7	5.7	42	0.97	32
	3	20.6	7.9	0.92	107	10.1	2.7	0.96	110	1.5	1.6	51	14.1	6.2	49	0.96	76
	4	20.5	8.7	0.93	75	6.2	2.5	0.97	76	1.0	1.0	53	9.3	8.6	47	0.97	31

Table 1: S.D. is for standard deviation, count is representing number of pixels, part is for contribution of each component to total signal.

DISCUSSION: Slightly different relaxation times can be found in the literature. Wang et al. reported a T_1 of 22 ms and a T_2* of 16 ms for bovine IVDs at 3T.[1] Moon et al. estimated a T_1 of 34 ms and a T_2* of 9.7 ms from human *in vivo* IVDs measurements at 3T.[2] Ooms et al. measured two IVDs ex-vivo using double-quantum-filter NMR spectroscopy at 9.4T and reported a T_2*_F/ T_2*_S of 0.9/7.7 ms in healthy and 1.7/7.3 ms in degenerated annulus, and a T_2*_F/ T_2*_S of 3.3/12.9 ms in healthy and 1.7/16.8 ms in degenerated nucleus.[3] Whereas our T_1 results are more similar to values from Wang et al.[1], our T_2* results are in better agreement with report from Moon at al.[2] Our T_2*_F and T_2*_S results are in similar ranges as data from Ooms et al.[3] Our findings suggesting shorter relaxation times in IVDs with higher degree of degeneration compared to less degenerated IVDs.

CONCLUSIONS: Novel vTE-GRE technique proved to be useful tool for the measurement of ^{23}Na T_1 relaxation times as well as both T_2*_F and T_2*_S components of biexponential transversal decay of ^{23}Na in the IVDs. Presented findings may provide the basis for absolute quantification of ^{23}Na content in human IVDs and could help to understand processes associated with loss of GAG from IVDs.

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