Quantitative Magnetization Transfer and Relaxation in Tissues at 3T

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INTRODUCTION:

Longitudinal, T_1 and transverse, T_2 relaxation time measurements are relevant in understanding water molecular dynamics in biological systems. T_1, T_2 relaxation times and MT depend on the chemical and physical environments of water protons in tissue. MRI contrast between normal and pathological tissue is often based on differences in tissue microstructure and therefore different T_1 and T_2 relaxation times. Moreover, T_1, T_2 and MT provide quantitative assessment of tissue pathology. The literature data regarding MR parameters at high fields (such as 3 T) is surprisingly limited. The goal of this study is to provide a comprehensive evaluation of MR parameters at 3 T to serve as reference for further MRI pulse sequence optimization.

EXPERIMENTAL METHODS

All 3 T, MR measurements were performed at 37°C using a research-dedicated, whole body GE SIGNA magnet. MR pulse sequences and data acquisition were controlled by an NMR spectroscopy console (SMIS, Surrey, England). Immediately after tissue excision, the samples (approximately 300µl by volume)were immersed in non-protonated, MR-compatible fluid (Fluorinert; 3M, London, Canada) to avoid dehydration and reduce magnetic susceptibility effects. Temperature was controlled by an air-flow mechanism with MR-compatible thermocouple (Luxtron) inserted into the measured sample. The MR parameters and biological variations for each tissue were determined from independent measurements of three tissue samples.

The MR measurements consisted of the following:

- T_2 relaxation data acquired using a CPMG sequence with TE/TR = 1/15000 ms, 6000 even echoes sampled, 24 averages and a DC phase cycling scheme.
- T_1 relaxation time data acquired using an inversion recovery (IR) sequence with 35 TI values logarithmically spaced from 1 to 32,000 ms, 20s between each acquisition and the next inversion pulse (TR) and two averages.
- Quantitative Magnetization Transfer (MT) was measured using a continuous-wave (cw) saturation pulse of 7 s duration. Quantitative MT data were fitted to a "two-pool" model (1,2) quantifying the exchange between an unrestricted (liquid) and a semisolid (macromolecular) pool of restricted mobility. The model estimates: R, the rate of MT exchange of longitudinal magnetization between liquid and semisolid pools, M_{0B}, the fraction of magnetization that resides in the semisolid pool and undergoes MT exchange and T_{2B}, the transverse relaxation time value of the macromolecular protons. To probe T_2 relaxation anisotropy in cartilage, the only tissue in this study to show this effect, the T_2 relaxation experiments were performed for two angular orientations in respect to the major collagen fibers: 0°, and the magic angle of 55° (3).

RESULTS

The MR parameters at 37°C and 3 T for the variety of measured tissues are presented in Table 1. There was no significant, statistical difference (within the experimental error) between the T_2 relaxation time values at 3 T and 1.5 T. T_1 relaxation time constants for all measured tissues were longer than those at 1.5 T. The percentage increase in T_1 values was not uniform across all measured tissues; it was the largest for kidney (~73%) and smallest for cartilage (~10%). White matter T_1 relaxation time increased by approximately 22%. T_1 increase in blood was approximately 34%; it was 41% for liver, 43% for heart, 40% for skeletal muscle, 62% for gray matter, 33% for spinal cord and optic nerve.Quantitative MT parameters at 3 T, also varied among measured tissues but The MT exchange rate, R and semisolid pool fraction M_{0B} were field independent. Inflammed and demyelinated white matter showed significant decrease in semisolid pool fraction and MTR, while MT exchange rate R, was independent on tissue pathology

DISCUSSION

Quantitative MT parameters varied between measured tissues. These differences can be explained by different macromolecular tissue composition. The tissues exhibiting high lipid (white matter, optic nerve, spinal cord) or high collagen content (cartilage) exhibited large MT macromolecular fraction, M_{0B}, (between 12.6 and 18.2%). Conversely, the MT exchange constant, R was low for neural, WM tissue (from 23 to 26 s^{-1}) and was much higher (from 40 to 66 s^{-1}) for muscle, liver, heart, kidney, gray matter and cartilage. The different R values between white matter tissue (WM, optic nerve and spinal cord) and muscoskeletal tissue (liver, muscle, heart, kidney, cartilage) suggest different exchange constants for lipids (myelin) and proteins or collagen (muscle tissue and cartilage). However, with the exception of blood, the semi-quantitative measure of magnetization transfer, MTR, did not exhibit such large differences between the measured tissue. This is consistent with the fact that MTR is proportional to $RM_{0B}*T_1$ (4).

Tissue	M_{0B} [%]	R [s^{-1}]	T_{2B} [µs]	MTR [%]	T1 [ms]	T2 [ms]
Liver	6.9 ± 0.7	51 ± 10	7.7 ± 0.2	77 ± 5	812 ± 64	42 ± 3
Skeletal Muscle	7.4 ± 1.3	66 ± 6	8.7 ± 0.1	88 ± 2	1412 ± 13	50 ± 4
Heart	9.7 ± 0.2	52 ± 7	8.1 ± 0.1	89 ± 1	1471 ± 31	47 ±11
Kidney	7.1 ± 1.0	46 ± 7	8.1 ± 0.3	82 ± 1	1194 ± 27	56 ± 4
Cartilage 0°	17.1 ± 2.4	57 ± 3	8.3 ± 0.1	85 ± 1	1168 ± 18	27 ± 3
Cartilage 55°	18.2 ± 0.4	60 ± 5	8.3 ± 0.1	86 ± 1	1156 ± 10	43 ± 2
White matter	13.9 ± 2.8	23 ± 4	10.0 ± 1.0	85 ± 1	1084 + 45	69 ± 3
Gray matter	5.0 ± 0.5	40 ± 1	9.1 ± 0.2	84 ± 1	1820 ± 114	99 ± 7
Optic Nerve	15.8 ± 1.1	23 ± 2	10.0 ± 0.6	86 ± 2	1083 ± 39	78 ± 5
Spinal Cord	12.6 ± 1.8	26 ± 5	10.5 ± 0.6	83 ± 1	993 ± 47	78 ± 2
Blood	2.8 ± 0.7	35 ±7	280 ± 50	11 ± 4	1932 ± 85	275 ± 50

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