Investigation of temperature dependence of tissue relaxation parameters for post-mortem imaging

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Target audience: Forensic radiologists and scientist interested in post-mortem imaging, as well as researchers interested in temperature dependence of relaxation parameters.

Purpose: MRI in forensics is becoming increasingly important for a non-invasive and objective documentation of findings in living victims and post-mortem before autopsy[1]. However, post-mortem scans often suffer from poor contrast when clinical sequences are applied as tissue temperatures usually are clearly lower (5-20°C) than in vivo. It is well known that temperature strongly influences the MR relaxation parameters T_1 and T_2 as well as proton density. This temperature dependence is utilized in MR thermometry where temperature models[2] have been established for different tissues. However, little is known about the validity of the published models for lower temperatures[3]. In this study the temperature dependence of various tissues and the water relaxation times were investigated between 4° and 38°C. Furthermore, as post-mortem angiography is becoming feasible[4] also the temperature dependence for the Gadovist relaxivities r_1 and r_2 was determined.

Methods: Porcine tissue (muscle, fat, liver) stored in a refrigerator for less than 48 hours served as specimen[4]. The tissue samples (1x1x3cm^3) were placed in Liebig condensers where the samples were suspended in Sodium Chloride solution (0.9%) in the inner tube, and kept at a specified temperature by the external flow of water from a temperature controlled water bath. Additionally, tap water and water doped with Gadovist (Bayer Schering, Germany) were investigated as controls (concentrations 0.94, 0.52, 0.27, and 0.02mmol/l). The temperature was varied from 4° up to 38°C so slowly such that the sample was allowed to get into equilibrium (duration approx. 6 hours), and constantly monitored with a fluoroptic temperature probe (Luxtron, Santa Clara, USA). Measurements were performed at 3T (Tim Trio and Skyra, Siemens, Germany); the protocol consisted of turbo inversion recovery (TR 8000/TE 13/TI 70-3100ms/6 contrasts) and multi-echo spin echo (TR 3500/TE 8.8ms, Echos 32) sequences. For data analysis mono-exponential models were fitted to the acquired data. Three different models (Molecular Motion Model2[2], linear, and quadratic model $A + B\cdot T + C\cdot T^2$) were used to fit estimated relaxation times regarding their temperature dependence. The dependence of image contrast on temperature was investigated for a SE sequence, and the temperature dependence of the relaxivities r_1 and r_2 was computed from the doped water samples.

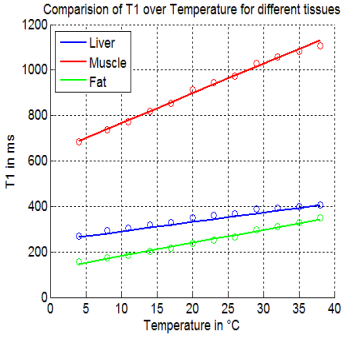

Fig. 1: T_1 versus Temperature

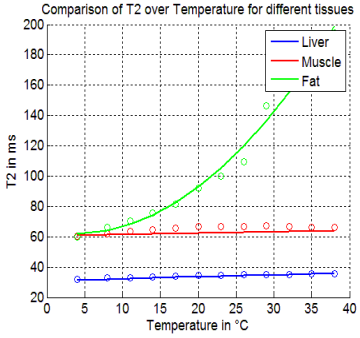

Fig. 2: T_2 versus Temperature

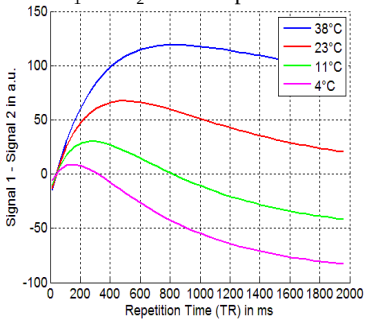

Fig. 3: Muscle-fat contrast for a SE sequence (TE=40 ms). T_1, T_2 and M_0 dependent on temperature.

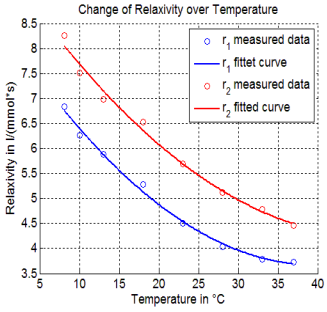

Fig. 4: Gadovist relaxivities versus Temperature.

Results: The Molecular Motion model was not suited to describe the relationship between temperature and relaxation times for our samples, and, thus, was not used further. In contrast, the residual errors of the quadratic and the linear model are small ($R^2 > 0.9$). The calculated parameters for the linear model are given in Table 1 together with parameters for grey and white matter brain tissue from the literature[3]. Figs. 1 and 2 show measured T_1 and T_2 values versus temperature. While T_1 increases for all samples, T_2 is relatively constant for muscle and liver, but increases for fat (coefficient for quadratic term C=0.12). M_0 showed to be rather constant for liver, but increased for fat and decreased for muscle tissue (data not shown). Fig. 3 illustrates how the contrast between muscle and fat changes in a spin echo sequence depending on TR and temperature. Temperature dependence of Gadovist r_1 and r_2 is shown in Fig. 4 (r_1=0.003 T^2 – 0.245 T + 8.546, r_2=0.003 T^2 – 0.237 T + 9.818).

Table 1: Parameters used to describe temperature dependency of relaxation times.

$T_{1,2} = A + B\cdot T$	(T in Celsius, $T_{1,2}$ in ms)			
	T_1		**T_2**	
Tissue	*A*	*B*	*A*	*B*
Muscle (porcine)	635.8	13.1	60.6	0.1
Fat (porcine)	124.8	5.8	23.9	4.1
Liver (porcine)	248.2	4.2	31.0	0.1
Water	723.5	102.6	1233.6	15.7
Grey Matter (human)[3]	1036.8	13.1	n.a.	n.a.
White Matter (human)[3]	711.0	2.8	85.0	-0.4

Discussion&Conclusion: Relaxation parameters are strongly dependent on temperature, but the relationship varies clearly with the tissue. A linear model seems to be suited to model temperature dependence of T_1 (for all investigated tissues) and T_2 (for liver and muscle tissue). However, a systematic relation for M_0 was not observed. Regarding contrast of a spin echo sequence the results showed that at e.g. 4°C for certain tissues it is impossible to achieve the same contrast as in vivo by adjusting TR. However, TR must be changed to obtain the maximum contrast. A quadratic relationship was found to describe a beneficial increase of Gadovist relaxivities for lower temperatures. For post-mortem MRI in forensic medicine or pathology different contrast has to be expected irrespective of the TR. However, the adaption of the acquisition parameters is crucial for sufficient image contrast.

References – Thali M, Dirnhofer R, Vock P (2010) The virtopsy approach: 3D optical and radiological scanning and reconstruction in forensic medicine. CRC Taylor & Francis. [2] T. R. Nelson und S. M. Tung (1987), Temperature dependence of proton relaxation times in vitro., *Magn Reson Imaging*, 5(3): 189-199. [3] Birkl C., Langkammer C., Haybaeck J., et al. (2012), Temperature induced changes of MRI relaxation rates in the brain: An unfixed postmortem study, *Abstracts of ESMRMB, Lisbon, MAGMA,*. 25: 101. [4] Grabherr, V. Djonov, K. Yen, et al. (2007), Postmortem angiography: review of former and current methods, *AJR Am J Roentgenol*, 188(3): 832-838. [5] M. E. Moseley, M. C. Nishimura, L. H. Pitts,et al. (1984), Proton nuclear magnetic resonance spectroscopy of normal and edematous brain tissue in vitro: changes in relaxation during tissue storage, *Magn Reson Imaging*, 2(3): 205-209.