Temperature Dependence of T1, T2 and T1rho in Agarose Phantoms

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INTRODUCTION

Despite the high sensitivity of MRI to pathological changes in tissue it has been difficult to make quantitative and reproducible measurements. One approach is to measure NMR relaxation times such as T1, T2 and, more recently, T1rho, in phantoms containing tissue mimics. The phantoms are scanned either separately or at the same time as is the subject in longitudinal studies (1,2,3). Understanding the reproducibility of measurements is important for calculating a measurement's reliability and for designing phantoms with adequate reproducibility (4,5).

AIM

To determine the sensitivity of the relaxation times T1, T2 and T1ρ (T1rho) to variations in temperature of the agarose gel.

METHOD

The phantom was created by the Phantom laboratory. It consisted of six, 50 mL conical centrifuge vials containing agarose gels with pairs of tubes at each of three concentrations (2%, 3%, & 4%). (figure 1).

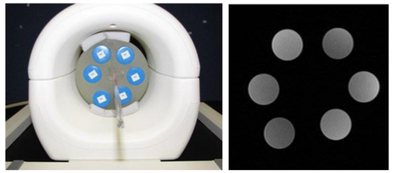


Figure 1. (left) Six vials of varying concentration of agarose gel inside cylindrical plastic phantom. Note thermometer placed inside phantom. (right) Transverse, T1-weighted image showing arrangement of vials.

Figure 2. Heating of the phantom was accomplished using (left) a temperature controlled water bath which circulated water through tubing wrapped around phantom. (right) Phantom was wrapped in insulating material to maintain its temperature.

METHODS: MRI

All imaging was done using a 3T, siemens Prisma scanner and a 15 channel transmit receive coil. T1 was measured using a series of 2D FLASH sequences with varying TR and flip angle α as shown in the table below. Individual ROI from each vial and for each image were extracted manually using NIH ImageJ. The ROI values were read into a custom-developed MATLAB program which estimated T1 by fitting the ROI data to the equation:

Table 1. Acquisition parameters used for 2D GRE to estimate T1.

TR (ms)	Alpha (°)
200	15
200	30
200	60
1000	10
1000	20

$$S(\alpha,TR) = S_0 \sin(\alpha) e^{-TE/T_2} \frac{1-e^{-TR/T_1}}{1-\cos(\alpha)e^{-TR/T_1}} \quad [1] \qquad S(TE) = S_0 e^{-TE/T_2} \quad [2] \qquad S(T_{sl}) = S_0 e^{-Tsl/T_{1\rho}} \quad [3]$$

T2 and T1ρ were estimated from 3D, multi-echo acquisitions. Each acquisition collected eight echoes with, for the T2 measurement, TE={5, 10, 20, 30, 40, 50, 60, 70 ms} and for the T1ρ prep at B1=500 Hz, and spin lock times of Tsl={0, 10, 20, 30, 40, 50, 60. 70 ms}. ROI from these images were fit to a mono-exponential (Eq 2 & 3) in EXCEL.
Temperature of the phantom was measured with standard laboratory and with an electronic thermometer at both the start and conclusion of imaging. Typically the difference was less than 0,5C. Five measurements made at temperatures between 3. °C and 26 °C.

RESULTS:

Results are shown for each vial. Vials were arbitrarily divided into two sets with a vial of each gel concentration in each set.

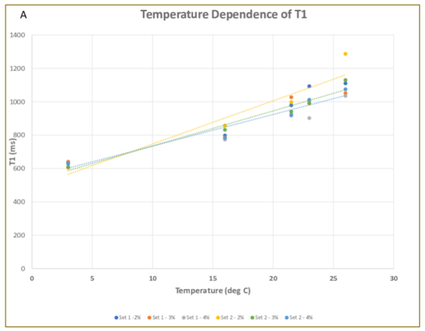
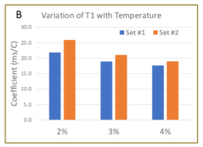


Figure 3. (A) variation of T1 with temperature. (B) Coefficient of variation with temp.



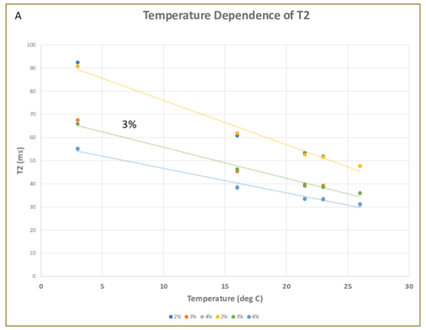
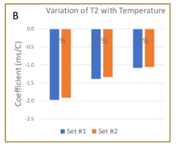


Figure 4. (A) variation of T1 with temperature. (B) Coefficient of variation with temp.



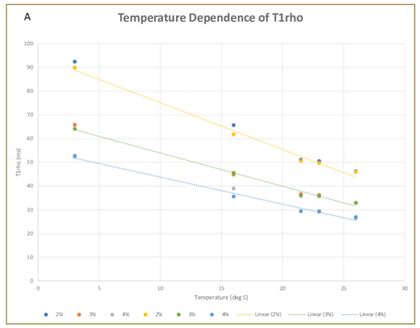


Figure 5. (A) variation of T1 with temperature. (B) Coefficient of variation with temp.

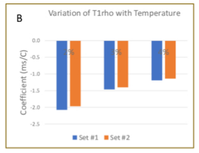


Table 2. Coefficients of variation of relaxation times with temperature and with gel concentration.

Relaxation time	Agarose concentration		
	2%	3%	4%
	(ms/°C)	(ms/°C)	(ms/°C)
T1	23.8	20.0	18.3
T2	-1.94	-1.36	-1.07
T1ρ	-2.02	-1.43	-1.17

Relaxation time	Agarose concentration		
	2%	3%	4%
	(%/°C)	(%/°C)	(%/°C)
T1	2.4	2.0%	2.0%
T2	-3.7%	-3.5%	-3.2%
T1ρ	-10.3%	-5.2%	-3.4%

The measurements varied smoothly with temperature with T_1 rising with increasing temperature and T2 and $T_{1\rho}$ falling with increasing temperature. The coefficients of variation are shown in figures and also in table 2.

CONCLUSIONS

All relaxation times are highly sensitive to temperature but T1ρ was the most sensitive.. The variation of T1 with temp is consistent with work of others (6,7). The change largely results from a decrease in the intermolecular correlation time with increasing temperature. There was a strong correlation between T2 and T1ρ. The inverted sign of the variation of relaxation time with temperature for T2 and T1ρ likely reflects the importance of cross relaxation with the agarose as the dominant factor determining these relaxation times.

The temperature coefficient T1ρ declined with increasing concentration of agarose perhaps because of the shorter distance for water to diffuse before encountering an agarose molecule.

Ambient temperature variation can be large ~±3C.

The results support the need to make phantoms from materials with lower sensitivity to temperature variation or to stabilize temperature in the MRI environment.

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