MRI Properties of Polyvinyl Alcohol Cryogel, Potential Material for Neonatal Brain Phantoms

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Introduction. The testing and optimization of MRI methods on human subjects is not always possible or appropriate, especially for neonatal and other pediatric subjects. The use of animal models represents challenges for MRI studies such as matching relaxation parameters and morphology to those of the human neonates. Thus, there is a need for "realistic" phantoms that will possess NMR and morphological features of the neonatal brain and other organs. Polyvinyl Alcohol Cryogel (PVA-C), the solid non-toxic gel obtained by freezing and thawing of the aqueous polymer solution [1], has been previously investigated as potential MRI phantom material [2]. In that work relaxation times were measured for 15% PVA-C as a function of number of freeze-thaw cycles at 1.5 Tesla. The measured relaxation times were within the physiological range (800 ms < T1 < 450 ms, 90 ms < T2 < 35 ms) required for mimicking certain tissues (e.g. human aorta, possibly adult brain). However, our goal is to explore the use of PVA-C as a phantom material to mimic neonatal brain regions which have very long relaxation times [3, 4]. Here we report on relaxation times and ADC values of low concentration PVA-C (6-15% by weight). Our investigation also differs from the previous work [2] by using a precise temperature control during freeze-thaw procedure.

Methods. PVA-C production: The 6, 8, 10, 12 and 15 % by weight mixtures of a dry polyvinyl alcohol powder with deionized water were slowly heated to 95°C in a heating mantel to obtain a uniform clear solution. This solution was sealed in molds, and, after a short settling period, placed into the temperature controlled bath for one freeze-thaw cycle. This cycle includes controlled freezing (0.1°/min from +20°C to -20°C), followed by 1 hour hold at -20°C and then controlled thawing (0.1°/min up to +20°C). The samples are stored in the water at 4°C. T1 measurements: Image-based measurements of T1 were carried out on 2 Tesla MRI system using inversion recovery spin-echo sequence with 20 values of inversion time (TI) in the range of 100 to 5000 ms with logarithmic spacing [5] (TR=5 s, TE=20 ms). Maps of T1 were created using pixel-by-pixel non-linear least squares regression to the equation $S = K[1-2\exp(-TI/T1)+\exp(-TR/T1)]$, where S is the signal intensity, K and T1 are adjustable variables. T2 measurements: Image-based measurements of T2 were performed using a spin-echo sequence with logarithmically spaced 20 values of echo times (TE) in the range of 15 to 550 ms (TR-TE=constant=3s). Maps of T2 were created by pixel-by-pixel log-linear least squares regression. ADC measurements were performed with Stejskal-Tanner diffusion gradients applied in a spin echo sequence at TR=1500 ms, TE=42 ms. Images were acquired with b = 34, 134, 301, 535, 837 s/mm^2 in three orthogonal directions. ADC maps were created using a log-linear least squares regression. Both positive and negative polarity diffusion gradient measurements were acquired to eliminate diffusion cross-terms produced by imaging gradients [6].

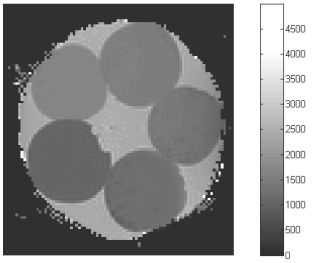

Fig.1. Example of T1 map, FOV=150mm, matrix 96x96

Results. Swelling of PVA-C samples (~30-40% increase in volume) was observed, which plateaued within the first 3-4 weeks. NMR measurements were performed after this period. An example of reconstructed T1 map of PVA-C samples placed in a water-filled container is presented in the Fig.1. The darkest structure is 15% PVA-C sample, followed next in the anticlockwise direction by the 12%, 10%, 8% and 6% (brightest) samples. Measured values of T1, T2 and ADC, are shown in the Figs. 2, 3 and 4 respectively. Error bars represent standard deviations. Evidently, these values fit to a linear regression within studied PVA-C concentration range; the linear relationship, however, is not necessarily expected to hold outside this region. The parameters of linear regressions are listed in the table 1.

Discussion. The range of T2 values (Fig 3) covers the range of values reported for neonatal brain regions in preterm infants at 1.0 T [3] as well as values reported for preterm and term infants at 3.0 T [4]. T1 values, however, are lower than those reported for white matter in term or preterm neonates at 3.0 T (T1 ~ 2500 – 2900 ms) [4]. The range of ADC also represents the values of neonatal brain (~ 1.00 – 1.55 10^{-3}mm^2/s [7]). The use of temperature controlled freeze-thaw procedure provides additional parameters (e.g., freezing/thawing rate) that may ultimately be manipulated to further alter MRI properties of PVA-C. In particular, further work will explore the possibility lengthening T1 by altering these parameters

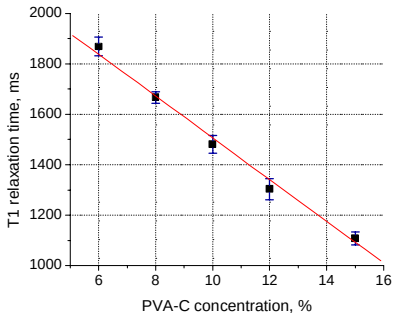

Fig.2. T1 relaxation times of PVA-C samples.

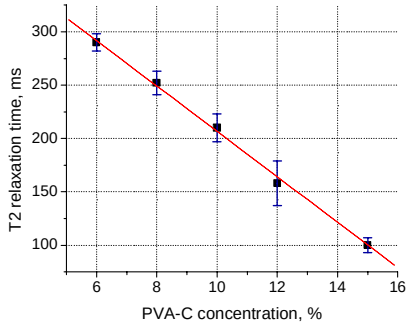

Fig.3. T2 relaxation times of PVA-C samples.

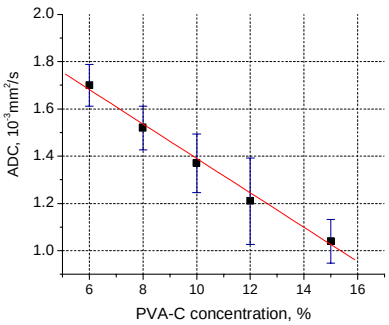

Fig.4. Apparent Diffusion Coefficient of PVA-C samples

	T1, ms	T2, ms	ADC, 10^{-3}mm^2/s
Intercept	2332.53±40.45	419.22±3.75	2.11±0.032
Slope	-82.71±3.73	-21.26±0.34	-0.0728±0.00309

Table 1. Linear regression parameters for T1, T2 relaxation times and ADC of 6-15% PVA-C

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