

MR Characterization and Temperature Dependence of Aqueous Polyvinylpyrrolidone (PVP) Solutions for use as MR Phantoms

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Synopsis

Diffusion-weighted MRI methods often contain variability and bias in diffusion parameters that are measured between sites, scanners, and vendors. There is a clear need for a calibrated diffusion phantom to help identify and mitigate these differences. Here we utilize a 7T spectrometer to characterize MR parameters of T_1 , T_2 , and the water self-diffusion coefficient in aqueous Polyvinylpyrrolidone (PVP) solutions and their dependence on temperature and PVP concentration, without imaging confounds. An empirical formula is presented for use with PVP aqueous solutions as a calibrated diffusion phantom. Data show that aqueous PVP solutions are well suited as a MR phantom material.

Introduction

Diffusion-weighted MRI (DWI) methods have widespread use both in clinical and research imaging. However, there is often variability and bias in the quantitative diffusion parameters that are measured between sites, scanners, and vendors. The sources of these differences may be hardware and software related, including both acquisition and reconstruction methods. There is a clear need for a calibrated diffusion phantom to help identify and mitigate these differences, as well as monitor quality control. Aqueous Polyvinylpyrrolidone (PVP) solutions have been shown to be ideal for diffusion phantoms as they are non-toxic, stable, inexpensive, high viscosity, and mean diffusion coefficients in the range of biological tissues^{1,2}. In this work, we characterize MR parameters of T_1 , T_2 , and the water self-diffusion coefficient (D) in aqueous PVP solutions and their dependence on temperature and PVP concentration. By utilizing small samples and acquiring spectroscopy data, the influence of hardware and software related imaging confounds and artifacts are negligible, allowing for the most accurate calibration.

Methods

Studies were conducted using a 7T Bruker wide-bore vertical spectrometer with a micro2.5 insert set capable of 1475 mT/m maximum gradient strength. Solutions of 0% (distilled water), 24.3%, 34.5%, and 46.6% PVP (Sigma-Aldrich, K40) were prepared and placed in susceptibility matched 5mm Shigemitsu tubes. NMR spectroscopy data were acquired under controlled temperature with a Bruker VT unit and 10 mm RF coil. The concentration of the PVP solutions were determined by weighting the samples before and after drying. T_2 relaxation data were acquired with a CPMG sequence, TR=5000ms, and 80 echoes with 20ms spacing. T_1 relaxation data were acquired with an IR-SE sequence, TE/TR=20/7000 ms, and TI from 6-5000 ms. Diffusion-weighted data were acquired with a SE sequence, TE/TR=55/7000 ms, diffusion time (Δ) = 25ms, gradient length (δ) = 3 ms and 32 b-values from 0 to a b-value that attenuated the signal to between 6% and 2% to avoid sampling rectified noise. Measurements were taken at temperatures from 19.1 to 37° C. When changing to a new temperature, the sample was left to equilibrate for 30 minutes.

Results

Figure 1 shows that there is a linear relationship between T_2 relaxation rate and PVP concentration. Figure 2 shows there is also a linear relationship between T_1 relaxation rate and PVP concentration, for both temperatures measured. Figure 3 shows a plot of the mono-exponential signal decay with b-value, for each PVP concentration, at a temperature of 19.1° C. D was calculated from the curves. Figure 4 shows the relationship between D and PVP concentration. The data deviates from a linear relationship and is better described by a quadratic function, which is reasonable for polymer-based aqueous solutions^{3,4}. This behavior is consistent, regardless of temperature. Figure 5 shows the relationship between D and temperature, for all concentrations studied. For reference, points are included for distilled water, 0%, from the 1973 study by Mills⁵. There is a linear relationship between D and temperature for all PVP concentrations. In addition, the slope of the line decreases with increased concentration. From these results an empirical formula was derived for predicting D given PVP concentration and temperature. The slope and intercept from each linear fit shown in Fig. 5, were plotted separately as a function of PVP concentration. A second degree polynomial was fit to the data. The resulting empirical formula is as follows: $D = mT + b$, where T is the temperature, $m = 0.0086C^2 - 1.2862C + 56.603$, $b = 0.1171C^2 - 24.033C + 934.45$, and C is PVP concentration.

Discussion

In this study, we measure the MR properties of aqueous PVP solutions. It is possible that solutions made with different molecular weight may differ in their MR properties than those reported here. T_2 and T_1 relaxation are linearly related to PVP concentration. Although the values for T_2 and T_1 will change with field strength, we expect this relationship to remain the same. However, the diffusivity should remain constant regardless of field strength. The mono-exponential signal attenuation vs b-value indicates Gaussian diffusion of a single population of spins. Our data was acquired with tight temperature control and without influence of imaging gradients and other “cross-terms”. Therefore, the derived empirical formula can be utilized with PVP aqueous solutions as a calibrated diffusion phantom. Deviation from the D calculated using the empirical formula can be attributed to errors from hardware and/or software. In addition, at room temperature, 23° C, the 34.7% PVP solution has a D and T_1 close to that of *in vivo* brain parenchyma. PVP solutions are well suited as a MR phantom material for clinical and research purposes.

Acknowledgements

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References

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Figures

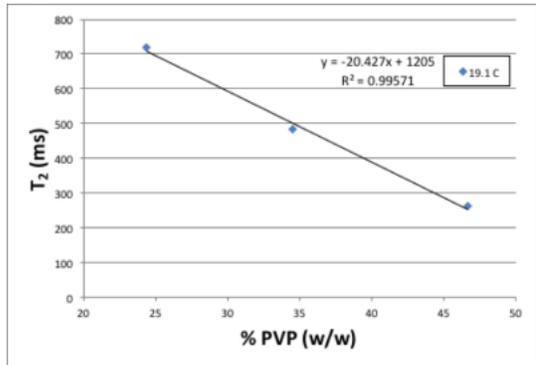


Figure. 1: T₂ relaxation as a function of concentration at 19.1° C. T₂ has a linear relationship with concentration.

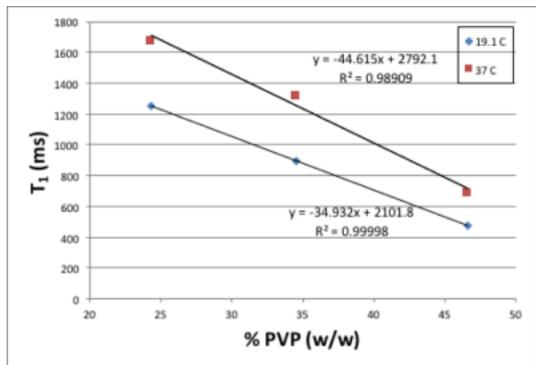


Figure. 2: T₁ relaxation as a function of concentration at 19.1 and 37° C. T₁ has a linear relationship with concentration.

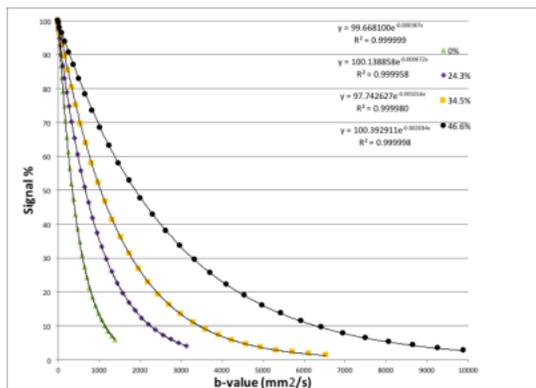


Figure. 3: Normalized signal intensity as a function of b-value for each concentration at 19.1° C. The signal decays as a mono-exponential.

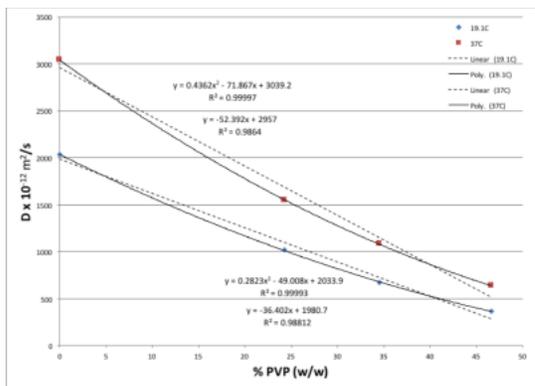


Figure. 4: D as a function of concentration at 19.1 and 37° C. A second order polynomial fits the data more accurately then a linear function.

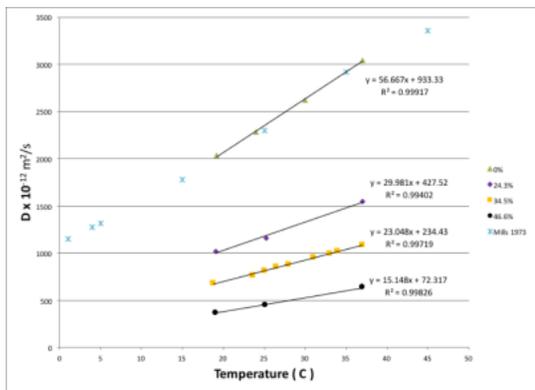


Figure 5: D as a function of temperature for all concentrations. D has linear relationship to temperature.