Polyvinylpyrrolidone (PVP) water solutions as isotropic phantoms for diffusion MRI studies

C. Pierpaoli[1], J. Sarlls[1], U. Nevo[1,2], P. J. Basser[1], and F. Horkay[1]

[1]NIH, Bethesda, MD, United States, [2]Department of Biomedical Engineering, Tel-Aviv University, Tel-Aviv, Israel

Introduction

As Diffusion Tensor MRI (DTI) and other diffusion MRI applications are becoming more widespread clinically, the need to develop a phantom for diffusion MRI calibration and quality control is essential. Standard MRI phantoms are often suboptimal as diffusion phantoms because they have diffusivities that are too large to be representative of those found in biological tissues. Tofts et al. (1) pointed out desirable features that a diffusion phantom should possess: covering a large range of diffusivities; being stable, cheap, and non-toxic; having a single proton spectral line with T1 and T2 values similar to that of tissue, and having high viscosity to reduce the effects of vibrations and convective motion. Tofts suggested that commercially available alkanes satisfied several of these conditions, and proposed their use to produce calibration phantoms for diffusion MRI. In our experience, however, the acceptance of these compounds in a clinical setting has been limited because of concerns about their flammability and potential toxicity. Here we evaluate the use of Polyvinylpyrrolidone (PVP) water solutions as potential isotropic phantoms for diffusion MRI studies. We found almost no previous data on diffusion measurements of PVP solutions (2). A large body of literature is available about the toxicology of PVP and this compound is considered safe for use in foods, beverages, cosmetics, and in several industrial applications (3).

Methods

Solutions of PVP (Sigma-Aldrich, K value 29-32) ranging from 15% to 65% w/v were prepared in either pure water or saline solution (0.9% w/v of NaCl). Concentrations as high as 71% were achieved with subsequent evaporation. 0.1 % sodium azide was added as a preservative. MRI data were acquired on a GE 3T Excite scanner with 40mT/m maximum gradient strength and a Nova 16 Channel coil at 22 ^{o}C. Diffusion data were acquired with single-shot EPI and consisted of 120 different gradient directions/b-values, with a maximum b=1100 s/mm^2. T1 relaxometry was performed with a DESPOT (3) acquisition (TR = 8.1 ms, four flip angles = 30, 19, 10, and 2 degrees, B1 mapping with 150, 450, and 750ms inversion recovery acquisitions). T2 relaxometry was performed with a spin echo acquisition (TE ranging from 10 to 700 ms). Additional NMR data were acquired in a 47% PVP solution on a Bruker 7T vertical spectrometer with 1000mT/m maximum gradient strength and a temperature-controlled probe set to 20.6° C. These experiments were aimed at evaluating the mono-exponentiality of the signal decay at b-values up to 6000 s/mm^2 and the effect of varying the diffusion time (Δ) from 20 to 200 ms.

Results and Discussion

The signal decay vs b-value was monoexponential up to the highest measured b-value of 6000 s/mm^2 and the measured averaged diffusivity <D> was independent of the diffusion time, Δ (Table 1) These findings indicate Gaussian diffusion of a single population of spins. This is a desirable feature in a diffusion phantom to be used for calibration purposes. <D> was approximately a linear function (R^2 = 0.992) of PVP concentration up to 50% PVP (fig 1) with slope -35.4 and intercept 2025 *10^{-12} m^2/s which is very closed to the expected value for free water at 22 ^{0}C. At higher concentrations this relationship diverged from linearity (fig 1). T1 was highly correlated with <D> (fig 2). At diffusivity values typical of gray matter (800 *10^{-12} m^2/s) T1 was 1392 ms, which is slightly higher than T1 of brain tissue. T2 was generally higher than that of brain tissue (e.g. T2=196 ms at 55% PVP). A 43% PVP solution stored in a sealed container was scanned 3 times over a period of 15 months. The coefficient of variation of the measured <D> over that period was 2%, indicating good stability of the compound. In summary, we conclude that aqueous solutions of PVP are good candidates for a non-toxic diffusion MR phantom suitable for use in a clinical setting.

Δ (ms)	<D> x 10^{-12} m^2/sec
20	379.0
60	371.5
120	370.5
200	369.1

Table 1: List of diffusion times with the corresponding calculated <D> for ~ 47% PVP.

Figure 1

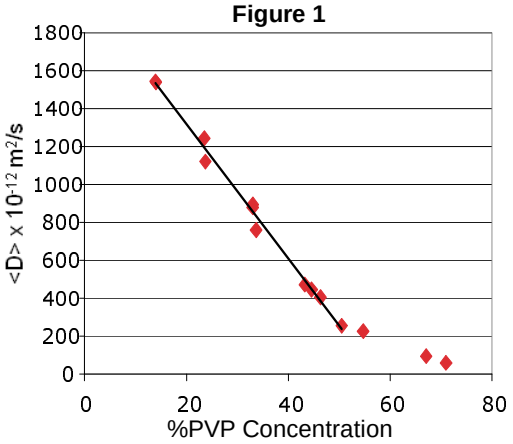
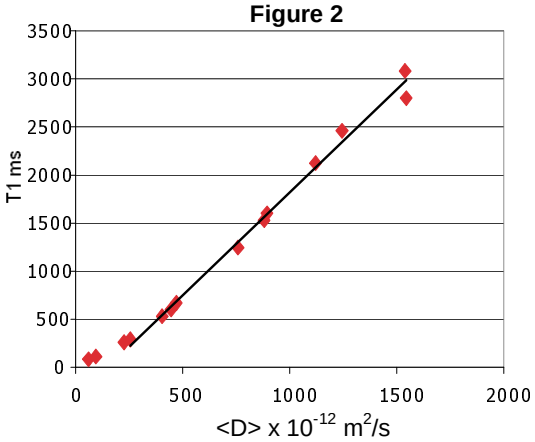


Figure 2



References: [1] Tofts PS et al. MRM 2000;43:368. [2] Fukuzaki et al. ISMRM 1999, pg. 1833. [3] Robinson et al., Lewis Publisher 1990 ISBN 0-87371-288-9. [4] Deoni, SC, JMRI 2007; 26:1106-11.