Temperature-controlled Isotropic Diffusion Phantom with Wide Range of Apparent Diffusion Coefficients for Multicenter Assessment of Scanner Repeatability and Reproducibility

Michael A. Boss[1], Thomas L. Chenevert[2], John C. Waterton[3,4], David M. Morris[4], Hossein Ragheb[4], Alan Jackson[4], Nandita deSouza[5], David J. Collins[5], Bernard E. van Beers[6], Philippe Garteiser[6], Sabrina Doblas[6], Stephen E. Russek[1], Kathryn E. Keenan[1], Edward F. Jackson[7], and Gudrun Zahlmann[8]

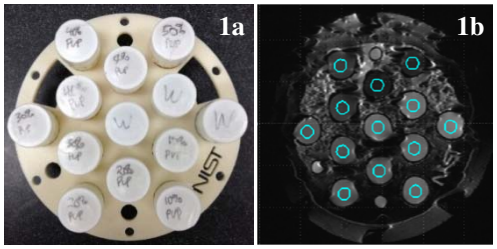
[1]National Institute of Standards and Technology, Boulder, CO, United States, [2]University of Michigan, Ann Arbor, MI, United States, [3]AstraZeneca, Macclesfield, United Kingdom, [4]University of Manchester, Manchester, United Kingdom, [5]The Institute of Cancer Research, Sutton, Surrey, United Kingdom, [6]INSERM, France, [7]University of Wisconsin, Madison, WI, United States, [8]F. Hoffman-La Roche Ltd., Basel, Switzerland

Purpose

The apparent diffusion coefficient (ADC) is an important biomarker in neurology and oncology, but there is currently low confidence that ADC values measured in different institutions or with different sequences are comparable. Our goal was to investigate variability in measured ADC with regard to different scanner vendor, magnetic field strength and clinical site by use of a multicomponent temperature-controlled phantom covering a wide range of physiologically relevant ADC.

Methods

A spherical phantom shell was 3D-printed in polycarbonate and poly(acrylonitrile butadiene styrene) with an outer diameter of 194 mm in order to fit into a wide range of MRI coils. Aqueous solutions of polyvinylpyrrolidone (PVP) were mixed in concentrations varying from 0 to 50% by mass PVP to vary the ADC of water protons.[1] These solutions were poured into 20 mL polypropylene vials and arranged into a holding plate at the center of the phantom (Fig. 1a). To control temperature, the phantom was filled with ice water[2] and allowed to equilibrate overnight in a refrigerator. The following morning, prior to imaging, more ice was added to maintain the PVP solutions at 0 °C, verified by a thermocouple with an accuracy of ±0.3 °C. The phantom was imaged at three sites, as a collaboration between the RSNA Quantitative Imaging Biomarker Alliance and the IMI QuIC-ConCePT projects using 1.5 (A, C) and 3 T (B) scanners. Image data was acquired in the coronal plane by use of a diffusion-weighted SS-EPI sequence with b-values of 0, 500, and 900 s/mm^2. Scans were performed a minimum of two times at each site during a single session in order to assess repeatability. Regions-of-interest (ROIs) were selected in the center of each vial and utilized to calculate ADC from b_0-b_{500} and b_0-b_{900} image sets.



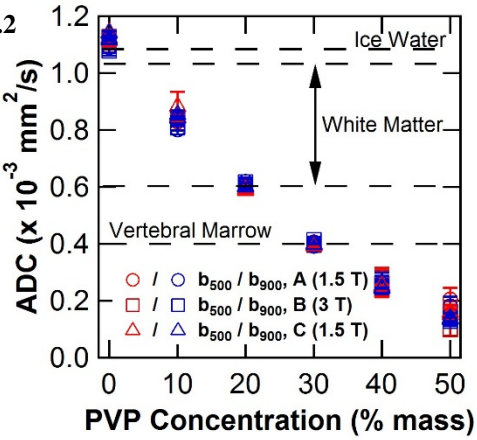
Results

Monoexponential decay was observed over a wide range of b-values. Fig. 1b shows a diffusion-weighted image of the phantom filled with ice and the ROIs chosen to calculate ADCs. The ADCs for each vial are plotted vs. PVP concentration in Fig. 2, with values ranging from below 0.2 to 1.1 x 10^{-3} mm^2/s, representing 50% and 0% PVP, respectively. The measured water ADC is in good agreement with previous literature results.[3] Coefficients of variation (CoV) were calculated for each of the vials to assess repeatability over all scans, with the mean CoVs for each vial set listed in Table 1 as a percentage. Little difference was seen between the CoVs for inner- and outer-ring vials of PVP, with the exception of the 50% vials.

Table 1: Mean CoV by PVP Concentration

	CoV (A, 1.5 T)		CoV (B, 3 T)		CoV (C, 1.5T)	
PVP %	$b_{0\text{-}500}$	$b_{0\text{-}900}$	$b_{0\text{-}500}$	$b_{0\text{-}900}$	$b_{0\text{-}500}$	$b_{0\text{-}900}$
0	1.10	0.01	1.18	1.16	0.96	0.43
10	1.75	1.31	2.18	1.58	3.52	1.26
20	2.35	1.80	1.70	1.69	4.23	2.41
30	2.69	1.82	3.98	3.62	1.08	0.21
40	14.8	12.1	11.9	7.43	0.42	1.36
50	20.5	22.2	15.4	13.7	14.28	16.49

Fig.2



Discussion and Conclusion

PVP is able to cover a wide range of physiologically-relevant ADC values. ADC results were consistent between inner- and outer-ring vials, indicating little spatial dependence (over approximately 35 mm). There was significant variation in the measured ADC of the 50% vials. This variation could be caused by a combination of signal noise and insufficient b-values to properly assess this most viscous solution. Susceptibility artifacts due to shell design were observed, but did not appear to adversely affect ADC measurements. Finally, results at 1.5 and 3 T were in agreement with one another, as were results calculated using the b_{500} and b_{900} scans. Future plans are to produce more phantoms for continued multicenter studies, and to further examine repeatability and reproducibility across sites.

References

1. Pierpaoli C, Sarlls J, Nevo U, Basser PJ, and Horkay F. Polyvinylpyrrolidone (PVP) water solutions as isotropic phantoms for diffusion MRI studies. In Proc Intl Soc Mag Reson Med, 2009. P. 1414. 2. Malyarenko D, Galbán CJ, Londy FJ, Meyer CR, Johnson TD, Rehemtulla A, Ross BD, and Chenevert TL. Multi-system repeatability and reproducibility of apparent diffusion coefficient measurement using an ice-water phantom J Mag Reson Imag. 2013;37:1238-1246. 3. Holz M, Heil SR, and Sacco A. Temperature-dependent self-diffusion coefficients of water and six selected molecular liquids for calibration in accurate 1H NMR PFG measurements. Phys Chem Chem Phys. 2000:2:4740-4742.