# A highly standardized, easy to produce and cost-effective isotropic PVP diffusion phantom for quality assessment and multi-center studies

Pim Pullens[1], Piet Bladt[1], and Paul M Parizel[1]
[1]*Radiology, University Hospital Antwerp & University of Antwerp, Antwerp, Antwerp, Belgium*

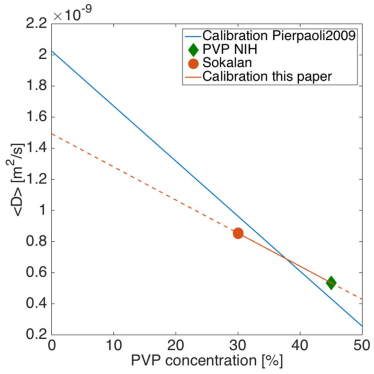
**Target audience** MR Physicists, MR Technologists, Multi-center study researchers.

**Purpose** There is a need for highly standardized isotropic diffusion phantoms. Most isotropic phantoms are difficult to manufacture in large quantities (i.e. [1][2]), are difficult to obtain (i.e. the NIH PVP phantom [1]), are expensive (i.e. [2] oral communication), contain toxic or flammable substances (i.e. Dodecane [3]) and/or require careful handling (i.e. ice-water phantom [3]), which makes them unsuitable for use in a clinical setting. For CENTER-TBI [4], a large European multi-center study to investigate effective treatments for traumatic brain injury in a clinical environment, 35 phantoms were needed. We have created an easy to use, robust, cost-effective, and safe isotropic diffusion phantom, which can be produced in a reproducible way.

**Methods** The phantom was developed as a replacement for the NIH PVP phantom [1], which, after extensive communication with and helpful assistance of Dr. Carlo Pierpaoli (NIH), proved to be impossible to obtain in sufficient quantity for our study. We were generously given one PVP phantom by Dr. Pierpaoli to test. The NIH PVP phantom contains a 45% PVP solution. We have used an alternative PVP solution, BASF Sokalan® K30 sol. 30% (BTC Europe GmbH, DE), which is a commercially available bulk 30% PVP solution used as binding agent or glue in industrial applications. It does not require a GHS label and is considered safe for use in industrial applications. From a 125kg barrel, 2 Liter Nalgene™ bottles (similar to Siemens QA bottles) were filled with Sokalan. Sokalan was compared against the NIH PVP and a Dodecane (Sigma-Aldrich, BE) phantom [3]. All phantoms were measured multiple times at 21°C, using a diffusion-weighted sequence with *b*=350, 700, 1050, 1400 and 1750 s/mm$^2$, 12 directions, 2x2x2 mm and 3x3x3mm voxels, 21 slices through the center of the phantoms. Measurements A and E (day 1), B and F (day 2) were performed on a Siemens 3T Magnetom Trio TIM with an 8-ch headcoil. Measurements C, D, G and H were performed on the same day on a Siemens 3T Magnetom Skyra system with a 32-ch head coil. Mean diffusivity (MD) calculation and further analysis was done in Matlab. Measured MD was compared to the calibration line MD = 2025*10$^{-12}$ - 35.4*10$^{-12}$*[%PVP] reported in [1].


**Table 1 Mean Diffusivity (MD) [*10$^{-12}$ m$^2$/s] at 21°C**

| # | description | NIH PVP | Dodecane | Sokalan |
|---|---|---|---|---|
| A | Trio 2mm iso | 536±15 | 769±20 | - |
| B | Trio 2mm iso | 532±16 | 767±18 | 854±12 |
| C | Skyra 2mm iso | - | - | 855.9±9.6 |
| D | Skyra 2mm iso | - | - | 850.7±8.9 |
| E | Trio 3mm iso | 535.7±5.7 | 768±11 | - |
| F | Trio 3mm iso | 535.8±5.9 | 768±13 | 854.5±7.4 |
| G | Skyra 3mm iso | - | - | 852.9±8.4 |
| H | Skyra 3mm iso | - | - | 856.7±8.9 |




**Results** The phantom we created is shown on the left. Data obtained from the diffusion-weighted sequence show that ln(*S/S0*) vs *b* is a straight line (data not shown). MD was calculated in a cylindrical region-of-interest (ROI) in the slice center (Table 1). The MD of the Sokalan-filled phantom is higher than for the NIH PVP and Dodecane phantoms, but fits excellent in the range of human white matter MD, which ranges from 690 to 930*10$^{-12}$ m$^2$/s [3]. MD of our Sokalan-filled phantom is slightly lower than predicted by the calibration line from [1] (right figure). Fitting a straight line through the mean of NIH PVP and Sokalan points, we obtain the calibration line MD = 1493*10$^{-12}$ - 21.3*10$^{-12}$*[%PVP]. However, we used different scanners (GE 3T Excite in [1] vs Siemens Trio/Skyra), a different DWI scan protocol and temperature was 1 degree Celsius higher in our measurements. MDs are highly consistent between measurements for all three phantoms.

**Discussion** Compared to the NIH PVP and Dodecane phantoms, we found that MD measurements for a Sokalan-filled phantom on a 3T Siemens Magnetom Skyra and TIM Trio system were highly reproducible and are very comparable between Skyra and Trio. 2mm isotropic and 3mm isotropic voxels yield highly similar MD.

**Conclusion** The BASF Sokalan® K30 sol.30% phantom is a safe, easy to manufacture and cost-effective isotropic diffusion phantom solution. Average MD ranges from 851 to 857*10$^{-12}$ m$^2$/s at 21°C in our experiments.

**References** [1] Proc ISMRM 17, #1414, 2009 [2] Proc ISMRM 22, #4505, 2014 [3] Derek Jones (ed.), *Diffusion MRI*, 2010 [4] www.center-tbi.eu