Calibrated Diffusion Phantom for 7T MRI

Joelle E Sarlls[1], Carlo Pierpaoli[2], Qi Duan[3], Wolfgang Devine[4], and Hellmut Merkle[3]

[1]*NINDS/NMRF, National Institutes of Health, Bethesda, MD, United States,* [2]*NICHD/STBB, National Institutes of Health, MD, United States,* [3]*NINDS/LFMI, National Institutes of Health, MD, United States,* [4]*NINDS-NIMH/RSB, National Institutes of Health, Bethesda, MD, United States*

Target Audience: MR scientists interested in diffusion imaging at high field

Purpose: MRI at high magnetic field strength provides an intrinsic increase in net magnetization, and is thus attractive for signal-starved diffusion-weighted imaging (DWI). However, high-field strength also brings many technical challenges, in particular inhomogeneous B_1 and increased susceptibility effects. Accordingly, there is much activity in DWI sequence development for 7T. To validate custom sequences and hardware, a calibrated diffusion phantom, free from flow artifacts, with dimensions similar to the head is needed. Such a phantom exists as a 16cm ball filled with 35% PVP solution, previously introduced by Pierpaoli *et. al.*[1], and is readily used at 3T. However, due to the combination of wavelength effects and phantom geometry, it is inadequate at 7T due to the consequent B_1 inhomogeneity. Variation in flip angle across the object does not affect the applied diffusion weighting in a spin-echo diffusion prep, however it does affect the SNR. It is well known that SNR can bias calculated diffusion parameters. In this study, we investigate the use of a straightforward solution to reduce B_1 inhomogeneity by changing the geometry and increasing the wavelength of the phantom with plastic rods[2], to introduce a calibration phantom for DWI at 7T.

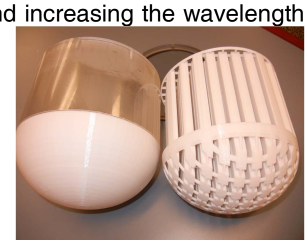

Fig. 1: cylindrical phantom and grid insert

Methods: A cylindrical phantom (17cm diameter and 17cm length), with one dome end, was fitted with a grid insert made up of 1x1 cm plastic (polycarbonate) columns that occupy ~50% of the total volume (Fig. 1) Data was acquired of the phantom filled with 40% saline, 0.2% gadolinium, and distilled water solution. Data was also acquired of the phantom filled with a 35% PVP solution (dielectric constant/relative permittivity=22.48 at 300 MHz). Data were also acquired on the 16cm ball filled with 40% PVP solution, currently utilized at 3T. Data were acquired on both 7T and 3T scanners using 32-channel phased-array coils at 23° C. DWI data were acquired with a spin-echo single-shot EPI sequence and the following scan parameters: TE/TR=79/8600ms, FOV=22cm, slice thickness=2mm, 70 slices, 110x110, GRAPPA=2, esp=0.67ms, bvalue=1100 s/mm^2, and 30 directions. B_1-mapping data were acquired at 7T with a modified Bloch-Siegert method[3]. TORTOISE[4] was used for preprocessing the DWI data to correct for eddy-current distortions and to calculate the diffusion tensor.

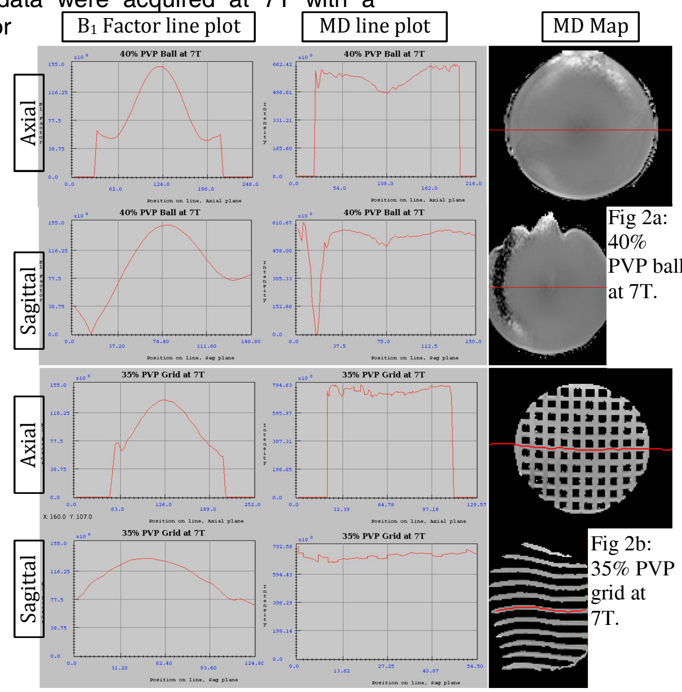

Fig 2a: 40% PVP ball at 7T.

Fig 2b: 35% PVP grid at 7T.

Results: As seen in Fig 2a, the relative B_1 varies in the ball phantom from 52% to 151% in the center axial plane and from 0% to 151% in the center sagittal plane of the nominal B_1 producing a factor of 8.6 and infinite increase in SNR, respectively. The calculated mean diffusion coefficient (MD) consequently varies by 26% in the axial and infinitely in the sagittal planes, following the spatial pattern of the B_1. Utilizing the proposed cylindrical phantom with grid insert dramatically improves the consistency of B_1 across the object. Filled with the saline/gadolinium solution, B_1 varied from 0% to 152% in both the axial and sagittal planes without the grid, compared with 32% to 140% in the axial and 47% to 138% in the sagittal plane with the grid. As seen in Fig 2b, filled with 35% PVP solution, the B_1 varies from 57% to 134% in the central axial plane and from 70% to 134% in the sagittal plane of the nomial B1 producing a factor of 1.8 and 1.7 increase in SNR, respectively. Thus, the consistency of the calculated MD was also dramatically improved; the MD varies by 8% in the axial and 10% in the sagittal planes. ~10% difference in MD is equivalent to that calculated in both phantoms in both planes on the 3T scanner. The mode of the whole phantom MD histogram was 592 and 741 mm^2/s for the the 40% PVP ball and 35% PVP grid phantom, respectively, on both the 3T and 7T, consistent with the expected MD for the given %PVP and tempature[1].

Discussion/Conclusions: Utilizing a cylindrical geometry and increasing wavelength through the insertion of a regularly spaced plastic column grid made the effective B_1 significantly more homogeneous across all dimensions of the PVP phantom. The SNR across the phantom is more homogeneous and the corresponding bias in the calculated MD from low SNR is removed. There maybe additional factors contributing to the reduced MD in the center of the 40% PVP ball at 7T, which are being investigated, that also seem to be mitigated by the grid phantom. The residual 10% variation in MD observed at both 3T and 7T is assumed to be due to gradient non-linearity, which needs to be confirmed. The introduced calibrated diffusion phantom provides the means to accurately test developed pulse sequences and hardware at 7T. Variations in diffusivity or anisotropy measured in this isotropic phantom points to errors in the developed method that needs to be addressed for quantitative studies.

References: [1] Pierpaoli, *et. al.*, 17th ISMRM, 1414, 2009. [2] Merkle, *et. al.*, MRM, 66:901-910, 2011. [3] Duan, *et. al.*, NMR Biomed, 26:1070-1078, 2013. [4] Pierpaoli, *et. al.*, 18th ISMRM, 1597, 2010. **Acknowledgement:** PVP permittivity measures by Dr. Ryan Brown, NYU.