Temporal and across-phantom evaluation of diffusion measures in multiple anisotropic diffusion phantoms

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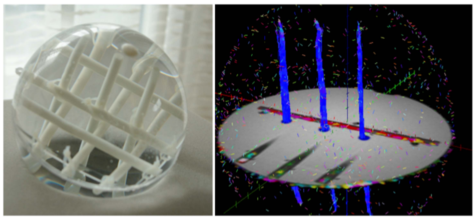
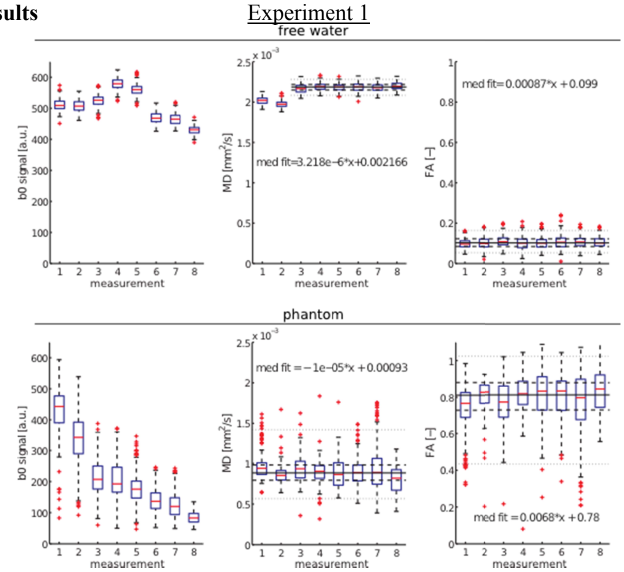
Introduction MR stability during a diffusion acquisition is important because deviations in the signal, not caused by the subject, might lead to changes in diffusion measures. Longitudinal DW-MRI studies require scanner stability and maintaining performance over time. DW-MRI quality assurance was previously carried out with the ACR phantom [1] or isotropic phantoms and human subjects [2]. Goals of the current study are: 1) to asses the temporal characteristics of an *anisotropic* diffusion phantom, and 2) to evaluate the agreement in diffusion measures in 5 different anisotropic DW-MRI phantoms.



Methods Experiment 1 A commercially available anisotropic DW-MRI phantom [3,4] was used, see left figure for a phantom used in Exp 2. The phantom contains 3 tubular anisotropic phantoms ("tubes"), each containing ~180,000, 10 µm parallel polyester fibers in an $MnCl_2$, NaCl and NaN_3 solution. During an 7-week period and one 1-year follow-up, the phantom was scanned in a 3T Siemens Allegra, single coil; first session of the day except from the 1 year follow up; with the following protocol: 1) Warm-up scan 2) localizer 3) 42 dir DWI: double-refocused DW-SE-EPI, 128x128 matrix, 80 slices, b=1000 s/mm^2, isotropic 2 mm voxels. The tubes were aligned parallel to B0 by eye. Temperature was recorded before, during and after DWI in a 0.5 l water bottle lying in the coil. Data analysis in FSL (FMRIB, Oxford). Tensor, FA and MD were calculated in native space. The edge image of the FA map was used to drive co-registration to a template extracted from the 7th measurement. All measurements underwent the same co-registration procedure to avoid interpolation artifacts. A ROI only containing voxels in a tube of the b0 image of the 7th measurement was used to mask the co-registered FA, MD and b0 data. Data was further processed in Matlab. Experiment 2 We evaluated the agreement in 5 anisotropic DWI phantoms built for several labs worldwide. Each phantom was built according to the lab's preferences. The phantoms each contained, besides crossing and/or kissing structures, 3 or 4 tubes. For quality assurance, each phantom was scanned within a week after construction. The protocol included a MPRAGE and 12 dir + b0 DWI (similar parameters as in Exp 1). Only tubes aligned parallel to B0 were evaluated. Data analysis was performed in the phantom's native space, and ROIs were defined individually on each tube.

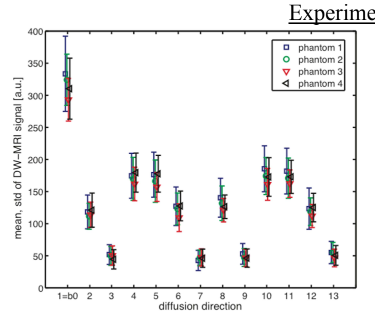
Results

Experiment 1

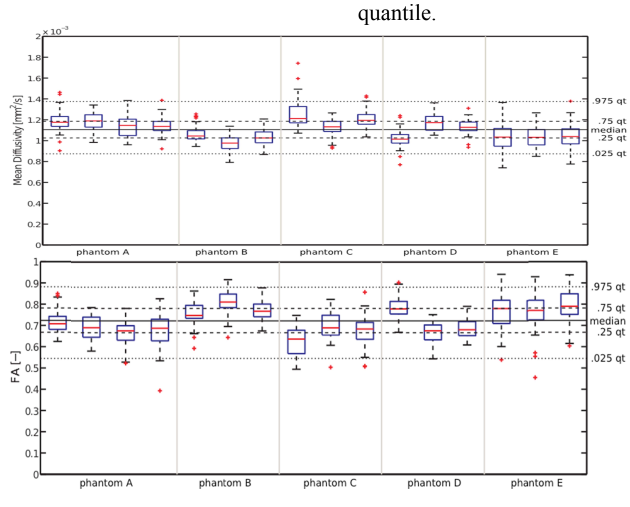


b0, MD and FA over time. #1-7 in a 7-week period, #8 after 1 year. Data is represented as a boxplot, with stems 1.5 quartile distance, box 1st and 3rd quartile and the median in red. Horizontal lines as in right figure >>
Top: b0, MD and FA for free water in the phantom. b0 shows variation, MD is stable for meas. 3-8. In meas. 1-2 T≈18.5°C, while in 3-8 T≈22°C. FA is overestimated in all meas by ~0.1 but stable across measurements, within 0.25-0.75 quartile of the whole dataset.
Bottom: b0, MD and FA for 8 measurements. b0 signal decreases over time, while MD and FA stay relatively stable, within 0.25-0.75 quartile of the whole dataset.

Experiment 2



Left: mean, std of DWI signal in phantom A, for 4 different tubes. The signal across DW dirs is highly similar.
Below: MD and FA box plot for 5 different phantoms. Variability within phantoms is smaller than across phantoms. Horizontal lines depict 0.025, 0.25, 0.5, 0.75 and 0.975 quantiles of combined data. Each tube fits in the 0.025-0.975 quantile.



Discussion Exp 1: Temporal stability *In water* the b0 signal intensity shows large variability; median signal varies from 431-579 a.u.. MD (2.166e-3 mm^2/s) is in close agreement with true D value for water at 22°C (2.1584e-3 mm^2/s). The effect of temperature on MD can be clearly seen. FA is overestimated by a constant value close to 0.1. *In the tubes*, we observe a considerable decrease of the b0 signal over time. This might indicate that either the water content in the phantom is decreasing over time or that $MnCl_2$ aggregates in the tubes over time, which decreases T_2, and thus signal. MD and FA are not affected to a large degree by the lower signal. Exp 2: multiple phantoms across tubes in one DW-phantom, the DW-MRI signal is in good agreement. FA and MD vary more.
Conclusion The b0 signal decrease needs to be further investigated and can now not serve as a longitudinal performance measure, but the median and 0.025/0.975 quantiles obtained can serve as a starting point to develop *non-parametric* (due to the non-normal distribution of the DW data) statistical process control of DW-MRI using anisotropic DW-MRI phantoms.

References 1. Wang et al *Med.Phys*. 38:4415-4421 (2011) 2. Zhu et al *NeuroImage* 56:1398-1411 (2011) 3. Pullens et al *jMRI* 32:482–488 (2010)
4. www.brainvoyager.com/diffusionphantoms