Quantitative evaluation of diffusion weighted-MRI phantoms

W. L. Pullens[1,2], A. Roebroeck[3], and R. Goebel[3]

[1]Maastricht Brain Imaging Center, Maastricht University, Maastricht, Netherlands, [2]Brain Innovation BV, Maastricht, Netherlands, [3]Maastricht Brain Imaging Center, Maastricht University, Netherlands

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Introduction

Qualitative and quantitative validation of DW-MRI still is a challenge. Validation attempts include animal tracer studies, fibrous vegetables and software phantoms. Recently, a phantom consisting of cellulose fibers was proposed [1], as well as a polyamid fiber phantom [2]. Both phantoms attempt to mimick DW-MRI properties of human white matter, but are ineffective in reaching sufficient anisotropy [1], or T_2 relaxation [2]. This paper presents DW-MRI phantoms with similar DW-MRI properties as human white matter, in terms of T_2 and anisotropy, combined with the possibility to create different geometries, to be measured with a clinical scanner and protocols.

Methods

Phantoms were constructed from Kuag Diolen™ (Kuag, Germany) fibers, with a diameter of approx 10μm, following the method described earlier in [3], which implies winding fibers to a bundle and restraining them by means of a shrink wrap tube. The number of fibers in each phantom ('fiber density') was varied from 8,000-12,000 fibers in a 5mm diameter shrink wrap tube (after shrinking in boiling water), or approx 400 – 600 fibers/mm^2. The phantoms were fixed in a container filled with water, and placed in a Siemens Allegra 3T MRI scanner. A multi-spin echo sequence with 16 echos (TR 2000, TE 16.6-265.6ms) was performed to estimate T_2. DW-MRI (50 slices, 2x2x2mm, TR/TE=8700/104ms) was performed in 3 orthogonal directions (perpendicular and parallel to the phantom), at *b*-values ranging from 100-3000s/mm2, to assess $ADC_\perp$ and $ADC_{||}$. A 2x2x2mm DW-MRI scan was performed using 54 directions at a *b*-value of 1000s/mm^2 (50 slices, 2x2x2mm, TR/TE=8700/104ms) to assess fractional anisotropy *FA*. Data analysis was performed in BrainVoyager QX 1.9 (Brain Innovation, NL), and in-house C/C++ and Matlab tools.

Results

Figure 1 shows a T_2-weighted image of a cross-section of the phantoms. In the water-based phantoms, T_2 was substantially higher (~600ms), than in human white matter T_2 (80-90ms). In figure 2 it is shown that $ADC_\perp$ versus $ADC_{||}$ is highest in the range b=500-1000s/mm^2 at a fiber density of approx 509 fibers/mm^2 (10,000 fibers). Figure 3 shows *FA* distribution of the 10,000 fiber phantom, with *FA* values approaching those of human white matter.

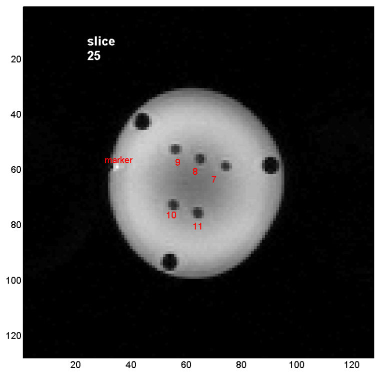

Fig 1: T_2 image of the phantoms in the water-filled container. In red, the number of fibers in each phantom (•10^3).

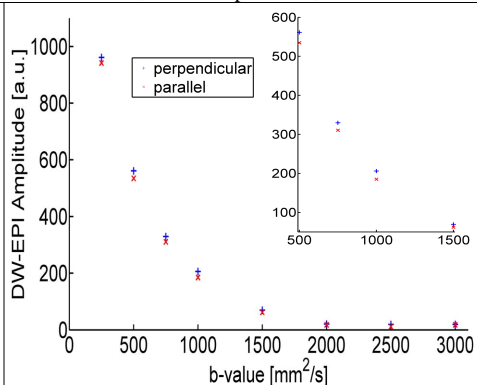

Fig 2: Signal vs *b*-value, showing exponential decay, and indicating that parallel diffusion is higher (blue) than perpendicular diffusion (red).

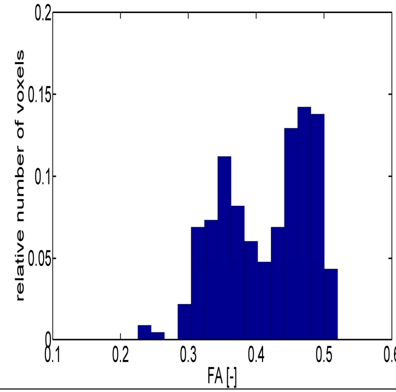

Fig 3: *FA* distribution of the same phantom, showing *FA* values similar to human white matter.

T_2 can be lowered by doping water with $MnCl_2$ [4]. Calibration solutions were made, ranging from 0.5-1.0g/l (2.53-5.05mM) $MnCl_2$•$4H_2O$, see fig 4. 41mM NaCl solution was added for resistive coil loading. T_2 was estimated from a multi-spin echo measurement. [4] reported an inversely proportional relation between T_2 and [$MnCl_2$]. From these measurements, shown in fig 5, the empirical relation of $T_2 \approx 25/[MnCl_2 \bullet 4H_2O]$ was established.

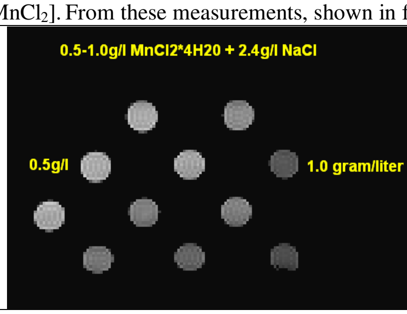

Fig 4: T_2 (TE=16.6ms) weighted image of the calibration concentrations, showing decreased signal as [$MnCl_2$•$4H_2O$] increases.

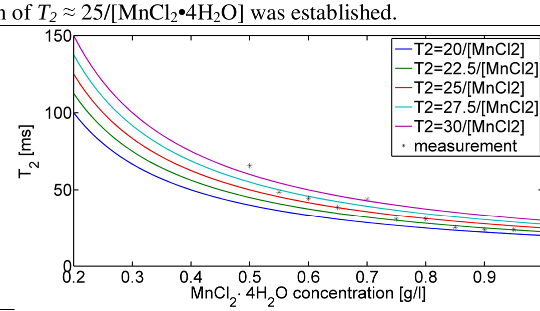

Fig 5: T_2 versus [MnCl2•4H2O]. The empirical relation of $T_2 \approx 25/[MnCl_2 \bullet 4H_2O]$ was established.

Discussion

T_2 values of the phantom are too high, but results of $ADC_\perp$ and $ADC_{||}$, combined with the *FA* histogram, are encouraging to continue phantom construction. To simulate a T_2 value similar to white matter (80-90ms), the phantom could be doped with 1.5mM $MnCl_2$•$4H_2O$. 41mM NaCl needs to be added to increase resistive coil loading [4]. From these initial measurements, optimal parameters for phantom construction can be determined. The phantom can be used for validation of fiber tracking methods, and the construction method is suitable for different geometries, such as crossing or kissing at various angles, as was demonstrated earlier in [3].

References

1. Phil Trans B (2005) **360** 881-891 **2.** Proc ISMRM 2007, 1526 **3.** Proc ISMRM 2007, 1479 **4.** MRM (2000) 43:589-593