Novel spherical phantoms for Q-ball imaging under in vivo conditions

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Introduction:

Diffusion Tensor Imaging (DTI) is successful in measuring and describing nerve fiber bundles consisting of one single fiber tract [1]. To resolve fiber crossings, more elaborate techniques like Q-Ball-Imaging (QBI) [2] and higher order diffusion tensors [3] were introduced. In order to validate these techniques under real measurement conditions, suitable phantoms of well known geometry are of great value. These QBI phantoms should provide a high diffusion anisotropy and sufficient signal in diffusion weighted images, they should be easy to construct, stable and capable of simulating various crossing angles and partial volumes. Many of the phantoms presented in the literature [example.g. 4,5,6] fulfill some of the above conditions, but they were mainly limited by their low diffusion anisotropy. Thus, the goal of this work was to construct QBI phantoms with crossing fiber bundles and high diffusion anisotropies.

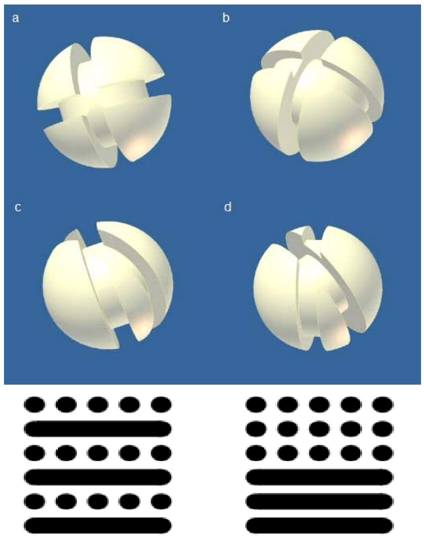

Fig. 1. Spindles for 90° (a,b) and 45° (c,d) QBI phantoms. Stacked (right) and interleaved (left) packing.

Material & Methods:

For the production of the phantoms, polyester fibers (15 µm) were winded on a spherical polyamide spindle. Two grooves were cut in the spherical spindle to simulate crossings of 90° (Fig. 1a,b) and 45° (Fig. 1c,d) angle. For each angle, two types of crossings were realized: “Stacked” and “Interleaved”. In stacked crossings (Fig. 1 right) the fibers bundles were winded consecutively, whereas in interleaved crossings (Fig. 1 left) the fiber bundles were winded alternating, with switching of the groove every 1500 windings. The fiber was led through a 83 g/l NaCl solution during the winding process. The concentration of NaCl was adapted to minimize the susceptibility difference between fluid and fibers [7]. After the production the phantoms were cast in a 3% agarose gel. The fractional anisotropy (FA) of the phantoms was regulated through adjustment of the fiber strain during winding. To evaluate reproducibility and long time stability, five simple phantoms without fiber crossing were produced under identical conditions. Diffusion weighted images were acquired using a twice refocused EPI sequence with FoV = 256x128 mm², TR = 3.4 s, TE = 123 ms, 5 averages, bandwidth = 2300 Hz/Px, partial fourier factor = 6/8, voxel size = 2x2x5 mm², b=1000 and 3500 s/mm² and 252 diffusion directions on a 3.0 T Magnetom Avanto tomography (Siemens, Erlangen, Germany). The “Orientation Distribution Function” (ODF) was calculated from the raw data [2].

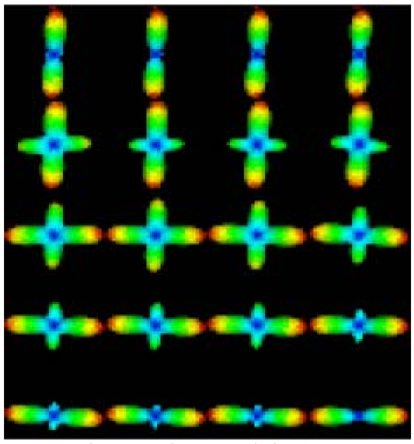

Fig. 2. ODFs of the 90° fiber crossing phantom, stacked geometry. The in plane resolution is 2 mm, the FA of individual fibers is larger than 0.9. The image plane was tilted to acquire a range of voxels with varying partial volumes of the two fiber bundles.

Results:

Through variation of the fiber strain, FA values (at b=1000 s/mm²) between 0.52 and 0.95 were achieved. The five identical copies of the phantoms displayed a high reproducibility (FA=0.93±0.02 at b=1000 s/mm²). After three month the measured FA deviated less than 2% from the initial FA for all phantoms. Fig. 2 shows the ODFs of the 90° crossing fiber phantom with stacked packing of the fibers at b=3500 s/mm². A wide range of partial volumes could be acquired by tilting the image plane. In fig. 3 the ODFs of a 45° interleaved phantom are depicted. The ODFs are well reconstructed; the 45° angle is correctly measured and clearly visible.

Discussion:

The proposed spindle geometry allows a much higher packing density than in previously reported QBI phantoms. Thus, for the first time, diffusion anisotropies that truly mimic in vivo fiber bundle crossings in a realistic fashion could be realized. Also the used voxel volumes correspond well to those usually acquired in vivo. Moreover, through variation of the fiber strain, almost any diffusion anisotropy measured in in vivo brain images can be reproduced using the same fibers. The different packing types have different advantages: The stacked phantoms allow the straightforward alteration of the partial volumes through a simple shift or tilt of the image slice. On the other hand, with the interleaved phantoms the SNR is easily variable through altering of the slice thickness. Thus, a wide spectrum of possible validity measurements can be performed using the presented QBI phantoms.

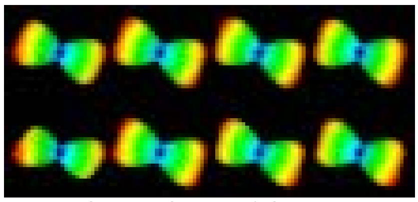

Fig. 3. ODFs of the 45° fiber crossing phantom, interleaved geometry. The 45° angle is clearly recognisable in the ODFs.

Citations:

[1] Basser et al. NMR Biomed 2002 [2] Tuch, Magn Reson Med 2004 [3] Liu et al. Magn Reson Med 2004 [4] Poupon, Philos Trans R Soc Lond B Biol Sci. 2005 [5] Fieremans et al. J Magn Reson 2008 [6] Yanasak et al. MRI 2007 [7] Laun et al, MRI 2009