The role of surface relaxivity and magnetic susceptibility in the design of anisotropic fiber phantoms.

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Introduction

Anisotropic fiber phantoms have been proposed for the validation of DTI on clinical MR-scanners [1] and to test fiber tracking algorithms, particularly in the case of fiber crossings [2,3,4]. Several fiber materials have been used: rayon [2], Dyneema® [1,3,4], hemp, linen, acrylic fibers [3], rayon, acrylic fiber [2], … Choosing the appropriate fiber material requires insight in the factors influencing the diffusion and the signal-to-noise ratio. The effects of the fiber diameter and fiber density on the diffusion properties have been described [5]. In this study, the surface relaxivity of several fiber materials has been measured and its effect on the T2 and diffusion properties has been evaluated. The effect of the fiber material susceptibility has been addressed.

Materials and methods

Fiber phantoms were manufactured with different fiber types: Dyneema® fibers, carbon fibers and optical fibers (see table 1). Straight fiber bundles were manufactured containing a varying number of fibers. The fibers were placed in water and surrounded by a shrinking tube. Air bubbles were removed using a vacuum chamber.
Measurements were performed at 20°C on a Siemens Trio scanner (3T) equipped with an 8-element head coil. T_2- and proton density fraction (PD) measurements were performed with a multiple spin echo sequence with 32 contrasts, an inter-echo time ΔTE of 40 ms, a TR of 10 ms and BW of 130 Hz/Px. The resolution was 0.9 mm x 0.9 mm x 2mm. Fiber phantoms were aligned parallel to the B_0 field. PD and T_2 were obtained by fitting S_0 to the T_2-decay function $S(TE)=S_0e^{-TE/T2}$.
Surface relaxivity ρ was obtained by fitting following formula to the data [6]:

$$R_{2\,fiber} = R_{2\,water} + \rho * \frac{S}{V} + R_{2\,IG} \quad (1)$$ with R_{2IG} the change in R_2 due to internal gradients caused by susceptibility differences.

The surface-to-volume ratio $\frac{S}{V} = \frac{1}{r_{fiber}} \cdot \frac{1-PD}{PD}$ with r_{fiber} the radius of the fiber (see table 1).

In addition, T_2 was measured of the fiber phantoms made of Dyneema® for varying angles between the fibers and the B_0–field.
Diffusion weighted imaging was performed in 60 directions with b-factors of 0 and 700 s/mm² using a TRSE-EPI sequence with a BW of 1275 Hz/Px, a TR of 8s and TE 93 ms. The resolution was 2 mm x 2 mm x 2 mm. The diffusion weighted images were used to calculate the fractional anisotropy (FA).

Results

The measured T_2–values as a function of the proton density are shown in figure 1 for the three tested fiber materials. Estimated values for r and R_{2IG} using formula (1) are given in table 1. The FA-values as a function of the proton density are plotted in figure 2 and compared with the simulated values for FA as in [5], where diffusion was simulated with random cylinder packing geometries without surface relaxation. The measured T_2–values as a function of the angle between fibers and the B_0-field are shown in figure 3.

Fiber materials	Diameter fiber filaments [μm]	Surface relaxivity ρ [μm/s]	R_2 IG [1/s]
Dyneema®	20	2.9	0.02
Carbon fiber	15	8.6	2.10
Optical fibers	10	28.9	1.95

Table 1

Discussion

For each fiber material, the FA increases with fiber density (equal to 1-PD). For a given fiber density, the material with the highest surface relaxivity exhibits the highest FA. Among the tested materials, Dyneema® is highly hydrophobe and has a low surface relaxivity. Its effect on the diffusion (simulated using Monte Carlo simulations according to [7]) was minimal and the diffusion properties can be predicted based on the fiber diameter and density [5]. The surface relaxivity of the material, proportional to its degree of hydrophilicity, influences the SNR and the measured diffusion properties.
As demonstrated in figure 3 for for Dyneema® fibers, differences in susceptibility between fiber material, shrinking tube and water induce local field inhomogeneities resulting in a decrease of the T_2, dependent on the angle between the fibers and the B_0-field, and possibly a change in the measured diffusion properties [8].
When fabricating fiber phantoms for dedicated purposes, the radius and the fiber density of the phantom should be chosen appropriately in order to obtain the desired diffusion properties such as ADC and FA [6]. In addition, also the surface relaxivity and the susceptibility of the material should be taken into account since both parameters might effect the measured diffusion and resulting SNR.

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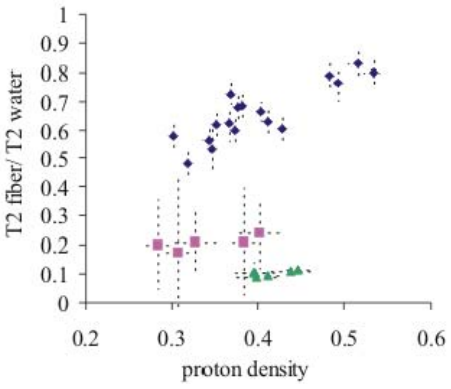

Figure 1

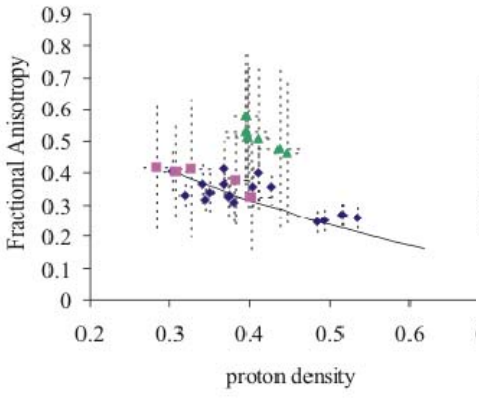

Figure 2

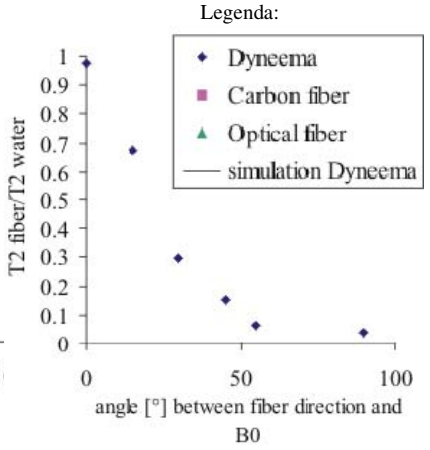

Figure 3