A crossing fibre phantom for diffusion MRI composed of co-electrospun fibres

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Target audience

Researchers wishing to validate diffusion MRI methods in complex geometries with axon-mimetic hollow fibres.

Purpose

Crossing fibres are commonplace in the brain and tractography methods which propose to pass through these areas require validation. Our aim is to test the principle of producing a crossing fibre phantom with co-electrospun fibres.

Methods

Phantom construction The fibres were co-axially electrospun, as described in references[1,2]. A rotating disk was used to collect aligned fibres at a layer depth of ~0.5 mm. During deposition the inner core solution evaporates, leaving a solidified outer sheath. The flow rate of inner solution was 0.8 ml/hr leading to an area-weighted mean inner diameter of 9.5μm, characterised by scanning electron microscopy. Two phantoms were prepared: one with all layers aligned along the axis of the tube and one where the layers were interspersed at 90° to one another. Both phantoms were packed into 25 mm glass tubes using plastic rods to ensure good packing (Figure 1). The tubes were filled with cyclohexane; a proton rich solvent capable of infusing into the hydrophobic polymer, with a suitable T_1 and apparent diffusion coefficient to mimic the free liquid in axonal bodies[3].

MR imaging Diffusion tensor imaging (DTI) with 30 gradient directions, b=800 s mm^{-2} (plus a b = 0 s mm^{-2}), δ = 4 ms, Δ = 20 ms, was carried out on a Bruker 7 T horizontal bore magnet (Bruker Biospin, Germany). Other sequence parameters were: coronal FOV 2.5 × 2.5 cm, 64 × 64 matrix, a single 2.5 mm thick slice, TR=5 s, TE =28.2ms. The diffusion tensor was calculated for all voxels for each phantom using the plotDTI function[4] in Matlab.

Results

Good SNR was observed for both phantom designs. The two phantoms show the expected trends, with a prolate diffusion tensor in the direction of the fibres for the aligned phantom and an oblate tensor for the crossing fibre phantom (Figure 2). Some heterogeneity is evident between voxels in the crossing fibre phantom.

Figure 1 Crossing fibre phantom immersed in cyclohexane. The layers are squeezed between two plastic rods.

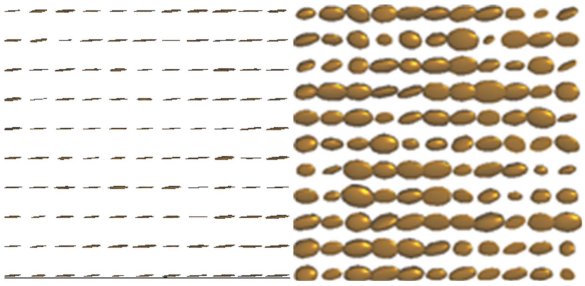

Figure 2 Diffusion tensor ellipsoids for coronal slices through the aligned phantom (left); and the crossing phantom (right).

Discussion

We have shown previously that the co-axial electrospinning process can be used to prepare hollow, aligned, micron-sized fibres with tunable inner diameter, which can be used to test the sensitivity of diffusion methods to microstructural dimensions[5] and that these fibres have suitable dimensions, alignment and diffusion properties to mimic axons in white matter[1,2]. Here we show that the current prototype can be easily modified to produce a simple crossing fibre phantom that leads to the expected loss of anisotropy and a corresponding inability to define the underlying microstructure using the diffusion tensor model.

Further work will test higher order tractography models that allow multiple fibre orientations to be distinguished, such as constrained spherical decovolution and q-ball. Perhaps more interestingly, this phantom prototype could be used to determine whether microstructural imaging can assist in untangling the 'crossing fibre problem', by producing layered phantoms with different fibre diameters. Co-electrospinning also holds promise for increasing the complexity of patterning, for instance in [1] we showed how the translational stage can be used to produce inter-digitated crossing fibres.

Conclusion

We present a proof-of-principle study of a simple crossing fibre phantom composed of co-electrospun hollow fibres with a biologically realistic inner fibre diameter.

References

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