Using q-space diffusion MRI for structural studies of a biological phantom at 3T clinical scanner

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Introduction

q-space imaging is an established method in NMR spectroscopy for retrieving structural information from biological materials [1]. Structural q-space imaging at a clinical scanner is more difficult to achieve due to limited gradient performance, however apparent mean displacement data has been presented *in vivo* [2]. The aim of this study was to investigate the possibility for absolute quantification of fibre structure sizes in a biological phantom, using the Full Width at Half Maximum (FWHM) of the diffusion propagator and microscopy images were obtained as a reference.

Materials and Methods

Experiments were carried out on a Siemens Allegra 3T head scanner with 40 mT/m gradients. The phantom consisted of whole green asparagus submerged in a water-filled plastic box. The asparagus were aligned parallel to the main magnetic field. An in-house developed stimulated echo pulse sequence was used to perform diffusion measurements in the six directions x, -x, z, -z, y and -y. Other imaging parameters were as follows: FOV=95×83 mm^2, slice thickness=10 mm, imaging matrix 128×128 (yielding a voxel size of 0.7×0.7×10 mm^3), repetition time (TR) = 4500 ms and NEX=4. The complex images were denoised by filtering in the wavelet domain [3]. Using a constant echo time (TE) of 89 ms and varying mixing times (TM) of 101, 141, 181, 220 and 258 ms different diffusion times (T_D) were obtained; 120, 160, 200, 240 and 280 ms. The signal was sampled for q-values ranging from 20-357 cm^{-1} equidistantly in 16 steps, yielding a resolution of $1/2q_{max}$=14 µm [4], with δ=24 ms. No zero filling were made on the q-space signal data. Parametric maps of the FWHM of the diffusion propagator [1] were calculated. Regions of interest (ROI) were positioned in the parametric maps according to figure 1. Microscopy images were obtained using a Zeiss WL research microscope as a validation in the determination of the structural sizes

Results

The results show a linear relationship between the measured FWHM and $\sqrt{T_D}$ for the freely diffusing water molecules in the water outside the asparagus, as expected from theory. In the most restricted diffusion direction, across the fibre structure, the FWHM is almost constant for increased $\sqrt{T_D}$. The FWHM in the x- and y-direction (⊥) of the asparagus was 23.9 ± 0.8 µm. From the microscopy image, we see that the capillary system highlighted in figure 2 has a diameter of 24.9 ± 6.1 µm.

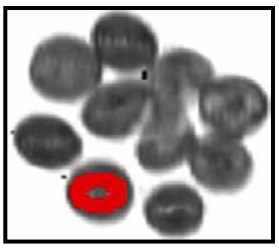

Figure 1. The used ROI, placed in the FWHM map, perpendicular to the fibres.

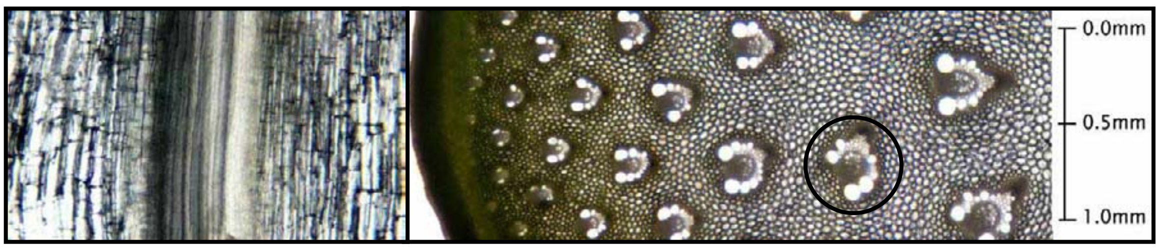

Figure 2. Left: Microscopy image of the asparagus along the fibres. Right: As left, but across the fibre structure. The bright structures within the circle above has a diameter of 24.9 ± 6.1 µm.

Discussion

Our FWHM results indicate that there exists a restriction in diffusion perpendicular to the main axis of the asparagus, with the size of approximately 24 µm. These results are in agreement with the result from the microscopy image. The FWHM parallel to the asparagus increases with $\sqrt{T_D}$, which suggest a more free diffusion in that direction. However, one should keep in mind that the dynamic displacement profile perpendicular to the asparagus represents the water both in the capillaries and in the surrounding cells and that this might influence the results. We conclude that it is feasible to measure structural sizes in biological materials in the range of approximately 20-30 µm with a clinical MRI scanner.

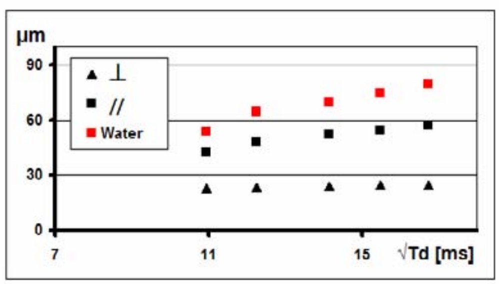

Figure 4. The diagram shows the obtained FWHM values as a function of $\sqrt{T_D}$.

T_D[ms]	$FWHM_{ASPARAGUS}$		$FWHM_{H2O}$
	⊥	//	
120	22.7	42.3	53.8
160	23.6	48.2	64.5
200	24.1	51.7	69.3
240	24.4	54.1	74.3
280	24.8	56.9	79.1

Table 1. The numerical results from the analysis; FWHM perpendicular (⊥), parallel (//) to the fibre structure and for freely diffusing water outside the asparagus.

References

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