Measuring accurate small compartmental dimensions using double-PFG NMR: from water-filled microcapillaries to biological cells

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Obtaining microstructural information such as pore size, anisotropy, and shape from opaque specimens is important in a variety of disciplines ranging from material science to neuroscience. Diffusion-NMR and especially the single-pulsed-field-gradient (s-PFG) methodologies (Fig. 1A) are useful for characterizing anisotropy in coherently-packed anisotropic pores, and the compartment size can be extracted from diffusion-diffraction minima if the pores are monodisperse. When the specimen is characterized by size distributions, the q-space approach can be used to infer on relative compartment sizes. Howeover, the s-PFG approaches require extremely strong gradient amplitudes to extract compartment dimensions, and are very limited when orientation distributions are present.

The double-PFG (d-PFG) methodology (Fig. 1B) is an extension of s-PFG that employs a second PFG pair. The angular-d-PFG experiment, in which the angle between the gradient pairs is varied, has gained interest owing to recent theoretical studies prediting that angular-d-PFG can afford new microstructural information even at low gradient amplitudes, and even when the pores are randomly oriented or have broad size distributions.

Therefore, we conducted angular-d-PFG experiments on water-filled microcapillaries with inner-diameter (ID) of 5±1 μm. Figure 2 shows the experimental points (symbols) and theoretical fits (lines) of the angular-d-PFG experiment. Importantly, a very accurate compartment size can be extracted from the bell-shaped functions using weak gradients (as low as 15 G/cm). For reference, the s-PFG could only extract such size using gradient strengths of 573 G/cm.

Recently, these findings were applied to randomly oriented yeast cells. The cell size extracted from d-PFG measurements was 5.46±0.46 μm, whereas light microscopy measurements yielded 5.32±0.32 μm. Such findings may become important in clinical d-PFG MRI, as well as in accurately characterizing porous media.

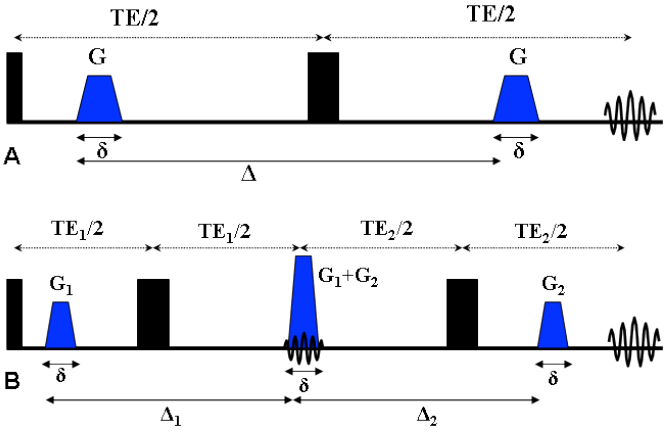

Figure 1

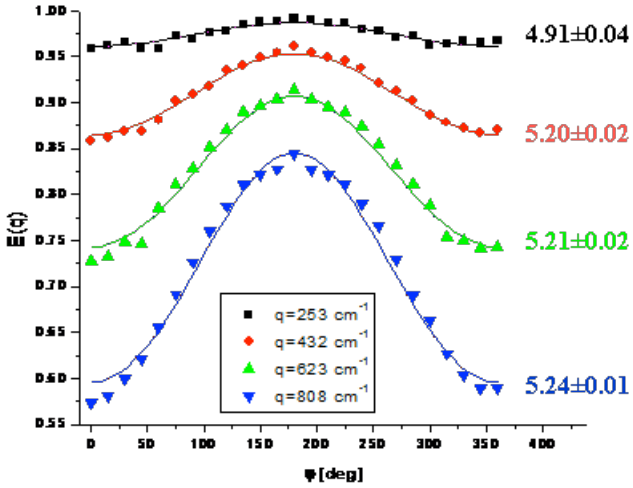

Figure 2