

## A Simple and Robust Test Object for Diffusion Kurtosis

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**Target Audience.** MR physicists with an interest in diffusion kurtosis imaging

**Purpose.** Diffusion processes in biological tissues are inherently non-Gaussian due to the presence of complex cellular microstructures such as membranes and organelles. Diffusion kurtosis imaging (DKI) is an extension of conventional diffusion-weighted MRI which fits a model to a series of diffusion  $b$ -value images from which a value of diffusion kurtosis  $K$ , the degree to which diffusion is non-Gaussian, may be obtained<sup>1</sup>. Amongst other applications, DKI has already shown promise for the improved grading of cerebral gliomas<sup>2</sup> and in the assessment of small airway diseases<sup>3</sup>. The non-exponential nature of the diffusion signal is the result of barriers present in the system, hence a test object in which barriers may be straightforwardly calculated and then subsequently compared to the measured kurtosis is highly desirable. Previous test objects for DKI have been based on perishable materials such as asparagus<sup>1</sup> and dairy cream<sup>4</sup>, which unfortunately do not provide known values for kurtosis nor can they be used over a long period of time to assess reproducibility. The aim of this work was to create a simple and robust test object for the assessment of diffusion kurtosis and to investigate the relationship between microscopic barrier concentration and measured kurtosis.

**Methods.** Colloidal particles are in the size range several nm to several  $\mu\text{m}$  in at least one dimension. They are therefore useful to study certain phenomena which occur at cellular length scales. Spherical colloidal particles, density-matched to water, with diameters  $D$  in the range  $10 \mu\text{m} \leq D \leq 45 \mu\text{m}$  (Cospheric, Santa Barbara) were prepared (Fig. 1) and placed in suspension in 17 samples, each with different concentrations in the range  $0 \leq \rho \leq 4.95 \text{ g cm}^{-3}$ . All samples were scanned individually on an *Achieva* 3T scanner (Philips, Best, The Netherlands) with a loop coil, big enough to encompass a test tube, using a diffusion MRI with  $b$ -values from 0 to  $4500 \text{ s mm}^{-2}$  at intervals of  $500 \text{ s mm}^{-2}$ . This was repeated for one sample over several weeks to assess the stability of the colloidal particles. A plug-in for *OsiriX*<sup>5</sup> was written to calculate the apparent diffusion coefficients (ADCs) and kurtosis values for all samples, fitting the following equation to the acquired images,

$$\log\left(\frac{I}{I_0}\right) = -bD + \frac{1}{6}b^2D^2K$$

where  $b$  is the diffusion-weighting ( $\text{s mm}^{-2}$ ),  $D$  is the ADC ( $\mu\text{m}^2 \text{ s}^{-1}$ ),  $K$  is the kurtosis,  $I$  is the signal intensity and  $I_0$  is the intensity at  $b=0 \text{ s mm}^{-2}$ .



**Figure 1.** Left panel: These colloidal particles have a diameter range of  $10 \mu\text{m} \leq D \leq 45 \mu\text{m}$ . Right panel: A selection of some of the 17 samples in order of increasing concentration  $\rho$  from left to right.

**Results.** On increasing the concentration of the colloidal dispersions, the kurtosis was found to increase due to the increasing microscopic barrier concentration (Fig. 2). The signal attenuation curves appear increasingly linear for increasing kurtosis since the quadratic term  $D^2K$  in the above signal equation becomes smaller for this test object since  $D$  decreases as  $K$  increases. Measured kurtosis values for the sample measured repeatedly over several weeks were 0.343 on each occasion.



**Figure 2:** Left panel: A selection of signal attenuation curves for the test object. Each curve represents a different concentration of colloids as indicated in the key. Right panel: The kurtosis  $K$  as a function of colloidal concentration  $\rho$  for the various samples that comprise the isotropic test object. A basic linear fit allows us to extrapolate the surface area of barriers required for a given kurtosis.

**Discussion.** We have investigated the use of colloidal particles as a test object to examine the diffusion kurtosis of water and in so doing have developed a plug-in for the *OsiriX* system to measure diffusion kurtosis from a series of diffusion-weighted images. As well as generating kurtosis maps, the plug-in produces ADC maps based on the fitted model, which may reflect better the actual diffusion. We have observed a simple linear relationship between concentration of barriers (and hence surface area per unit volume) and diffusion kurtosis, therefore demonstrating that as the barrier concentration is increased in the system, the diffusion process becomes less Gaussian. The simple nature of these colloidal particles offers the possibility to model and calculate the actual diffusion kurtosis. The ability to link kurtosis values to microscopic barrier concentration for *in-vivo* data presents an interesting future line of investigation.

**Conclusion.** Colloidal particles provide a suitable and stable test object for the assessment and reproducibility measurement of DKI.

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**References.** [1] J.H. Jensen et al., *MRM*, **53**, 1432 (2005). [2] P. Raab, et al. *Radiology* **254**, 876 (2010). [3] R. Trampel, et al. *MRM* **56**, 733 (2006). [4] E. Fieremans, et al. *MRM* **68**, 537 (2012). [5] see <http://www.osirix-viewer.com/> Accessed 11 Nov 2012