EFFECTS OF B-VALUE AND SNR IN PRECLINICAL CARDIAC DIFFUSION SPECTRUM IMAGING

Irvin Teh[1], Dunja Aksentijevic[1,2], and Jurgen E Schneider[1]

[1]*Division of Cardiovascular Medicine, Radcliffe Department of Medicine, University of Oxford, Oxford, United Kingdom,* [2]*Cardiovascular Division, The Rayne Institute, King's College London, London, United Kingdom*

Target Audience Clinicians, physicists and technologists with an interest in the characterisation of myocardial tissue structure.

Purpose Diffusion spectrum imaging (DSI) enables the measurement of the diffusion probability density function (PDF) in a model-free manner [1]. In preclinical cardiac imaging, DSI compared favourably to diffusion tensor imaging in resolving tissue orientations in regions of complex fibre architecture [2]. Estimating the PDF also provides access to parameters that may be associated with cardiac tissue structure. However, it has been shown in simulations and phantoms that some of these parameters are highly sensitive to experimental parameters [3]. Earlier work optimized the b-values used in DSI in the brain with respect to resolving single and crossing fibre populations by retrospective interpolation of diffusion-weighted (DW) data [4]. Here, we investigated four DSI-derived parameters for assessing myocardial structure, including the mean squared length (MSL), generalised fractional anisotropy (GFA), probability at zero displacement (P(0)) and mean kurtosis (MK) and their sensitivity to b-value and signal-to-noise ratio (SNR) via prospective sampling of multiple DSI datasets.

Methods One ex-vivo rat heart was prepared and embedded in agar [5]. MRI was performed using a 9.4T preclinical scanner (Agilent Technologies, Santa Clara, CA) and an ID = 20mm volume transmit-receive RF coil (Rapid Biomedical, Rimpar, Germany). DSI data were acquired in the heart with a 2D echo planar imaging sequence with Stejskal-Tanner DW, where TR = 1000 ms, TE = 23.7 ms, in-plane resolution = 375 μm, thickness = 2 mm, δ = 5 ms, Δ = 12 ms, repetitions = 3, #DW directions = 257, acquisition time = 52m. Data with maximum b-values, b_{max} = 3000 to 16000 s/mm^2 were acquired by adjusting the diffusion gradients from 395 to 923 mT/m. To avoid effects of inadequate SNR at high b_{max}, the data were acquired with high SNR, where SNR(B_0) = 397 and SNR(b=16000 s/mm^2) = 9.7. Here, SNR was measured as the mean intensity in tissue divided by the standard deviation of the background noise. A second dataset was acquired with b_{max} = 10000 s/mm^2, thickness = 1mm, repetitions = 32, acquisition time = 9.6h. The magnitude data from 32 repetitions were averaged, and Rician noise were added progressively to generate data where SNR(B_0) ranged from 38 to 494. The half sphere q-samples were mirrored about q(0) to yield 514 q-samples, and the PDFs were generated by applying the Fourier transform to the signal in q-space in a voxel-wise manner. Maps of MSL, GFA, P(0) and MK were calculated [3, 6, 7], and normalized values in a region-of-interest (ROI) were reported. The ROI was specified throughout the left ventricle of a single slice, avoiding the edges and associated partial volume effects.

Results Figures 1a-d illustrate maps of MSL, GFA, P(0) and MK in a mid-ventricular transverse slice of the myocardium. In this healthy heart, little contrast is seen in the MSL and P(0) maps, while the GFA and MK exhibited greater heterogeneity. Figure 2 shows the relationship between the parameters, as normalised to the b_{max} = 10000 s/mm^2 data, and the maximum b-value applied. Across the full range of b-values, we observed that the (i) nMSL showed an increasing trend from 0.489 +/- 0.065 to 1.34 +/- 0.23, (ii) nGFA remained stable from 0.95 +/- 0.24 to 0.88 +/- 0.24, (iii) nP(0) decreased from 2.50 +/- 0.34 to 0.67 +/- 0.16 and (iv) nMK decreased sharply from 4.5 +/- 1.0 to 0.84 +/- 0.31, where n refers to the normalized values. Figure 3 presents the relationship between the parameters, as normalised to the SNR = 494 data, and SNR(B_0). Across the range of SNR, we found that (i) nMSL remained stable from 0.981 +/- 0.050 to 1.000 +/- 0.065, (ii) nGFA remained stable from 1.11 +/- 0.13 to 1.000 +/- 0.084, (iii) nP(0) remained stable from 0.970 +/- 0.061 to 1.00 +/- 0.11 and (iv) nMK decreased sharply from 2.39 +/- 0.51 to 1.00 +/- 0.36.

Discussion The most striking result is the marked overestimation and lower precision of MK at low b_{max} and low SNR. At low b_{max}, inadequate sampling at high b-values curtailed information relating to non-gaussian diffusion. At low SNR, the rectified noise floor would have biased the diffusion signal at high b-values [8], and increased the tails of the PDF leading to higher kurtosis. P(0) was likewise affected at low b_{max} but not at low SNR. Both MSL and GFA, which relate to the mean diffusivity and diffusion anisotropy, were relatively stable at lower SNR. These data support the use of b_{max} ≥ 9000 s/mm^2 and SNR(B_0) ≥ 150. Other parameters including the diffusion pulse duration, δ and effective diffusion time, T_d are also likely to influence the accuracy and precision of the measurements [3], and will be investigated in further work.

Conclusion DSI-derived parameter maps offer insight into hindered and restricted diffusion arising from complex tissue structure. These could potentially serve as more sensitive markers in cardiac disease such as ischemia and hypertrophy. These parametric maps may be highly sensitive to the experimental protocol, and careful optimisation of the imaging parameters is therefore vital.

References [1] Wedeen V.J., et al. MRM. 2005; [2] Sosnovik D.E., et al. Circ Cardiovasc Imag. 2005; [3] Latt J., et al. MRI. 2008; [4] Kuo L.W., et al. ISMRM. 2007; [5] Plank G., et al. Phil Trans Series A. 2009; [6] Kuo L.W., et al. Neuroimage. 2008; [7] Tuch D., et al. MRM. 2004; [8] Jones D.K., et al. MRM. 2004.

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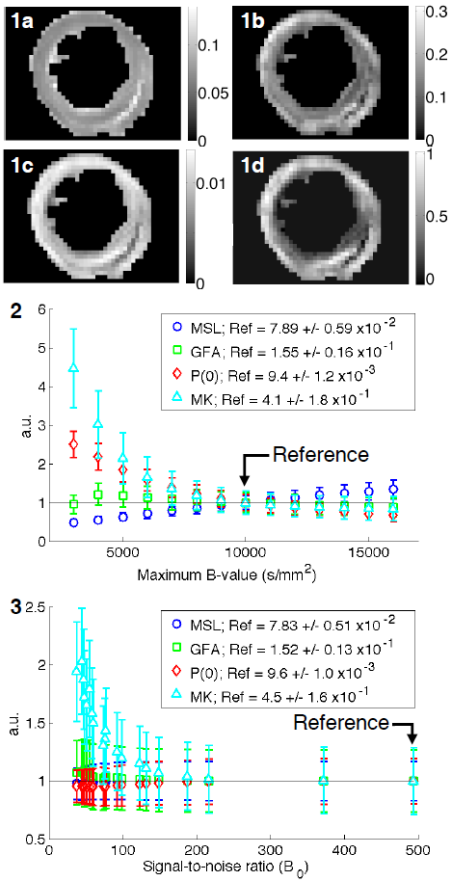

Figures 1a-d. Mean squared length (MSL), generalised fractional anisotropy (GFA), probability at zero displacement (P(0)) and mean kurtosis (MK); **Figure 2.** Normalised DSI parameters as a function of maximum b-value; **Figure 3.** Normalised DSI parameters as a function of signal-to-noise ratio (SNR) of the B_0 image.