Test-Retest Reliability in Fibre Orientation Distribution (FOD) Measurements in HARDI Data

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Introduction We evaluated the test-retest reliability for measures based on the fibre orientation distribution (FOD) using constrained spherical deconvolution (CSD [1]). We derived measurements in the peak direction identified from the FOD, and evaluated the test-retest reliability for these FOD peak amplitudes using the intra-class correlation (ICC) coefficient. We visualized the ICC coefficients on the FOD orientation plot. We compared the reliability of measuring the FOD peak amplitudes and the fractional anisotropy (FA) derived from the diffusion tensor imaging (DTI) model.

Method Materials High Angular Resolution Diffusion Imaging (HARDI) data were acquired using a 4T Bruker Medspec MRI scanner. Each dataset consists of 11 images without diffusion sensitization (b=0), and diffusion weighted images (DWI) with 94 gradient directions at b = 1159 s/mm^2. 39 subjects were scanned at baseline and after a 3-month interval.

Data Processing The acquired DWI images were corrected for eddy current distortion and subject motion [2, 3]. The N4 bias-field correction was performed [4]. Image intensity was normalized across the subjects. CSD is used to reconstruct the FOD, up to 4th-order spherical harmonics, describing the distribution of the underlying fibre population with respect to spatial orientation at each voxel. A population average template is created to spatially normalize the FOD images. FOD images were registered to the template using a symmetric diffeomorphic non-rigid registration, with the FOD descriptors reoriented and modulated by the deformation field [5]. The tensor reconstructions are also warped using the same non-rigid transformations, with tensors reoriented.

Statistical Analysis For the average FOD template, 3 peaks in the FOD profile with maximal amplitudes are identified by find_SH_peaks available from the mrtrix package. Then, in each registered FOD image, the peaks are found to match the peaks identified on the FOD template. We evaluated the intra-class correlation (ICC) for the amplitudes of each FOD peak, in repeated scans.

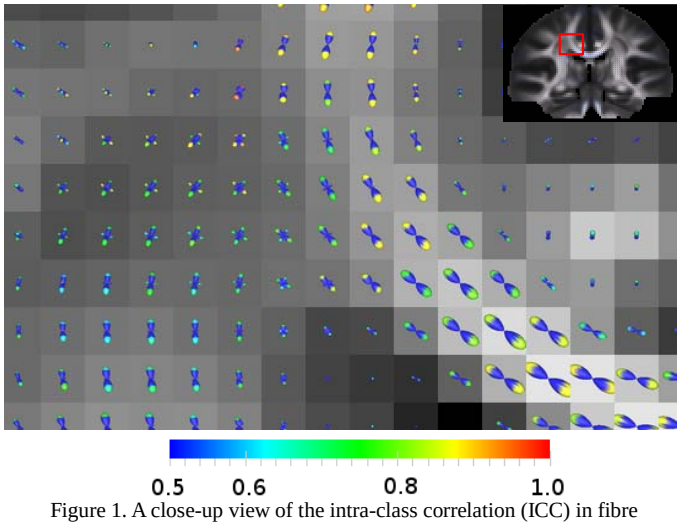

Figure 1. A close-up view of the intra-class correlation (ICC) in fibre orientation distribution (FOD) peak amplitudes, plotted on an average FOD template, with the cap of corresponding peak color-coded, and overlaid on the fractional anisotropy (FA) map.

For the DTI model, we estimated the standard measurement of FA, and tested its ICC across repeated scans. Particularly, we also evaluated the test-retest reliability in the white matter (WM) area with a substantial fibre population. We derived a WM mask from the average FA map by thresholding at FA>0.2. We also created a region of interest (ROI) of single fibre with a threshold FA>0.7. By a threshold on the amplitude of the second peak in average FOD, we identified an ROI for crossing fibres.

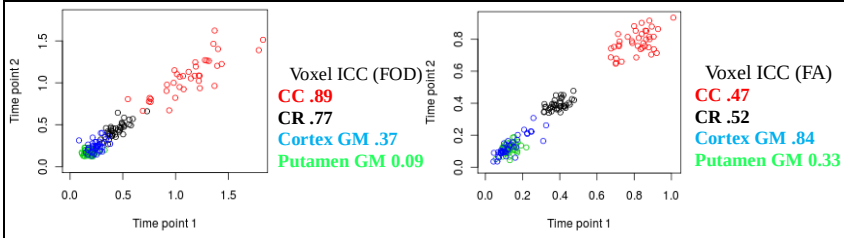

Figure 2. Examples of measurements in 4 typical voxels. Left: FOD peak amplitudes, right: FA. **Red**: corpus callosum; **black**: corona radiata; **blue**: cortical gray matter (GM); **green**: gray matter (GM) in the putamen.

Results The ICC for the FOD peaks (plotted on the template FOD) is shown in **Figure 1**. Each peak is color coded by the ICC value of the amplitude of the corresponding FOD peak. Measurements from four typical voxels in corpus callosum, corona radiata, and grey matter are shown in **Figure 2**. The following table lists the average ICC for the FOD peak amplitudes and the FA measurements.

Table. ICC in different regions of interest (ROIs)

	FOD peak	FA
White matter (avg. FA>0.2)	0.678	**0.724**
Single fibre (avg. FA>0.7)	**0.855**	0.632
Crossing fibres (avg. FA>0.3 & 2nd peak in avg. FOD > 0.2)	**0.740**	0.709

Discussion The FOD based measurement describes the partial volume density of fibre diffusion orientations in each voxel, while FA characterizes the white matter integrity. Both the FOD peak amplitudes and the FA show high the test-reliability in terms of ICC in the WM region. Comparing the FOD peak measurement with the FA, the FOD peak amplitude is more concentrated in the region where fibre structures dominate (single and crossing fibres), where it showed higher test-retest reliability than the FA. The FA displays higher correlation than the FOD peak value in the WM regions with lower fibre integrity. This may be due to the diffusion isotropy in these regions, where the FA estimation does not take into account the directional information. By contrast, in the estimation of FODs, the peaks are identified and matched based on their directions, and thus display lower ICCs.

Conclusion We evaluated the test-retest reliability of the FOD measurement in diffusion MR images at peak amplitude and compared it with the FA. The FOD showed high repeatability in the white matter fibre region.

References

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