Interpolation of DWI prior to DTI reconstruction, and its validation

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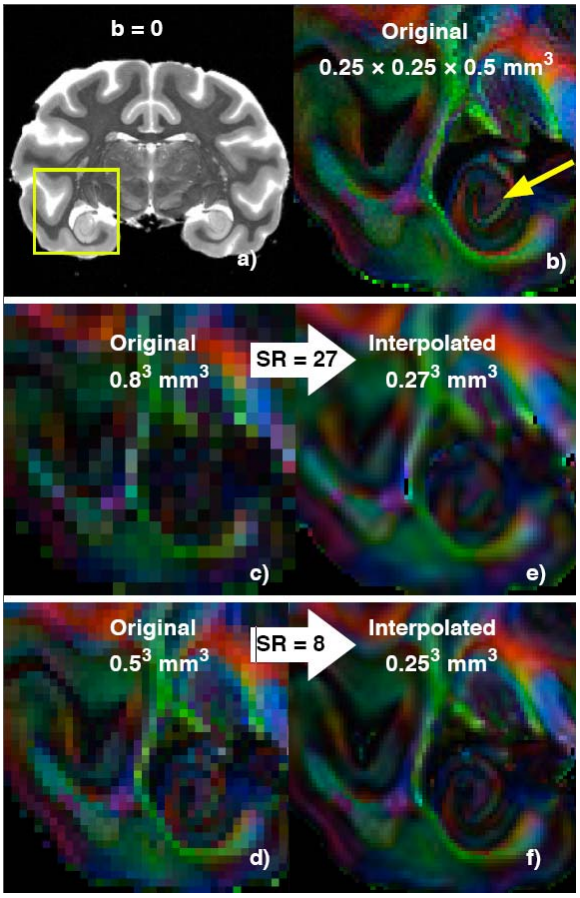
Introduction: The resolution of diffusion weighted imaging (DWI) is mainly limited by hardware constraints and a negative relationship between image resolution and signal-to-noise ratio (SNR). Moreover, SNR can only to a limited extent be improved by repeating the measurements. Super-resolution (SR) is a technique that fuses information from a series of interpolated low resolution images to create a single high resolution image. A prerequisite is that the multiple low resolution images contain statistically independent data of the same object, e.g. capture a static object displayed from different spatial viewpoints. Since this is the case for HARDI DWI, we hypothesized that SR can extract anatomical details from HARDI DWI data that are obscured by partial volume effect (PVE) and thus, are currently only visible when DWI is acquired at a higher spatial resolution, from such data sets. In contrast to previous SR methods which are limited to special acquisition sequences[1] or require the introduction of additional complex SR reconstruction methods applied after fibre reconstruction[2,3], we introduce a simple and general SR framework for HARDI DWI. We propose that by incorporating standard interpolation of the acquired (low resolution) DWI data, and then applying the diffusion tensor model for reconstruction (though any fibre reconstruction method can be used), we are able to significantly increase the spatial resolution of the final image and hereby to visualize more anatomical details. Preliminary results from SR interpolation of low-resolution high-quality ex vivo HARDI DWI datasets acquired on perfusion fixed monkey brain are validated against high resolution acquisitions of the same datasets.

Method: Ex vivo imaging of an 82 month healthy perfusion fixed Vervet monkey brain was performed on an experimental 4.7 tesla Varian Inova scanner. Two whole brain DWI datasets were acquired with isotropic voxels of size 0.8 and 0.5 mm respectively (no gap). As a validation golden standard a high-resolution DWI dataset was also acquired, comprising 30 coronal slices partly covering the brain, with in-plane resolution 0.25 x 0.25 mm, slice thickness 0.5 mm and 0.5 mm gap. High SNR was ensured by NEX of 1, 4 and 7, resulting in a final SNR of 52, 48 and 16 respectively. For all datasets: TR=5500 ms, TE=47 ms, 3 x b0 volumes and 61 dw directions. For the ex vivo DWI, the setup of Dyrby et al. (2010) was employed, and from there a b-value of ~4300 s/mm^2 was selected. Conditioned airflow surrounded the brain during scanning. All data sets were acquired in a single scanning session and no additional processing was needed. Ethical rules concerning care and handling of live animals were followed.

Analysis: The suggested SR framework was realised by interpolating the original DWI data followed by fibre reconstruction using the diffusion tensor model. We define the SR factor as the ratio between the volume of original and the interpolated voxels, hence unit SR factor is conventional DTI. Data was resliced using 7th-order B-spline interpolation using SPM8, and DTI matrices were calculated using Camino[5]. Only interpolation to isotropic voxels was employed which ensured optimal rotational invariance in the SR-DWI data.



Results: DTI reconstruction from high resolution DWI data showed anatomical details not visible at conventional resolutions (Fig 1, b). Using our simple SR approach upon the low resolution DWI datasets, similar anatomical details became more apparent (Fig 1, c & d vs. e & f). An SR of 27 upon 0.8^3 mm^3 voxels (Fig 1, c & e) extracts many of the hidden anatomical details seen in (Fig 1, b), though with slight smoothing when compared with SR=8 upon the 0.5^3 mm^3 data (Fig 1, f). The latter is similar to the golden standard (Fig 1, b).

Figure 1. Hidden anatomical details in HARDI DWI can be extracted retrospectively using our generic super-resolution approach. a) Coronal slice of b=0 s/mm^2 showing the region investigated in the colour-coded FA images b)-f). b) High resolution DWI acquisition (golden standard) (SR=1). Note the fine folding of hippocampal layers each with different coherent fibre direction (yellow arrow). c) and d) are the low resolution DWI datasets used for generating the interpolated versions at SR 27 (e) and SR 8 (f).

Discussion and conclusion: Preliminary results show that, using a simple SR-DTI framework, hidden anatomical details can be extracted up to an SR factor of eight from the original 0.5^3 mm isotropic voxels (empirically found), verified by comparison with the high resolution DWI dataset; choosing too high an SR factor simply seems to increase the data size without any further effect (Fig 1, e). Interpolation of diffusion MRI before fibre-reconstruction has been widely used, but mainly only for reslicing non-isotropic datasets into isotropic ones. Although the simple SR approach still is rather preliminary, it seems to have future potential for any HARDI DWI dataset acquired both clinically and pre-clinically. However, several caveats exist. For example, the interpolation method employed has significant impact upon the quality of the SR results. The partial volume effect (PVE) due to low acquisition resolution, and in combination with the selected b-value, set a upper bound upon how detailed the extracted anatomical information can be. Importantly, the SR framework shows high performance in voxels with a PVE due to dense/complex fibre configurations (such as crossing fibres in WM, or in hippocampus), whereas single fibre voxels or voxels with low anisotropy due to a high cellular density, e.g. cerebral cortex, show little additional information.

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Literature: 1)Greenspan, MRM2002, 2)Arsigny, MRM2006, 3)Nedjati-Gilani, ISBI2008 4)Dyrby, HBM2010, 5)Cook, ISMRM2006