

Advanced Diffusion Acquisition

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Highlights

- Multiband imaging can greatly accelerate DWI.
- Currently used by both consortia in the human connectome project.
- Further progress is possible to circumvent current limitations of peak RF voltage and total power

Multiband Imaging

Target Audience: Methodologically oriented scientists interested in accelerating the acquisition of diffusion-weighted data using multiband/simultaneous multi-slice techniques.

Outcome/Objectives: The presentation will explain how to acquire and reconstruct multiband images with diffusion weighting. The audience should understand the additional constraints imposed by performing diffusion-weighting as compared to the application of multiband acquisition for T_2^* -weighted EPI, in particular with respect to limited total echo time and the effects of eddy currents and motion. Current applications of multiband DWI in the human connectome project and elsewhere will be explained. The audience should also gain insight into how to perform high resolution DWI with multiband techniques, and the possibility of reducing power deposition using PINS radio-frequency pulses.

Purpose: Multiband imaging techniques offer significant reductions in acquisition time for DWI imaging. In the standard application of DW-EPI TR values in excess of 10s are often reported in applications such as DWI of the human head at high spatial resolution.

Methods: Multiband imaging is implemented by modifying the RF pulses used in the DWI sequence. This is generally done by adding RF pulses, each of which has an additional linear phase gradient corresponding to the desired frequency offset [12]. The SAR of the resultant multiband pulse is proportional to the number of superposed pulses. The peak voltage can be reduced by optimising the phase of the pulses [10], or by shifting them in time [7]. Total SAR can be reduced by the application of PINS RF pulses that periodically excite a potentially infinite number of slices [13]. The blipped version [16] of the CAIPIRINHA technique [2] makes

it possible to shift adjacent slices relative to each other in the phase-encoding direction, and thus improve the fidelity of the image reconstruction. The most commonly used reconstruction technique is currently slice-GRAPPA that necessitates the prior acquisition of reference data [16]. There is a sensitivity compromise that commonly needs to be made when using DWI-EPI. Shortening the echo train will on the one hand reduce the sensitivity, because less data are acquired, and the efficiency of the sequence diminishes, on the other hand a shorter echo train also leads to a shorter TE, which can improve the sensitivity. The shorter the T_2 of the tissue of interest, the more crucial it is to reduce the TE, and hence this consideration is more crucial at 7 T than at 3 T and lower. If a sufficiently short TE can be obtained then the greater sensitivity of 7 T can permit high resolution DWI, with a spatial resolution of the order of 1 mm^3 which has mainly been combined with some form of zoom imaging technique in order to reduce the size of the acquisition matrix [9, 8].

Results: Much of the recent progress in multiband diffusion acquisition has been made by the two parts of the human connectome project. The Wash. U- Minnesota consortium initially proposed multiband acceleration based on a combination of SIR (which sequentially excites multiple slices [11], and interleaves their echoes in an EPI readout [6]) with multiband. [5]. The use of SIR has the advantage that sequential excitation does not give rise to high peak voltages, but its use was discontinued in subsequent acquisition protocols owing to the increased length of the EPI readout [19]. The final Wash U. Minnesota protocol for 3T acquisition uses a MB factor of 3, that is limited by peak RF voltages and power deposition, as compared to an MB factor of 8 in the fMRI protocol [19]. In plane acceleration was also not used because the SNR loss was feared to lead to increased uncertainty in tracking crossing fibres [18]. The final protocol acquires data with a spatial resolution of 1.25 mm at a TE of 89 ms. The maximum gradient strength of 100 mT/m makes it possible to acquire data on 3 shells with b -values, of 1000, 2000, and 3000 mm^{-2} .

The MGH-UCLA consortium has dedicated its entire effort to the measurement of structural connectivity. To achieve their goals they have constructed a unique 3 T scanner replete with a gradient set capable of generating 300 mT/m gradients with a slew rate of 200 T/m/s [15, 17]. They also pioneered the use of their blipped CAIPI technique for DWI [15], which is now used by both HCP consortia. The enormous gradient strength available makes it possible for the MGH-UCLA consortium to obtain data up to b -values of 20 000 mm^{-2} with a TE of under 60 ms. This combined with a tight-fitting 64 channel receiver coil gives unprecedented sensitivity. As with the Wash U. MGH consortium typical multiband factors of 3 are used, though with this equipment both partial Fourier, and in-plane acceleration have been successfully employed [17].

Multiband applications of DWI outside the HCP have been fairly limited. Saritas et al. utilised the periodic excitation profiles of 2D-RF pulses to limit the imaging field of view and then used Hadamard encoding rather than simultaneous multi-slice imaging to obtain the corresponding single slice images [14]. Eichner et al. combined zoomed imaging, in plane acceleration and multiband imaging with PINS refocusing pulses to obtain 1 mm isotropic whole brain coverage at 7T at a b-value of 1000 smm^{-2} and a TE of 64 ms [4].

Discussion: Multiband or simultaneous multi-slice imaging has already proven capable of dramatically accelerating the acquisition of diffusion-weighted images. Current limitations imposed by high peak voltages can be overcome by the full integration of techniques such as temporal echo shifting [1] or periodic excitation [13], and SAR limitations can also be resolved using the latter technique or VERSE [3]. Unresolved issues remain with regard to the optimal balance between slice- and in-plane-acceleration, and the degree to which different effects of motion and possibly eddy currents between the slices could possibly compromise the multiband image reconstruction.

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