Scan time reduction in 3D Diffusion-Weighted Steady-State Free Precession Imaging using Constrained Reconstruction

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TARGET AUDIENCE:
Researchers interested in 3D diffusion-weighted imaging, parallel imaging with nonlinear regularization, and DTI.

PURPOSE:
The primary goal is to reduce imaging times for isotropic, high-resolution 3D DTI by using a 3D undersampled diffusion-weighted steady state free precession (DW-SSFP) acquisition with a constrained non-linear parallel imaging reconstruction. DW-SSFP is an efficient multi-shot diffusion preparation amenable to fast 3D DTI acquisitions with proper phase navigation [1-3]. Undersampling in k-space reduces scan time at the expense of image artifacts, a well-known trade-off. Non-linear parallel reconstruction using a Total Generalized Variation (TGV^2) constraint has been shown to mitigate undersampling artifacts by leveraging on coil sensitivities and a judicious choice of penalty term. Here, fully sampled *in-vivo* DW-SSFP DTI data is retrospectively undersampled to explore the feasibility of scan-time reduction using TGV^2 reconstruction.

METHODS:
MRI: Imaging was performed on a healthy subject at 3T (GE 750) with a 32-channel head coil using a 3D DW-SSFP sequence with a 3D navigator acquisition and a spiral projection readout for 3D imaging [3]. Sequence parameters were as follows: isotropic 1.37 mm^3 resolution, 220 mm^3 FOV, TR 26.5 ms, scan time 2.2 min per direction for 15 diffusion directions, 2 b0 images, 5000 spiral interleaves per volume, diffusion gradient width 6 ms with 1ms ramps, with amplitude 4 G/cm.

Recon: Each interleaf was corrected for rigid-body motion using the navigator data [4]. Undersampling was performed retrospectively by taking every fourth interleave (R=4) or every eighth interleave (R=8). Images were reconstructed using gridding and using the TGV^2 constrained reconstruction [5]. For each diffusion direction, *i,* the TGV^2 constrained reconstruction finds the 3D image, u_i, that solves

$$\min_{u_i} \frac{1}{2}\left\|F(u_i)-k_i\right\|_2^2+\alpha\cdot TGV^2(u_i).$$

where k is the k-space data F is the non-Cartesian Fourier operator and $TGV^2()$ is the penalty function

Analysis: To remove residual spatial variations in the DW-SSFP signal due to non-rigid-body motion spatial filtering was performed according to ref [3]. FA and principle eigenvector maps were computed from each reconstructed dataset. Difference maps of the FA of each undersampled reconstruction were computed by subtracting the FA map of the fully sampled reconstruction and taking the absolute value.

RESULTS:
Color FA maps from TGV^2 (**Fig 1 e,f**) were less noisy than those from gridding (**Fig 1 c,b**) and more closely resembled the fully sampled gridding image (**Fig 1a**). Also the white matter in the TGV^2 color FA maps had higher intensity than in gridding, reflecting the more accurate FA values in the TGV^2 images (**Fig 2**). FA maps from TGV^2 (**Fig 2c**) were more quantitatively similar to the fully sampled FA maps (**Fig 2a**) than the gridding FA maps (**Fig 2b**). The difference maps from the same slice are shown below each FA map (**Fig 2 d,e**) and demonstrate the higher FA error of the gridding map in the white matter (yellow arrow).

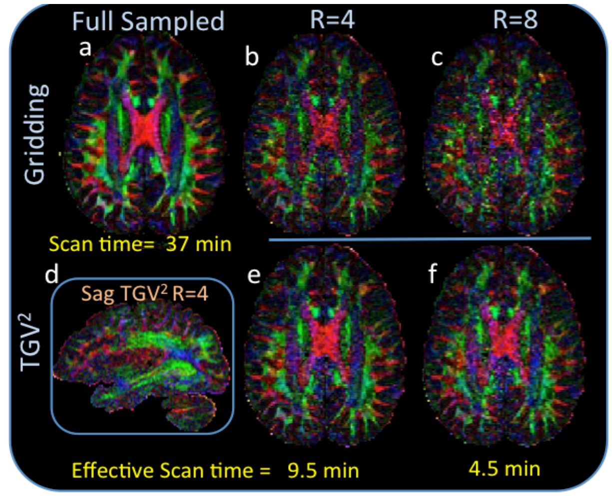

Fig. 1 – Color FA maps from an axial slice of the gridding reconstruction (b,c) and the TGV2 reconstruction (e,f) are compared to the fully sampled gridding reconstruction (a) at R=4 (b,d) and R=8 (c,e). At each reduction factor the gridding result appears noisier than the TGV^2 reconstruction, especially in the large white matter tracts. A sagittal view of the TGV^2 map at R=4 is shown to demonstrate the isotropic coverage (d).

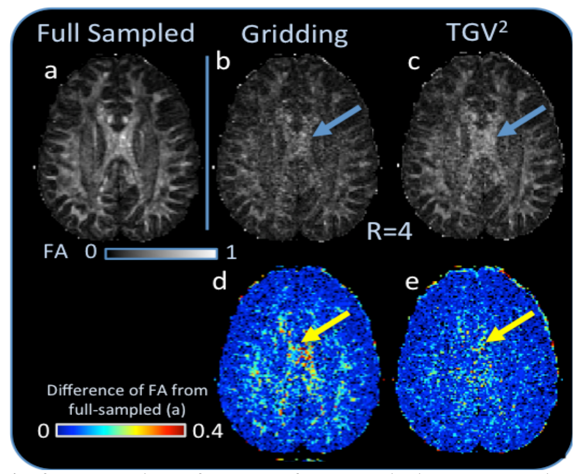

Fig. 2 – Comparison of FA maps from the gridding reconstruction (b) and the TGV^2 reconstruction at R=4 to the fully sampled reconstruction (a) with difference maps of each (d,e) from the fully sampled image (a). Note the higher error of the gridding reconstruction in the large white matter tracts like the corpus callosum (yellow arrow). The difference is given as an absolute value.

DISCUSSION and CONCLUSIONS:
These results suggest that scan-time reductions of factors of at least 4 are possible for DW-SSFP tensor acquisitions using undersampled TGV^2 reconstruction. For this particular exam this would bring the scan time from 37 min to 9.5 min. The trade-off to this time savings is a reduction of SNR that is apparent in the quantitative parametric maps. However with the TGV^2 constrained reconstruction the increased noise and artifact is not as severe as the gridding case (especially in the R=8 case, **Fig 1 c,e**). This provides more freedom in designing protocols as well as a potential strategy for dealing with severe motion, beyond the resolution of the 3D navigator, in which many interleaves might have to be discarded. The time savings can be invested in scanning more diffusion directions, which in turn would enable HARDI protocols and simultaneously improve SNR.

REFERENCES:
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