Wave-CAIPI and TGV for fast sub-millimeter QSM at 7 Tesla

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TARGET AUDIENCE

Researchers interested in phase imaging, quantitative susceptibility mapping and cortical susceptibility.

INTRODUCTION

Quantitative susceptibility maps (QSM) are calculated from MR phase images and while isotropic resolution up to 1 mm can be obtained in clinical studies, sub-millimeter resolutions are hampered by long acquisitions times and low SNR due to small voxel sizes. Recently, echo planar imaging (EPI) was proposed as a fast means for obtaining high resolution images [1-3]. Although EPI readout strategies are very efficient, they induce geometrical distortions most pronounced in the cortex, which can be mitigated using parallel imaging and segmented acquisition, but cannot be fully eliminated. In this work we combined a novel efficient acquisition approach based on 3D gradient recalled echo (GRE) with wave-CAIPI acceleration [4] for its usefulness in quantitative susceptibility mapping at higher spatial resolution. The acquired GRE data was processed with a single step QSM reconstruction based on total generalized variation (TGV) [5].

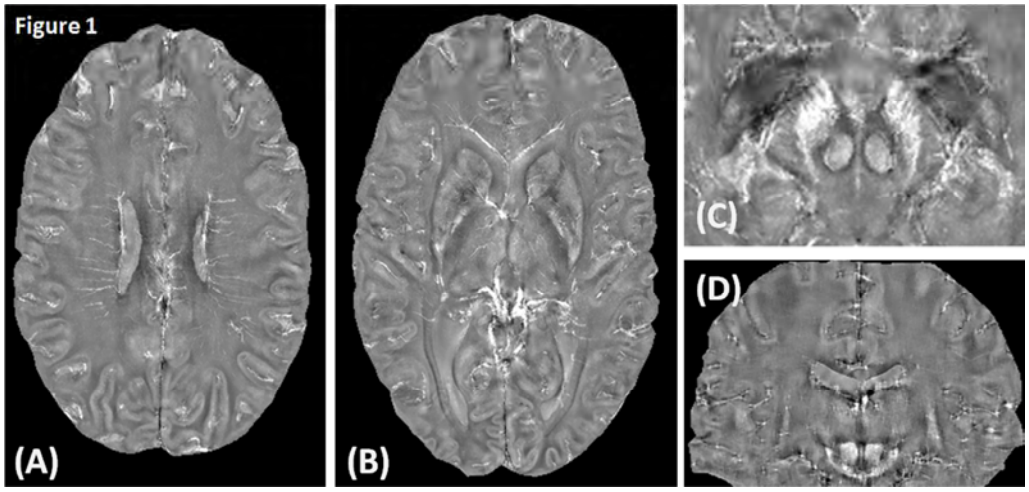
METHODS

MRI: Five patients with multiple sclerosis and one healthy volunteer (age range 31-45 years) underwent MR imaging at 7 T (Siemens Magnetom) with a 32 channel receive coil array. Imaging included an anatomical T1-weighted sequence with 1 mm isotropic resolution and a spoiled 3D GRE sequence with Wave-CAIPI acceleration (TE/TR = 15/25 ms, 0.5 mm isotropic resolution, BW = 100 Hz/px, matrix size = 384×512×240, R=3×3, acquisition time = 4:16 minutes). Wave-CAIPI traverses an efficient corkscrew k-space trajectory that spreads the aliasing evenly in 3D and fully exploits the variation in coil sensitivities to enable accelerated imaging with low artifact and noise amplification (maximum g-factor penalty g_{max}=1.14).

QSM: The Laplacian of the unwrapped phase $\Delta\phi$ was obtained from the wrapped phase ϕ_w by $\Delta\phi = \Im((\Delta\exp(j\phi_w))\exp(-j\phi_w))$ [6]. The TGV functional itself is a variational problem defined as $TGV_\alpha^2(\chi) = min_w \alpha_1 \|\nabla\chi - w\|_M + \alpha_0 \|\varepsilon w\|_M$, with w denoting all complex vector fields and ε its symmetrized derivatives. The regularization parameters $\alpha = (\alpha_1, \alpha_0)$ balance first and higher order terms. QSM was reconstructed by $\min_{\chi,\psi} \int |\psi|^2 dx + TGV_\alpha^2(\chi)$ subject to $\Delta\psi = \frac{1}{3}\frac{\partial^2\chi}{\partial x^2} + \frac{1}{3}\frac{\partial^2\chi}{\partial y^2} - \frac{2}{3}\frac{\partial^2\chi}{\partial z^2} - \frac{1}{2\pi T_E \gamma B_0}\Delta\phi$ in Ω, where the background field was implicitly integrated by an auxiliary variable ψ for which its Laplacian equals the discrepancy of the equation on the brain mask Ω [7]. The algorithm was implemented in the Python programming language using an iterative primal-dual solver.

RESULTS

Figure 1 shows the results of the TGV-QSM reconstructions with the images scaled from -0.2 to 0.2 ppm. QSM images could be reconstructed from all subjects. Deep gray nuclei, subcortical vessels as well as cortical structures yielded exquisite QSM contrast compared to adjacent white matter (Figure 1AB). Additional, small iron-loaded structures such as the substantia nigra, nucleus ruber and dentate nucleus can be delineated well (Figure 1CD). Please note that the level of striking artefacts induced by regularization is notable low given the GRE data has been obtained only from a single orientation which can be observed in coronal view (Figure 1D).



DISCUSSION AND CONCLUSION

The proposed setup applying Wave-CAIPI as acceleration technique allows acquiring GRE phase data of the entire brain with 0.5 mm isotropic resolution in 4 minutes. The reconstruction utilized for QSM is a single-step technique, which permits background removal and dipole inversion to be calculated in a single integrative iteration step. The shorter acquisition time compared to conventional parallel imaging techniques consequently strongly reduces the occurrence of motion artefacts in 3D imaging. In conclusion, these features render the proposed setup useful for the application in a clinical setting with patients with multiple sclerosis or other neurological disorders, especially for investigations of the susceptibility in the cortex.

REFERENCES

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