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Radial Echo-Planar Imaging with Subspace Reconstruction for Brain MRI

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Synopsis

While echo planar imaging (EPI) is successful in many MRI applications, this study demonstrates that radial EPI is applicable to brain MRI as well. Initial volumetric brain experiments at 1 mm isotropic resolution show that radial EPI is capable of rendering high-quality T1- and T2*-weighted images at 2.5 and 1.3 minutes scan time, respectively. Further, radial EPI requires neither magnetization preparation nor fat saturation.

INTRODUCTION

Echo-planar imaging (EPI) [1] and its varinat EPTI [2], a breakthrough rapid MR imaging technique, reads out multiple echoes per RF excitation. Given its fast k-space coverage and T_2^* sensitivity, EPI has been successful in functional, diffusion and quantitative MRI. However, EPI is challenging due to the use of reversed readout polarities between echoes and susceptibility artifacts induced by long readout time. Therefore, this work aims to explore the applicability of radial EPI [3,4], as an alternative to the standard Cartesian EPI, for brain MRI.

METHODS

Numerical Simulations of Single-Shot Radial EPI, Spiral, and Cartesian EPI

A numerical simulation framework [5,6] based on analytical FFT has been implemented to study single-shot acquisitions with the existence of static off-resonance. As shown in Figure 1, different single-shot trajectories lead to their corresponding characteristic off-resonance artifacts with NUFFT [7] or FFT reconstructions. Radial EPI shows signal void and streaks due to the overlap of all echoes in the k-space center; Single-shot center-out spiral acquisition shows ripple-like artifacts; Cartesian EPI shows spatial distortion due to phase shifts along the phase-encoding direction. These off-resonance artifacts can be removed with B_0-informed iterative reconstruction based on the conjugate gradient method (results not shown).

Segmented Radial EPI

The segmented radial EPI sequence we implemented is displayed in Figure 2. In the k_x-k_y plane, multiple echoes with different radial angles are sampled per RF excitation with the use of blip gradients. This set of echoes forms one segment in k-space, and is repeated for all k_z partitions in stack-of-stars acquisition [8]. The subsequent excitation starts the sampling of the next segment.

Brain MRI Experiments

All experiments were conducted at 3 T (Skyra, Siemens Healthineers, Erlangen, Germany), with a 20-channel head/neck coil. Three volunteers with written consent participated in the brain experiments. Two types of scans were performed:

1. Ultrafast whole brain T_1-weighted scan with 1 mm isotropic resolution and without magnetization preparation. Detailed imaging parameters are: flip angle 12 degree, bandwidth 840 Hz/pixel, FOV 220 mm, matrix size 220 x 220 x 192, 125 excitation per partition, 3 echoes per excitation with TE 1.7, 3.2, 5.7 ms and TR 6.4 ms. Total scan time is 2.5 minutes. Images were reconstructed with density-compensated NUFFT [7].
2. Ultrafast whole brain T_2^*-weighted scan with 1 mm isotropic resolution. Detailed imaging parameters are: flip angle 4 degree, 7 excitation per partition, 35 echoes per excitation with TE ranging from 1.70 to 55.7 ms and TR 57.4 ms. Total scan time is 1.3 minutes. The other parameters are the same as the first protocol. Images were obtained via local low-rank constrained subspace reconstruction in BART [9].

RESULTS

Rapid whole brain T_1-weighted scan with 1 mm isotropic resolution and without magnetization preparation

With the efficient and rapid triple-echo stack-of-stars FLASH technique, high-quality images are obtained with good T_1 contrast. Specifically, we observe clear boundary between white and gray matters, and the CSF region appears dark. Although promising, future work would be required to optimize imaging parameters for better T_1-weighted rapid brain scan.

Rapid whole brain T_2^*-weighted scan with 1 mm isotropic resolution

Similar to EPI, the proposed radial EPI sequence is well suited for T_2^*-weighted brain imaging with ultra short scan time. Residual streaking artifacts are still visible in regions with large static B_0 inhomogeneity. The reason may be the limited range of B_0 values in the dictionary and the small number of subspace coefficients, which are insufficient to capture the full B_0 inhomogeneity range. As show in Figure 5, larger B_0 range in the simulated signal requires more subspace coefficients to closely represent the full dictionary.

DISCUSSION & CONCLUSION

This work demonstrates the applicability and efficiency of the radial EPI sequence for brain MRI. Initial experiments focused on rapid T_1- and T_2^*-weighted scans. First, we did not employ any magnetization preparation pulse for the T_1-weighted scan, but the resulting T_1 contrast looks acceptable. The total acquisition time is rather short. The reason is that for the specific TR required for good T_1 contrast, multi-echo acquisition is used such that no time is wasted before TR. Second, radial EPI requires no fat saturation and shows no chemical-shift spatial shift artifact. This is because in radial EPI all echoes pass through k-space center, which results in intrinsic fat saturation via "phase cancellation" effect.

B_0 field inhomogeneity causes image artifacts. To alleviate this problem, both B_0-informed reconstruction and subspace reconstruction are feasible. The former requires either a joint estimation or a calibrated B_0 field map. The latter approach instead reconstructs linear subspace coefficients. However, care must be taken on the selection of B_0 range in the dictionary and the coefficient number. Although larger subspace coefficients may be beneficial to capture fast B_0 field change, it requires longer computation time during the iterative subspace reconstruction. Therefore, as a next step, it would be logical to explore an appropriate reconstruction for T_2^*-weighted radial EPI scan for broader clinical applications.

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References

[1] Mansfield P. Multi planar image formation using NMR spin echoes. J Phys C 1977;10:L55-L58.

[2] Dong Z, Wang F, Chan KS, Reese TG, Bilgic B, Marques JP, et al. Variable flip angle echo planar time-resolved imaging (vFA-EPTI) for fast high-resolution gradient echo myelin water imaging. NeuroImage 2021;232.

[3] Sliva AC, Barbier EL, Lowe IJ, Koretsky AP. Radial echo-planar imaging. J Magn Reson 1998;135:242-247.

[4] Tan Z, Voit D, Kollmeier JM, Uecker M, Frahm J. Dynamic water/fat separation and B0 inhomogeneity mapping -- Joint estimation using undersampled triple-echo multi-spoke radial FLASH. Magn Reson Med 2019;82:1000-1011.

[5] Koay CG, Sarlls JE, Özarslan E. Three-dimensional analytical MRI phantom in the Fourier domain. Magn Reson Med 2007;58:430-436.

[6] Guerquin-Kern M, Lejeune L, Pruessmann KP, Unser M. Realistic analytical phantoms for parallel MRI. IEEE Trans Med Imaging 2012;31:626-636.

[7] Fessler JF. https://github.com/JeffFessler/mirt.

[8] Block KT, Chandarana H, Milla S, Bruno M, Mulholland T, Fatterpekar G, et al. Towards routine clinical use of radial stack-of-stars 3D gradient-echo sequences for reducing motion sensitivity. J Korean Soc Magn Reson Med 2014;18:87-106.

[9] Uecker M. https://github.com/mrirecon/bart.

Figures

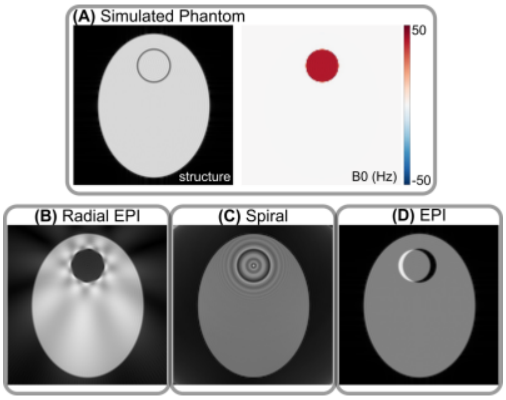

Figure 1. (A) Simulated phantom structure and its corresponding B0 field inhomogeneity map. **(B)** NUFFT reconstruction of single-shot radial EPI sampled k-space data. **(C)** NUFFT reconstruction of single-shot spiral sampled k-space data. **(D)** FFT reconstruction of the standard single-shot Cartesian EPI data.

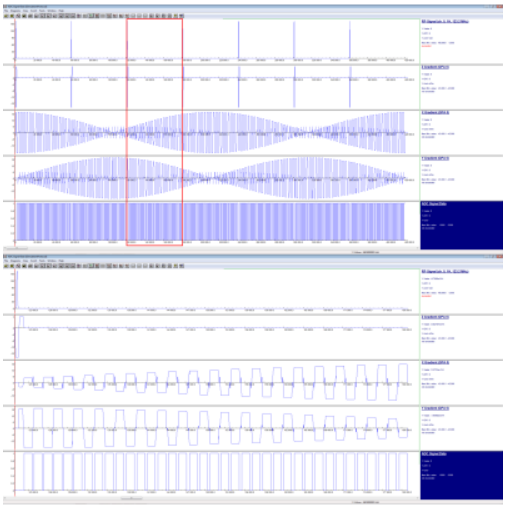

Figure 2. (Top) Screenshot of the segmented radial EPI sequence implemented on Siemens pulse sequence programming platform. Here, one complete k-space consists of seven excitation (segments). **(Bottom)** Zoomed-in sequence diagram of the third TR block.

Figure 3. Whole brain 1 mm isotropic T1-weighted volumetric scan with 2.5 minutes scan time. Images were reconstructed with density-compensated NUFFT. Due to the constraint on figure size, only the central 32 slices in there orientations are displayed as a gif movie.

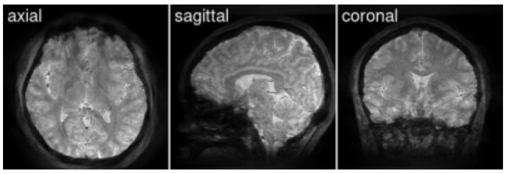

Figure 4. Whole brain 1 mm isotropic T2*-weighted volumetric scan with 1.3 minutes scan time. Subspace reconstruction was employed, with subsequent back projection to echo images, and finally root sum of square of all echo images. Displayed gif movie comprises the central 32 slices in there orientations.

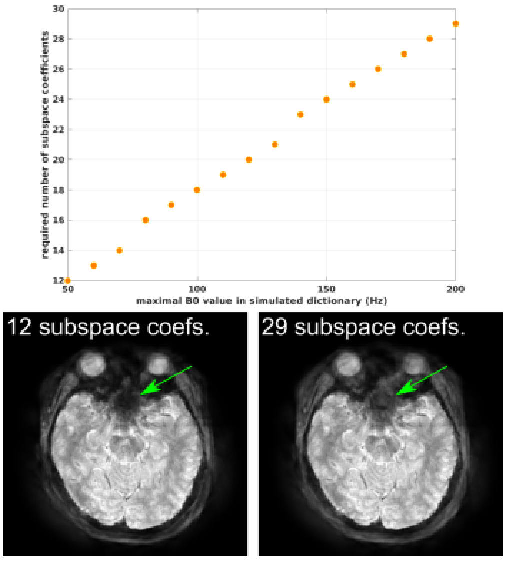

Figure 5. **(Top)** Plot of the required number of subspace coefficients against the maximal B0 value used for simulating the dictionary. The number of subspace coefficients is determined as, the minimal number whose corresponding relative error between the subspace-represented and the full dictionary is less than 0.0001. **(Bottom)** Subspace reconstruction results with 12 and 29 subspace coefficients, respectively. More coefficients represent a large B0 range, and thus help to partially recover signal loss.

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