Accelerated 3D EPI using 2D blipped-CAIPI for high temporal and/or spatial resolution

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Target audience: MR physicists and Neuroscientists

Purpose: Improved volumetric EPI reconstruction for neuroscience applications

Introduction

3D EPI can offer advantages over 2D EPI when operating in the thermal noise regime (high spatial resolution)[1,2,3]. Furthermore, considerable reductions in volume acquisition times can be achieved by parallel acceleration along the secondary (k_y) phase encoding direction. Similar to the recently proposed simultaneous multislice (SMS) EPI[4,5] this increases BOLD (MRI) sampling rates and reduces the vulnerability to physiological fluctuations, and ultimately increases BOLD sensitivity[3].

Conventional SENSE or GRAPPA along the two phase-encoding directions is independently limited by the coil sensitivities along the two dimensions. Furthermore, the g-noise is greatest at the center where both aliases overlap. We propose 2D blipped-CAIPIRINHA[6,7] to lift these limitations, to achieve a higher undersampling factor, and to gain full flexibility how to utilise it.

Theory

2D CAIPIRINHA ("CAIP")[6] has been developed for optimal exploitation of the FOV and coil encoding: strategic sampling of the partial k-space controls the alias so as to distribute it over the FOV. A prominent feature of CAIPI is that it can exploit coil sensitivities in one direction to undersample along another. The conventional notion of an in-plane (AFPE) and through-plane acceleration factor (AF3D) is therefore lost, and the reconstruction characterized by total undersampling/acceleration AFtot and a "CAIPI pattern". For one-shot-one-line methods (e.g. FLASH) the pattern does not affect scan time, which follows AFtot. In the proposed 3D EPI acquisition the entire k_y-k_z plane is acquired per shot, thus the flexibility added by CAIPI does impact on scan time: The total undersampling capability can be invested to (a) reduce the number of EPI shots[7], (b) reduce the number of lines per shot[8], or (c) any desired tradeoff between the two[9]. We demonstrate each of these cases with AFtot=16.

Methods

CAIPI-enabled 3D multi-echo EPI was implemented on a Siemens 7T with 32ch head coil: The EPI readout is either modulated by Δk_z-blips (for AFPe≥AF3D), or successive k_y-planes are shifted by Δk_y and appropriate echo shifts (for AF3D≥AFPe). Human scans were in accordance with IRB protocols. We demonstrate three choices at AFtot=16: 1) High temporal resolution (3.0mm voxels, 64x64x64 matrix, CAIPI 1x16_z6, TE=19ms, TR_shot=49ms, TR_vol=148ms; normal GRAPPA 1x12 as reference); 2) High spatial resolution, multi-echo (0.8mm voxels, 240x240x208 matrix, CAIPI 16x1_y4 (Æ4x4_z1) TE=9/22/35ms, TR_shot=47ms, TR_vol=7330ms); 3) an intermediate choice (0.8mm voxels, 240x240x208 matrix, CAIPI 4x4_z2 TE=19ms, TR_shot=49ms, TR_vol=1911ms; normal GRAPPA 4x4 as reference).

Results

The flexibility of CAIPI 3D EPI has been illustrated and good image quality and signal-to-noise ratios (SNR) were observed with AFtot=16. Practical use may warrant more modest choices. All coil encoding can be utilised along one phase-encode direction, but it also yields higher SNR than regular GRAPPA when sharing between both.

Discussion and Conclusion

The flexibility of CAIPI 3D EPI has been illustrated and good image quality and sSNR were observed with AFtot=16. Practical use may warrant more modest choices. All coil encoding can be utilised along one phase-encode direction, but it also yields higher SNR than regular GRAPPA when sharing between both.

An interesting next step is the comparison to blipped-CAIPI 2D SMS-EPI with slice-GRAPPA reconstruction[10] which can turn in-plane coil sensitivities into through-plane acceleration in same way, but it cannot exploit through-plane sensitivities for additional in-plane acceleration as here shown with volumetric CAIPI.

References

[8] Poser BA, p587; ISMRMB 2013
[10] Poser BA, p287; ISMRMB 2013