Accelerated Multiband SSFP Imaging with Controlled Aliasing in Parallel Imaging and integrated-SSFP (CAIPI-iSSFP)

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Target Audience: Clinicians and physicists interested in accelerated imaging acquisition using bSSFP for imaging the brain.

Introduction: Controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) is an acceleration technique that uses phase modulated multiband (MB) excitation pulses to simultaneously acquire slices [1,2]. Its application in balanced-SSFP (CAIPI-bSSFP), however, has been limited because the phase modulation of CAIPIRIHNA results in shifted off-resonance profiles and subsequent banding artifacts in simultaneously excited slices [3-5]. A unique case of an SSFP-FID sequence allows for removing banding artifacts while maintaining the unique bSSFP tissue contrast by averaging the bSSFP signal profile (integrated-SSFP or iSSFP) [3,4]. In this study, we propose to combine the CAIPIRINHA and iSSFP techniques (CAIPI-iSSFP) for faster imaging, while maintaining sufficient T2/T1 contrast without banding artifacts in 3T brain imaging.

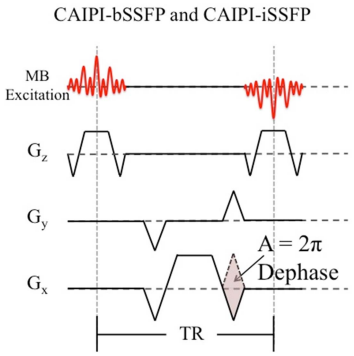

Fig 1: *Difference between CAIPI-bSSFP and CAIPI-iSSFP sequences. A dephasing gradient is played right after the readout gradient (dotted line and red area) for CAIPI-iSSFP, and the spoiling gradient area is such that it dephases the spins across a 2π cycle.*

Methods: The CAIPI-iSSFP sequence was modified from a standard CAIPIRIHNA bSSFP (CAIPI-bSSFP) sequence by including a dephasing gradient right after the readout gradient to provide proper gradient spoiling (the spins within a voxel to dephase across a 2π cycle) for iSSFP (Fig 1). The dephasing gradient is applied in the readout direction to allow for greater blood contrast [3]. CAIPIRINHA uses a MB excitation RF pulse to simultaneously excite multiple slices that are phase shifted [1,2,6], and the phase shifting is uniformly distributed across a 2π cycle. For example for MB factor of 4 (MB-4), the images would have a phase shift of 0, π/2, π, and 3π/2 (0, FOV/4, FOV/2, 3*FOV/4 shift in the phase encoding direction respectively).

Three healthy volunteers were scanned using a 32-channel head coil on a Siemens 3T Trio scanner. Each subject underwent CAIPI-bSSFP and CAIPI-iSSFP scans with MB-2, MB-3, and MB-4 respectively, and with a single-band or SB reference scan. Common imaging parameters include: 24 slices with a resolution of 1.3 x 1.3 x 5 mm^3, FOV of 256 x 256 mm^2, TR = 4.29ms, TE = 2.15ms, 192 x 192 matrix size, and a flip angle of 30°. The total scan times for SB, MB-2, MB-3, and MB-4 were 19.7s, 9.8s, 6.6s, and 4.9s respectively.

Regions-of-interest (ROIs) were manually drawn to cover the ventricles, white matter (WM), and gray matter (GM) areas without banding artifacts to evaluate the relative contrast-to-noise ratio (CNR) of each of the sequences and with the different MB acceleration factors. The relative CNRs between WM and the ventricles, and between WM and GM were averaged across the 3 subjects. The relative CNR was determined by $CNR_{relative} = |ROI_1 - ROI_2|/\sigma_{SB-noise}$, where $ROI_{1,2}$ are the values from the ROI's that were drawn, and $\sigma_{SB-noise}$ is the standard deviation of the background noise of the SB reference image.

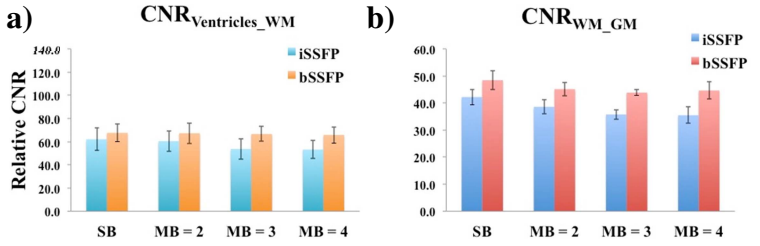

Fig 2: *Comparison of relative CNRs for CAIPI-bSSFP and CAIPI-iSSFP. CNRs were averaged for each of the 3 cases comparing white and gray matter (a), and the ventricles and white matter (b) contrast. There is a decrease in CNR as MB factor increases for both sequences, and CAIPI-iSSFP has lower CNR comparatively to CAIPI-bSSFP images.*

Results: The relative CNRs are about 10-20% lower in CAIPI-iSSFP compared to the CAIPI-bSSFP (Fig 2). The differences on CNR increased from 9% to 18% as the MB factor increased 2 to 4 between CAIPI-bSSFP and CAIPI-iSSFP. Fig 3 shows image slices that were acquired simultaneously for MB-4 with their phase shifting listed on top. The arrows point to banding artifacts that are present in the CAIPI-bSSFP images, but not in the CAIPI-iSSFP images.

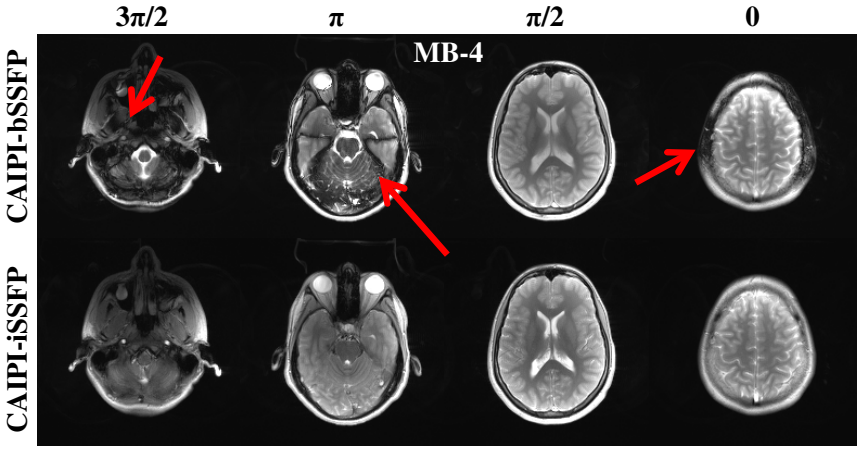

Fig 3: *CAIPI-bSSFP (top row) and CAIPI-iSSFP (bottom row) images that were acquired simultaneously with MB-4 and respective phase shift (top of figure). CAIPI-iSSFP has comparable Ventricle, GM, and WM contrast to CAIPI-bSSFP. Arrows point to banding artifacts present in CAIPI-bSSFP, but not in CAIPI- iSSFP images.*

Discussion and Conclusions: CAIPI-iSSFP offers similar tissue contrast as CAIPI-bSSFP (9% reduction in MB-2 and 18% reduction in MB-4), which cannot be achieved in other gradient echo sequences [4]. Applying the dephasing gradient only in the readout direction allows for flow compensation in the y- and z-directions and bright fluid contrast. This study demonstrates that CAIPI-iSSFP can provide fast imaging time (4x acceleration) while removing the banding artifacts seen in CAIPI-bSSFP imaging and maintain sufficient brain tissue contrast (compromising about 20% reduction of a relative CNR, compared to CAIPI-bSSFP).

References: [1] FA Breuer, et al., MRM 2005. [2] M Blaimer, et al., MRM 2013. [3] EM Haacke, et al., Radiology 1990. [4] BA Hargreaves, JMRI 2012. [5] KL Miller, et al., Imaging in Medicine 2011. [6] D Stäb et al., MRM 2011.