Increasing parallel imaging performance and correcting field inhomogeneity artifact in MS-CAIPIRINHA using view angle tilting technique (CAIPI-VAT)

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Purpose: To increase parallel imaging performance in multi-slice controlled aliasing in parallel imaging and to reduce field inhomogeneity artifact using view angle tilting technique.

Methods: Controlled aliasing in parallel imaging (CAIPI)[1, 2] technique makes each excited slice shift along phase encoding (PE) direction by inducing linear phase using different RF phase at each slice. Then the coil sensitivity of each slice is virtually shifted and it makes easy to solve parallel imaging problem. In other words, ill-conditioned unaliasing problems due to similar coil sensitivities of excited slices are conditioned well by retaining the independency (reducing the similarity) of coil sensitivity using CAIPI shift. In addition, aliased portions which need to be resolved are reduced as well. Here, we combine view angle tilting (VAT)[3] technique with CAIPI excitation scheme. VAT technique can correct in-plane field inhomogeneity artifacts by introducing slice-selection gradient at readout timing. This VAT gradient can be regarded as separation gradient in simultaneous multislice acquisition (SMA)[4]. However, VAT blurring can be occurred due to the additional slice-selection gradient during readout time. Here, we address the blurring by k-space demodulation using slice profile information[5]. Reconstruction is performed using slice-GRAPPA[2] technique. For accurate and simultaneous multi-slice excitation, Shinnar-Le Roux (SLR)[6] is adapted. Three slices with 9.0 mm gap are simultaneously excited and ±FOV/3 shift are induced by RF phase variation at each TR. All experiments are performed on a 3T scanner (Tim Trio, Siemens Medical Solutions, Erlangen, Germany). The imaging parameters are TR/TE = 650.0/12.0ms, resolution = 1.0 x 1.0 mm^2, slice thickness = 2.0 mm and readout bandwidth = 390 Hz/pixel and the view angle is 63.1°. Phantom experiments are performed to compare the acceleration performance between CAPI and CAIPIVAT and to show the compensation of field inhomogeneity artifact. In addition, invivo head experiments are also performed on healthy volunteer to show chemical-shift artifact robustness as well as acceleration.

Results: Cylinder water phantom images with multi-band factor 3 are shown in Fig. 1. FOV/3 shift are induced along PE direction using CAIPI and RO direction shifts are additionally induced using VAT. Compared to CAIPI acquisition, the aliased portions (regions) are reduced in CAIPI-VAT and thus it results in smaller difference with reference images as shown in Fig. 1. Therefore, the reconstruction images from CAIPI-VAT show better quality than from CAIPI only. In addition, field inhomogeneity artifact which appeared as slight signal pile up and chemical shift artifact are corrected in CAIPI-VAT acquisition as shown using water-fat-air model phantom images in Fig. 2. In invivo imaging, the chemical shifts due to fatty tissue around skull are corrected in CAIPI-VAT and it shows less parallel imaging artifact. VAT blurrings due to additional slice-selection gradient are reduced using simple k-space demodulation technique.

Discussion and Conclusion: First of all, the number of voxels to solve the unfolding problem is reduced because of the bi-directional shifted image along both PE and RO direction according to its slice location. Furthermore, ill-conditioned problems due to similar coil sensitivity of each slice can be conditioned better by increasing independency of coil sensitivity. Therefore, this feature results in reducing g-factor and increasing multi-slice excitation factor. In addition, VAT technique has its own ability compensating in-plane field inhomogeneity artifacts at the cost of partial volume blurring due to VAT gradient. However, it can be compensated by k-space demodulation with the kernel from slice profile information. In conclusion, by combining CAIPI and VAT techniques, parallel multi-slice imaging with better performance than CAIPI and field inhomogeneity corrected acquisition can be achieved.

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References: **1**. Breuer FA, Blaimer M, Heidemann RM, et al. Controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) for multi-slice imaging. MRM 2005;53(3):684-691. **2** Setsompop K, Gagoski BA, Polimeni JR, et al. Blipped-controlled aliasing in parallel imaging for simultaneous multislice echo planar imaging with reduced g-factor penalty.MRM. 2012;67(5):1210-24. **3**. Cho ZH, Kim DJ, Kim YK. Total inhomogeneity correction including chemical shifts and susceptibility by view angle tilting. Med. Phys. 1988;15(1):7-11. **4**. Weaver JB. Simultaneous multislice acquisition of MR images. MRM 1988;8(3):275-284. **5**. Zho S-Y, Kim D-H. Time-varying view angle tilting with spiral readout gradients. MRM 2012;68(4):1220–1227. **6.** Pauly, J, Le Roux, P, Nishimura, D, et al. Parameter relations for the Shinnar-Le Roux selective excitation pulse design algorithm. IEEE TMI 1991;10:53–65.

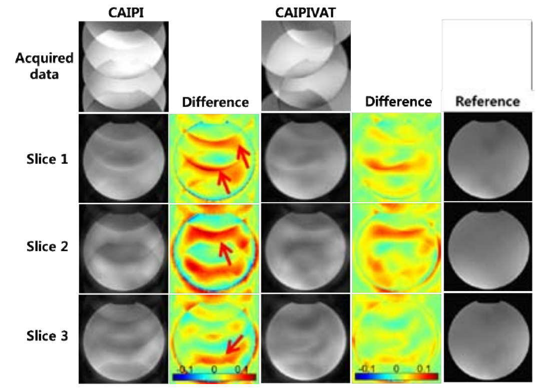

Figure 1. Cylinder water phantom images are presented to show the acceleration performance. Acquired images using CAIPI with FOV/3 shift and CAIPIVAT are shown (top row from left to right) and corresponding reconstructed and difference images (second to bottom row) with reference (last column) are shown also. CAIPI-VAT has reduced parallel imaging reconstruction artifacts compared to CAIPI as indicated with red arrows.

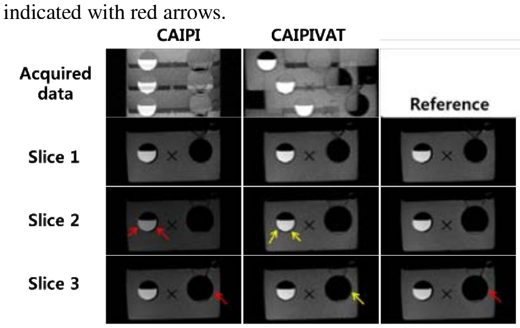

Figure 2. Water-fat-air phantom images with the same presentation scheme as figure 1 except difference image column. Chemical shift artifacts (slice 2) and air-water field inhomogeneity artifacts (slice 3) are indicated by red arrows and their corrected versions with CAIPI-VAT are indicated by yellow arrows.

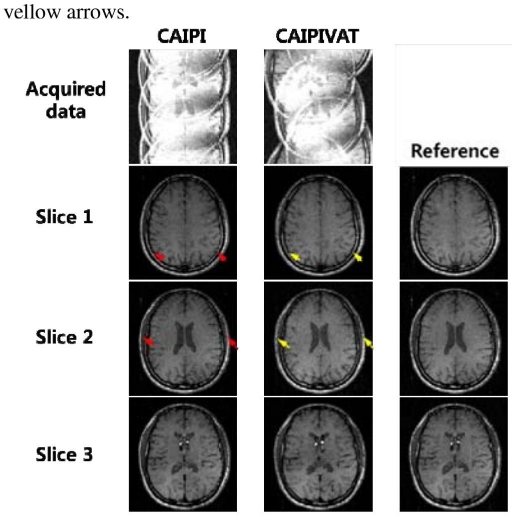

Figure 3. Invivo brain images with the same presentation scheme as figure 2. Chemical shift artifacts are indicated by red arrows and their corrected versions are indicated by yellow arrows in CAIPI-VAT.