Multislice Acquisition With Incoherent Aliasing (MICA)

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Purpose: Conventional simultaneous multislice (SMS) acquisitions, such as CAIPIRINHA [1] and blipped-CAIPI [2], create coherent aliasing of the simultaneously excited slices. Here we propose a new SMS technique, in which the slice-aliasing is incoherent. We name the proposed technique 'Multislice acquisition with InCoherent Aliasing (MICA)'.

Methods: An SMS acquisition can be viewed as a 3D acquisition [3], where k_x is fully sampled and the k_y-ω_z plane is undersampled. Here ω_z (belongs to [0, 2π]) represents the normalized frequency domain of the simultaneously excited slices. The CAIPI (including both CAIPIRINHA and blipped-CAIPI) acquisition scheme samples ω_z at the DFT frequencies, $2\pi m/N$, where m=0,1...N-1 and FOV_y/N is the relative shift in y between adjacent slices. Fig. 1a displays the undersampling pattern for CAIPI on the k_y-ω_z plane with N=3. A 2D view of the 3D slice-aliased data can be obtained by projecting the 3D data along the ω_z axis. The 2D view of the 3D CAIPI data (Fig. 1b) show that the slice shifting in CAIPI results in coherent aliasing of the three simultaneous slices.

Instead of repeatedly sampling the DFT frequencies, MICA uses each echo to sample a unique frequency along ω_z, and the sampling is performed in an irregular manner. Here we propose two irregular sampling schemes: **(1) Random MICA.** Each echo randomly samples a frequency on the interval [0, 2π] basing on a uniform probability density on [0, 2π], as depicted in Fig. 1c; **(2) Bit-reversed MICA.** The N_e echoes sample N_e uniformly distributed frequencies on the interval [0, 2π] in a bit-reversed order. Fig. 1e shows an example with N_e=8, where the echoes 0,1,2,3,4,5,6,7 sample the frequencies $\omega_z = (2\pi/8) \times (0,4,2,6,1,5,3,7)$, respectively. Both random MICA and bit-reversed MICA create incoherent aliasing of the simultaneous slices, as shown in Fig. 1d,f. SENSE [4] can be used to reconstruct the MICA data. As the first step of the reconstruction 1D iFFT is conducted along the fully sampled k_x dimension to transform the data into the x-k_y-ω_z space. For each point x_0 along x, there is an undersampled k_y-ω_z plane, on which the measured signal is $s(x_0,k_y(n),\omega_z(n),c) = \sum_y\sum_z m(x_0,y,z)\, S_c(x_0,y,z)\, \exp(-i2\pi k_y y/N_y)\, \exp(-i\omega_z z)$, where n is the echo index, z is the slice index, m is the magnetization, S_c is the sensitivity of the c^{th} coil and N_y is the matrix size in y. m is the only unknown in the signal equation, and it can be found using the pseudoinverse of the known encoding matrix.

Results: Simulations are conducted using 5 single-slice images with 24 mm gap between adjacent slices. CAIPI, random MICA and bit-reversed MICA data are synthesized and the same Gaussian distributed noise is added to the three synthesized data sets. Individual slices are reconstructed by SENSE. The normalized root mean squared (RMS) errors between the original single-slice images and the reconstructed images are calculated. Fig. 2 displays the results from a simulation which uses 3 of the 5 single-slice images to simulate 3× slice acceleration and no inplane acceleration. The performance of MICA is comparable to CAIPI. Bit-reversed MICA performs a little better than random MICA with the SENSE reconstruction. Fig. 3 displays simulation results with different acceleration factors for CAIPI and bit-reversed MICA. The overall performance of bit-reversed MICA is comparable to CAIPI. The relative performance of the two acquisition schemes depend on the specific acceleration factor used. For the case with 3× slice and 3× inplane acceleration, CAIPI does not introduce any interslice shift and is thereby having much worse performance than MICA. Fig. 4 displays 3 simultaneous *in vivo* slices acquired by a SMS echo planar imaging (EPI) sequence. The image quality of bit-reversed MICA is comparable to CAIPI, and they are both superior to the acquisition with unaltered aliasing.

Discussion: MICA is a new SMS acquisition technique which introduces incoherent aliasing of the simultaneous slices. MICA is applicable to both EPI and non-EPI acquisitions. The SENSE-reconstructed images show that the image quality of MICA is comparable to CAIPI, and they are both superior to SMS acquisition with unaltered aliasing. The quality of the SENSE-reconstructed images indicates how well the encoding matrix for each acquisition scheme is conditioned. The relative performance of MICA and CAIPI depend on the acceleration factor when other acquisition parameters are fixed, as shown by Fig. 3. We expect the relative performance will also depend on other acquisition parameters such as the distance between adjacent slices, matrix size and coil configuration but have not yet examined this dependence.

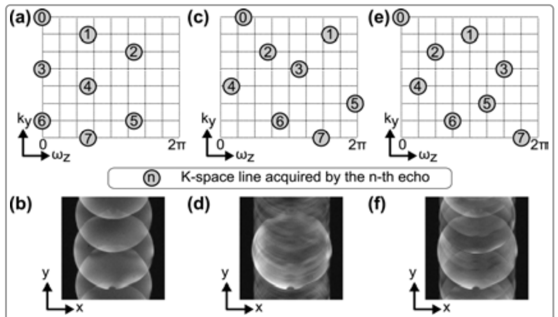

Fig. 1. *Undersampling pattern on the k_y-ω_z plane (top row) and the 2D view of the 3D slice-aliased data (bottom row) for (a)-(b): CAIPI; (c)-(d): Random MICA; (e)-(f): Bit-reversed MICA.*

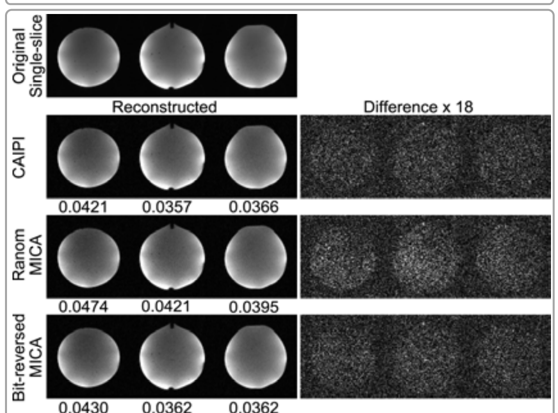

Fig. 2. *Simulation of 3× slice acceleration and no inplane acceleration. Normalized RMS errors are displayed under the SENSE reconstructed images.*

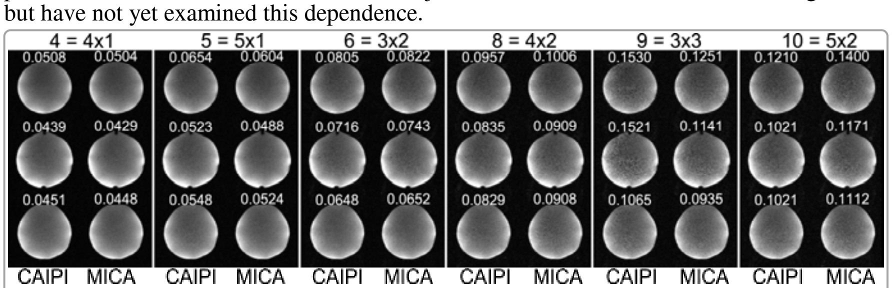

Fig. 3. *Simulation of CAIPI and bit-reversed MICA for different acceleration factors. Three SENSE reconstructed simultaneous slices are shown. The acceleration factor (Total = Slice×Inplane) is displayed at the top of each group of images. The normalized RMS error is displayed above each reconstructed image.*

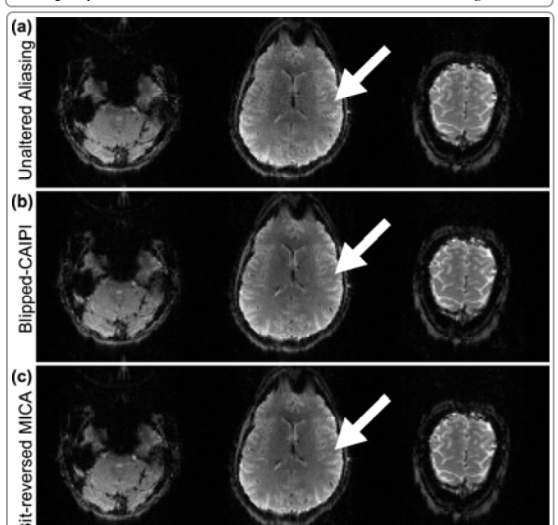

Fig. 4. *Three simultaneous slices from SMS EPI acquisitions at 3T with 3× slice acceleration and no inplane acceleration. Three acquisition schemes are used. (a): Standard SMS EPI with unaltered aliasing; (b)blipped-CAIPI; (c): Bit-reversed MICA. Images are reconstructed by SENSE. Some artifacts seen in the acquisition with unaltered aliasing do not exist in blipped-CAIPI or MICA, as depicted by the white arrows.*

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