# Further scan time reduction of Bunched Phase Encoding using Sensitivity Encoding

H. Moriguchi[1], J. L. Sunshine[1], J. L. Duerk[1]

[1]Departments of Radiology and Biomedical Engineering, University Hospitals of Cleveland / Case Western Reserve University, Cleveland, OH, United States

**Introduction**

Bunched Phase Encoding (BPE) has recently been proposed as a new fast data acquisition method in MRI [1]. In this method, more than one phase encoding line is acquired during a single readout by applying a rapid oscillatory phase encoding gradient during readout. This allows the total number of TR cycles, and hence scan time, to be reduced. Parallel imaging methods which use multiple receiver channels, such as sensitivity encoding (SENSE), have also gained in popularity as alternative methods to achieve rapid MR data acquisition [2]. In this study, we show that combination of BPE with SENSE can lead to further acceleration in data acquisition in MRI. We also propose a new efficient reconstruction technique for data acquired using BPE with SENSE.

**Methods**

Figure 1 shows a schema of the k-space trajectories of BPE. In BPE, k-space data are sampled along zigzag lines at a rate higher than normal sampling rate, i.e., more than one phase encoding line is acquired during a single readout. The spacing from one phase encoding line to the next is typically greater than 1/FOV. Therefore, the total number of TR cycles can be reduced. Image reconstruction is based on Papoulis' generalized sampling theory [3]; here, the original data can be mapped to a regular rectilinear grid via matrix inversion. Theoretically, the total number of TR cycles can be further reduced when SENSE is used with a BPE acquisition; unfortunately image reconstuction via matrix inversion would be extremely computationally intensive. The conjugate gradient (CG) method has been proposed as a reconstruction method for SENSE acquisitions with nonuniform data acquisition; the method avoids inversion of large matrices and uses an iterative algorithm to gain computational efficiency. [4]. In our newly proposed reconstruction technique for the combination of BPE with SENSE, the SENSE CG method is altered (refer to Figure 2).

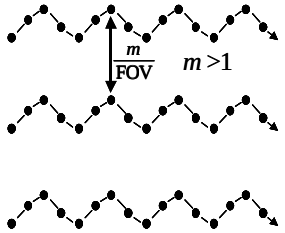


**Fig.1. BPE sampling scheme**

Here, k-space data are simply distributed to large rescaled matrice rather than using convolution based gridding, in a manner similar to the previously described iterative next neighrbor regridding (INNG) [5]. We refer to this algorithm as CG-INNG. In Fig.2, small and large squares represent $N$ x $N$ and $sN$ x $sN$ matrices, where $N$ is one side of the target image matrix and $s$ is a scaling factor. In matrices (a), k-space data from each coil are distributed to large rescaled matices initially set to zero. The distributed data are density-compensated. Inverse Fourier Transforms (IFT) are performed on matrices (a) leading to matrices (b). The reconstructed images at the center of the (b) matrices are extracted. The images are combined and intensity-corrected, resulting in the matrix (c). The image (d) is generated after the image (c) is processed using the CG algorithm. Each sensitivity map, multiplied by the image (d), is set to the center of a large matrix of zeros, as shown in matrices (e). FTs are performed on the images (e) leading to updated k-space data on larger rescaled matrices (f). In matrices (f), only k-space data where the original data exist are retained and compensated by their local density. Data at other locations are set to zeros. IFTs are performed on matrices (f), resulting in matrices (g). The reconstructed images at the center of (g) are combined and intensity-corrected, leading to the image (h). CG algorithm is again performed on (h). The procedures surrounded by dashed lines are repeated until the image converges.

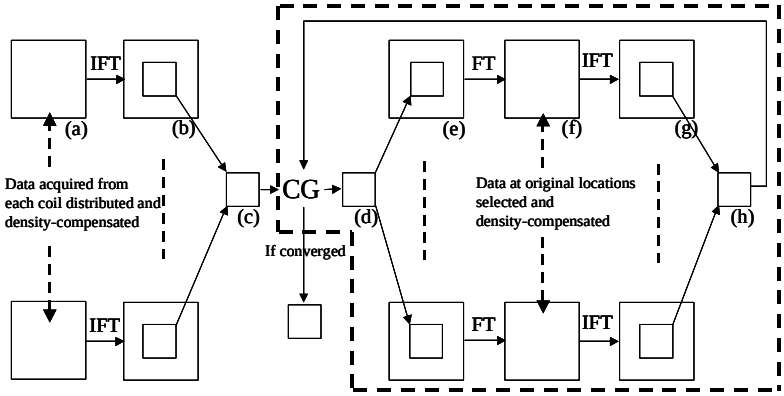


**Fig.2. A flow chart of CG-INNG algorithm**

MR experiments were performed to test the proposed method using a 1.5 Tesla Siemens Sonata Scanner. A resolution phantom was scanned with a zigzag FISP sequence and a standard FISP sequence using two receiver channels. TE/TR/FA=10.0/20.0ms/30° in both sequences. In the zigzag FISP, 128 oscillations were designed during each readout. Each sequence consisted of 64 TR cycles with 1024 samples acquired for each TR; in total a reduction of a factor of 4 over a normal 256 x 256 acquisition was achieved. A 256 x 256 image was reconstructed from the data acquired with each sequence via CG-INNG method described above. In the CG-INNG reconstruction, the scaling factor was set to 16 and 30 iterations were performed. For each sequence, an image was also reconstructed using the conventional gridding for comparison [6].

**Results**

Figure 3 shows the following reconstructed images ((a): Zigzag FISP with conventional gridding; (b): Zigzag FISP with CG-INNG after 15 iterations; (c): Standard FISP with conventional gridding; and (d): Standard FISP with CG-INNG after 15 iterations.). In each CG-INNG reconstruction, no significant change was observed in the images after 15 iterations. As seen in (a) and (c), images reconstructed using the conventional gridding were affected by substantial aliasing artifacts in both zigzag and standard FISP sequences. No apparent aliasing artifacts were observed in image (b) while aliasing artifacts still remain in image (d).

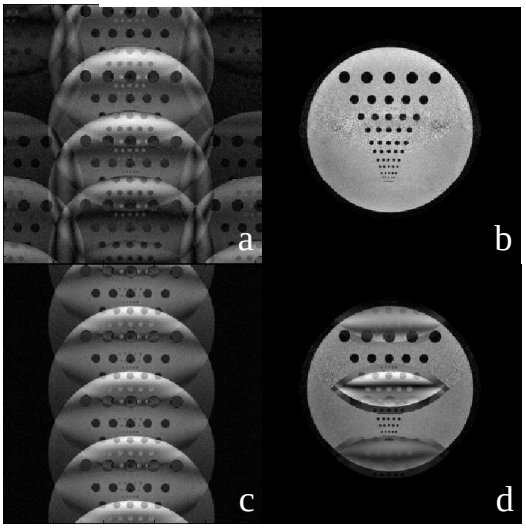


**Fig.3. Reconstructed images**

**Discussion and Conclusions**

In our experiments, each sequence had 64 TR cycles while the target image matrix was 256 x 256. Therefore, the acceleration factor was 256/64 = 4. Since we used only two receiver channels, it is not possible to reconstruct an image without aliasing artifacts if standard acquisition was used, as observed in Fig.3 (d). However, when the BPE sampling method (Fig.1) was employed, it enabled us to reconstruct an image with no apparent aliasing artifacts, as seen in Fig.3 (b). This alias-free image can occur from only 64 TR cycles because each zigzag line in BPE acquisition samples data from more than one phase encoding to better fill k-space from each single readout. Since the acceleration of BPE is independent of that of SENSE, the combination of these fast imaging methods can lead to further reductions in scan time. The newly proposed combination method of 'BPE with SENSE' offers significant advantages for fast MRI. This work represents a first example of MR acquisitions which combine parallel imaging with a new class of pulse sequences that acquire multiple phase encoding lines per sampling interval.

**Acknowledgements** NIH/NCC Grants R01 CA81431 and R33 CA88144, Siemens Medical Solutions.

**References** [1] Moriguchi H, et al. Proc RSNA 2004. [2] Pruessmann KP, et al. MRM 1999;42:952-962. [3] Papoulis A. Signal analysis. 1977;431p. [4] Pruessmann KP, et al. MRM 2001;46:638-51. [5] Moriguchi H, et al. MRM 2004;51:343-52. [6] Jackson JI, et al. IEEE TMI 1991;10:473-8.