Bunched Phase Encoding in Projection Reconstruction

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Introduction: Projection reconstruction (PR) acquisitions have re-emerged in MRI since they have several advantages over rectilinear acquisition methods. First, images reconstructed from PR acquisitions show reduced motion artifacts when compared with images from rectilinear acquisitions [1]. Second, aliasing artifacts from PR acquisitions with a modest reduction in the number of projections are often not as apparent as those from rectilinear acquisitions with a comparable level of reduced phase encoding (PE). However, aliasing artifacts (a.k.a. streaking artifacts) remain and thus degrade image quality when the number of acquired projections is significantly reduced. Ideally, it would be desirable if aliasing artifacts in PR acquisition could be reduced without increasing the number of projections. Bunched Phase Encoding (BPE) has recently been proposed as a new fast data acquisition method in rectilinear sampling in MRI [2, 3]. In BPE, oscillating gradients are applied along the PE direction during readout. Therefore, data are acquired along zigzag k-space trajectories, rather than straight lines. The total number of TR cycles and hence the scan time in the BPE acquisition can be reduced. In this study, we have extended rectilinear BPE to PR acquisitions to reduce the number of projections. This is comparable to oscillating data collection between multiple projections within each sampling interval. The newly proposed method is referred to as 'PR-BPE'. In PR-BPE, k-space data are acquired along zigzag projections. Here, we show that a previously proposed conjugate gradient-iterative next neighbor gridding (CG-INNG) algorithm [3] can effectively reduce streaking artifacts in PR-BPE. We have compared images reconstructed using different PR acquisitions and different reconstruction methods and confirmed that the newly proposed PR-BPE is useful to reduce the scan time of PR MRI acquisitions.

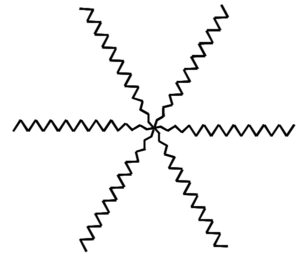

Fig.1. PR-BPE

Methods: Figure 1 shows a schema of k-space trajectories of PR-BPE. K-space data are acquired in a zigzag fashion along each projection. These k-space trajectories can be generated by applying rapid oscillatory gradients in both the *x* and *y* directions to a PR pulse sequence. An image is reconstructed from the data acquired with PR-BPE using CG-INNG algorithm [3]. In ref. 3, the CG-INNG algorithm was proposed for a combined technique of rectilinear BPE with parallel imaging when data were acquired using multiple receiver channels. In our experiments using PR-BPE acquisitions described below, the CG-INNG reconstruction algorithm was applied to acquired k-space data (albeit without parallel imaging).

Actual MR experiments were performed to test the proposed PR-BPE acquisitions. Both phantom and *in-vivo* images were acquired. In the phantom experiments, center-out PR with 128 projections were designed. Both regular PR and PR-BPE were implemented. 256 samples were acquired during a readout. In PR-BPE, 64 oscillations were designed for each projection. In both regular PR and PR-BPE, TE/TR/FA=2.0/20.0ms/30° and FOV=300mm. In the image reconstruction, both conventional gridding [4] (Kaiser-Bessel window with 2.5 Cartesian steps) and the CG-INNG algorithm were tested for each k-space data acquired with regular PR and PR-BPE. In the CG-INNG algorithm, the scaling factor was set to 16 and 20 iterations were performed. In the *in-vivo* experiments, axial abdominal images were acquired from an aymptomatic volunteer using a center-out PR-BPE with 256 projections. 1024 samples were acquired during a readout. 128 oscillations were designed for each projection. TE/TR/FA=4.6/20.0ms/30° and FOV=370mm. In the image reconstruction, both conventional gridding and the CG-INNG algorithm were tested. The parameters of the reconstruction were the same as those of the phantom experiments.

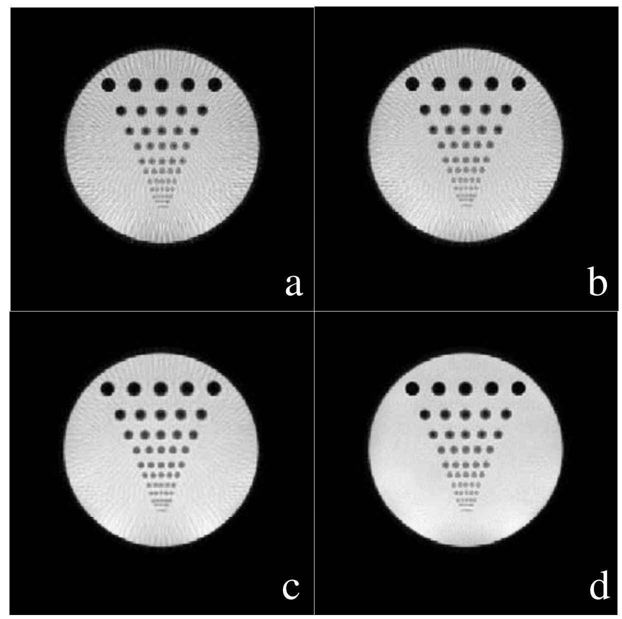

Fig.2. Phantom images

Results: Figure 2 shows the reconstructed phantom images ((a): regular PR using conventional gridding; (b): PR-BPE using conventional gridding; (c) regular PR using CG-INNG; and (d): PR-BPE using CG-INNG.). Images (a) and (b) are affected most by streaking artifacts while no apparent streaking artifacts are observed in image (d). Streaking artifacts in image (c) are reduced from those in images (a) and (b). However, resolution loss can be observed in image (c) when compared with other images. Figure 3 shows the abdominal images ((a): PR-BPE using conventional gridding; and (b): PR-BPE using CG-INNG.). As indicated by arrows, streaking artifacts are observed in image (a). The artifacts are considerably reduced in image (b).

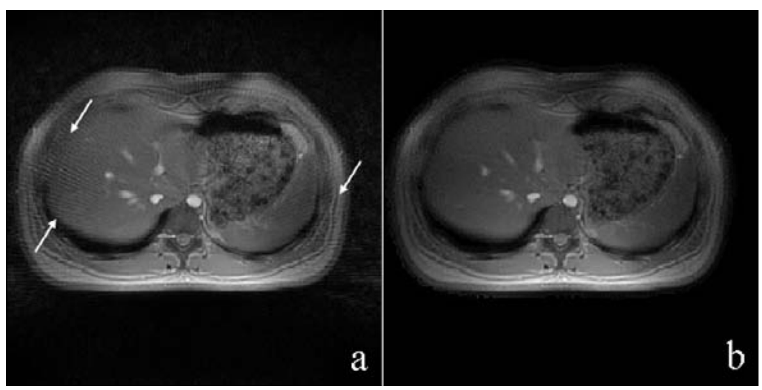

Fig.3. in-vivo images

Discussion and Conclusions: From our experiments, images are affected by streaking artifacts when conventional gridding is used for reconstruction independent of the types of undersampled PR acquisitions. Since conventional gridding performs convolution with a small kernel, the estimated k-space data on a rectilinear grid are often not accurate when k-space data are sampled with a reduced number of projections. However, the CG-INNG algorithm seeks the least-squares solution that maintains all acquired k-space data at the original k-space locations when the scaling factor is large. As seen in Fig.2(d) and Fig.3(b), the CG-INNG reconstruction method is quite useful to reduce streaking artifacts when data are acquired using PR-BPE with reduced number of projections. On the other hand, as observed in Fig.2 (c), when the CG-INNG algorithm is used with regular PR, quality of the image is degraded from that of Fig.2 (d). From these observation, both PR-BPE and the CG-INNG reconstruction method are essential when k-space data are acquired using PR with a reduced number of projections. The newly proposed PR-BPE acquisition together with CG-INNG reconstruction represents a very useful method to reduce acquisition time in PR MRI while maintaining image quality.

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References: [1] Glover GH, et al. MRM 1992;28:275-89. [2] Moriguchi H, et al. Proc RSNA 2004. p451. [3] Moriguchi H, et al. Proc ISMRM 2005. p287. [4] Jackson JI, et al. IEEE TMI 1991;10:473-8.