Variable Density Bunched Phase Encoding

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Introduction: Bunched Phase Encoding (BPE) has recently been proposed as a new fast data acquisition method in MRI [1, 2]. In BPE, data are acquired along zigzag k-space trajectories using rapidly oscillating gradients along the PE direction. Sampling frequency of BPE is higher than that of normal acquisition. Since BPE acquisition scheme is comparable to acquiring multiple PE lines in a single readout, the total number of TR cycles and hence the scan time can be reduced. In BPE, zigzag k-space trajectories often need to be measured to reconstruct images because actual trajectories often deviate from designed trajectories due to eddy currents. The trajectory measurement usually needs to be done only once unless the imaging plane is changed. However, trajectories have to be measured when the scanning plane is changed because different gradient coils are used to produce the gradient waveforms. Although trajectory measurement is not technically difficult, it is sometimes cumbersome in practice. Furthermore, measurement errors are unavoidable even if sophisticated measurement methods are used. These facts give rise to difficulties in actual implementation of BPE. In this study, we show an improved BPE acquisition method that does not require k-space trajectory measurement. In our newly proposed method, variable density (VD) zigzag trajectories are used to acquire k-space data, i.e. the Nyquist criterion is satisfied only in the central portion of k-space and the other k-space regions are sampled with a PE step size that is beyond the Nyquist limit (Fig.1a). The newly proposed method is referred to as 'VD-BPE'. In VD-BPE, the central k-space data are taken advantage of to compute the k-space trajectories. Images are reconstructed based on the computed trajectories. VD-BPE obviates the need for cumbersome k-space trajectory measurement and achieves accurate image reconstruction. VD-BPE is quite useful and facilitates implementation of BPE in practice.

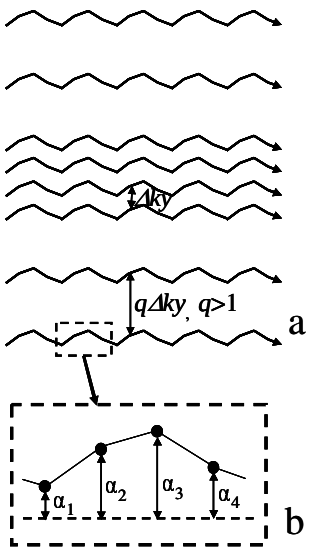

Fig.1. VD-BPE acquisition

Methods: It is assumed that a zigzag trajectory used in BPE consists of repetition of the same oscillation pattern. For example, Fig.1 shows that there are four samples in each oscillation (Fig.1b) and that multiple sets of this oscillation form a zigzag trajectory (Fig.1a). In Fig.1b, α_i ($1 \leq i \leq m$, where m is #samples in each oscillation) denotes the distance of each samples from the reference line along the PE direction. The reference lines are set at every $q\,\Delta ky$ along the PE direction, where q is a reduction factor of BPE and Δky is defined as $1/(FOV_y)$. In VD-BPE, all α_i are computed from the central data that satisfy the Nyquist criterion. Figure 2 shows a flow chart of VD-BPE. A low pass filter is first applied to the central data along ky direction. i-th datum is extracted from each oscillation. Each data subset that consists of i-th datum from each oscillation is inverse Fourier transformed. Note that this sub-image shows aliasing artifacts only along x direction because the Nyquist criterion is met along ky direction for the central data. m sets of these aliased sub-images are decomposed using α_i to reconstruct an image with a prescribed FOV. Every α_i is first set to zero. α_i are updated after each iteration. The central k-space data are computed based on the decomposed image and the current α_i. i-th datum in each oscillation is extracted from the computed k-space data to form a data subset. An IFT is performed on each data subset to reconstruct an aliased sub-image. For each i, phase difference between the aliased sub-image reconstructed from the computed data and that reconstructed from the original data is measured. Each α_i is updated based on this phase difference. These updated α_i are then used to decompose m sets of the aliased sub-images reconstructed from the original data. The procedures described above are repeated until α_i are converged.

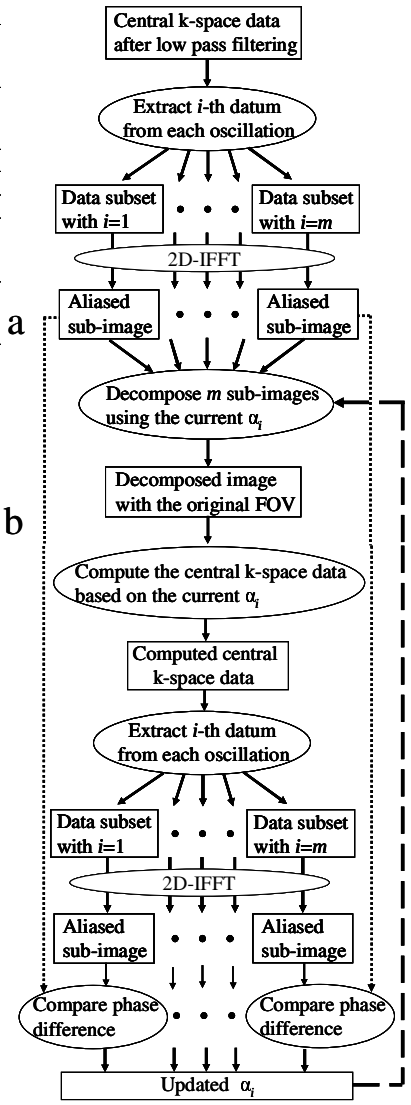

Fig.2. A flow chart of VD-BPE

MR experiments were performed to test the VD-BPE using a 1.5 Tesla Siemens Sonata Scanner. A resolution phantom was scanned using a FISP sequence with TE/TR=10.0/20.0ms in this experiment. The target image matrix size was 256 x 256. A zigzag trajectory we designed consisted of 128 oscillations. Eight samples were acquired in each oscillation, i.e. m=8. Reduction factor was set to two, i.e. q=2. The total number of TR cycles was 138, i.e. 128 with additional 10 at the central k-space. Six iterations were performed to compute α_i.

Results: Figure 3 shows (a) an image reconstructed using initial values of α_i, i.e. all zeros, (b) that reconstructed using α_i after the first iteration, and (c) that reconstructed using α_i after six iterations. Aliasing artifacts observed in image (a) are reduced in image (b). The artifacts are almost negligible in image (c). These results indicate that trajectories computed using VD-BPE are quite accurate, thereby enabling us to reconstruct images without aliasing artifacts.

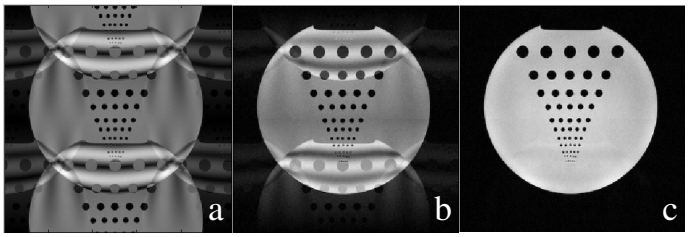

Fig.3. Reconstructed images

Discussion and Conclusions: In VD-BPE, since the central data are acquired with the Nyquist criterion fulfilled along ky direction, each sub-image in Fig.2 shows aliasing artifacts only along x direction. These aliasing artifacts that result from kx subsampling can be removed because all kx coordinates of the acquired data are known. Therefore, if aliasing artifacts appear in the decomposed image (Fig.2), they result from the data shift along ky direction. We can take advantage of this fact to compute the ky coordinates, i.e. α_i. In some parallel imaging techniques such as VD-AUTO-SMASH [3] and GRAPPA [4], k-space data are fully sampled only in the central k-space and sparsely sampled in the other k-space regions to accelerate the acquisition. These techniques do not require calibration or prescan since the central data can be used as 'self-calibrated signals'. VD-BPE is analogous to these parallel imaging methods in the sense that both methods use the central data to calculate parameters that are essential for image reconstruction. The newly proposed VD-BPE is a quite useful technique that enables us to readily implement BPE in practice.

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References: [1] Moriguchi H, et al. MRM 2006;55:633-48. [2] Moriguchi H, et al. Proc ISMRM 2005. p287. [3] Heidemann RM, et al. MRM 2001;45:1066-74. [4] Griswold MA, et al. MRM 2002;47:1202-10.