A single scan two-point ghost phase cancellation method using Bunched Phase Encoding

H. Moriguchi[1], M. A. Griswold[1], J. L. Sunshine[1], J. L. Duerk[1]

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

Introduction: It is well known that periodic or quasi-periodic motion causes ghost artifacts along phase encoding (PE) direction in rectilinear sampling of MRI [1, 2]. Methods for suppression of ghost artifacts using a few sets of images have been proposed [3, 4]. These methods take advantage of the fact that these types of ghost artifacts differ only in phase but that there is no significant difference among the magnitudes of these ghosts. However, the scan time of these methods must be extended since they require multiple image sets. This is a primary drawback of these ghost phase cancellation methods [3, 4]. Bunched Phase Encoding (BPE) has recently been proposed as a new fast data acquisition method in MRI [5, 6]. 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 this study, it is shown that the BPE technique enables us to reduce the total data acquisition time of two-point ghost phase cancellation (2PGPC) method [4] to that of a single acquisition. To the best of our knowledge, this is the first demonstration of application of BPE to the 2PGPC method to reduce the scan time.

Methods: In the original 2PGPC method [4], two sets of complete k-space data are acquired. In these two sets of data, their PE orders are slightly shifted from each other. In the newly proposed BPE-2PGPC method, two sets of half k-space data are acquired with their PE orders shifted from each other. In other words, when the sequence consists of *N* TR cycles, each of these two images is reconstructed from the data acquired for *N*/2 TR cycles. Note that neither these images are affected by aliasing artifacts because the BPE technique is taken advantage of [5, 6]. However, the images may be affected by ghost artifacts due to motion/flow. Figure 1 shows a k_y-t plot of the BPE-2PGPC acquisition scheme. In this plot, the horizontal and vertical axes represent k_y coordinate (PE direction) and time, respectively. Δk_y is defined as $1/FOV_y$ where FOV_y is the prescribed field-of-view along PE direction. Each dot in the plot denotes an event of data acquisition in each TR. Similar plots of other acquisition schemes are found in ref. 7. As shown in Fig.1, k-space data at $k_y = -k_{max}$ are acquired in the first TR. In the second TR, k-space data at $k_y = -k_{max} + p\Delta k_y$ are acquired, where p is a small positive integer. In the third TR, k-space data at $k_y = -k_{max} + 2\Delta k_y$ are acquired. Similary, k_y locations of the k-space data acquired in n-th TR can be expressed as $k_y = -k_{max} + (n\text{-}1)\Delta k_y$ when n is odd and $k_y = -k_{max} + p\Delta k_y + (n\text{-}2)\Delta k_y$ when n is even. As mentioned in ref. 4, for the last several even-numbered TR, k_y locations of the k-space data are between $-k_{max} + \Delta k_y$ and $-k_{max} + (p\text{-}1)\Delta k_y$ with $2\Delta k_y$ separation to cover the k-space data equidistantly from $-k_{max}$ to $+k_{max}$. In the BPE-2PGPC method, an image is reconstructed from the data acquired for each of odd-numbered and even-numbered TR's. After two images are reconstructed, 2PGPC algorithm [4] is applied to these images to cancel the ghost artifacts. Figure 2 show a flow chart of the BPE-2PGPC method.

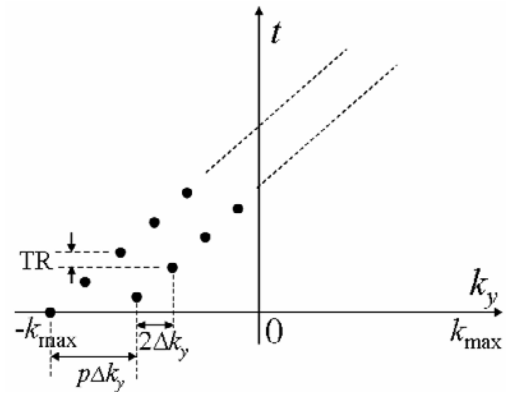

Fig.1. k_y-t plot of BPE-2PGPC acquisition

MR experiments were performed to test the proposed BPE-2PD method using a 1.5 Tesla Siemens Sonata Scanner. Axial abdominal images were acquired from an asymptomatic volunteer under breath-hold. The experiments were performed under an institutional-review-board-approved protocol for volunteer scanning. A series of triangular gradients with the maximum amplitudes ±3.7mT/m was used to produce a zigzag k-space trajectories. 128 oscillations were designed during each readout. The readout is 10.24 ms in duration and 1024 samples were acquired during a readout. The sequence was a FISP sequence [8] with TE/TR/FA=10.0/80.0ms/30° and FOV=370mm. The sequence consisted of 256 TR cycles, i.e., each image was reconstructed from the data acquired for 128 TR cycles. K-space shift between the data sets, *p* in Fig.1, was set to 5 in this experiment. Data were acquired using a four-element phased array surface coils. The reconstructed image matrix was 256 x 256. An image was reconstructed independently from the data acquired from each receiver channel. An improved ghost suppression method [9] was used to determine parameters to cancel ghosts. The images were combined using the sum-of-squares method [10].

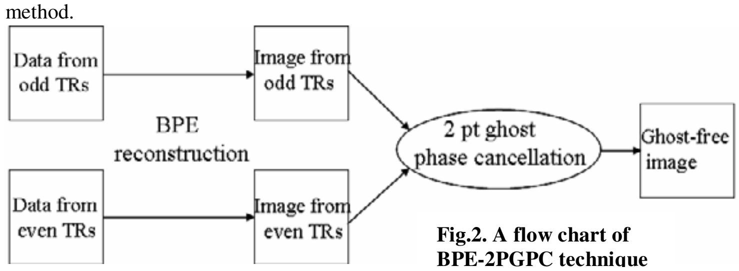

Fig.2. A flow chart of BPE-2PGPC technique

Results: Figure 3 shows the reconstructed images ((a): Image reconstructed from the data acquired for even numbered TRs; (b): Image after ghost phase cancellation.). As indicated by arrows in (a), replicas of signals from aorta appear along PE direction while no apparent ghost artifacts can be observed in (b).

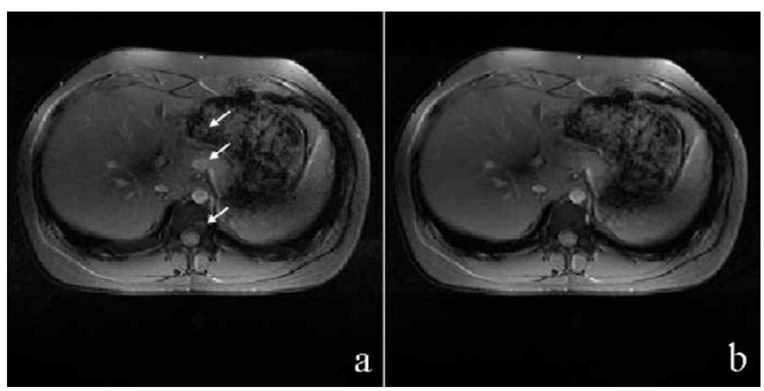

Fig.3. Reconstructed images

Discussion and Conclusions: The previously proposed three-point GPC (3PGPC) and 2PGPC methods [3, 4] do not require any gating and therefore it is convenient to implement these methods in practice. In the previous study, the 2PGPC method has been shown to have almost the same performance of ghost artifact suppression as the 3PGPC method using only two sets of images while the 3PGC method requires three sets. However, the total acquisition time of the 2PGPC method is still twice as long as that of the regular acquisition method. The extended scan time increases motion and/or flow artifacts and patients' burden when breath-hold is required during scanning. The newly proposed BPE-2PGPC method has overcome these disadvantages of the original 2PGPC method by achieving the reduction in scan time by 50%. As observed in Fig.3b, ghost artifacts can effectively be suppressed using the BPE-2PGPC technique while not inducing other types of artifacts. This fact suggests that the BPE acquisition methods do not disrupt phase relationship between ghosts in two sets of images thereby enabling us to apply the original 2PGPC algorithm to these images reconstructed using the BPE technique. The BPE-2PGPC technique is a new, fast and effective ghost reduction method that is quite useful in practice.

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