Bowtie PROPELLER: A fast and efficient motion correction method in MRI

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Introduction: Periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) has shown to have significantly reduced sensitivity to motion artifacts [1]. In PROPELLER, k-space data acquired during each TR form a blade consisting of several parallel lines. The blade is rotated around the k-space center until the whole target k-space is acquired. In this sampling method, the central small disc is acquired in each blade. Therefore, the disc region sampled by each blade can be used to correct for both translation and rotation. Since the central disc in k-space usually contains high intensity signals, PROPELLER is a robust correction method for rigid body motion. A primary disadvantage of PROPELLER is extended scan time. The scan time of PROPELLER is at least 50% longer than that of conventional multishot fast spin echo (FSE) due to oversampling in the central k-space region [2]. In this study, we demonstrate a novel sampling and reconstruction technique that can significantly reduce the scan time of PROPELLER. Specifically, the total scan time of our newly proposed technique is 60~80% of that of conventional FSE and therefore usually shorter than 50% of that of PROPELLER. This new technique is referred to as 'bowtie PROPELLER' since the shape of each blade appears to be a 'bowtie' as shown in Fig.1. In the image reconstruction, we capitalize on the focal underdetermined system solver (FOCUSS) that has recently been successfully adapted to undersampled projection reconstruction [3]. Although bowtie PROPELLER undersamples the peripheral k-space region, there are no apparent aliasing artifacts in the reconstructed images. Bowtie PROPELLER is a very useful motion correction technique that can considerably reduce the scan time of PROPELLER while maintaining the image quality.

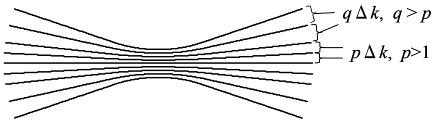

Fig.1. A blade of bowtie PROPELLER

Methods: K-space sampling scheme of bowtie PROPELLER is shown in Fig.2. Each bowtie-shaped blade sample the central portion of k-space with the Nyquist criterion satisfied. Note that several lines at the periphery of each blade are overlapped with those of the neighboring blade. Thus, as shown in Fig.1, spacing between lines in each blade are varied. In Fig.1, $p\Delta k$ and $q\Delta k$ represent distance between neighboring lines at the edges of each blade, where Δk is 1/FOV and $q>p>1$. p and q are usually set to 2~4 and 4~8, respectively. For motion correction, since the Nyquist criterion is fulfilled in the central portion of each blade, the same correction method as PROPELLER can be applied to bowtie PROPELLER, i.e., magnitude and phase of k-space data in the central disc is compared between blades to correct for rotation and translation, respectively. In image reconstruction, since the Nyquist criterion is not met for most of the target k-space except the central region, aliasing artifacts is often unavoidable when conventional gridding method is used. In our technique, FOCUSS is taken advantage of to reduce aliasing artifacts [3]. FOCUSS is approximately equivalent to L1 minimization algorithm. Since the algorithm described in ref.[3] can be applied only to projection reconstruction, it is linked to gridding based method so that FOCUSS can be applied to bowtie PROPELLER sampling scheme. This reconstruction algorithm is similar to spiral FOCUSS [4].

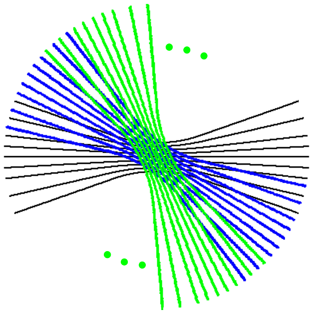

Fig.2. k-space trajectories of bowtie PROPELLER

MR experiments were performed to test bowtie PROPELLER using a 3.0 Tesla Siemens Trio Scanner. In these experiments, axial brain images were acquired from an asymptomatic volunteer using a quadrature head coil. All procedures were done under an institutional review board approved protocol for volunteer scanning. The bowtie blade we designed consisted of 15 lines with p=3 for the central nine lines and q=6 for the peripheral six lines. An FSE sequence was modified to collect k-space data in bowtie PROPELLER. The sequence parameters were: TR/TE 3000/130ms, FOV 230mm, slice thickness 10mm. Twelve blades were collected in the bowtie PROPELLER sequence. The image matrix size was 256 x 256. Images were acquired with and without motion. In motion experiments, the volunteer was instructed to deliberately move his head during the scan. The extent of motion was estimated as 30mm translation in the x direction, 5mm translation in the y direction, and 15° rotation along the z direction.

Results: Figure 3 show images reconstructed from the data acquired using bowtie PROPELLER with (a-c) motion and without (d,e) motion.
(a) and (b) are images reconstructed using conventional gridding before (a) and after (b) motion correction, respectively. (c) is an image reconstructed using FOCUSS after motion correction. (d) and (e) are static images reconstructed using conventional gridding and FOCUSS, respectively. As observed in Fig.3, artifacts due to motion observed in (a) are considerably reduced in (b) and (c). While (b) shows streaking artifacts for the entire image domain, these artifacts are significantly reduced in (c). In (d), although there are no apparent artifacts due to motion, streaking artifacts remain. The level of the streaking artifacts are almost the same as those observed in (b). These artifacts that appear in (d) are significantly reduced in (e).

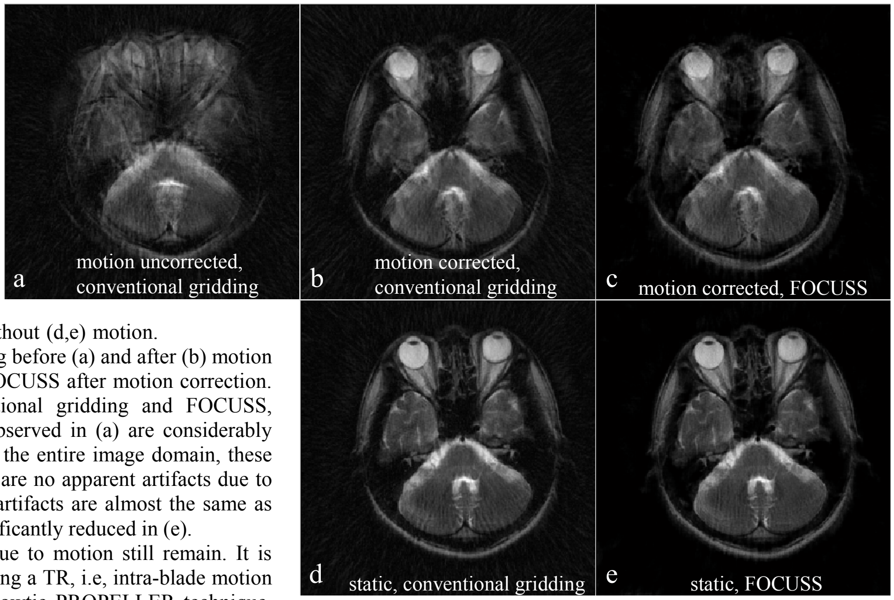

Fig.3. Reconstructed images of bowtie PROPELLER

Discussion and Conclusions: In Fig.3(b) and (c), artifacts due to motion still remain. It is presumed that these artifacts resulted from motion occured during a TR, i.e, intra-blade motion and thus are difficult to correct for. In the newly proposed bowtie PROPELLER technique, bowtie-shaped blades (Fig.1) have significant advantages over rectangular blades used in conventional PROPELLER. In bowtie PROPELLER, since the central region of k-space can be acquired by each blade with the Nyquist criterion fulfilled, artifacts due to motion occured between shots can be corrected using the same method as conventional PROPELLER. Furthermore, although peripheral regions in k-space are sampled below the Nyquist limit, streaking artifacts due to undersampling can be siginificantly reduced using FOCUSS reconstruction, as observed in Fig.3 (c,e). Thus, the total number of blades, i.e, TR cycles to acquire data in the target k-space can be substantially reduced in bowtie PROPELLER from conventional PROPELLER. If a conventional FSE with ETL 16 is used to collect 256 phase encoding lines, 16 TR cycles are required. Therefore, the total scan time of the bowtie PROPELLER is 0.75 (=12/16) times of that of the conventional FSE sequence. Since the scan time of conventional PROPELLER is usually at least 1.5 times of that of the conventional FSE [2], 50 % reduction in scan time can be achieved in bowtie PROPELLER compared with conventional PROPELLER. The newly proposed bowtie PROPELLER technique is a quite useful fast data acquisition method that can reconstruct images with reduced artifacts.

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References: [1] Pipe JG. MRM 1999;42:963-969. [2] Arfanakis K, et al. MRM 2005;53:675-683. [3] Ye JC, et al. MRM 2007;57:764-775. [4] Moriguchi H, et al. Proc ISMRM 2009. p4572.