Multi-band PROPELLER Imaging with Auto-calibration

Mengye Lyu[1,2], Yilong Liu[1,2], Victor B. Xie[1,2], ErPeng Dai[3], Hua Guo[3], and Ed X. Wu[1,2]

[1]Laboratory of Biomedical Imaging and Signal Processing, The University of Hong Kong, Hong Kong, HKSAR, China, [2]Department of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, HKSAR, China, [3]Center for Biomedical Imaging Research, Tsinghua University, Beijing, Beijing, China

INTRODUCTION PROPELLER MRI is widely used nowadays for motion correction. One major drawback of PROPELLER MRI is the long scan time. Previous studies have investigated in-plane acceleration (SENSE and GRAPPA) in PROPELLER[1,2]. However, multi-band (MB) simultaneous multi-slice acquisition, without SNR penalty proportional to square root of acceleration ratio, can be a more suitable solution for accelerating PROPELLER. In addition, MB acquisition combining PINS RF pulses[3] can reduce RF pulse power deposition, which is particularly useful for alleviating the SAR issue in FSE-PROPELLER at high field. A considerably low g-factor is possible in MB PROPELLER because its rotating phase encoding directions can consequently lead to a well-conditioned unwrapping problem. Another advantage of MB PROPELLER is that 3D coil sensitivity maps (CSMs) can be directly estimated from the oversampled k-space center, without acquiring additional calibration data[2].

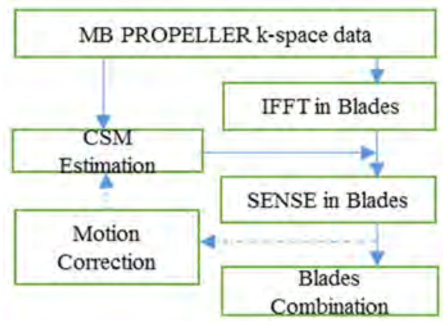

Fig. 1 Proposed MB PROPELLER reconstruction procedure. The dotted lines show the iterative motion correction steps.

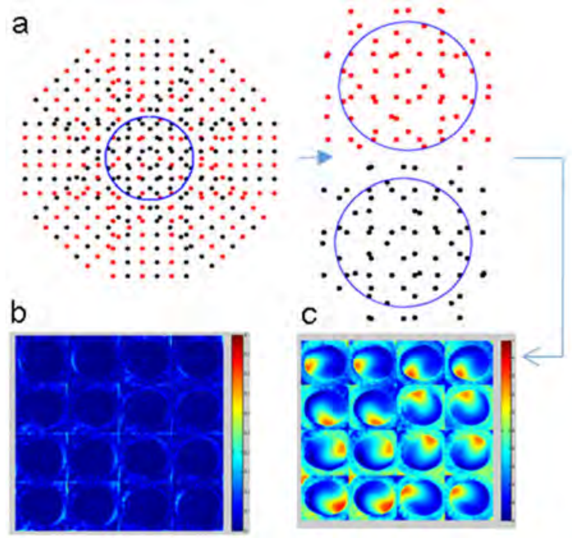

Fig. 2 Illustration of auto-calibration at 4 blades, N_{MB} =2. (**a**) Converting MB 2D k-space to 3D k-space: red dots for phase shift =0 (k_z=0); black dots for phase shift = π (k_z=1); blue circle for central k-space. (**b**) Estimated CSMs of two slices. (**c**) The error map between estimated CSMs and reference CSM.

METHODS Fig. 1 shows the MB PROPELLOR reconstruction procedure. From 3D k-space view[4,5], MB phase modulation is equivalent to kz encoding and each phase encoding line belongs to a specific k_z. By dividing phase encoding lines into corresponding k_z planes, a 3D k-space is obtained. Although each k_z plane is undersampled by 1/ N_{MB}, its center is still oversampled by (blade number)/ N_{MB}, so that coil sensitivity maps can be estimated using non-uniform FFT (NUFFT) (Fig. 2a). In order to reduce artifact in CSMs, the central phase shifts (k_z when k_y=0) of blades are interleaved to ensure a relatively uniform sampling pattern. After adjusting CSMs according to central phase shifts, the overlapped slices are unwrapped for each blade using SENSE and images are combined from all blades with k-space sampling density compensation.

Numerical simulations were performed using the k-space data acquired by conventional FSE-PROPELLER on a 3T Philips scanner with 8-channel head coil, TR/TE=4000ms/111ms, blade number=23, phase encoding steps in each blade=30, matrix size=436×436×24, slice thickness=4 mm. MB PROPELLER k-space data were synthesized[6,7] for N_{MB}=3, 4, and 5 with slice gap=20 mm by imposing phase modulation along phase encoding directions for all blades. For comparison, SENSE PROPELLER[1] and Cartesian MB[6,7] reconstruction with same acceleration ratios were also simulated. The residual error maps were calculated to evaluate reconstruction quality.

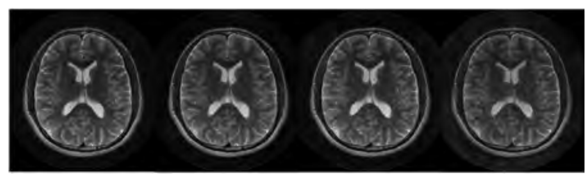

Fig. 3 Reference image and simulated MB PROPELLER reconstruction at N_{MB}=3,4,and 5 (from left to right). Only one representive slice is shown.

RESULTS The CSMs were correctly estimated from the 3D MB k-space center. They were nearly the same as the directly measured CSMs (Fig. 2c), which led to successful and accurate SENSE unwrapping. As shown in Fig. 3, MB PROPELLER reconstruction and reference images reconstructed from fully sampled data were almost identical at N_{MB}=3. No severe artifact was observed up to N_{MB}=5. Compared to SENSE PROPELLER and Cartesian MB, the reconstruction error in MB PROPLLER was smaller, spatially more uniform and less sensitive to the increase of acceleration ratio (Fig. 4).

DISCUSSION AND CONCLUSION We proposed a MB PROPELLER protocol and demonstrated that such simple combination of MB and PROPELLER techniques has unique advantages. (i) PROPELLER contains rotating phase encoding directions that decreases the difficulty (g-factor) in MB slice unwrapping; (ii) oversampling in central k-space readily provides auto-calibration; and (iii) MB PROPELLER shortens scan time and reduce SAR while preserving SNR. Here, the PROPELLER motion correction capability is expected to be well preserved in the MB PROPELLOR because the motion correction can be performed for each slice immediately after slice unwrapping (Fig. 1). In presence of inter-blade motions, the true CSM for each blade may differ from the initially estimated one, and motion artifacts can be corrected by an iterative process (Fig. 1) that consists of initial CSM, rough SENSE, motion estimation, motion correction, CSM updating, and SENSE reconstruction. The proposed MB PROPELLER is generally applicable to sequences such as FSE and EPI. It offers the intrinsic advantages associated with both MB and PROPELLER, particularly at high field. At low field, such approach may also benefit the routine clinical FSE-PROPELLOR T2-weighted based protocols where minimal TR is often dominated by the number of slices.

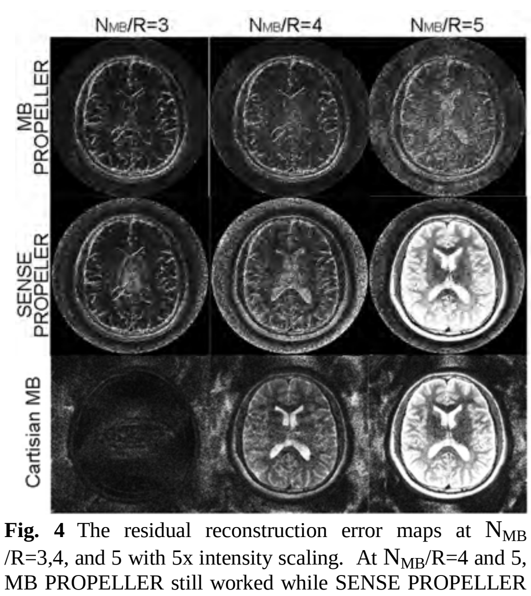

Fig. 4 The residual reconstruction error maps at N_{MB} /R=3,4, and 5 with 5x intensity scaling. At N_{MB}/R=4 and 5, MB PROPELLER still worked while SENSE PROPELLER and Cartesian MB were already dominated by noise.

REFERENCES [1] Chuang, TC, et al (2006). MRM 56(6): 1352-1358. [2] Skare, S, et al (2008). MRM 60(6): 1457-1465. [3] Norris, DG, et al (2014). MRM 71(1): 44-49. [4] Zahneisen, B, et al (2014). MRM 71(6): 2071-2081. [5] Zhu, K, et al (2012). ISMRM 2012. [6] Breuer, FA, et al (2005). MRM 53(3): 684-691. [7] Setsompop, K., et al (2012). MRM 67(5): 1210-1224.