Respiratory self-gating with PROPELLER encoding: Application to free-breathing cardiac imaging

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Introduction

For clinical cardiac MR imaging, patients are generally required to hold their breath during the scan to minimize respiratory motion-related artifacts. However, some patients cannot hold their breath due to illness or limited breath capacity. To solve this problem, several methods have been developed including gating from the signal of respiratory belt or navigator echoes. Recently, Larson et al. reported a novel self-gating technique that continuously extracts the respiratory trace from low-resolution images acquired by radial scanning with each heart beat [1]. Similarly to radial scanning, the PROPELLER encoding method [2] can reconstruct a low-resolution image from every blade due to k-space center oversampling. In this study, we investigated the feasibility of extracting respiratory-trace from the blades acquired by PROPELLER encoding for the application of free-breathing high resolution cardiac imaging.

Material and Methods

A PROPELLER-encoded ECG-triggered Turbo-Field Echo (TFE) sequence with T2 magnetization preparation (T2-prep) [3] was implemented on a 3T whole-body MR system (Achieva 3T, Philips) for T2-weighted myocardial imaging. Three subjects participated in this study. For each subject, a set of one hundred PROPELLER blades were collected using the following parameters: FOV: 340mm, TR/TE:4ms/2.3ms, flip angle: 10 degrees, $TE_{T2\text{-}prep}$:50ms, end-systolic ECG gating, PROPELLER blade size: 30x256, PROPELLER rotation step: 7 degrees. The phase-encoding order for each blade was set to centric-reordering to maximize T2 contrast from the magnetization preparation.

The collected blades were processed with Matlab® (Mathworks, Natick, MA, USA) using a self-gating PROPELLER reconstruction algorithm. In order to extract the respiratory trace, the low resolution blades were first transformed to image domain and then smoothed using a median filter. A ROI was selected over the myocardium and all blade images were cropped using the same ROI. The correlation analysis was applied between the cropped blades and one selected blade. The series of correlation coefficients (CC) for the full set of 100 blades was used to identify the respiratory phases. Finally, the low resolution blade images with CC values higher than a preset threshold were combined and the PROPELLER reconstruction algorithm was applied to reconstruct a high resolution image.

Results

Fig.1 shows the respiratory trace obtained from cross correlation of the PROPELLER blades (see Fig.2) collected in one of the subjects. Notice that the respiratory duration detected from this trace was approximately 5 to 7 heart beats, which roughly matched the respiratory period observed on the subject outside the scanner. Fig.3 shows the reconstructed T2-weighted myocardial images with four different CC thresholds (a:0.0 , b:0.5, c:0.9, d:0.95) and the number of blades with CC values larger than each of the four threshold values (a:100, b:73, c:47,d:27). The images show blurring instead of ghosting due to the PROPELLER k-space trajectory. Fig.3.a, corresponding to a non respiratory-gated image, shows most blurring. The other images (Fig.3.b-d) appear progressively sharper with increasing CC threshold values.

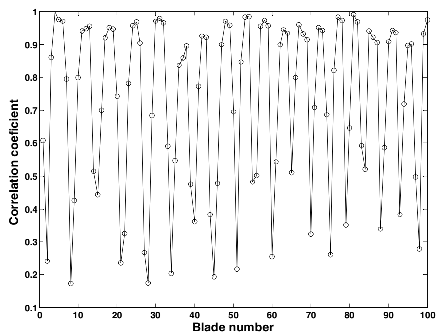

Fig.1 Respiratory trace extracted from cross-correlation of blade images cropped over the heart.

Discussion and Conclusions

In this study, PROPELLER encoding was implemented with a T2-prep TFE sequence to acquire high resolution cardiac images without breath-holding. Using the k-space center over-sampling property of PROPELLER encoding, the heart position can be identified in each low-resolution blade acquired in a heart beat. Thus, a high resolution image can be reconstructed from the blades selected with almost the same heart position. The scan efficiency depends on the CC threshold. From our results, the reconstructed image showed less blurring with half of the blades selected for PROPELLER reconstruction. An even sharper reconstructed image can be obtained with less scan efficiency (ex. Fig.3(d) :27%). Further enhancement of the scan efficiency may be achieved by image domain registration if the myocardium movement can be assumed "in-plane" [2]. In our study, free-breathing high resolution T2-weighted myocardium imaging was achieved with the proposed self-gating method. The method can be applied to myocardial BOLD investigations for which signal averaging is desired to enhance detection of small T2-related signal changes during vasodilatory stimulation. Using our method, the myocardial blades collected at rest and during vasodilatory challenge can be retrospectively selected, yielding registered myocardial images for BOLD signal analysis. In clinical application of myocardial viability imaging with delayed enhancement, patients have to hold their breath repeatedly with each high resolution slice acquisition. The respiratory self-gating method could greatly facilitate such routine exam for the patient. By comparison to the streak artifacts characteristic of radial trajectories, the phase-encoding of each PROPELLER blade is essentially a Cartesian trajectory, yielding low resolution blade images without aliasing artifacts. Furthermore, most imaging method applicable to Cartesian encoding can be applied to each blade (e.g. partial Fourier and SENSE). However, contrary to the directionally uniform sampling of radial scans, the PROPELLER blades are prone to achievable precision from the low spatial resolution in the phase-encoding direction, thus limiting the precision of the detected respiratory trace. Nonetheless, our study demonstrated that the respiratory phases could be clearly identified from the estimated traces and the reconstructed images did not show prominent blurring. The PROPELLER encoding has thus the potential to offer a robust method for free-breathing cardiac imaging.

Reference

[1] Larson AC et al, MRM (2005) 53(1):159. [2] Pipe JG ,MRM(1999) 42(5):963. [3] Huang TY et al., 13th ISMRM (2005), p.521.

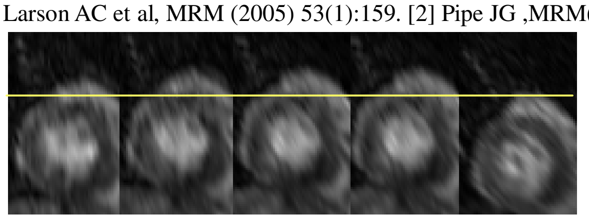

Fig.2. Series of low resolution blade images acquired during successive heart beats. Notice that the heart movement can be clearly identified and the respiratory trace can be extracted.

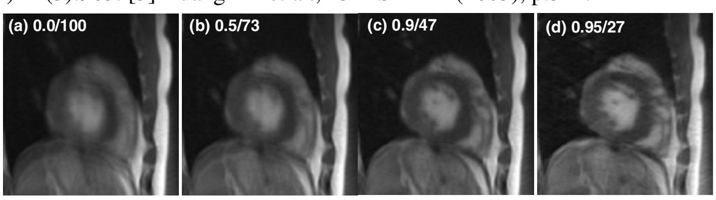

Fig.3. Series of propeller images reconstructed with different CC thresholds (a:0.0 , b:0.5, c:0.9, d:0.95) and corresponding number of blades with cc values higher than the specific threshold (a:100, b:73, c:47,d:27).