

Respiratory and cardiac self-gated free-breathing cardiac CINE imaging with multi-echo 3D hybrid radial acquisition

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INTRODUCTION

Respiratory and cardiac motions superimpose but have different temporal frequencies (respiratory: 0.1~0.5 Hz, cardiac: 0.6~3 Hz), hence they can be separated by filtering with corresponding frequency bands. 2D SSFP with an extra k-space center acquired at each TR has been proposed to achieve simultaneous compensation of cardiac and respiratory motion [1]. In this study, we present a 3D cine imaging method using hybrid radial sampling and with simultaneous cardiac and respiratory motion compensation without using navigator echoes or ECG electrodes. This 3D radial sequence improves upon the 2D sequence by providing 1) contiguous volume coverage with high resolution along the depth direction, 2) high SNR, 3) sampling of the center of k-space each TR for robust motion detection via center of mass detection along the slice encoding direction without extra sampling time, and 4) approximately uniform k-space sampling with perpetually distinct projections for flexible reconstruction by incrementing radial projection angles by π over the golden ratio.

MATERIALS AND METHODS

Cardiac imaging was performed at 1.5T (GE EXCITE 14.0 with 3.3 mT/m max, slew-rate 120 mT/m/s) using an 8-channel cardiac coil. Self-navigator cardiac 3D cine imaging was performed on seven subjects at short-axis, two-chamber and four-chamber views. Imaging parameters were BW = ± 125 kHz, FOV = 32 or 34 cm (image size 256x256) TR = 4.4 ms. 10 slices of 10 mm thickness were acquired for short-axis views, and 8 slices of 8 mm thickness for two-chamber and four-chamber views. Thus the reconstructed images have a temporal resolution of n_z TR = 35 ms and 44 ms respectively with n_z the number of slices. Acquisition time was ~5 min.

3D cine imaging used a stack of multi-echo radial sampling (Cartesian slice encoding with radial projections filling in k_x - k_y plane), by acquiring distinct radial lines during conventional readout pulses as well as during dephaser and rephaser gradients to maximize efficiency for high spatial and temporal resolution [4]. Projections at a given angle through all the slice encodes are acquired sequentially before switching to the next projection angle (Fig. 1). During scanning the projection angle was incremented by $\pi/r = 111.2^\circ$ (golden ratio $r=1.618$) to give distinct angles perpetually. This interleaving profile provides approximately uniform sampling and allows robust flexible sliding window or temporal filtering for variable temporal resolution and arbitrary duration reconstructions [6].

Points along the k_z axis are 1D Fourier transformed to provide the z-intensity profile for self gating. The center of mass along slice encodes was calculated every n_z TR. The changing of this center of mass through time corresponded to respiratory and cardiac motions occurring during data acquisition (Fig. 1). Superimposed respiratory and cardiac motions were separated by filtering at the appropriate frequency bands. The coil with the most consistent self gating intervals was selected for gating. Different coils could be optimal for tracking respiratory motions and cardiac motions. A histogram of the filtered center of mass for respiratory gating was calculated, and about 20~30% of data acquired around end-expiration was used for image reconstruction. Because of variation in the beat to beat interval, the number of cardiac phases to reconstruct was chosen based upon the most frequent cardiac gating interval. Acquired projections could then be assigned with cardiac phase indexes for reconstruction employing iterative temporal filtering to allow some utilization of high-frequency k-space data from adjacent phases [5].

RESULTS AND DISCUSSION

Short-axis, 2-chamber and 4-chamber views with the proposed free-breathing respiratory and cardiac self-navigator techniques are shown in Fig. 2, Fig. 3 and Fig. 4 (from different volunteers). Two representative phases at end systole and end diastole are shown. Although respiratory and cardiac motions are complex with multiple degrees of freedom and cardiac imaging usually happens along oblique planes relative to the scanner physical coordinates, there are always myocardial motion and blood volume changes in k_z direction that are useful for generating both cardiac and respiratory gating signals suitable for effective cardiac phase ordering and respiratory gating. Images at end systole are slightly blurred compared to those at end diastole due to faster motion occurring at end systole.

Respiratory gating was more challenging due to greater breath to breath variation in respiratory rate and inspiratory volume which complicated the filtering process. This possibly can be improved with an iterative filtering technique. The current data utilization efficiency based on respiratory gating is low and it could be improved to reduce scan time by either applying window sharing to respiratory motion or introducing motion correction. Gating resolution (n_z TR) can be improved with a sliding window applied to the k-space centers acquired through time. Computation time is 12 minutes per phase on a 2.8GHz MacBook running an implementation in Matlab.

CONCLUSIONS

Free breathing 3D cardiac cine imaging acquired with radial projections and self gating of both cardiac and respiratory motion is presented. The k_z -axis self-navigator for simultaneous tracking of both cardiac and respiratory motions was effective for short axis, 2-chamber and 4-chamber acquisitions even though the k_z axis is oriented differently for each of those imaging planes. This eliminates the need for electrode and bellows placement on the patient and there is no extra scan time required for motion detection.

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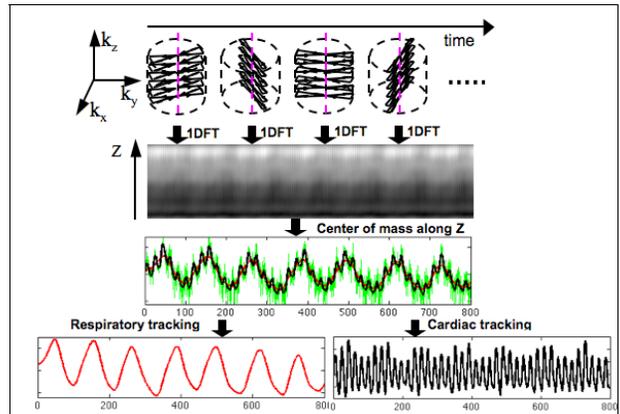


Fig.1 Respiratory and cardiac self-navigator method in 3D radial imaging. The temporal resolution for motion monitoring is n_z TR.

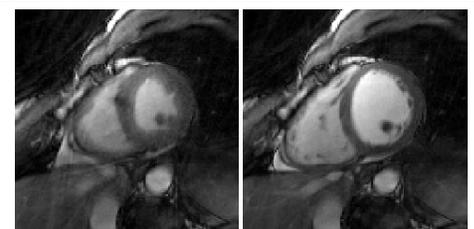


Fig.2 Short-axis view a) End systole b) End diastole.

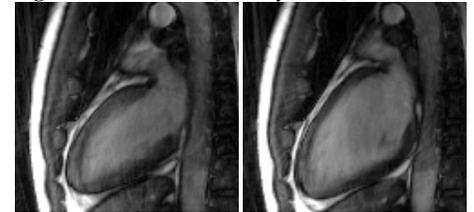


Fig.3 2-chamber view a) End systole b) End diastole.

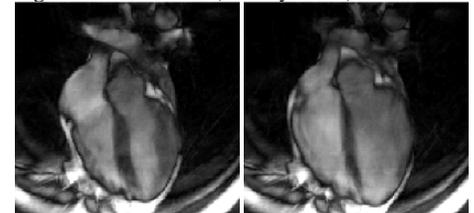


Fig.4 4-chamber view a) End systole b) End diastole.