Self-Gating Reconstruction of Multiple Respiratory Phases using Undersampled Golden-Radial Phase Encoding Trajectory

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INTRODUCTION: Navigator gating is a proven approach to reduce respiratory motion artifacts in free-breathing 3D MRI. Moreover, self-gating techniques to avoid steady state interruption [1, 2], and automatic navigator window selection of the most common respiratory phase [3], have been proposed. However, the most common respiratory position does not necessarily give the best image quality, as has been shown in [4]. Here, we propose a new self-gating radial-like acquisition scheme which allows the retrospective undersampled reconstruction of different high resolution respiratory phases, giving the operator the choice of the best phase as in [4]. This approach takes advantage of the recently introduced Golden-Radial Phase Encoding (G-RPE, [5, 6]) trajectory and uses the, inherently acquired, central *k*-space profiles (*c-ksp*) to derive the respiratory signal. Moreover, an image quality surrogate has been derived to estimate prospectively the set of respiratory positions which can be reconstructed with appropriate image quality.

METHODS: G-RPE combines an undersampled radial acquisition scheme in the phase encoding plane (k_y,k_z) with Cartesian sampling in the readout direction (k_x). The angular step between consecutive profiles is given by the Golden Ratio, $\theta_{GR}=111.25°$ [7]. As can be observed in *Fig.1*, this trajectory allows undersampling in both, angular and radial, directions.

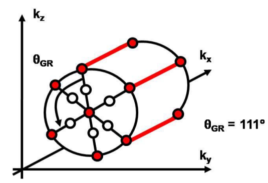

Fig.1: G-RPE trajectory.

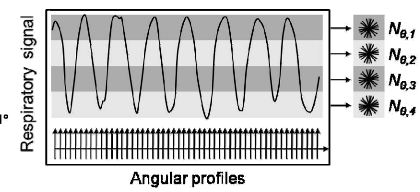

Fig.2:Retrospective combination of profiles. B respiratory phases are reconstructed from B bins.

The *c-ksp* is acquired repetitively in each radial profile to derivate the respiratory signal. N_θ *c-ksp* are sampled at a rate of $N_r \cdot TR$ *msec*, where N_θ and N_r are the number of phase-encodes along the angular and radial directions, and *TR* is the repetition time. The 1D-FFT of the *c-ksp* results in the 3D projection of the body along the feet-head (FH) direction. By maximizing the cross-correlation between each profile and a reference (first) profile, the respiratory signal is computed.

In G-RPE the retrospective combination of radial profiles allows the reconstruction of images with a trade-off between different spatial and temporal resolutions. For our purposes, we combine profiles according to their respiratory position to reconstruct multiple respiratory phases. The retrospective reconstruction of *B* different respiratory phases is achieved by gating the respiratory signal into *B* bins (*Fig.2*). Each image I_b is reconstructed using the profiles $N_{\theta,b}$ belonging to the bin $b \in [1,B]$ and non-Cartesian iterative SENSE [8].

a) Simulations: To estimate how many profiles $N_{\theta,b}$ per bin *b* are required to allow an appropriate image quality, simulations were performed on a numerical phantom *P*. Images were reconstructed with iterative SENSE using different breathing surrogates (normal, deep, fast) and a varying number of profiles. For each bin *b*, we estimated the reconstruction accuracy by considering (i) the squared differences (SD) between the reconstructed phantom and *P*, (ii) the maximum appearing angle in the profile trajectory, $\alpha_{max,b}$, and (iii) the peak-to-sidelobe ratio (PSLR) of the trajectory's point-spread function (PSF).

b) In-vivo experiments: Three volunteers were scanned on a 1.5T Philips scanner using a 32 channel coil (*T1-Segmented FFE,* FOV=$288mm^3$, *TR/TE=4.5/2.1ms,* flip angle = *10°,* isotropic resolution = $1.5mm^3$, N_θ = *1010* profiles and an undersampling factor of 2 in the radial direction). An anterior coil, sensitive to the motion of the right hemi-diaphragm, was used to derive the respiratory signal.

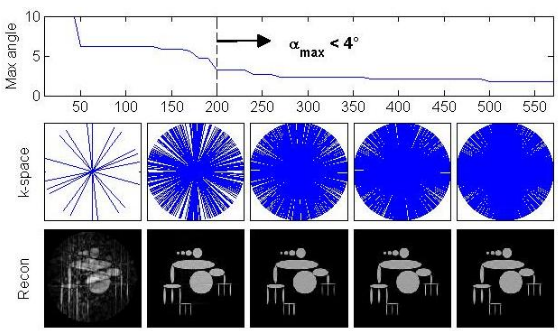

Fig.3: Maximum appearing angle α_{max} (top row) in the distribution of the radial profiles in the (ky,kz) plane (middle row), and corresponding reconstructions (bottom row).

RESULTS: *a) Simulations:* All quality measurements considered (SD, $\alpha_{max,b}$, PSLR) showed a consistent behavior. For simplicity we considered $\alpha_{max,b}$ as our image quality surrogate. Simulations for an expiratory bin *b* from a respiratory signal of a normal breathing volunteer are shown in *Fig. 3*. According to $\alpha_{max,b}$ (*Fig.3*, top row), at least $N_{\theta,b} = 200$ profiles and $\alpha_{max,b} < 4°$ per bin *b* are required to assure an appropriate image quality.

b) In-vivo experiments: The reconstructions of *B = 4* respiratory phases, from end-exhale (left) to end-inhale (right), are shown in *Fig. 4*. Three of the four respiratory positions considered (bins 1 to 3) show high image quality (accepted to be presented to the operator). However, a decrease in image quality due to a high maximum angular step ($N_{\theta,4} = 169/\alpha_{max,4} = 8.5°$) is observed for bin 4.

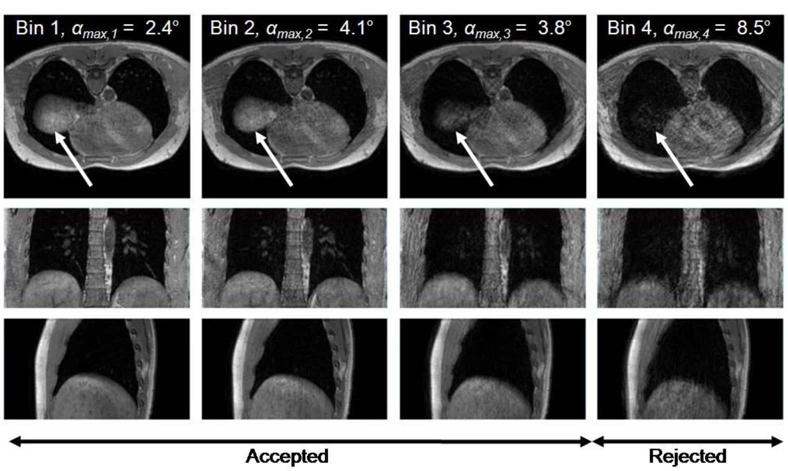

Fig.4: Reconstructions of B = 4 respiratory phases from end-exhale (left) to end-inhale (right) in transversal, coronal and sagittal view. Good image quality is achieved for Bins 1 to 3.

CONCLUSION: A self-gated reconstruction of different high-resolution respiratory phases in free-breathing 3D-MRI has been presented. This approach is robust against changes in the breathing pattern and allows reconstruction at several respiratory positions, giving the operator the choice of the optimal phase. Good image quality can be estimated before reconstruction by considering the maximum appearing angle in the radial trajectory as image quality surrogate (α_{max} < *4°*). We plan to measure α_{max} in real-time during acquisition to re-measure gaps in the radially filled profile distribution, if required. The techniques will be used to study the respiratory motion of the heart, lung and liver. Future work in motion field estimation in hybrid PET-MR imaging will be addressed.

REFERENCES: [1] Pearlman et al, Rad 1990, [2] Uribe et al, MRM 2007, [3] Jhooti et al, ISMRM 2006, [4] Jhooti et al, ISMRM 2008, [5] Boubertakh et al, MRM 2009, [6] Prieto et al, ISMRM, 2009, [7] Winkelmann et al, IEEE 2006, [8] Pruessmann et al,MRM,1999.