Undersampled Reconstruction of Multiple 3D High-Resolution Respiratory Phases Using Non-Rigid Registration

C. Buerger[1], A. P. King[1], T. Schaeffter[1], and C. Prieto[1]
[1]Division of Imaging Sciences, King's College London, London, United Kingdom

INTRODUCTION: In various medical image applications like image-guided interventions, radiotherapy treatment planning or motion-compensated reconstructions, it is desired to reconstruct multiple motion-free high resolution respiratory phases from free-breathing 3D MRI. Common navigator gating techniques [1-3] are a proven approach to reconstruct single or reduced number of motion-free respiratory phases, by rejecting all data acquired outside of the navigator window. Here we propose a technique to reconstruct multiple 3D high resolution respiratory phases by combining an undersampled self-gating radial-like acquisition with a non-rigid image registration scheme. This approach uses all the acquired data to reconstruct a single high spatial resolution (*HSR*) phase at the most visited respiratory position (commonly at end-exhale) and multiple respiratory resolved (*RR*) images at the remaining respiratory phases followed by an improving of image quality for all *RR* images (which suffers from remained aliasing artifacts) by applying a non-rigid registration procedure. The registration aligns the features of the *HSR* image with all remaining *RR* phases, leading to a sequence of time-resolved high resolution respiratory phases. Results for 3D respiratory motion of the thoracic organs are presented for 6 different phases, acquired in the same time as a single navigated respiratory phase.

METHODS: *Fig.1* illustrates our approach for reconstructing multiple high resolution respiratory phases as a three-step procedure:

1) Self-gated undersampled reconstruction: Our self-gating radial-like acquisition approach takes advantage of the recently introduced undersampled Golden-Radial Phase Encoding (G-RPE, [4]). G-RPE combines Cartesian sampling in the readout-direction (k_x) with an undersampled radial scheme in the phase-encoding plane (k_y,k_z), where the angular step between two consecutive profiles is given by the Golden-Ratio, $\theta_{GR}=111.25°$ [5]. The central *k*-space profiles (*c-ksp*) are acquired repetitively in each radial profile to derive the respiratory signal. We combine profiles according to their respiratory position to reconstruct one high spatial resolution (*HSR*) image (most common respiratory position) and multiple respiratory resolved (*RR*) images. The retrospective reconstruction of *B* different respiratory phases is achieved by gating the respiratory signal into *B* bins. Each image I_b is reconstructed using the profiles $N_{\theta,b}$ belonging to the bin $b \in [1,B]$ and non-Cartesian SENSE [6]. Low values of $N_{\theta,b}$ could result in remained aliasing artifacts and decreased signal to noise ratio in the *RR* images.

2) Non-rigid image registration: Non-rigid image registration is performed to improve the image quality for the *RR* images. The registration aligns the floating *HSR* image I_1 with each of the respiratory resolved reference images I_b resulting in a set of estimated motion fields R_b, $b \in [2,B]$.

3) High resolution image reconstruction: Based on the registration parameters estimated in *2)* the *HSR* image I_1 is warped to be aligned with all remaining *RR* phases I_b. This results in a sequence of high quality *HSR* and *RR* phases as the transforms T_b of I_1, with $b \in [2,B]$.

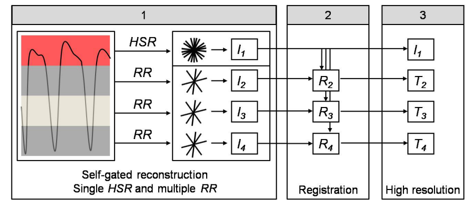

Fig.1. Reconstruction of time-resolved high resolution respiratory phases as a three-step procedure. Self-gated reconstruction (1) of a single high spatial resolution (HSR) image I_1 and multiple respiratory resolved (RR) images. Image registration (2) leads to multiple high resolution images as deformations of I_1 (3).

RESULTS: Three volunteers were scanned on a 1.5T Philips scanner using a 32 channel coil (*T1-Segmented FFE,* FOV = *288mm³*, *TR/TE = 4.5/2.1ms,* flip angle = *10°,* isotropic resolution = *1.5mm³*, $N_\theta = 576$ profiles and undersampling of 2 in radial direction). An anterior coil, sensitive to the motion of the right hemi-diaphragm, was employed to derive the respiratory signal. *B = 6* respiratory phases were reconstructed from end-exhale (*b = 1*) to end-inhale (*b = 6*).

Reconstruction results before and after registration are shown in *Fig.2* and *Fig.3*. Results for *B = 6* respiratory phases in a region of interest are shown in *Fig.2*. Poor image quality is observed before registration in bins 3, 4 and 5, due to remained aliasing artifacts (low number of profiles used for reconstruction $N_{\theta,3} = 69$, $N_{\theta,4} = 39$, $N_{\theta,5} = 54$). However, a clearly improved in image quality is observed for the same phases after registration.

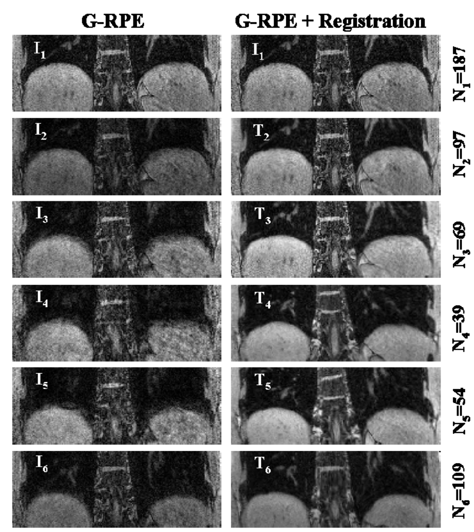

Fig.2. B = 6 respiratory phases from end-exhale (top row) to end-inhale (bottom row) before (left column) and after (right column) registration.

Coronal and sagittal views of the whole FOV for two respiratory phases (end-exhale I_1 and end-inhale I_6) are shown in *Fig.3*. Since image quality of end-inhale is poor, an improved end-inhale image is obtained after registration (T_6). As can be observed in the absolute difference between I_6 and T_6, image features were correctly aligned.

CONCLUSIONS: We presented a method for reconstructing multiple high resolution respiratory phases by estimating motion fields in free-breathing 3D-MRI. With an increased number of respiratory phases, image quality of certain phases suffers from remained aliasing artifacts (due to reduced number of profiles used for reconstruction). To improve these specific respiratory phases, we applied a non-rigid image registration procedure which aligns the features of the most visited respiratory position (and therefore the highest quality image) with all remaining phases. The proposed technique will be applied in respiratory motion modelling of abdominal organs. Registration of two poor quality respiratory phases to obtain one high quality phase (and therefore reducing the acquisition time) will be addressed in future work.

REFERENCES: [1] Pearlman et al, Radiology 1990, [2] Jhooti et al, MRM 2000, [3] Jhooti et al, ISMRM 2009, [4] Prieto et al, ISMRM, 2009, [5] Winkelmann et al, IEEE 2006, [6] Pruessmann et al,MRM,1999.

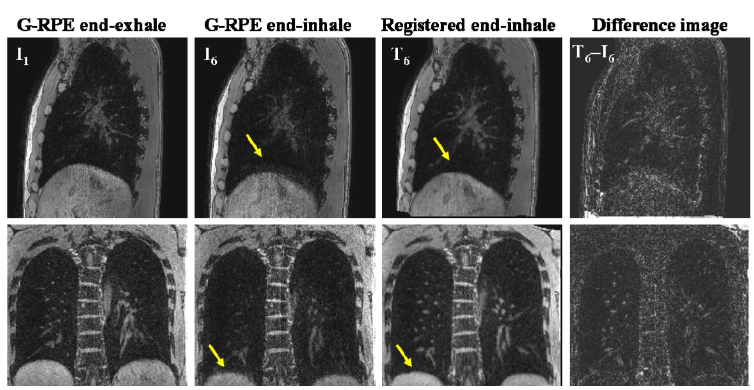

Fig.2. Respiratory phases at end-exhale(I_1) and end-inhale(I_6) position. Poor image quality in I_6 is improved by warping I_1 to align with I_6 leading to the transform T_6. Image features were correctly aligned, as illustrated by T_6-I_6.