A Novel Golden-Angle Radial FLASH Motion-Estimation Sequence for Simultaneous Thoracic PET-MR

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Introduction: Accurate lesion characterization is crucial for initial staging, follow up and assessment of response to treatment in non-small cell lung cancer. Conventional PET-CT suffers from a temporal mismatch between PET and CT, due to longer PET than CT acquisitions needed for achieving good PET SNR. This mismatch yields artifacts that affect PET diagnostic specificity as well as quantitation accuracy ("banana" and "mushroom" artifacts).These artifacts lead to underestimation of tumor activity, especially in the region near the diaphragm, where motion effects are greatest. Gated 4D CT can be used to correct for motion; however, this is not usually done routinely due to longer exams and greater radiation dose.

Simultaneous MR is a promising modality which is capable of tracking respiratory motion during the entire course of the PET exam with no additional ionizing radiation. We have shown that MR can be used to monitor the respiratory motion [1]. However, real-time imaging for the entire volume of the lung with good spatial resolution remains challenging due to the limit on acquisition rate. Lack of signal from lung with most MRI sequences makes this endeavor even more challenging.

In this work, we present a slice-interleaved golden-angle radial FLASH sequence with short-duration slice-projection navigation for lung respiratory motion measurement and respiratory motion tracking for motion-corrected PET reconstruction using simultaneous PET-MR.

Methods: *A. MR Sequence.* As shown in Fig. 1, in each TR the sequence first acquires a fast (3.3ms) slice-projection navigation signal (NAV) to track the diaphragm position. The prescription of the NAV slice is shown in Fig. 2a. It then acquires radial data in a slice-interleaved fashion. The same k-line is acquired from all the prescribed coronal slices in each TR. From TR to TR, the radial k-lines are acquired according to the golden angle formula: $\theta_k = \text{mod}(2.39996 \cdot k, 2\pi)$. Golden-angle radial acquisition was chosen because of its rebinning flexibility [2].

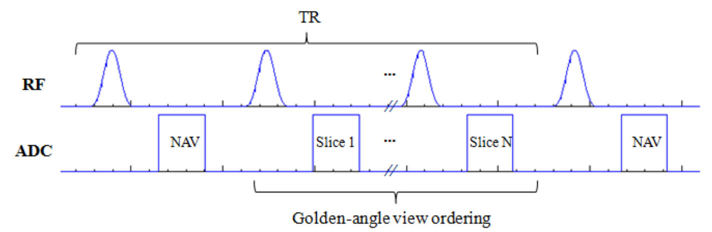

Fig. 1. Schematic plot of our lung motion estimation sequence. Except for the NAV, all the slices are coronal slices. The same k-line is prescribed for all slices in one TR. Radial k-lines are prescribed according to the golden-angle formula from TR to TR.

B. PET-MR Acquisition. In vivo simultaneous PET-MR imaging (Siemens Biograph mMR) was performed on a volunteer with 5 mCi ^{18}FDG and Magnevist injected 1 hr and 10 min before the exam, respectively. Slice thickness = 5 mm (in the consideration of PET resolution), 23 slices were used to cover the lung, TR = (23+1)×3.3ms = 79.2ms, bandwidth = 1kHz/pixel, 4096 radial lines with 256 samples per line were acquired in each slice during the course of PET acquisition (~5.5min). The excitation angle (30° used) was chosen based on the Ernest angle.

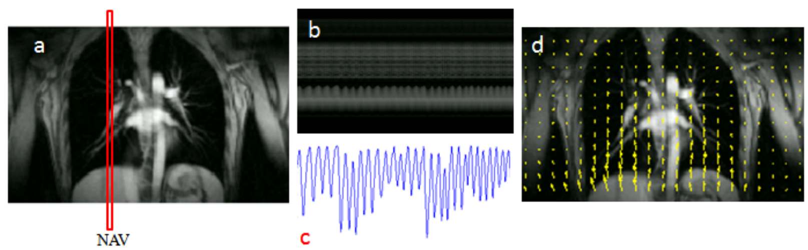

Fig. 2. a) The positioning of the NAV slice. b) The projection signal obtained from the NAV pulse. c) The plot of the respiratory phase (diaphragm position) obtained from b). a) and d) are images of the same slice corresponding to two respiratory phases which are reconstructed from the respiratory-phase binned radial k-lines. The yellow arrow in d) are the motion field estimated using a) and d).

C. MR Reconstruction. The 4096 NAV projections (~2000 shown in Fig. 2b) acquired were processed to extract the diaphragm movement (Fig. 2c) which corresponds to respiratory phases. The slice-interleaved golden-angle radial k-lines were rebinned according to their respiratory phases obtained from NAV signal. In this study, 8 image volumes corresponding to 8 respiratory phases were obtained from the rebinned k-lines using compressed sensing reconstruction [3].

D. Motion Corrected PET Reconstruction Although the lung images suffer from the lack of signal, the pulmonary vessels are visible using our FLASH sequence. Intensity-based 3D non-rigid image registration based on diffeomorphic demons [4] was performed on the 8 image volumes to obtain the motion fields. The estimated motion field was then incorporated into a maximum *a posteriori* (MAP) PET reconstruction algorithm with motion correction [5]. Separate attenuation maps for 8 phases were also calculated using the 8 image volumes.

Results: Fig. 2a and 2d show the images of the same coronal slice of two respiratory phases reconstructed from radial k-lines rebinned according to the NAV signal. The motion field estimated using the reconstructed images is also overlaid onto Fig. 2d. As shown in Fig. 2d, the estimated respiratory motion is dominated by vertical motion and the motion is larger in the region close to the diaphragm, which agrees with expectation. Fig. 3a and b show the uncorrected and motion-corrected PET images respectively. In this preliminary scan, there were no lung lesions for us to study. However, magnification of a blood vessel located near the diaphragm (also visible in the MR image) reveals prominent motion-induced blurring in the uncorrected PET image(Fig. 3c). This artifact is absent in the motion-corrected image (Fig. 3d).

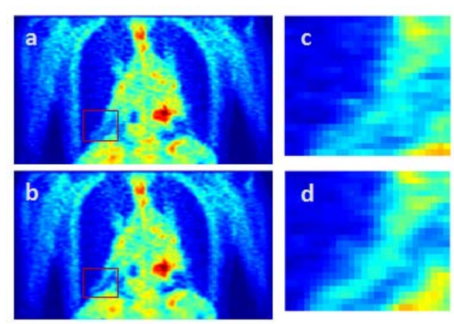

Fig. 3. (a) Uncorrected PET image, (c) Motion-corrected PET image, (c) Magnified blood vessel with motion artifact in uncorrected image (d) The same blood vessel in the motion-corrected image.

Conclusions and Discussion: We developed and validated a novel golden-angle radial FLASH motion estimation MR sequence for motion corrected PET reconstruction using simultaneous PET-MR. We found that respiratory motion is dominated by vertical motion and the motion is larger in the region close to the diaphragm, which agrees with expectation. Using the proposed lung respiratory motion estimation technique, we showed that motion blurring in the lung is reduced which will enhance the ability to detect small lesions in the lung. Studies on patients with lung lesions will be conducted to further validate this technique in the future.

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