A navigated bSSFP sequence for volumetric liver respiratory motion measurement

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Target Audience: Scientists and clinicians interested in liver respiratory motion measurement and/or correction.

Purpose: Many clinical applications including respiratory motion compensated image acquisition/reconstruction[1,2] and image-guided interventions in the liver[3,4] require tracking the respiratory motion of the liver. Recent advancement in simultaneous MR-PET acquisitions enables accurate performance of MR-assisted liver PET respiratory motion correction using liver motion measured by MR. So far, T_1-weighted (T_1w) MRI[1,2] and tagged MRI[5] have been investigated for this purpose. However, neither T_1w MRI nor tagged MRI is optimal for liver respiratory motion measurement in humans due to lack of contrast in T_1w images in the liver and fading of tags (T_1 of liver is approximately 700ms while respiration cycle is about 5s).

In this work, we propose a strategy to obtain the volumetric liver motion field using a navigated slice-by-slice balanced steady-state free precession (Nav-bSSFP) sequence.

Methods: The schematic plot of the proposed acquisition strategy is shown in Figure 1. During the slice-by-slice bSSFP acquisition, navigators placed at the dome of the liver as shown in Figure 2 are acquired before each bSSFP image. In this work, each bSSFP image was acquired in approximately 300ms. To ensure minimal impact on the bSSFP images, a pencil beam navigator with small flip angle is used. The duration of each such navigator was approximately 20ms.

The navigator data is processed to obtain the respiratory phase of the corresponding bSSFP image. The acquisition is advanced to the next slice when images corresponding to all respiratory phases have been acquired for that slice. The scan ends when all slices covering the entire liver have been acquired. In this preliminary work, the coverage of all respiratory phases were ensured by setting the acquisition time for each slice about twice of the respiratory cycle.

After the acquisition is completed, image volumes of the liver corresponding to each respiratory phases are generated from the slice images based on their respiratory phase. Motion estimation of the liver is then performed using a B-spine non-rigid registration the image volumes[6].

To validate the estimated motion in the context of MR-assisted PET motion correction, and to demonstrate the utility of this acquisition strategy, the measured motion fields were incorporated into PET image reconstruction using PET listmode data acquired simultaneously with the Nav-bSSFP MR data. The acquisition was performed using a simultaneous MR-PET scanner (Siemens Biograph mMR) on a 79 yo male subject with known liver tumors. The study was approved by the Institutional Review Board, and an informed consent was obtained from the subject. The scan was performed approximately 2 hours after a routine PET-CT examination in which 592 MBq ^{18}FDG was injected. The Nav-bSSFP was performed with: TE=1.67 ms, TR=3.2 ms, flip angle= 51°, pixel size = 2mm, slice thickness = 8mm, 25 sagittal slices were used to cover the entire liver. The proposed acquisition took less than 3 minutes. Post-contrast T_1w images were also acquired 30 minutes after the contrast injection.

The PET reconstruction was performed using an in-house 3D iterative reconstruction algorithm that corrects the LORS for material deformation. In the reconstruction, the attenuation maps were also deformed using the obtain motion fields and incorporated into the iterative PET reconstruction.

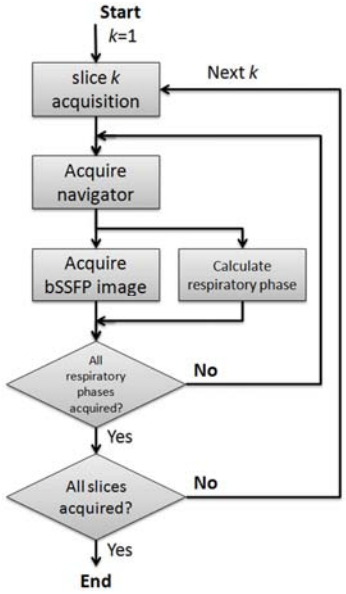

Figure 1. Schematic plot of the proposed acquisition scheme.

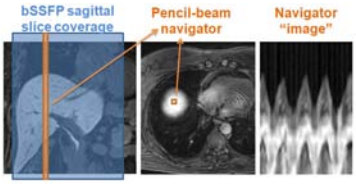

Figure 2. Navigator placement and navigator data

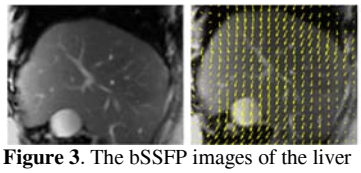

Figure 3. The bSSFP images of the liver at two respiratory phase. And the motion fields estimated between the two phases.

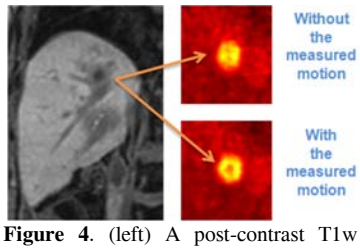

Figure 4. (left) A post-contrast T1w image of the liver tumor with necrotic core and (right) the corresponding PET images with and without motion correction based on the motion measured by the proposed strategy.

Results: Figure 3 shows images of the same liver slice at different respiratory phases together with the motion field estimated between the two phases (yellow arrows). It can be seen that unlike T_1w images, the bSSFP images provides excellent contrast between liver tissue and blood vessels. The bright signal of the vessels acts as landmarks for the non-rigid registration algorithm. Intuitively, due to better contrast of the landmarks, better motion estimation can be expected compared to approaches based on T_1w images.

Figure 4 shows the results of the PET image reconstructed with and without the liver respiratory motion estimated by the proposed strategy. As can be seen, the liver respiratory motion fields obtained from the proposed technique enabled the recovering of the heterogeneous FDG uptake distribution of the tumor. The donut shape uptake distribution is due to the necrotic core of this tumor which can be observed on the post-contrast T_1w MR image. However, when the motion measured by the proposed strategy is not used in the PET reconstruction, the heterogeneous FDG uptake is blurred and hardly identifiable. This demonstrates that the liver respiratory motion estimated by the proposed strategy can be used to compensate for liver respiratory motion in MR-PET scans.

Discussion: This study demonstrates liver respiratory motion can be measured by the proposed strategy; better delineations of fine PET uptake structure can be achieved when the measured respiratory motion is incorporated into the PET reconstruction. Although this demonstrates the utility of the proposed strategy, the accuracy of it still needs to be further studied.

In this work, liver respiratory was assumed to be almost periodic throughout the entire acquisition (~3min). Changes in breathing pattern can lead to error in the motion measurement. However, this is a common concern for all non-realtime liver motion measurement techniques.

Conclusion: The proposed strategy has been shown to provide motion fields for liver respiratory motion. Better delineation of PET uptake distribution in the liver can be achieved by incorporating the motion measured by the proposed strategy into the motion corrected PET reconstruction.

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