Simple Motion Correction for Hepatic DCE-MRI: Registration of Sequential Breath Holds in 3D Radial Time-Resolved Scans

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Introduction: Respiratory motion compensation remains a major challenge when performing quantitative dynamic contrast-enhanced (DCE) MR imaging of the liver. High spatial resolution is necessary to enable visualization of small (<1 cm) hypervascular liver lesions, while correction for respiratory motion is required to permit accurate estimation of perfusion parameters[1]. In addition, due to the rapid first-pass of contrast through the liver, high temporal resolution (3-4s[2]) is needed to capture enhancement dynamics. Because of these requirements, many traditional methods of respiratory compensation are ill-suited for quantitative liver DCE-MRI: scan efficiency is reduced when navigators are used to track diaphragm position[3], and respiratory gating during free-breathing creates gaps in data during the arterial and portal venous phases of enhancement. In this work, we utilize a 3D radial sequence[4] to acquire whole-liver image volumes with 4s true temporal footprint during sequential breath holds (BHs). We subsequently register BH-averaged image volumes to correct for subject motion and variations in residual lung volume between BHs.

Methods: For this IRB-approved study, eight subjects (4 normal volunteers and 4 patients with HCC) were imaged on a 3.0T scanner (MR750, GE Healthcare) using a 32-channel torso coil (Neocoil). A multi-echo 3D radial sequence[4] was used to acquire data for 180s, while a real-time display returned low-resolution images every 1s to permit BH coordination with contrast arrival. After injection of 0.1 mmol/kg of gadobenate dimeglumine and 25 mL of saline (both at 2.0 mL/s), patients were instructed to conduct three 20-25s BHs at mid-expiration during arterial, portal-venous and delayed phases of liver enhancement. Respiratory motion was recorded with respiratory bellows to enable retrospective identification of BH periods[5]. Scan parameters included: TR=2.7ms, TEs=0.4/1.0/1.7ms, flip=12°, BW=±250 kHz, FOV=48cm spherical, matrix=256^3 with 2.0mm^3 isotropic spatial resolution. Images were reconstructed using an iterative SENSE algorithm[6] which generated 180 frames with 4s true temporal footprint.

Registration: After scan completion, average image volumes for the three BHs were generated and cropped to include relevant anatomy (liver and surrounding structures). The image volumes corresponding to the portal venous and delayed phases were registered to the arterial phase image for each subject using the open-source ITK (Insight Toolkit), implemented with rigid (affine) transformation and gradient descent using mutual information. The mutual information metric was chosen because of temporal changes in signal intensity, due to the use of contrast agent.

Results: Figs. 1a/b show representative portal venous phase image slices (averaged over the BH period) in a healthy volunteer before and after registration, while Fig. 1c shows an absolute difference image of the two slices. The major correction seen in Fig. 1c is translation in the S/I direction, consistent with the results generated by the registration process. Figure 2 shows a plot of S/I translation vs. frame for each of the three breath holds conducted by this volunteer – while translations within a single BH are small (sub-voxel), there are 1-2 voxel translations between BHs due to subject motion and variations in lung volume at mid-expiration. Table 1 shows unsigned average values of the translations (S/I, A/P and L/R) and rigid rotations about image volume centers for the eight scans. The average translation magnitude in the S/I direction is largest, likely due to the fact that diaphragmatic motion occurs primarily in this dimension. The maximum translation in the S/I direction amongst all patients was approximately two voxels (4mm), and occurred in a volunteer whose bellows waveform demonstrated significant shift between breath hold periods. Average translations in the A/P and L/R directions as well as average rotations about the S/I, A/P and L/R axes were all quite small; this result was somewhat unexpected given that the liver undergoes rotation and deformation during free breathing[7], but may be related to the rigid constraint on the registration process.

Discussion and Conclusions: We have demonstrated that sequential BHs during the arterial, portal venous and delayed phases of liver enhancement provide images that are relatively free of respiratory motion artifact. Registration of average image volumes corresponding to the three BHs resulted in small, but significant corrections for inter-BH motion in some patients; and negligible (sub-voxel) corrections in others. The magnitude of registration-derived corrections was observed to correlate with BH consistency; patients whose bellows waveforms demonstrated shifts between BH periods tended to require the largest corrections. Of note, none of the HCC patients had difficulty maintaining BHs for at least 20s. Surprisingly, the magnitude of rigid rotation corrections for all scans was very small; only corrections for translation appear to be required. A major limitation of using sequential BHs for liver perfusion imaging is that timeframes outside the BH intervals are corrupted by respiratory motion and cannot be used for perfusion modeling. Future work will investigate the possibility of sequentially registering frames during free-breathing to the final frame of the previous breath hold, which may enable their use for this purpose.

References: **1.** Llovet *et al*, NEJM 359(4):378('08) **2.** Pandharipande *et al*, Radiology 234(3):661-73('03) **3.** Firmin *et al*, J Card Mag Res 3(3):183-93('01) **4.** Brodsky *et al*, MRM 56(2):247-54('06) **5.** Horng *et al*, Proc. 19th ISMRM #2673('11) **6.** Johnson *et al*, MRA Club 10.9 97('10) **7.** Shirato *et al*, Sem Rad Onc 14(1):10-18('04).

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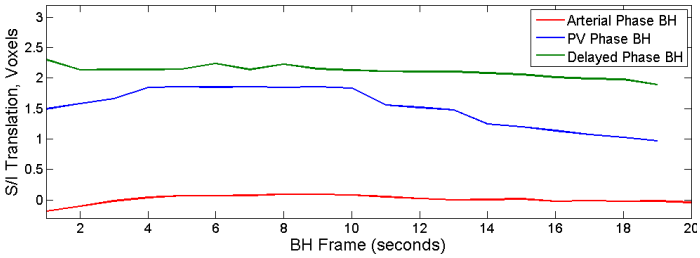

Figure 2: S/I translation vs. frame for BH periods in a normal subject. There are 1-2 voxel translations between BHs; drift within BHs is sub-voxel in magnitude.

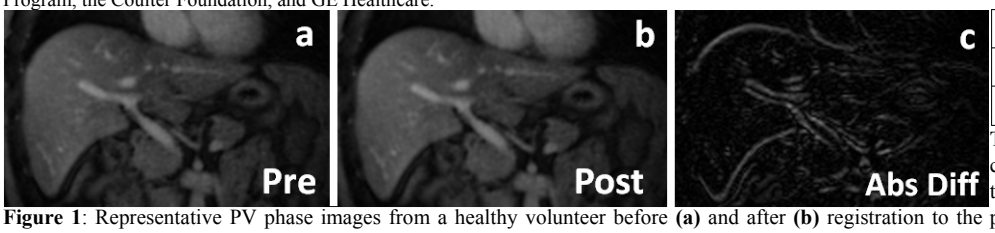

Figure 1: Representative PV phase images from a healthy volunteer before **(a)** and after **(b)** registration to the arterial phase image volume. An absolute difference image **(c)** shows that the largest correction is S/I translation.

$T_{S/I}$	1.49 mm	$Rot_{S/I}$	0.05°
$T_{A/P}$	0.65 mm	$Rot_{A/P}$	0.12°
$T_{L/R}$	0.15 mm	$Rot_{L/R}$	0.09°

Table 1: Absolute values of translation and rotation corrections averaged over all subjects. The largest translation correction (S/I) corresponds with the principal dimension of diaphragmatic motion. Rotation corrections are all negligible in magnitude.