Irregular respiratory motion correction in 3D T2w-TSE (PACE) liver imaging

S-Y. Zho[1], J. Park[2], and D-H. Kim[1,2]

[1]Electrical and Electronic Engineering, Yonsei University, Shinchon-Dong, Seoul, Korea, Republic of, [2]Radiology, Yonsei University, Shinchon-Dong, Seoul, Korea, Republic of

Introduction: Prospective Acquisition CorrEction (PACE) technique which directly measures the position of the diaphragm has been shown to be robust and provides high quality free-breathing abdominal MR images [1]. Particularly for T2-weighted 3DFT liver imaging, it is almost impossible to acquire the whole k-space data during a single breath-hold. Thus, using the PACE technique enables acquiring high-resolution full coverage 3DFT imaging. 3DFT data acquisition has the benefit of higher Signal-to-Noise Ratio (SNR) and enables the acquisition of thinner slices compared to multi-slice 2DFT imaging. Due to its long acquisition time however, T2-weighted Turbo spin echo (TSE) 3DFT imaging sequence has a relatively long echo train length (ETL).

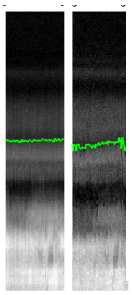
This long ETL makes it susceptibility to motion during data acquisition. For example, if there is irregularity in the patient breathing pattern, artifacts can exist in the image even with accurate navigator (NAV) triggering because the irregular breathings can vary the diaphragm position when acquiring near k-space center at the desired echo-time (TE). To overcome this, image-metric based motion correction algorithms can be applied to correct superior-inferior (SI) direction translational motion, but its processing time can be unacceptably long due to the size of the 3DFT data set [2]. In this work, we propose an alternative and simple method to decrease motion artifacts for 3DFT T2w-TSE imaging with PACE that are due to irregular breathing patterns. The method observes the navigator information before and after imaging and interpolates the motion patterns during the echo train acquisition.

Theory and Methods: We assume irregular breathing patterns that change the respiration period at large. Irregularities such as coughing or sighing are excluded. Even for well controlled breathing, changes in the respiration period occur. With this, we can find SI directional motion (Δz) to the first order from navigator images acquired before (NAVb) and after (NAVa) triggering because each navigator image is acquired at the same time position with regard to the imaging data. Afterwards, we can correct SI direction translational motion component with the interpolated Δz value.

Detailed procedures of whole algorithm are as follows. First, we need to know the average respiration period and the relative displacement (Δz) during a respiration cycle. This information can be obtained from the training NAV data. Typically, 5~6 respiration periods for 30~40 seconds of the initial scan are used for setting the expiration position and the acceptance window in PACE algorithm. From these training NAV, we build a reference motion model of the diaphragm. When the actual imaging starts, we extract NAV data before and after triggering (before and after actual image data acquisition). By using time and amplitude scaling of the reference diaphragm model, we interpolate the motion of the diaphragm during actual image acquisition. The position of the diaphragm from each NAV image is found by detecting the edge which maximizes the correlation to the reference model. Using the interpolated diaphragm motion, we extract Δz for each echo train, which is then applied to the phase of the k-space data.

Liver images from healthy volunteers (N=4) were acquired using Siemens 3T scanner with TSE variable flip-angle sequence with the following parameters. TR_{eff}=4626ms, TE=266ms, LR readout direction, SI slice-encoding direction, FOV=263x350x192mm (y,x,z), slice thickness=2mm, ETL=199 (phase-encoding direction to cover one slice) with echo-spacing=3.4ms. The NAV data were acquired using a 2D slice excitation positioned on the diaphragm (TR=7.1ms, TE=3.4ms, FOV=256x512mm, slice thickness=10mm, matrix size=12x256 (PE, readout) and flip angle=3°).

Results:



(a) (b)

Figure 1: NAV edge before echo train imaging acquisition (a) and after imaging (b)

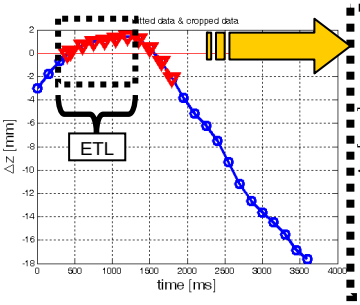


Figure 2: estimation of Δz (red) during echo train acquisition

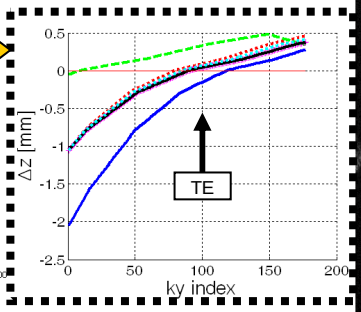


Figure 3: Δz values that has been interpolated near center of k-space

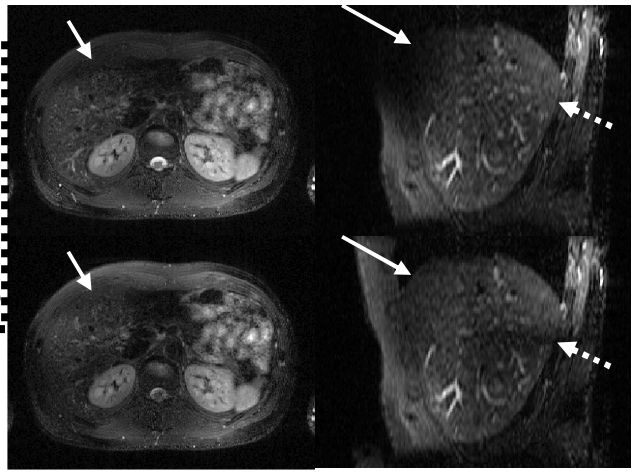


Figure 4: before (top row) and after (bottom row) correction

Figure 1 shows the detected edges of the NAV image before and after triggering during a full 3D data acquisition. It can be seen that irregularity is more serious after the echo trains (Fig. 1(b)), which can be attributable to irregular respiration. Figure 2 shows a typical Δz (red) that has been interpolated. Data acquisition of the echo trains occurs during this interval and therefore diaphragm motion information is missed during this time. Blue line represents NAV data that is actually acquired. In Fig. 3, interpolated Δz during echo trains are given for several TRs. As seen, at the echo time where motion related artifacts can be most sensitive, variations of Δz can occur in the range of ±1mm. Figure 4 shows resulting images before (top row) and after (bottom row) our correction algorithm is applied. After phase correction, signal recovery particularly in the upper region of liver can be identified (solid arrow). However, in some regions shading artifacts seem to appear as well (dotted line). These artifacts were especially visible in regions remote from the diaphragm wall. The reason for miscorrected regions is probably due to the fact that the correlation of motion in these regions is smaller than in regions close to the diaphragm where the NAV data are interpolated.

Conclusion: We have proposed a simple method for correcting respiration irregularity. As shown in Fig. 1, navigator edge after triggering has more variation than before triggering. Even for well controlled breathing, the NAV data after imaging showed variations. Using the interpolated motion, signals can be recovered especially for parts near the diaphragm. But away from it, there are still some limitations which are probably due to the decreased correlation of motion in this region compared to the upper regions. Also, motion of the liver in the lower parts can often have more Δy (AP) components [3]. Methods to incorporate these motion information would need to be addressed for clinical usefulness.

References : [1] C. Klessen, et al., JMRI, 21:576-582, 2005 [2] P. McGee, et al., AJR, 176:513-518, 2001 [3] M von Siebenthal, et al., Phys. Med. Biol. 52:1547-1564, 2007