Respiratory Triggered DENSE Imaging With Navigator Echoes: Initial Experience

M. M. Fung[1], P. Aksit[1], S. N. Gupta[1], A. Shankaranarayanan[2], P. J. Beatty[2], A. H. Aletras[3], E. J. Schmidt[4], M. N. Hood[5], and V. B. Ho[5]

[1]Global Applied Science Lab, GE Healthcare, Bethesda, MD, United States, [2]Global Applied Science Lab, GE Healthcare, Menlo Park, CA, United States, [3]LCE, NHLBI, National Institute of Health, Bethesda, MD, United States, [4]Global Applied Science Lab, GE Healthcare, Boston, MA, United States, [5]Radiology, National Naval Medical Center, Bethesda, MD, United States

Introduction: Displacement encoding with stimulated echoes (DENSE) provides high spatial density myocardial circumferential shortening (CS) and radial thickening (RT) strain maps for evaluating cardiac contractility [1]. However, as the repetition time is constrained to 1-2 heartbeats due to the limitations of single breath-hold acquisitions, the achievable SNR is restricted by T1-weighted magnetization saturation, resulting in lower reliability of the resulting strain measurements.

Objective: DENSE SNR may be improved if the breath-hold imaging constraints are removed, allowing for reduced magnetization saturation. A respiratory-triggered DENSE acquisition using navigator echoes was developed, such that the repetition time could be increased to 4-5 seconds (1 respiratory cycle), and thus translated to a significant SNR improvement. Since DENSE is motion sensitive, a leading and trailing navigator were used to minimize the extent of respiratory motion occurring during the DENSE encoding and acquisition window. Accelerated imaging using the hybrid (x,k_y)-space based parallel imaging reconstruction technique ARC (Auto-calibrating Reconstruction for Cartesian sampling method)[2] was also adopted to minimize the total acquisition time, in order to reduce the opportunity for temporal variability in breathing patterns.

Methods: Seven healthy subjects (3 Male, 4 Female; ages 48±8 years) volunteered to participate in this IRB-approved protocol and were imaged on a 1.5T MRI (GE Healthcare, Waukesha WI) using an 8-channel cardiac phased-array coil. A mid-ventricular slice was acquired with ECG-gated systolic-phase DENSE in all cases with the following parameters: FSE readout (meta-DENSE) ETL: 24-32; TE: 4.4ms; 128x128, 36x 27cm FOV, 8mm slice thickness, 6 mm/π encoding strength, displacement encoding interval (TM time) ranged from 210ms to 350ms. DENSE images were acquired with two protocols; a single breath-hold scan and a free-breathing respiratory-triggered scan with single navigator. In the breath-held protocol, the DENSE TR was 1 heart cycle. In the respiratory-gated protocol, a two-dimensional spatially-selective excitation (Navigator-echo) [3,4] was used to excite a cylindrical column at the right hemi-diaphragm, thus continuously detecting respiratory motion. The DENSE sequence was triggered once every respiratory cycle at the end expiratory level, upon ECG trigger detection. Immediately after the DENSE acquisition, the navigator-echo acquisition was resumed, and played every 50 ms until a subsequent end-expiratory trigger was observed. In the later 3 of the 7 cases, dual-navigators were used. An algorithm compared the diaphragm location immediately before (leading navigator) and after (trailing navigator) the DENSE sequence, and re-acquired views when the two diaphragm locations differed by more than a user-specified threshold (typically set at 3 mm). SNR and strain map confidence measures of the images acquired with the two protocols were evaluated using dedicated software (Denseviewer, GE Healthcare). The strain map confidence measures were compared using a paired t-test (breath-held vs. respiratory triggered with navigator), applied to the intra-sector standard deviations of the CS and RT values of the six circumferential myocardial sectors. In normal volunteers, with the CS and RT expected to be relatively homogeneous, lower intra-sector standard deviation was assumed to indicate higher confidence in the strain map results.

Results: Figure 1 shows the DENSE images acquired with breath-hold (BH) (1a) and with single navigator respiratory triggering (RSP)(1b). SNR was higher with respiratory triggering (BH vs. RSP: 36.0±13.8 vs. 57.7±18.2, $p<0.05$), since a longer repetition time was possible. The improvement in SNR resulted in circumferential and radial strain maps with lower intra-sector standard deviations and higher confidence (BH vs. RSP: CS Stdv 13.5% vs. 11.7%, $p<0.05$; RT Stdv 12.2% vs. 11.0%, $p=0.085$). The CS values were consistent between the two approaches (BH vs. RSP: CS 24.0% vs. 23.1%, $p=0.232$) while the RT values were slightly lower in the RSP approach (BH vs. RSP: RT 27.9% vs. 26.3%, $p<0.05$), and these values were consistent with previously reported values for healthy humans [5]. The in-vivo noise floor in the strain measurement was established by repeating the same gradient waveforms three times in the same direction. Similar noise floors were observed in the two approaches (BH vs. RSP: CS 0.0%±10.2% vs. -0.3%±8.3%, $p=0.362$; RT 0.7%±10.6% vs. 0.9%±8.1%, $p=0.542$) and the noise standard deviation was lower in the RSP approach. The improved SNR can also allow for the use of higher ARC acceleration factors, thus reducing the total scan time (Figure 2a). The dual leading and trailing navigator acquisition (Figure 2b) further improved motion suppression, by rejecting views corrupted by significant motion. In our initial experience, the best strain maps were obtained in cases with a regular breathing pattern and with a consistent (non-drifting) end-expiration level.

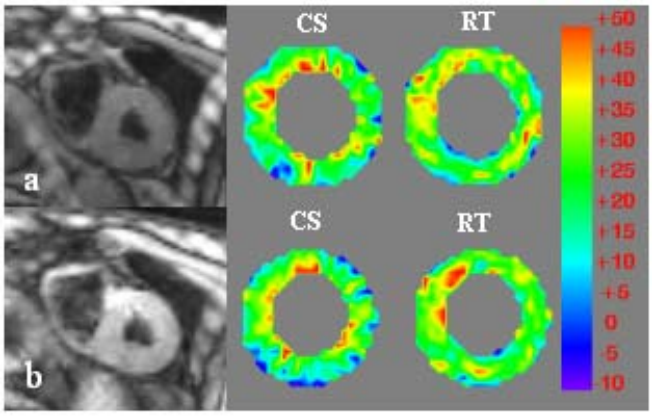

Figure 1. DENSE acquired in (a) breath-hold and (b) during free breathing with navigator triggering in a healthy volunteer. Magnitude image (Left), circumferential shortening (Middle) & radial thickening (Right) strain maps are shown. SNR was improved with navigator triggering, and the resulting strain maps were similar in both techniques.

Conclusion: We have shown that free-breathing DENSE scans using navigator echoes yielded higher SNR and therefore improved the confidence of DENSE strain maps. A trailing navigator can further improve motion suppression and increase the accuracy of the resulting strain maps.

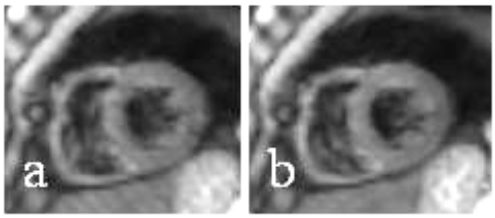

Figure 2. Free-breathing DENSE average magnitude images with ARC acceleration factor of 2; (a) without and (b) with trailing navigator. Sharper myocardial boundary was observed with the use of the trailing navigator. Images maintained a high SNR despite the 2-fold acceleration.

Reference:

[1] A.H. Aletras et. al., MRM. 46:523–534; 2001,[2] Beatty et. al. ISMRM 2007, p1749, [3] C.J. Hardy et.al., JMR 87:639-645; 1990, [4] J. Pauly et. al., JMR 82: 571-587; 1989, [5] A.H. Aletras et. al. JMR. 176 (1): 99-106;2005.