Real-time Quantification of Regional Contractility of the Heart Using Fast-SENC

L. Pan[1], M. Stuber[2], D. L. Kraitchman[2], N. F. Osman[2]

[1]Department of Biomedical Engineering, Johns Hopkins School of Medicine, Baltimore, MD, United States, [2]Department of Radiology, Johns Hopkins School of Medicine, Baltimore, MD, United States

Introduction: Strain Encoded (SENC)[1] MRI has been introduced as a technique that can *directly* quantify, and thereby display, regional contractility of the heart without a need for time-consuming post-processing. In this study, an accelerated SENC imaging sequence, called *fast-SENC*, with a scan time as short as a single heartbeat, was implemented. This imaging technique included three features: 1) interleaved low- and high-tuning frequencies (required for SENC imaging) in a single acquisition, 2) localized excitation for reduced FOV without foldover artifacts, and 3) spiral imaging for rapid acquisition. Fast-SENC imaging can be used for real-time, dynamic acquisition and display of myocardial contractility.

Methods: Background: SENC imaging: Rather than applying tagging gradient in the phase encoding or frequency encoding direction as in 1-1 SPAMM, SENC imaging applies tagging (modulation) gradient (A, Fig. 1) in the slice selection direction. By applying another tuning (demodulation) gradient (B, Fig. 1) during the refocusing lobe of the slice selection gradient, images can be acquired at a specific tuning frequency. By combining the magnitude images acquired at two tuning (low- and high-tuning) frequencies, the local strain orthogonal to the image plane can be obtained. Interleaved Tuning: Instead of obtaining the low- and high-tuning images in two separate acquisitions as in SENC imaging, the pulse sequence was modified so that the two tuning images were acquired in an interleaved fashion throughout the cardiac cycle. Therefore, the imaging time is reduced in half. Localized Excitation: To shorten the scan time, a reduced FOV enables the size of the sampled matrix in the *k*-space to be reduced. Similar to a technique proposed by Fischer et al.[2], a *2D localized Excitation* was developed (Fig. 1). The signal from the surrounding untagged region is suppressed in the acquired images, and a smaller FOV image without foldover artifacts can be acquired. Spiral Imaging: A spiral readout is used to shorten the acquisition intervals. Due to the fact that most of the information of SENC images is localized in the center of *k*-space, spiral imaging with a densely sampled center of *k*-space is particularly well-suited for SENC image acquisition. Fast-SENC Acquisition: By the combination of interleaved tuning, localized excitation, and spiral imaging (a single spiral with a relative long acquisition window), SENC image sequence can be acquired in one cardiac cycle.

Experiments: Normal Human Subject: MR imaging was performed on a Philips 1.5 T MR whole body system. Images were acquired in a four chamber view using conventional SENC (two breath-holds, 12 heartbeats each, TR=22.4ms) and fast-SENC (one heartbeat, TR=37.2ms) from a normal human subject. Conventional SENC and fast-SENC circumferential strains at six points, located in the basal-, mid-, & apico-septum and basal-, mid-, & apico-lateral region of the left ventricle were compared. Animal Study: The fast-SENC pulse sequence was tested in four infarcted dogs. In one example dog with 9-week old reperfused myocardial infarction in the anteroseptal left ventricle, a fast-SENC image sequence was acquired in one heartbeat with TR=37.2ms. After an intravenous contrast injection of 0.2 mmol.kg^{-1} Gd-DTPA, a high resolution image sequence was acquired using conventional SENC in two breath-holds (48 heartbeats each) with TR=22.6ms. Fifteen minutes after contrast injection, a delayed enhancement image (TI=175 ms) was obtained to determine the infarct location.

Results: Fast-SENC images, acquired in one heartbeat from a normal subject, show a similar circumferential strain pattern in both the left and right ventricles when compared to conventional high resolution SENC images that require two breath-hold acquisition (Fig. 2). Moreover, the conventional SENC and fast-SENC circumferential strains, when interpolated to obtain identical temporal resolution, demonstrated high agreement ($r^2 = 0.81$, $y = 0.96x + 0.65$). Fig. 3 shows the SENC images at end-systole corresponding to the delayed enhancement image in the example infarcted animal study. Both the SENC and fast-SENC images clearly show the dysfunctional area (shown as blue due to akinesia), indicated by the arrows, which very closely matches the infarcted area in the delayed enhancement image.

Conclusions: The fast-SENC imaging enables the acquisition of strain encoded images in a single heartbeat, which can be visualized without major post-processing or segmentation, and yields strain results equivalent to conventional long breath-hold acquisitions. Thus, fast-SENC has the potential to dynamically display the onset of myocardial dysfunction from ischemia as may occur during dobutamine stress testing. In addition, since this technique can be performed in a single heartbeat, cardiac arrhythmias, and the concurrent alterations in contraction, can be imaged without difficulty.

References:

[1] Osman NF *et al.* Magn Reson Med 2001;46:324-334.
[2] Fischer SE *et al.* Magn Reson Med 1994;31:401-413.

***Acknowledgements*:** This research was supported by NIH grants RO1 HL072704, RO1-HL73223, and KO2-HL05193. The authors wish to thank Danielle L. Fritzges, Dr. Wesley D. Gilson, Dr. Asif Mahmood and Carlisle Rand for assistance with the animal preparation.

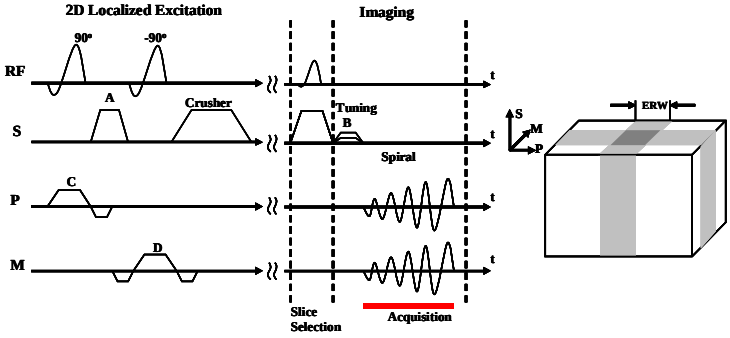

Fig. 1. SENC pulse sequence with 2D Localized Excitation. Both 90-degree tagging RF pulses were modified from non-selective to slice-selective at both measurement (M) and the phase-encoding (P) direction. The tagged region is restricted to a cuboid orthogonal to the slice selection (S) direction. Gradient A and B are SENC modulation and demodulation (tuning) gradients, respectively. ERW = Excitation Region Width.

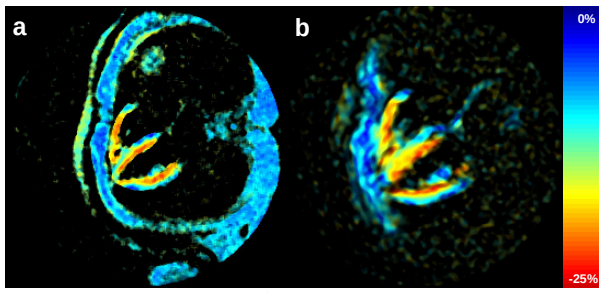

Fig. 2. Four-chamber view of (a) SENC image (two breath-holds, 12 heartbeats each, TR=22.4ms) and (b) fast-SENC image (one heart beat, TR=37.2ms) acquired from a normal human subject.

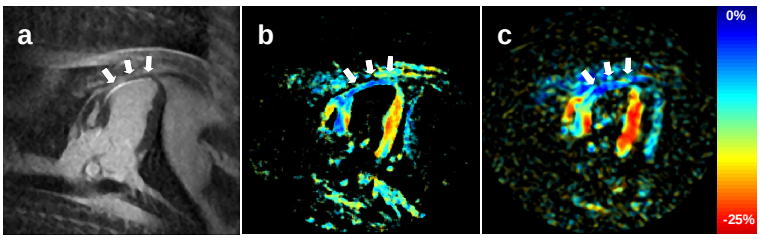

Fig. 3. Fast-SENC in a reperfused, infarcted dog. a. Delayed enhancement image 15 minutes after gadolinium injection (TI = 175ms, t = 185ms) with non-viable infarcted myocardium hyper-enhanced (arrows). b. Conventional SENC functional image (t = 219ms, TR=22.6ms) showing dysfunction (arrows) in infarcted myocardium. c. Fast-SENC functional image (t = 239ms, TR=37.2ms) showing lack of contraction in infarcted tissue (arrows).