Imaging the evolution of 3-D myocardial strains using a combined HARP-SENC MRI pulse sequence

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Introduction

The development of a rapid 3-D strain imaging and post-processing system with high temporal resolutions still remains a challenge. We present a pulse sequence that combines two tag based magnetic resonance imaging methodologies — harmonic phase (HARP) [1] and strain encoded (SENC) [2] — to provide rapid dense 3-D strain imaging for a stack of short-axis slices in one-two short breath-holds. Using the pulse sequence, evolutions of 2-D in-plane normal strains (circumferential and radial) and 1-D out-of-plane normal strains (longitudinal) can be computed for a stack of *n* contiguous short-axis slices prescribed in the left ventricle from data acquired in a single breath-hold lasting *6n* heartbeats.

The Imaging Technique

This new pulse sequence, called HARP-SENC MRI [3], was designed and tested on a 1.5T Signa CV/i whole body MR system (GE Medical Systems, Waukesha, WI). A typical HARP-SENC MRI scan requires a six-heartbeat acquisition for each slice (See Fig. 1). Multiple slices are acquired in a sequential fashion. At the beginning of each heartbeat, specialized 1-1 SPAMM tags are applied at end-diastole. During the first and second heartbeat, reference datasets are acquired for phase–sensitive reconstruction of the four-channel receiver coil data [8]. The third and fourth heartbeats are then used to acquire the harmonic images and during the fifth and sixth heartbeats, the SENC images are acquired at tuning frequencies s1 and s2 respectively. During each heartbeat, a four-shot interleaved gradient-echo based echo planar imaging scheme is employed to acquire small regions of interest of size 32×32 around the spectral peak of interest. An incrementing train of imaging flip angles is also employed to prevent the characteristic tag decay due to the imaging pulses. Typically, a CINE sequence of around 10-15 images are acquired every heartbeat, each with a temporal resolution of 38.8ms. Data presented in this abstract is from a normal volunteer. Five SA axis slices were prescribed with a field-of-view of 320 mm. The acquisition was split functionally into two short breath-held scans. During the first breath-hold lasting 10 heartbeats, the reference datasets for the five SA slices were acquired. Following this, a 20-heartbeat long breath-held scan was performed during which a sequence of 14 HARP (horizontally and vertically tagged) and 14 SENC (with tuning frequencies 0.42 mm^{-1} and 0.48 mm^{-1}) images for all five slices were acquired. A tag separation of 8 mm was used for the HARP images, while a tag separation of 2.5 mm was used for the SENC images. Dense measures of Eulerian in-plane normal strain (Err and Ecc) are obtained from the HARP images by computing local spatial derivatives of the HARP phase in the appropriate directions [1]. Dense measures of Eulerian out-of-plane normal strains (Ell) are also obtained from the SENC images [2]. It can also be shown that in-plane shear strains (Ecr) and out-of-plane shear strains (Elc) can also be computed from the datasets acquired.

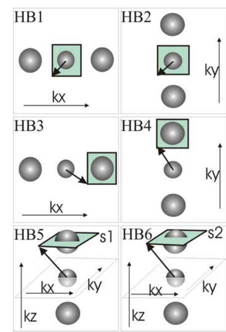

Fig. 1. A typical 6-heartbeat HARP-SENC scan

Results

Fig. 2 shows representative normal color-coded strain maps with in-plane synthetic tag overlay for one end-systolic time frame and an apical short-axis slice. Note the circumferential shortening, the radial thickening and the longitudinal compression in these images. In Fig. 2(c), in particular is interesting as a visual aid as in-plane synthetic tags are overlaid on an out-of-plane longitudinal strain map providing a visual correlation between in-plane motion and out-of-plane strain. To visualize strain in all five slices at once, eight regions in the left ventricle were defined and strains in each of these regions were averaged and color-coded to generate bullseye plots as seen in Fig. 3. Here, the evolution of Eulerian longitudinal strain is depicted over twelve time frames. Note the increased longitudinal shortening during end-systole.

Discussion and Conclusion

In this paper, we have demonstrated the ability to measure the dynamic evolution of 3D myocardial strain using the HARP-SENC MRI technique. It was shown that post-processing of the datasets acquired from just two breath-holds provides full quantification and visualization of three-dimensional myocardial strain with high temporal resolution.

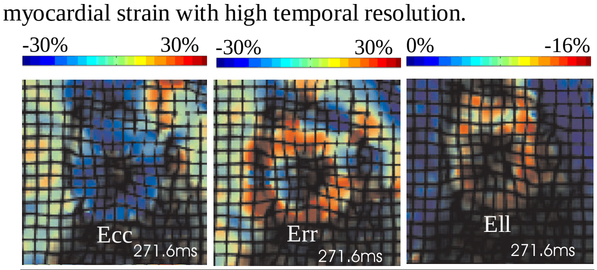

Fig. 2. Eulerian strain maps depicting (a) circumferential strain, (b) radial strain, and (c) longitudinal strain at an end-systolic time frame. In-plane synthetic tags are overlaid.

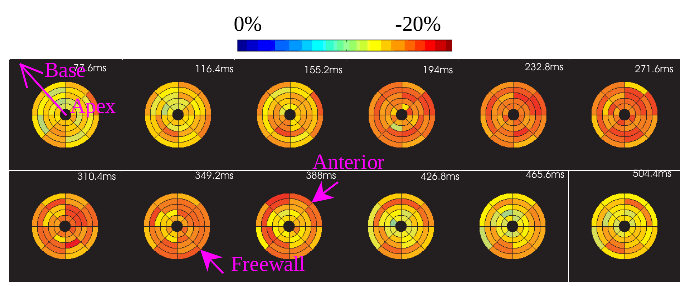

Fig. 3. Bullseye plots depicting the evolution of Eulerian longitudinal strains in octants defined in all five short axis slices.

References

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