Myocardial Tagging in a Single Heartbeat with EPI-SSFP and TSENSE

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Synopsis: Cardiac tagged images are acquired within a single heartbeat using a combination of EPI-SSFP and TSENSE. Images with matrix sizes ranging from 256x120 to 160x120 and with TRs from 5.2 to 3.9 ms were acquired with rate 4 acceleration rates, leading to temporal resolutions of 52 to 39 ms, and to ~15-25 cardiac phases acquired in a single heartbeat. The resulting real-time functional cardiac movies can be used for direct visualization of the beat-to-beat response to stress, or treatments such as RF ablation or ethanol injections.

Introduction: Myocardial tagging [1,2] has proven valuable in the assessment of global and regional cardiac function [3]. However, tagging usually requires breath-held acquisitions 10 to 12 heartbeats which can be challenging for many patients. We present an implementation of myocardial tagging, in combination with EPI-SSFP [4] and TSENSE [5] accelerated imaging, in which a complete sequence of images is acquired within a single heartbeat, making breath-holding unnecessary, and the observation of transient hemodynamics and cardiac mechanics possible. The echo train length 3, EPI-SSFP sequence combines the high SNR available with SSFP with increased data acquisition efficiency by acquiring multiple echoes within a single, short TR. The use of hardware optimized (HOT) gradient waveform design [6, 7] minimizes dead periods and maximizes data acquisition efficiency.

Methods: All human images were acquired on a 1.5 T LX CV/i scanner (GE, Waukesha, WI) utilizing a custom built 8-channel receiver [8] and an 8-coil chest phased array (Nova Medical, Wakefield, MA). Myocardial tagging was applied in combination with SSFP as described in [9]. Imaging was performed using an EPI-SSFP sequence based on [6] that utilized hardware optimized trapezoidal (HOT) waveforms [7]. TSENSE was applied with acceleration rates (R) of 4, leading to temporal resolutions of 52 to 39 ms per cardiac phase. Imaging parameters for 256x120, 192x120, and 160x120matrices were: rectangular FOV = 37x28, ±125kHz bandwidth, ETL= 3, TR = 5.2, 4.3 and 3.8ms, TE = TR/2, 45° imaging flip angle, 8 mm slice thickness, interleaved phase encode ordering. The acquisition was run continuously, during both breath-hold and free breathing for 30-40 heartbeats. Reconstruction was performed offline. Coils sensitivity profiles (B_1 field maps) were obtained using TSENSE. Myocardial tagging was performed as shown in [9] with a 7 pixel tag spacing. Tags were created using 5 RF pulses with a total 180° flip upon the detection of an ECG trigger.

Results: Fig 1 displays select sequential cardiac phases from a real-time cardiac movie, each frame obtained from a single-heartbeat using R = 4 and 256x120 matrix size. Temporal resolution was 52 ms or ~19 phases per heartbeat. Figure 2 displays select cardiac phases from a single-heartbeat image obtained using R=4 and 192x120 matrix size. Temporal resolution was 43ms for leading to a real-time movie comprising ~23 images per cardiac cycle. Multiple, consecutive cardiac cycles were imaged to observe breathheld and non-breathheld cardiac function. In both sets of images, the tagged myocardial wall motion is clearly apparent. Fig 3 shows Images were also acquired during a valsalva maneuver, showing the dramatic change in cardiac function from beat to beat during the increase in thoracic pressure.

Conclusion: This work demonstrates myocardial tagging acquired in real-time. The use of high-efficiency, high SNR EPI-SSFP in combination with TSENSE allowed the acquisition of 15-25 frames within each single heartbeat of a real-time acquisition. Though quantitative analysis of tagged image data sets still requires post-processing, the visual information conveyed by single-heartbeat tagged images can be useful in many instances such as imaging patients with severe difficulty breath-holding or when studying the changes in cardiac function that occur at a per-heartbeat basis (i.e. alternans). This technique could also be applied within the setting of real-time interventional imaging, where immediate visualization of cardiac response to treatments such as RF ablation or ethanol injections is necessary.

References:

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Figure 1: Select cardiac phases spanning systole acquired within a single heart beat. Imaging parameters were: 256x120 acquisition matrix, SENSE acceleration rate R = 4, temporal resolution of 52ms

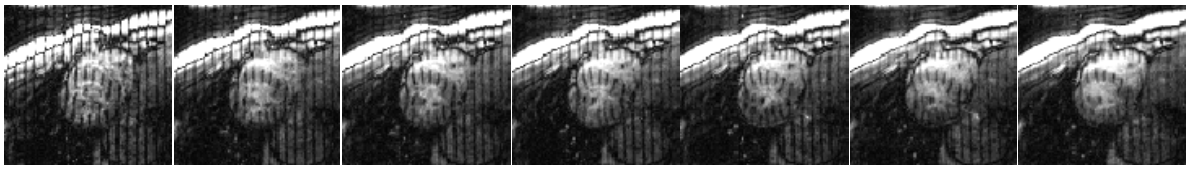

Figure 2: Select cardiac phases of a series spanning the complete cardiac cycle acquired within a single heart beat. Imaging parameters were: 192x120 acquisition matrix, SENSE with R = 4, temporal resolution of 43 ms (~ 23 cardiac phases per heartbeat).

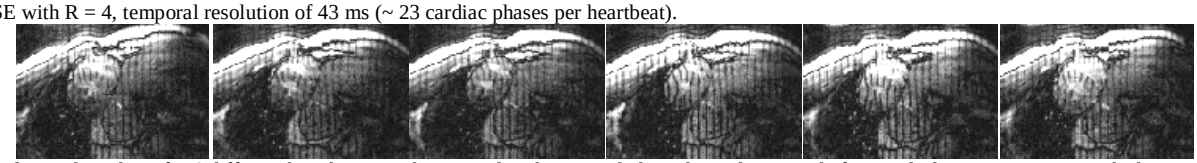

Figure 3: Systolic cardiac phase for 6 different heartbeats, each acquired within a single heart beat, during and after a valsalva maneuver. Note the beat-to-beat variability in cardiac function as well as the motion other organs within the chest cavity.