Ultrahigh temporal resolution cardiac tagging using phase train imaging

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Introduction: Studying the evolution of cardiac strain during the early stages of systolic contraction and diastolic relaxation is important to determine strain variations related to mechanical dyssynchrony, and to potentially assist in determining regions of electrical dyssynchrony. Herzka, et al. [1] demonstrated the use of multi-echo SSFP (MESSFP) techniques to acquire high temporal resolution tagged datasets; however, their approach is limited to approximately 5 ms temporal resolutions due to the need to minimize phase jumps in k-space (by using echo-shifting, flyback gradients, or similar schemes). Recently, a novel variant of the MESSFP technique, called phase train imaging (PTI), has been proposed [2] which permits acquisition of even higher temporal resolutions in a single breathhold. In this approach, the same phase encoding value is used for each echo in the multi-echo readout and assigned to a different cardiac phase; when combined with parallel imaging approaches, this permits high temporal resolution acquisition in a breath-hold. We have used this approach to acquire cardiac tagged short axis datasets on normal volunteers and patients to demonstrate the ability to acquire and analyze ultra-high temporal resolution tagged cardiac images.

Methods: Phase train imaging was used to acquire high resolution tagged cardiac images. A conventional, manufacturer-supplied, retrogated FLASH sequence was used to acquire lower resolution tagged data, for comparing to the data acquired using the PTI approach. The specifications for the sequences were as follows: **PTI**: echotrain length: 5, TR/TE: 7.6 ms / 1.6 ms (to the first echo), inter-echo spacing: 0.81 ms, flip angle: 40^0, field-of-view: 360 x 300 mm^2, Resolution: 192 x 54 pixels, SENSE rate: 3, breathhold duration: 18 heartbeats, phases acquired: 575, acquisition window/heartbeat: 900 ms, line tags (7 mm). **RetroFLASH**: TR/TE: 53 ms/3.42ms, flip angle: 15^0, resolution: 192 x 140 pixels, 'retro' phases acquired: 25, breathhold duration: 20 heartbeats. Tagged data in the short axis orientation was acquired in two separate breathholds (orthogonal tags) for each of the sequences. All data were acquired on a Siemens Avanto scanner (Siemens Medical Solutions, Malvern, PA). The tagged data was analyzed by means of an in-house developed semi-automated analysis package. Strain calculations were performed through early diastole in both datasets.

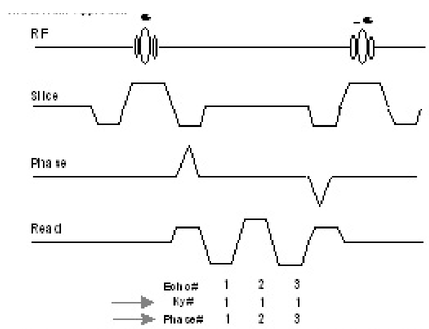

Figure 1. Phase Train Imaging

Results: Figure 2 shows the tagged snapshot images acquired using the PTI approach. 5 successive time frame images are shown, along with their timestamps. Note that while inter-echo time spacing is 0.81 ms, the average temporal resolution is 1.57 ms due to the time delay between repeating echotrains. Figures 3(a) and 3(b) show the circumferential and radial strains, respectively, determined by both approaches.

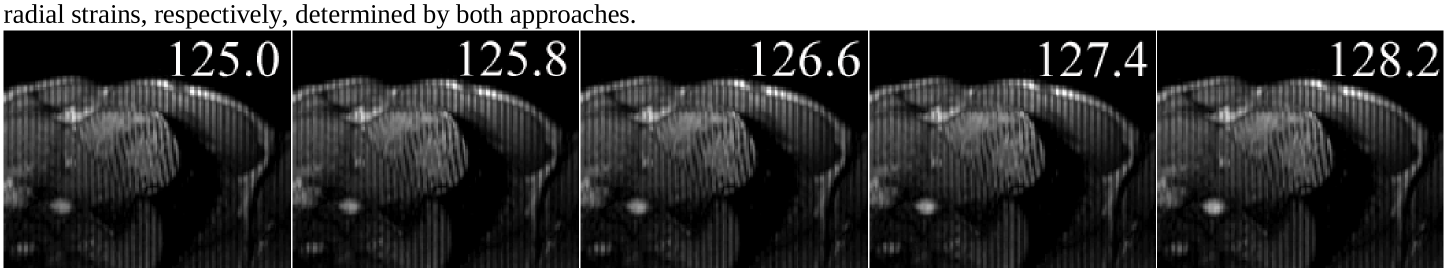

Figure 2. Five successive time frames (timestamps in ms indicated) of short-axis tagged dataset acquired with phase train imaging.

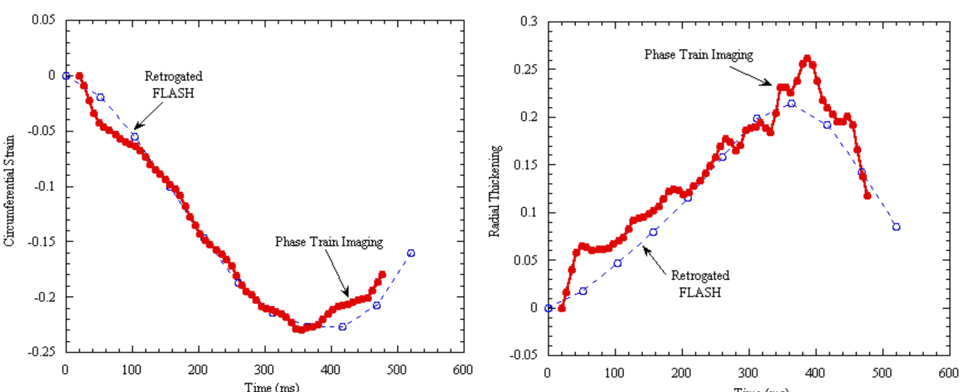

Figure 3. A. Circumferential Shortening, B. Radial Thickening

Discussion: While there is excellent agreement between the circumferential shortening determined from both approaches through most of systole, there is significant underestimation of early systolic shortening, as well as early diastolic recovery, by retrogated FLASH, due to the poor sampling rate. A similar observation can be made for radial thickening, with the low resolution data underestimating early systolic and early diastolic thickening. It would also appear from the PTI data that peak shortening (and peak thickening) occur significantly earlier (and later) than estimated by conventional clinical sequences. These observations indicate the potential importance of using high-temporal resolution tagged imaging for studying the mechanical behavior in early phases of systole and diastole.

References: 1. Herzka DA, et al., MRM 2002; 47(4):655-64. 2. Pai VM, et al. accepted for presentation at SCMR 2005.