Phase Train Imaging: High Temporal Resolution Imaging in a Breathhold Duration

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Introduction: Very high temporal resolution cardiac MR imaging may prove to be very useful for evaluating mechanical dyssynchrony, a key indicator for chronic heart failure, especially in early stages of systolic contraction and diastolic expansion. While multi-echo SSFP techniques [1] have been developed for acquiring high temporal resolution cardiac images, they are naturally restricted to a maximum temporal resolution of 4.5 to 5 ms. This is due to the need to implement techniques to minimize phase discontinuities which can arise due to acquisition of multiple phase-encoding lines per repetition. While single-echo SSFP techniques can provide very high temporal resolution, they are limited in their practical applicability due to the high number of RF pulses, and the reduced persistence of tagged magnetization (when used to acquire tagged cardiac data) and similar magnetization preparation pulses. The phase train imaging (PTI) approach presented here eliminates the problems associated with both the techniques indicated above. Since all the echoes acquire the same k-space line for different cardiac phases, there is no phase discontinuity in the phase-encode direction associated with this approach; since multiple echoes are acquired, the number of RF pulses is correspondingly lesser than that for single echo sequences, and effects of magnetization preparation pulses such as tagging can persist for a relatively longer duration. Implementation of phase train imaging in conjunction with parallel imaging approaches enables this .

Methods: Figure 1 illustrates the implementation of the phase train imaging over a repetition (a), and over a cardiac cycle (b). As can be seen, the phase train assigns data from each echo of the multi-echo train to a separate cardiac phase, rather than acquiring multiple phase-encode lines. For each phase, only one phase-encode line is acquired per cardiac cycle; this can cause the duration of the scan to be longer than conventional breathhold durations. Utilization of parallel imaging approaches such as TSENSE [2] (figure 1(b)) permits reduction of scan time, and enables breathhold scanning. The sequence has been implemented on 1.5T clinical scanners (Siemens Medical Solutions, Malvern, PA) and high temporal resolution datasets (up to 1.5 ms) have been acquired on human volunteers. For these scans, SENSE rates of 2 to 3, and echo train lengths of 3 (TR:6ms) to 5 (TR:7.6ms) were used. Breathhold durations ranged between 18 heartbeats (SENSE rate: 3) and 24 heartbeats (SENSE rate: 2). For the cine images, flip angles of 60^0 were used, and for the tagging implementation, 45^0 flip angles were used.

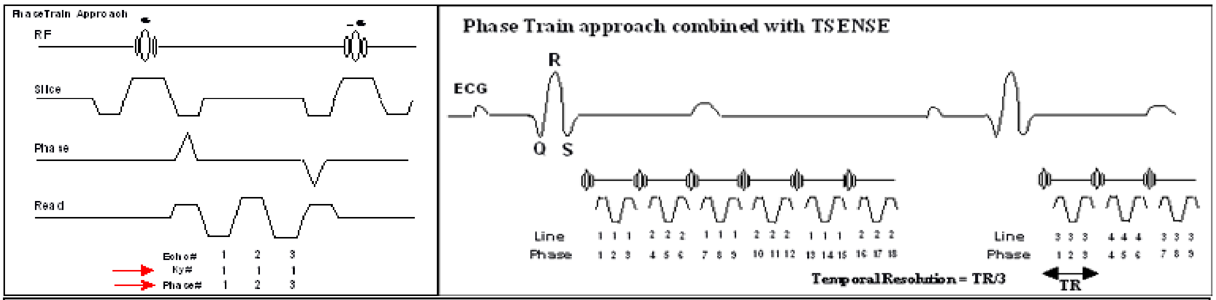

Figure 1. Phase Train Imaging. (a) over a single repetition (TR), (b) over a cardiac cycle, with SENSE rate of 2.

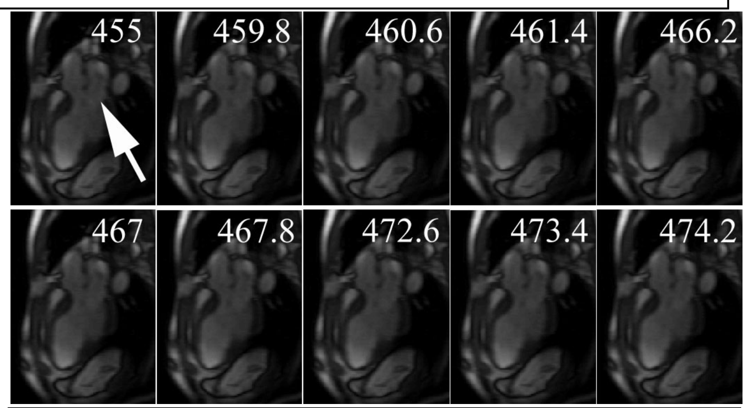

Figure 2. PTI implementation for long axis cardiac imaging. Numbers indicate time from R-wave, and arrow indicates the mitral valve. Echotrain: 3, SENSE Rate: 2

Results: Figures 2 and 3 show two different implementations of the PTI sequence, along with the time stamps for individual frames. Long axis 2-chambered cine view of the heart is shown in Figure 2 (echo train: 3), while short axis tagged view of the heart is shown in Figure 3 (echo train: 5).

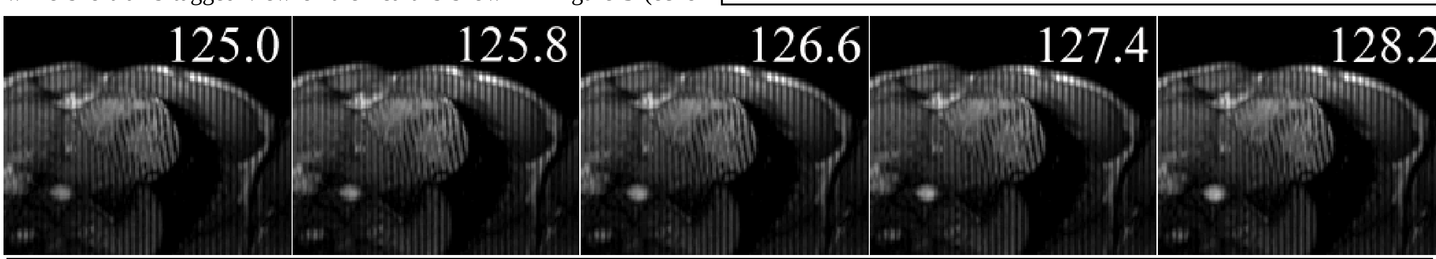

Figure 3. PTI implementation for short-axis tagging. Numbers indicate time from R-wave. Echotrain:5, Sense Rate: 3

Discussion: Figure 2 shows the negligible artifacts from the PTI sequence implementation in the long axis. The arrow indicates the position of the mitral valve, and the frames shown are when the mitral valve has just opened in diastolic filling. Figure 3 shows the PTI implementation for tagging study. Since the TR is fairly long (7.6 ms for phase train of 5 echoes), note the presence of the off-resonance banding artifact on the posterior wall of the left ventricle. Note that since some time is spent applying the RF pulses, the temporal resolution on average is 2 ms for figure 2, and 1.5 ms for figure 3. References: 1. Herzka DA, et al., MRM 2002; 47(4):655-64. 2. Kellman P, McVeigh E. MRM 2001; 46(2):335-43.