Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Towards high temporal and spatial resolution cardiac imaging with parallel MRI

Vinay M. Pai[1]
[1] Department of Radiology, New York University School of Medicine, New York, USA.

Very high temporal resolution cardiac MRI studies can potentially provide detailed information about cardiac motion, including during the early phases of systolic contraction and diastolic relaxation. Such information could be useful for evaluating local mechanical dyssynchrony or studying valvular function. Mechanical dyssynchrony has been shown to be a better indicator of electrical dyssynchrony in the setting of chronic heart failure than the conventionally used indicator, the elongated QRS complex. On the other hand, very high temporal resolution flow imaging may prove to be very useful for evaluating valvular dynamics, and for studying flow patterns in the cardiac chambers. Several new approaches for dynamic function and flow imaging with MRI at high temporal and spatial resolutions are presented.

Higher temporal resolution cardiac MRI methods have been developed over the last few years. In particular, multi-echo steady-state free precession (MESSFP) readouts have been developed] which acquire multiple phase-encode lines per repetition in order to acquire high resolution data within a breathhold. While Herzka, et al. were able to achieve a temporal resolution of 5 ms with this approach [2], studying details of early mechanical activation and contraction may require even higher temporal resolution. However, the MESSFP approach presented by Herzka, et al. is naturally limited to 5 ms temporal resolutions due to the need to incorporate means to minimize phase discontinuities between successive echoes in the echotrain readout. While single echo SSFP sequences can provide higher temporal resolution (~ 2.5 ms), these are not usually utilized for high resolution imaging, due to the large number of RF pulses that need to be applied in order to acquire the data.

Phase Train Imaging:

Recently, we have introduced the phase train imaging (PTI) approach [3] which attempts to overcome some of the limitations indicated above. While it is a multi-echo SSFP technique, it differs from the conventional implementations in that each echo of the echotrain acquires the same phase-encoding line; this line is then assigned to a different cardiac phase.

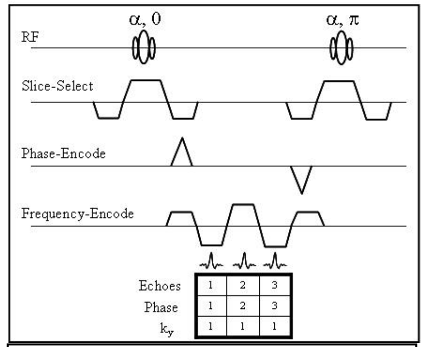

Figure 1. Phase Train Imaging. Each echo acquires a separate cardiac phase for the same phase-encoding.

The data for each cardiac phase is reconstructed separate from the data of the other echoes. This eliminates the need to align all the lines acquired by the echoes of an echotrain; which in turn reduces the duration of the echotrain. Also, since each echo of the echotrain provides a different image, the temporal resolution of the acquisition is higher than that achieved by conventional MESSFP (cMESSFP) approaches or single-echo TrueFISP techniques. Due to the fact that no image acquisition is performed during slice prescription, there is a staggered acquisition of data points, making it difficult to define a true temporal resolution for this sequence; for this purpose, an average temporal resolution can be defined by the TR (repetition time) divided by the number of echoes in the echotrain. Figure 1 shows the implementation of phase train imaging (PTI) over a single repetition (echotrain length (ETL) of 3 echoes is considered in this example).

Shifted k-space Imaging (SKIM):

The SKIM approach was initially developed as a means for acquiring hyperpolarized ^{3}He images of the lungs in a rapid fashion [4]. Figures 2 and 3 illustrate this approach for a multi-echo sequence where each echo acquires a different image and phase-encoding blips are applied between the echoes such that the time to reach the center of k-space for each of the echoes can be controlled.

The SKIM approach can be adapted for acquiring high spatial resolution (and relatively high temporal resolution) cardiac images in a short breathhold. For a single-echo cardiac acquisition, SKIM can be performed across multiple repetitions, enabling higher spatial resolution data to be acquired in a short breathhold. Using a 32-channel cardiac array at 3T in combination with GRAPPA [5] (parallel imaging rate 3), cardiac images with spatial resolution of 900 x 900 μm^2 with 50 ms temporal resolution have been acquired in a 18 second breathhold scan. Preliminary TrueFISP and FLASH images are shown in Figure 4.

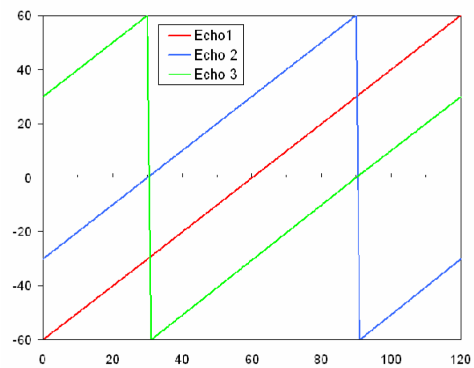

Figure 2. k-space travel by each echo of multiecho sequence (illustration of an echo train of 3 echoes)

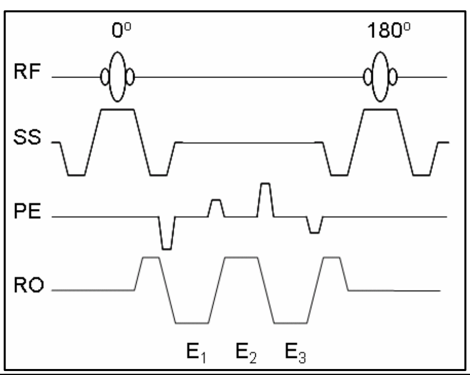

Figure 3. Pulse sequence per TR. SS: Slice-select, PE: phase encode, RO: frequency-encode (readout direction), Ei: i^{th} echo (i: 1..3)

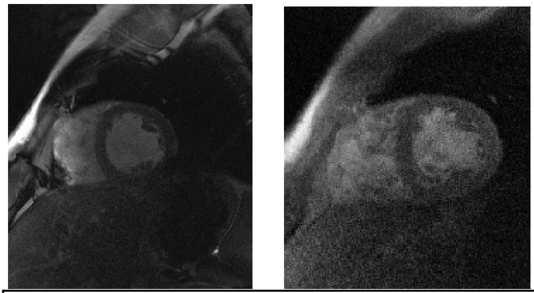

Figure 4. High spatial resolution cardiac imaging at 3T with SKIM approach. (L) TrueFISP, (R). FLASH.

Summary:

Multiecho SSFP approaches may be successfully exploited, in combination with parallel imaging, to obtain cardiac flow and function information with higher temporal and spatial resolutions than are currently available, and in clinically relevant breathhold durations.

References

[1] Herzka DA, Kellman P, Aletras AH, Guttman MA, McVeigh ER. Multishot EPI-SSFP in the heart. Magn Reson Med 2002;47(4):655-664.

[2] Herzka DA, Derbyshire JA, Kellman P, McVeigh ER. “Ultra High Temporal Resolution Cardiac Function in a Single Breath-hold” presented at Proc Euro Soc Magn Reson Med Biol (ESMRMB), 2003. p S116.

[3] Pai VM, Axel L, Kellman P. Phase Train Approach for very high temporal resolution cardiac imaging. J Cardiovasc Magn Reson 2005; 7(1):98-99.

[4] Pai VM, Kamenetskiy I, Lee R, Johnson G. “High Temporal Resolution Hyperpolarized Helium Imaging,” presented at Proc Int Soc Magn Reson Med, 2006

[5] M. Griswold, P. Jakob, R. Heidemann, M. Nittka, J. Wang, B. Kiefer, and A. Haase, "Push-button PPA Reconstructions: GeneRalized Autocalibrating Partially Parallel Acquisitions (GRAPPA)," presented at Proc Int Soc Magn Reson Med, 2001.