High Spatial and Temporal Resolution Myocardial Tagging in a free-breathing exam using multi-echo SSFP and PAGE

Vinay Pai[1], Leon Axel[1], Dan Kim[1], Peter Kellman[2]

[1]*New York University School of Medicine, New York, NY,*

[2]*National Heart, Lung and Blood Institute, National Institutes of Health, Bethesda, MD*
paiv01@med.nyu.edu

INTRODUCTION:

Magnetization tagging [1, 2] has been used to study regional myocardial motion. The development of high temporal and spatial resolution tagging imaging methods may permit the evaluation of regional activation and relaxation patterns in early systolic and diastolic phases. In this abstract, we present an approach to obtain high temporal and spatial resolution myocardial tagging data under free-breathing conditions. We also introduce a dual tagging approach in order to have high tag contrast in both early systolic and diastolic phases.

METHODS:

In order to acquire high spatial and temporal resolution images, a multi-echo steady-state free precession (MESSFP) pulse sequence [3] (Figure 1) was combined with a phased array approach to ghost elimination (PAGE) [4]. In addition to the zeroth gradient moment condition for SSFP, the first gradient moment was nulled in the readout and slice-select directions. The use of the PAGE technique enabled minimization of the first gradient moment in the phase-encoding direction. The coil sensitivity profile was determined adaptively over the entire scan. Combined cardiac and respiratory gating was incorporated into the pulse sequence to permit the acquisition of the higher resolution data under free-breathing conditions. In order to minimize the artifacts that arise when transitioning from the tagging pulse to the MESSFP readout, a geometric ramp flip angle was used for the first 5 readout pulses [5] (Figure 2).

In order to evaluate the motion in early phases of systole and diastole, this study also included a dual-tagging approach. It has been previously shown[6] that increasing the readout flip angles for SSFP sequences reduces the tag persistence in the diastolic phases of the cardiac cycle, and that a lower flip angle reduces the blood-myocardium contrast. Using a flip angle of 40^0 enabled us to obtain good tag contrast through systole for fast rate rates (70 bpm+). For slower heart rates (< 70 bpm), diastolic analysis was hindered due to the reduction in tag contrast. In order to alleviate this problem, we have adopted the approach of using high flip angles (60^o – 80^o) for the MESSFP readout, in conjunction with applying the tagging pulse after the R-wave (early systole) and in early diastole, as shown in Figure 3. Dummy scans are played out between the systolic and diastolic acquisition, in order to maintain steady-state and to further reduce tag persistence from the previous acquisition. A standard cine (manufacturer supplied) sequence is used to determine the approximate temporal location of end systole, before running the dual tagging sequence.

The sequence was implemented on a 1.5T clinical scanner (Sonata, Siemens Medical Solutions), and evaluated on human volunteers and patients. Typical scan parameters were: echo train length (ETL)= 3, TR= 7 ms, TE= 3.57 ms, FOV= 320 x 320 mm^2, resolution= 384 x 234 $pixel^2$, slice thickness= 8 mm, flip angle= 40^o (single tagging) - 75^o(dual tagging), respiratory acceptance window= 15% of end-expiration, receiver bandwidth= 868 Hz/pixel, 5-7-9-7-5 SPAMM pulse; tag spacing = 6 mm, phased array elements = 6 (4 anterior and 2 posterior).

RESULTS:

Using the approach presented above, we acquired tagged cine images with spatial resolution of 0.8 x 1.4 mm^2 (frequency-encoding direction X phase-encoding direction), and temporal resolution of 7 ms. Typical acquisition times for the scans ranged between 4 and 6 minutes per slice (average gating acceptance efficiency: 30%). Dual tagging was used to acquire 20 cardiac phases for each half of the cardiac cycle (7 ms temporal resolution), with the second tagging pulse played 270 – 320 ms after the R-wave. Single tagging (i.e. tagging applied only at end-diastole) was used to acquire 60 – 100 cardiac phases. Figure 4 shows representative images from the single tagging experiment. Figure 5 a-b shows representative images from the first and second halves of the dual-tagging experiment, respectively.

DISCUSSION:

High-resolution myocardial tagging may enable clinical studies quantifying distinct patterns of contraction, as well as the rapid filling phase, observed in normal, infarcted and reperfused myocardium. In this abstract, we present an approach combining multi-echo SSFP, PAGE, and combined cardiac and respiratory gating to acquire high temporal and spatial resolution myocardial tagging data. A dual tagging may be an alternative approach to maintain high tag contrast throughout the cardiac cycle, allowing tagged imaging of early contraction and rapid filling phases during the cardiac cycle.

Basic High Resolution Study

MESSP and PAGE, in combination with combined cardiac and respiratory gating, can be used to acquire 100 - 200 cardiac phases under free-breathing conditions. In order to preserve tag persistence through to early diastole, it is necessary to reduce the RF flip angle to $30^o – 45^o$. However, this minimizes the blood-myocardium contrast, which can make it difficult to extract the contours of the myocardial surfaces. Combined cardiac and respiratory gating allows free-breathing examinations to be performed; the efficiency of such scans is 30% on average. This efficiency is similar to those reported by other approaches such as navigators.

Dual Tagging High Resolution Study

Applying the tagging pulses at the end of systole and diastole, in theory, should permit the study of early ejection and filling phases more clearly. It is necessary to ensure that tags applied at the start of imaging either systolic (diastolic) phases do not persist into the start of imaging the diastolic (systolic) phases. Using high flip angle readouts, besides ensuring reduced tag persistence, also permits high blood-myocardium contrast. However, SAR issues need to be taken into consideration; even though the present implementation is a multi-echo readout, the low efficiency of the respiratory gated examination can lead to significant RF deposition. An alternative approach could be to use lower flip angles for readout, and cycling to higher flip angles during the interleaved dummy scans, minimizing SAR issues while still minimizing tag persistence.

While the start of systolic ejection is easy to determine (by tracking the R-wave), it is harder to accurately determine the start of filling-in. Cine movies acquired prior to the high-resolution scan can provide a rough estimate of the start of diastole.

Summary

Free-breathing high resolution tagged imaging can be used to track early phases of systole and diastole. This should permit motion evaluation during ejection and early fill-in periods, and the study of regional activation and relaxation patterns in the heart.

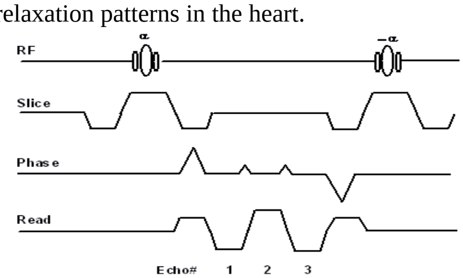

Figure 1. MESSFP implementation

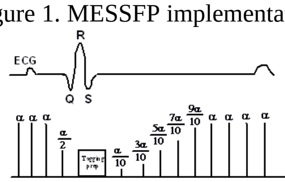

Figure 2. Geometric Ramp to minimize artifacts during transition from tagging pulse to MESSFP readout

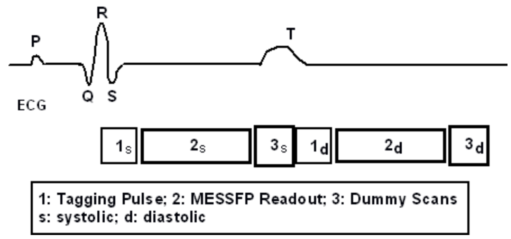

Figure 3. Schematic of dual tagging during a cardiac cycle

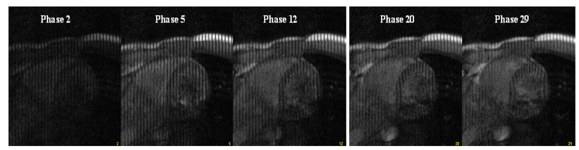

Figure 4. High resolution tagged cardiac data set obtained using single tagging pulse (selected phases displayed).

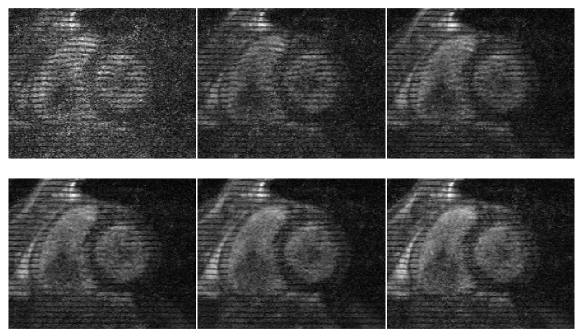

Figure 5a. Early systolic phases (2 – 7) obtained using dual tagging

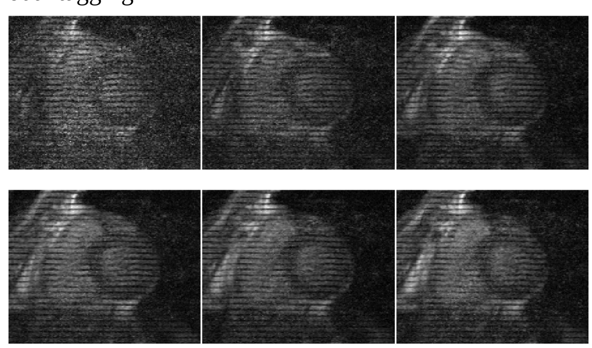

Figure 5b. Diastolic phases (2 – 7) obtained using dual tagging.

REFERENCES:

[1] Zerhouni EA, et al., Radiology 1988; 169:59-63.
[2] Axel L, Dougherty L. Radiology 1989; 171:841-845.
[3] Herzka DA, et al., MRM 2002; 47(4):655-64.
[4] Kellman P, McVeigh E. MRM 2001; 46(2):335-43.
[5] Deshpande VS, et al. MRM 2003; 49:151-157.
[6] Herzka DA, Guttman MA, McVeigh ER. MRM 2003; 49:329-340.