3D Myocardial Tagging with Joint ECG Triggering and Respiratory Gating

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***Introduction*:** Spatial modulation of magnetization (SPAMM) is a well-established MRI technique for assessing 2D intramyocardial function [1]. The heart is a 3D structure with highly complex contraction pattern. Some researchers have combined multiple short-axis and long-axis views to reconstruct 3D strain models that may be more consistent with the 3D fiber architecture of the heart [2,3]. These multi-slice imaging techniques with sequential breath holding are prone to several problems including image misregistration and is restricted to relatively thick slices that are sensitive to through-plane motion. Recently a 3D complementary SPAMM (CSPAMM) technique was introduced to image the deformation of a 3D grid pattern magnetically saturated in the heart [4]. This technique has several potential disadvantages for tag analysis: (a) CSPAMM tag profiles are relatively smooth, (b) 3D tag patterns are difficult to analyze, and (c) navigator-assisted approach still requires a large number of breathholds. The purpose of this study was to develop a fast 3D tagging sequence that produces sharp parallel tag patterns and to implement joint electrocardiogram (ECG) triggering and respiratory gating that permits free breathing during scanning.

***Background*:** Volume data can be acquired with either contiguous multi-slice imaging or true 3D imaging. Compared to multi-slice imaging, 3D imaging provides thinner continuous slices and additional signal-to-noise benefit at the cost of increasing the scan time. Echo-planar imaging (EPI) can be used to speed up the 3D acquisition. To this end, we used a hybrid gradient echo EPI sequence optimized for myocardial tagging [5] and extended it for 3D imaging. In the context of 3D myocardial tagging, the effects of cardiac motion can be accounted for by synchronizing the image acquisition to ECG. Breath holding or navigators are commonly used to suppress the effects of respiratory motion. The long scan time needed for acquiring volume data makes breath holding impractical. Navigator techniques are ill-suited for multi-phase tagging because they take up a portion of the duty cycle. The navigator-assisted approach may help achieve consistent breath-hold positions for a relatively short period; the large number of breathholds required for 3D acquisition makes this technique prone to image misregistration. Joint ECG triggering and respiratory gating has shown to be an effective method for suppressing motion artifacts in myocardial tagging [6]. Unlike the navigator-assisted breath-hold method, this technique is straightforward to implement and requires less technologist set-up and patient cooperation. The previous version of joint gating was implemented as an external hardware device that samples the ECG and respiratory signals and returns an external trigger pulse to the MRI system for data synchronization [6]. Our implementation is embedded into the pulse sequence environment, which has real-time access to sampled ECG and respiratory bellows signals. In our implementation, ECG triggering is always enabled, and data are acquired only if the respiratory signal is within a user-defined acceptance window. Data acquisition efficiency depends on the heart rate, respiratory rate, and respiratory acceptance window.

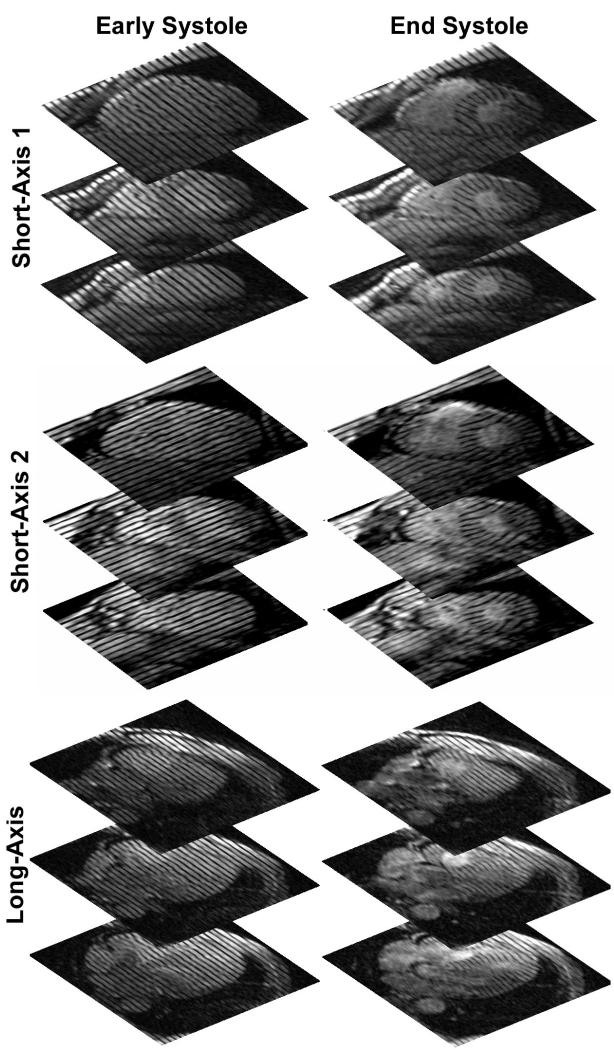

Figure 1. Representative multi-slice views of 3 orthogonal 3D tagged data sets at early systole and end systole.

***Methods*:** All imaging was performed on a 1.5 T whole-body scanner (Sonata, Siemens, Erlangen, Germany) equipped with a 6-channel phased array RF coil. Healthy volunteers were imaged using the proposed 3D tagging technique under informed consent. We imaged the deformation of sharp parallel patterns with an asymmetric voxel resolution, where the tag pattern was always perpendicular to the direction with highest resolution (frequency encoding). This protocol provides high spatial resolution sampling of parallel tags in three orthogonal directions by using the volumetric "cross" sampling of k-space. Pertinent imaging parameters included: field of view = 250 x 250 x 100 mm^3, matrix = 192 x 90 x 24, slice per slab = 32, slice thickness = 5 mm, TR = 17.7 ms, tag spacing = 7 mm, flip angle = 14°, receiver bandwidth = 1302 Hz/pixel, echo train length = 5, phase-encode lines acquired per cardiac phase = 10, temporal resolution = 35.4 ms, and scan time = 37.7 min. Partial Fourier acquisition with a factor of 0.75 was obtained along 3D phase-encoding in k-space that has constant signal-strength weighting. Missing k_z-planes were zero-filled. The mean heart rate during the scan time was about 60 beats per minute. The theoretical breath-hold duration for this heart rate was calculated as 12 min, which means that joint ECG triggering and respiratory gating had an efficiency of 31.8 %.

***Results*:** Figure 1 shows representative short-axis and long-axis views at 3 slice locations of one volunteer in early systole and end systole. Within each orientation, the tags and the myocardium were well registered. However, we observed misregistration up to 6 pixels between orthogonal orientations, possibly due to inconsistent breathing pattern or patient movement.

***Discussion*:** We have shown that 3D FGRE-EPI using joint ECG triggering and respiratory gating has potential to be a robust technique for imaging high quality 3D tagged images with an effective isotropic resolution of 1.3 x 1.3 x 1.3 mm^3 and a temporal resolution of 35.4 ms in a scan time of around 40 min. Incorporating parallel imaging techniques can further reduce the scan time by at least a factor of 2. Combining this tagging technique with a semi- or fully automated analysis program could make studies of 3D myocardial mechanics in normal and ischemic heart disease more practical.

References

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