Parallel imaging and 2 R-R acquisition for tagged imaging of 100% or more of the cardiac cycle with improved CNR

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Introduction: It is desirable to be able to measure cardiac motion during the entire cardiac cycle (R-R). However, in most commonly used tagging procedures [1][2], there are intervals (e.g. a pre-trigger delay for magnetization recovery and a post-trigger delay while the actual tagging sequence is played out) for which motion information is not available. Furthermore, as the imaging acquisition window is increased to provide extended coverage of the cardiac cycle, the available time for magnetization recovery is reduced, to the detriment of the tag contrast-to-noise ratio (CNR) and longevity.

In this work, we demonstrate a method for acquiring sets of cine images covering in excess of 100% of the cardiac cycle with superior CNR to a typical 80% R-R acquisition. The method employs a 2R-R acquisition scheme: tagging and imaging are performed during the first R-R, with the preponderance of the succeeding R-R being used to allow magnetization recovery (see Figure 1). The total scan time is kept constant by the use of rate two parallel imaging. The parallel imaging noise penalty ($g\sqrt{2}$) is more than offset by the enormous increase in the recovered magnetization that is available for tagging preparation and therefore tag contrast.

Methods: MR imaging was performed using a 1.5T Siemens Espree scanner (Siemens Medical Solutions, Erlangen, Germany) equipped with gradient coils rated for amplitudes of 33mT/m and slew rates of 100T/m/s. A gated, sequential, multi-phase 2D balanced-SSFP ramped-flip-angle [3] imaging sequence with a 1-1 SPAMM (180° total flip angle and phase sensitive reconstruction [4]) tagging preparation was employed. At the end of the image data acquisition window, the flip angle was ramped down to zero to allow for magnetization recovery in anticipation of the next tagging preparation.

All in-vivo studies were approved by the IRB of the NHLBI, with informed consent from all subjects. Typical imaging parameters were: 6mm tag separation; 300x300 mm^2 imaging FOV, 256x130 acquisition matrix; TE/TR= 2.5/5.0ms; 5mm slice thickness; and 5 TRs-per-segment for a temporal resolution of 25 ms.

To demonstrate the method, data was obtained from a healthy, 31 year old, female volunteer, with 82bpm heart rate (R-R = 731ms). A reference set of cine images was acquired using our standard, non-accelerated tagged imaging protocol: 1R-R, 20-50° ramped flip angle and ~80% (600ms) acquisition window. Further sets of cine images were acquired using the proposed 2R-R / Rate 2 TSENSE acquisition scheme with 20-50°, 20-70° and 20-90° ramped flip angles were employed and an extended, 110% R-R (800ms) data acquisition window. All 1R-R and 2R-R scans were performed in the same 26-heartbeat breath-hold time (20s).

Results: A comparison of the images obtained using a standard 1R-R acquisition and the 2R-R / rate R=2 TSENSE acquisition are show in Figure 2. Images are reconstructed in SNR units [5] and shown with identical window leveling. It can be clearly seen that the 2R-R acquisition has CNR that is superior to the 1R-R scan. Furthermore, the tagging contrast persists through 110% of the cardiac cycle into early part of systole of the second cardiac cycle.

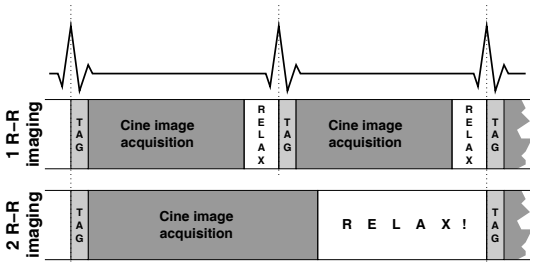
Discussion: The sequence employed in this work incorporates several recent technical developments for improved tag CNR and longevity: balanced SSFP provides better SNR efficiency and reduced tag fading [6]; a ramped flip angle distributes the available tagging contrast evenly over the acquisition window [3]; and the use of fully inverted tags with phase sensitive reconstruction [4] provides an increase in the contrast over standard saturation tags. To these we now add 2R-R acquisition with R=2 TSENSE which, in addition to improving CNR, also provides the ability to scan > 100% of the cardiac cycle capturing late diastole, atrial filling and atrial contraction.

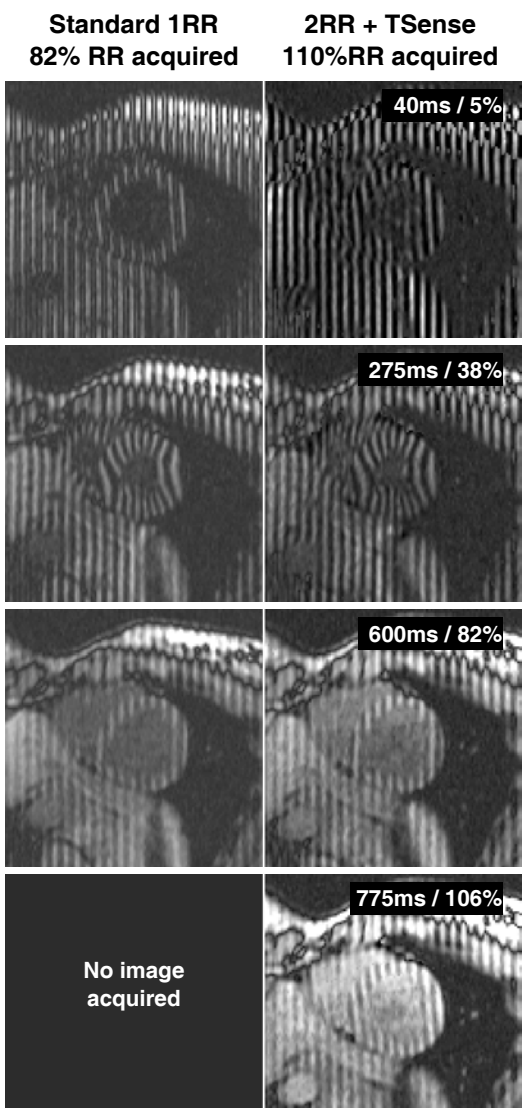
The benefits of the 2R-R / rate R=2 parallel imaging method are also applicable to other magnetization prepared cardiac imaging methods such as cine-DENSE.

In principle, and with appropriate modifications (e.g. the use of slab selective tagging), the second quiescent heartbeat could be used to concurrently image a second, different slice in the same breath-hold. Alternatively, this window could be used to perform an entirely different imaging procedure: e.g. a respiratory gating navigator for non-breath-held imaging, low-flip angle SENSE reference map, etc..

Using 3 or more R-R acquisitions with R>=3 SENSE imaging is likely to provide diminishing returns over the 2 R-R / R=2 SENSE method demonstrated here. In the 3rd and later R-Rs the magnetization recovery is slower than in the 2nd R-R. Also, reduced sampling times and larger G-factors associated with higher SENSE accelerations will cause much more image noise.

Conclusions: Improved tag CNR and longevity can be achieved using a 2R-R acquisition with rate 2 SENSE imaging whilst maintaining a constant breath-hold time. Sets of cine images covering 100% or more of the cardiac cycle can now be achieved with excellent tagging contrast. These improved methods permit the visualization of cardiac function during late diastole, prestretch during atrial contraction and early systole which were previously difficult to obtain in a standard tagged cine imaging sequence.





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