Myocardial perfusion imaging with an interleaved multi-slice acquisition for steady-state readout without saturation preparation or gating

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PURPOSE: First-pass myocardial perfusion imaging is a powerful noninvasive method for characterizing ischemic heart disease. Much of the work in first-pass myocardial perfusion imaging has used saturation preparation and an ECG trigger. A new ungated acquisition with no saturation preparation was proposed recently [1,2]. This approach uses either a 3D acquisition [1] or images a single 2D slice sequentially [2] to maintain steady-state. In this study, we propose interleaving 2D slice readouts in an ungated acquisition to enable a 2D multi-slice acquisition at steady-state. This has the added benefit of increasing the TR, which can improve CNR [3]. We compare the new ungated technique with interleaved acquisition to a conventional saturation recovery sequence, using both radial and Cartesian sampling patterns.

METHODS: Four different pulse sequences were studied. The first sequence was (1) Cartesian ungated interleaved spoiled gradient echo (SPGR), with matrix size kx-ky-slice = 144 x 108 x 3, 240 temporal frames, acceleration factor R = 6, and 24 phase encodes per slice. The effective TR was tripled (from interleaving the readout lines of 3 slices) yielding TR/TE = 7.8/1.1 msec. The second sequence was (2) Cartesian gated acquisition with saturation recovery, TR/TE = 2.6/1.1 msec (not interleaved), other parameters as in sequence (1). The third sequence was (3) radial ungated interleaved SPGR, with matrix size kx–ky-slice = 144 x 144 x 3, 240 temporal frames, and 24 rays acquired for each slice in golden ratio order. TR/TE = 8.4/1.1 msec. The fourth sequence was (4) radial gated acquisition with saturation recovery, TR/TE = 2.8/1.1 msec, and other parameters as in sequence (3). For sequences (2) and (4), a non-selective saturation recovery pulse with TI = 40ms triggered by ECG signal was applied. All three slices were acquired in one time frame after a single saturation pulse in sequential order so each slice had a different saturation recovery time.

Simulation: A numerical simulation of a cylinder phantom was designed to estimate the signal levels across a range of T1 values for four different sequences. Predicted signal levels were simulated based on the reconstruction of appropriately weighted k-space data, which was generated by the Bloch equation using the parameters listed above. An additional analytical simulation was performed based on the Bloch equation for centric and reverse centric Cartesian trajectories with both gated and ungated acquisitions. The image contrast for the gated saturation recovery sequence was defined as the simulated signal level during the first phase encode for the centric order and the final phase encode for the reverse centric case. For the SPGR sequence with no sat pulse, image contrast was defined as the steady state signal level.

Experiments: The four sequences described above were implemented on a 3T Siemens Trio whole-body scanner (Siemens Medical Systems, Erlangen, Germany). Two uniform vial phantoms with T1 of ~300ms and ~1000ms were imaged using the four different sequences to determine the relative signal level and CNR between the peak signal intensity and pre-contrast signal intensity. Additional parameters used in each sequence include a fast RF pulse, bandwidth = 1389 Hz/pixel, slice thickness = 5mm, and flip angle = 14 deg. For sequence (2), a reverse-centric phase encode order was employed. The ungated radial SPGR sequence was also tested in vivo on two volunteers using a 32-channel coil and contrast injection.

Reconstruction: Image reconstruction for all of the datasets and the simulations was performed using a compressed sensing algorithm with total variation (TV) applied as the constraint term in both the temporal and spatial directions [4].

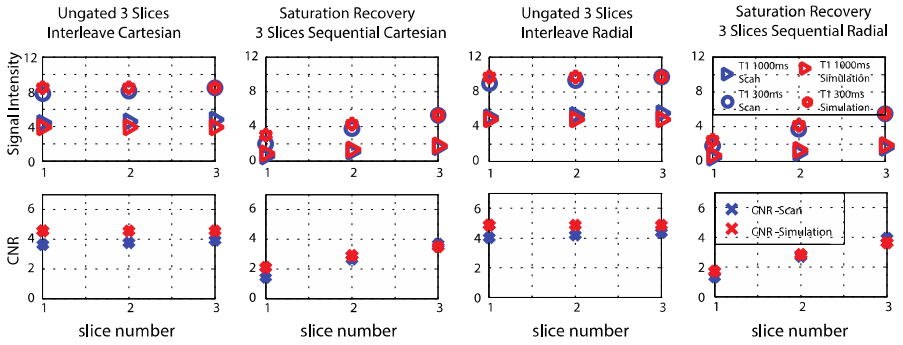

Fig 1: Comparison of simulation results and real data for signal intensity (top) and CNR (bottom) for four different acquisition patterns. The 3 slices ungated acquisition show similar signal level and CNR for all slices both in radial and Cartesian, and the saturation recovery sequence provides different signal levels due to the sequential acquisition order, the first slice have SRT about 40ms, the second slice have SRT about 100ms, and the SRT for the third slice approximate 160ms.

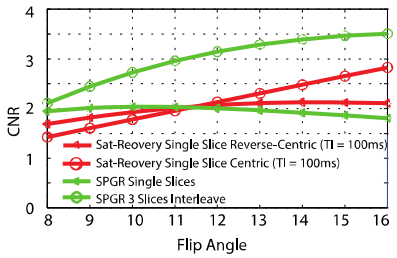

Fig 2: Analytical simulation result shows the CNR with different flip angle for different acquisition types.

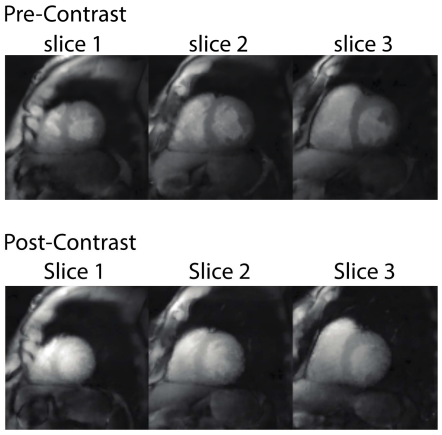

Fig 3: In vivo result with ungated 3 slices interleaved radial acquisition. The top row is pre-contrast and the bottom row is post-contrast.

RESULTS & DISCUSSION: From the numerical simulation and the phantom study (Fig 1), it can be seen that the ungated interleaved acquisition pattern can provide higher signal intensity and higher CNR than the conventional gated acquisition with magnetization preparation due to the longer effective TR. As expected, the signal level for the ungated interleaved acquisition is essentially the same from slice to slice due to the interleaved acquisition pattern, which enables all 3 slices to remain at steady state. From Fig 2, based on the analytical simulation we find that the interleaved patterns provide better CNR than both the ungated single slice SPGR sequence and single slice saturation recovery sequence with centric and reverse-centric orders. Fig. 3 shows an initial in vivo result, with significantly enhanced myocardial tissue post-contrast. A limitation of the interleaved approach is that the temporal resolution of each slice is decreased. Instead of three slices each being read out in ~50 msec, the set of slices is read out in ~150 msec. This is still likely fast enough to freeze cardiac motion, but interleaving more than 3 slices may not be a good approach unless even higher undersampling factors can be achieved. Another way to achieve more slices at steady-state is to use simultaneous multi-slice methods that excite two or three slices together with each alpha pulse [5]. It is also not well-studied how large of an effect deviations from steady-state have on cardiac perfusion imaging. The work here demonstrates that ungated interleaved multi-slice SPGR is feasible, and that higher CNR can be obtained through the increased effective TR of the interleaved acquisition pattern. More work is needed to evaluate the method in practice.

REFERENCE: [1] E DiBella et al., MRM 67:609–613, 2012. [2] B Sharif et al. JCMR 15(Suppl 1):O1, 2013. [3] P.Kellman et al., MRM 51: 200–204, 2004. [4] G Adluru et al., JMRI 29:466–473, 2009. [5] JB Weaver, MRM. Nov;8(3):275-84. 1988