Inversion recovery-prepared SSFP for cardiac-phase-resolved delayed enhancement imaging

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Introduction: There is increasing interest in using an SSFP readout following an inversion recovery pulse for T_1 quantification [1] or for myocardial delayed enhancement (DE) imaging [2,3]. In this work, simulations were performed to analyze the signal behaviour during an inversion-recovery prepared SSFP (IR-SSFP) sequence in the setting of DE imaging. A segmented, cardiac-gated IR-SSFP sequence was developed that acquires images throughout the heart cycle at various stages of T_1 signal recovery. The resulting images depict wall motion and a range of contrasts to more easily differentiate between healthy myocardium, blood, and infarct. This provides viability and cardiac function using a single pulse sequence. The IR-SSFP sequence was applied to patients with suspected myocardial infarct (MI).

Simulations: Simulations were performed to examine the effect of the SSFP readout flip angle, α, on the magnetization recovery curves of myocardium, infarct, and blood. The SSFP pulses played out after the inversion pulse limit the regrowth of the magnetization M_z to varying degrees depending on α and the T_2/T_1 ratio of a particular tissue (Fig 1). Thus, M_zs of the various tissues prior to the second and all subsequent pulses are not equal, altering their recovery curves relative to each other. It was found that $\alpha = 30^o$ results in healthy myocardium and blood having the same null point (Fig 1); this provides a DE image with bright infarct and no signal from myocardium or blood. The previous studies using IR-SSFP for DE imaging [2,3] were single shot acquisitions and therefore did not see this effect.

Methods: Based on the simulations, a segmented IR-SSFP pulse sequence was implemented using one inversion recovery pulse plus multiple SSFP readouts per heartbeat. The first inversion pulse is used to set up a consistent signal for the ensuing heartbeats. After the second and all subsequent inversion pulses, imaging is performed via a segmented SSFP-based acquisition. A specific TI is not required because this sequence produces multiple images each at a different effective TI. The IR-SSFP parameters were: $\alpha = 30^0$, TR/TE = 2.7/1.3 ms, FOV = 320 mm, slice thickness = 8 mm, VPS = 16, 192 x 192 imaging matrix and NEX = 1. This sequence required 12 heartbeats to acquire a single slice, and yielded 20 images over the cardiac cycle. For comparison, an IR-GRE sequence was also applied with the following parameters: $\alpha = 20^0$, TR/TE = 4.6/2.3 ms, FOV = 320 mm, slice thickness = 8 mm, VPS = 20, 192 x 192 matrix and NEX = 2. This sequence yielded a single DE image in mid-diastole from a 20-heartbeat acquisition. Five patients with suspected MI undergoing myocardial viability MRI scans were included in this study. The protocol was approved by our institution's research ethics board. Short-axis MR images were acquired using a 1.5-T scanner (CV/i, GE Healthcare, Milwaukee, WI) 10-25 minutes after the injection of 0.2 mmol/kg of Gd-DTPA. Conventional cine images were also acquired using a segmented SSFP sequence with the same parameters as the IR-SSFP sequence.

Results & discussion: Infarcts were detected in three out of the five patients by both DE methods (the other two patients had no infarcted tissue). A series of IR-SSFP images and the IR-GRE image of the corresponding slice are shown in Fig 2. Image 3 in Fig 2 shows how healthy myocardium and blood are nulled at the same time point, while infarct appears bright. This allows subendocardial infarcts adjacent to the blood pool to be easily detected, which is not the case with the IR-GRE image, where the blood pool is bright. Wall motion can be visualized in the 13 of 20 IR-SSFP cine images where T_1–based signal changes are small. The ejection fractions measured with conventional cine SSFP images were not statistically different than the ejection fractions measured using the IR-SSFP images ($p = 0.75$). We are currently determining the optimal placement of the inversion pulse to ensure that the DE-equivalent images are in mid-diastole, which also ensures that wall motion abnormalities in systole can be easily detected. With the multi-contrast images produced by this sequence, T_1 values for motion-compensated regions of interest can be calculated to improve differentiation and characterization of tissue pathologies. We are confident that this will lead to more accurate grading of cardiomyopathies and infarct heterogeneity, information of interest in a range of conditions including arrhythmias and diabetes.

Summary: We have developed and tested a gated IR-SSFP sequence yielding images that can be used to visualize both viability and wall motion. Multiple DE images are acquired throughout the T_1 recovery at various cardiac phases, allowing for improved discrimination between infarct, myocardium and blood.

References:

1. Scheffler et al, MRM, 2001;**45**:720-723
2. Li et al, JMRI, 2004;**20**:327-330.
3. Kellman et al, MRM, 2005;**53**:194-200

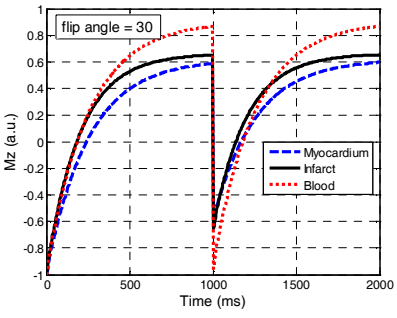

Figure 1: Simulated signal recovery of healthy myocardium, infarct, and blood undergoing IR-SSFP imaging.

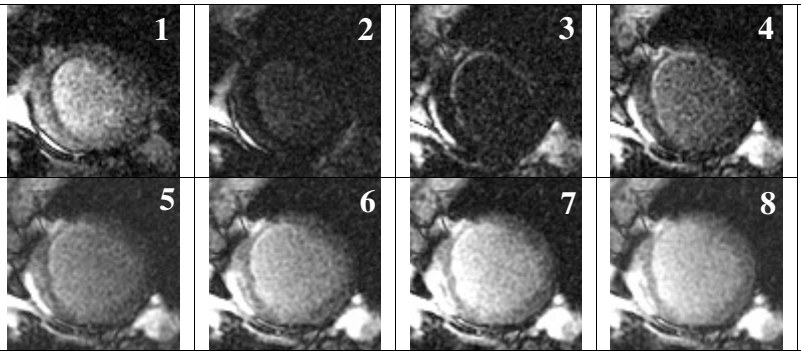

Figure 2: Eight consecutive IR-SSFP cine images from a single slice showing a subendocardial septal infarct as an area of fast T_1 recovery (hypoenhanced in image 1 and hyperenhanced in images 2-5), along with an IR-GRE image of the corresponding slice. Note the extent of the infarct is different between the two methods because the IR-SSFP images showing the infarct are at the end of systole, while the IR-GRE image is in mid-diastole.