Rapid Breath-held T1 weighted Double Inversion Recovery Black-Blood (DIR-BB) Turbo Spin Echo (TSE) Cardiac Imaging Using SENSE, ZOOM and Variable Refocusing Flip Angle Readout

feifei qu[1], Ramkumar Krishnamurthy[2], Amol Pednekar[3], Benjamin Y Cheong[4], Claudio Arena[4], Pei-Herng Hor[1], and Raja Muthupillai[4]

[1]Physics, University of Houston, Houston, TX, United States, [2]BioEngineering, Rice University, Houston, TX, United States, [3]Philips HealthCare, Houston, TX, United States, [4]Radiology, St. Luke¡¯s Episcopal Hospital, Houston, TX, United States

Introduction: The need for short repetition time (TR), and echo time (TE) for T_1 weighted imaging, imposes significant constraints for T_1 weighed spin echo imaging of the heart for the following reasons. The need for short TE puts a limit on the length of the turbo-spin echo (TSE) readout and prolongs the acquisition time beyond the respiratory capacity of most patients for a reasonable breathhold, and TR is essentially determined by the heart rate of the patient. Because of these limitations, in clinical practice, as an alternative, often an inversion recovery or gradient echo based T_1 weighted imaging of the heart is obtained [1-2]. Most institutions use a cardiac gated, multi-NSA, T_1 weighted sequence that lasts several minutes as an alternative.

In this work, we hypothesized that a combination of three strategies can be used to develop a multi-shot double-inversion recovery prepared turbo-spin echo method for T_1 weighed cardiac imaging (DIR-TSE) which include: (a) Reducing the total number of phase encoding steps by exciting a reduced FOV in the phase encoding direction by using 90º and 180º pulses that are orthogonal to each other (ZOOM method), (b) Applying parallel imaging in the RFOV direction using a high-density (32-channel) receive coil, and (c) Preserving the myocardial signal intensity the refocusing flip angle during the readout. The purpose of this work is to test the validity of this hypothesis using numerical simulations, phantom studies, and in subjects.

Methods: ***Theory***: Extended phase graph algorithm was used to calculate the variable flip angles to preserve the myocardial ($T_2 = 55ms/T_1 = 870ms$) signal keep as constant when crossing the center of k space [3-4] (Figure 1 The first five refocusing angles were used to make the system go to static pseudo steady state (SPSS). The echoes got form these angles are not necessary to be used as dummy echo, actually in the low to high profile order sequence, the improved contrast is produced by the first five echoes.). To minimize the sensitivity of the variable refocusing angle readout to cardiac motion, the smallest refocusing angle was set to the highest possible value within the limits of the readout [5-6].

Figure1. The flip angles used in the variable flip angle readout sequence and the corresponding normalized signal.

MR Imaging: The sequence was implemented as a patch on a commercial MR imager (Achieva, Philips 1.5T). All data acquisition occurred in diastole, and signal was received using a 32 channel RF coil (16 x 2 elements in the A/P direction). The FOV along the phase encoding direction was reduced by 50% using the ZOOM approach to have an effective FOV of: 320mm x 160mm; acquired voxel size: 2 mm x 2 mm x 8 mm; SENSE factor: 2 along the RFOV direction; TR/TE_{eff}: 1 RR interval/30ms. Following a double IR preparation, a TSE readout with variable refocusing flip angle (as shown in Figure 1) was used to acquire imaging data; Acquisition time is 5-7 RR intervals. Without SENSE and ZOOM, the scan time per slice was 20 RR intervals, for the same spatial resolution. **Subjects**: 5 normal subjects who provided written informed consent (4 male, 32.8+/- 7.9 yrs) were recruited for the study.

Results: Theoretical predictions were confirmed in using 1DFT analysis of non-phase encoded data in phantoms. Representative images from a subject are shown in Figure 2. Note that the phase encoding direction can be set to FH, and parallel imaging (SENSE) can be applied in the same direction, when ZOOM based spatial localization is used. The mean myocardial to liver contrast (CNR) improved from 4.3+/- 2.06 to 6.44+/- 2.89, using the new technique. To individually evaluate the effect of the variable refocusing angle during the readout, the conventional TSE sequence was also applied in conjunction with SENSE and ZOOM. Figure2 shows the image got from subject2 (male, heart rate is around 65bpm).

Figure2. A Normal MSH sequence
B Normal MSH sequence with SENSE and ZOOM
C MSH sequence with SENSE, ZOOM and variable flip angle.Low to high profile order is used, TSE factor is 10, scan time is 5RR.

Conclusions: The combination of SENSE, and ZOOM allowed us to reduce the total number of phase encoding steps without compromising spatial resolution, as well as the incorporation of variable refocusing flip angle readout to maintain the myocardial signal intensity during the readout, allows one to acquire DIR-BB prepared T_1 weighed images of the heart within a reasonable breathhold of 5-7 s per slice.   Our results show that myocardial to liver contrast can be improved by 50 %.

Reference: (1)Teng-Yi Huang et al, Med.Phys 2012 39(8): 4896-4902; (2) K.U.Bauner et al, European Journal of Radiology 2011 78:93-98; (3) Henning J, Magnetic Resonance, 1991 3:125-143; (4) Henning J et al, Magnetic Resonance 2004 51:68-80; (5)A.J.Madhuranthakam et al, Mag. Reson. Med 15 2007: 2523; (6) R. F. Bus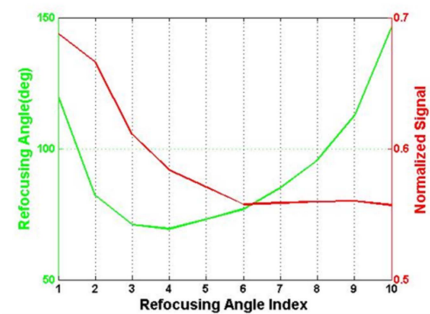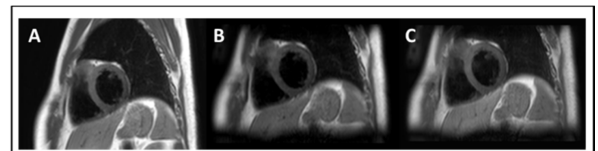se, Mag. Reson. Med 14 2006:2430;