Magnetization Transfer Effects in Cardiac Balanced SSFP Imaging at 3T

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Introduction: Balanced steady state free precession (bSSFP) imaging has an established role in the assessment of cardiac function and wall motion [1]. Bieri et al. recently showed that magnetization transfer (MT) may attribute an apparent signal reduction in bSSFP imaging [2] and MT can be utilized as a new type of contrast [3]. MT in 3T cardiac bSSFP imaging could be one possible application and therefore a thorough evaluation of MT is necessary. In this work, we evaluate the range of MT ratio (MTR) as a function of TR and relative RF pulse power within common imaging parameters, such as a repetition time (TR) range of 3 - 5ms and an excitation flip angle between 30˚ and 50˚. Multiple measurements are performed to establish repeatability and variation range in 3T cardiac imaging.

Theory: The steady state of bSSFP imaging may lead to an overall signal reduction in the liquid pool. This occurs when short TRs and large flip angle saturate macromolecular spins (semisolid pool), which exchange with liquid spins. The time-averaged saturation rate of longitudinal magnetization in the semisolid pool supplies the MT effect [4] and is dependent on the TR and RF pulse power. Fig 1 illustrates two ways to control the MT effect. We assumed a method where a change in TR would produce possible signal variation due to frequency responses, based on the typical off-resonance range (± 130Hz) over the left ventricle (LV) at 3T. Therefore, we evaluated only the RF pulse elongation factor by fixing the TR. The elongated RF pulse (Fig 1b) would have the different RF pulse energy and bandwidth while having the same flip angle. The reduction in RF energy (scale β) decreases the saturation effects by a factor of β^2.

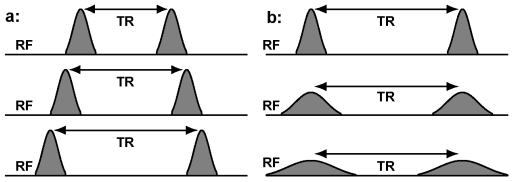

Figure 1. Factors contributing the MT effects in bSSFP imaging: (a) TR and (b) RF pulse elongation.

	3.6ms	4.0ms	4.4ms	4.8ms	5.2ms	5.6ms
Scale 1	56.0	50.4	45.8	42.0	38.8	36.0
Scale 2		12.6	11.5	10.5	9.7	9.0
Scale 3			5.1	4.7	4.3	4.0
Scale 4				2.6	2.4	2.3
Scale 5					1.6	1.4
Scale 6						1.0

Table 1. Relative saturation factors (SF) for different TR/RF scale combinations.

Methods: Experiments were performed on a GE Signa EXCITE HD 3.0T system. The T1 relaxation effect during excitation was measured in a uniform ball phantom (T1/T2 = 200/30 ms) from RF scale 1 to 3. The results showed no significant signal variation (less than 1.2%) with respect to the changes in the RF pulse elongation. Cardiac cine loops were acquired with an 8-channel cardiac phased-array coil in 4 healthy volunteers. An ECG gated bSSFP sequence was used with a total breath-hold time of 8 heartbeats. The RF pulse duration (τ) was 0.488ms (TBW=2) for the RF scale of 1. The TR elongation effect was measured with 6 different TRs (ranged from 3.6 to 5.6 ms). For each TR, we started with the RF scale of 1, and increased the scale factor until the timing limitation was reached. Accordingly, only one RF scale factor (=1) was used for the shortest TR (3.6ms), and six RF scale factors (1 to 6) were used for the longest TR (5.6ms). Table 1 shows the relative saturation factors (SF) for TR/RF scale combinations. MT measurements were made for the upper triangular region of Table 1. Repeatability was tested for 3 different TR/RF scale combinations (shaded regions in Table 1) with 5 measurements acquired in separate breath-holds.

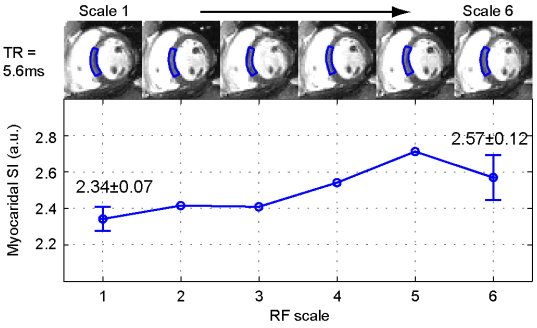

Figure 2. Cardiac images with different RF pulse elongation scales with the TR of 5.6ms. 5 repeated measurements were performed on the scale 1 and 6.

Imaging parameters were: FOV = 30 cm, acquisition matrix = 128 × 128, views per segment = 16, excitation angle = 45˚, and slice thickness = 5 mm. Regions of interest (ROIs) containing the septal myocardium were manually selected to avoid the banding artifacts based on the off-resonance map, acquired with 2 different echo times. B1+ inhomogeneity was measured by the cardiac B1+ mapping [5], and the actual flip angle over the ROI was computed for each subject. The MTR over the ROI was computed by

$$MTR = \frac{SI_{\max.RF\,scale} - SI_{\min.RF\,scale}}{SI_{\max.RF\,scale}} \times 100(\%). \quad (1)$$

Results: Fig 2 shows representative cardiac images as a function of the pulse elongation scale for a constant TR of 5.6ms. MTR was computed to be 8.9%. Fig 3 shows the MTR values as a function of the TR for 2 different subjects. The actual flip angle for each subject was computed by the B1+ maps to determine the actual RF pulse energy (the nominal flip angle was 45˚). The TR/RF scale combination of 4.4/3 produced the maximum MTR (ΔSF = 40.7) for the actual flip angle of 31.4˚ while 5.2/5 produced the maximum MTR (ΔSF = 37.2) for the actual flip angle of 25.2˚. The maximum MTR values for each subject ranged from 12 to 19% across all 4 subjects.

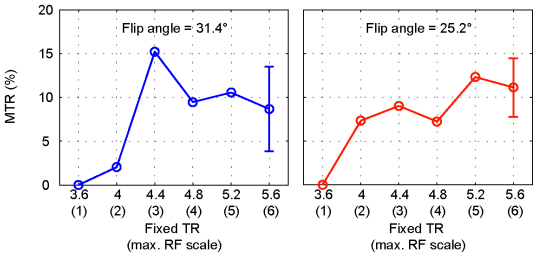

Figure 3. MTR values as a function of fixed TRs when the actual flip is (a) 31.4˚ and (b) 25.2˚.

Discussion: Our observed results suggest a MTR of 12-19% in 3T bSSFP cardiac imaging, which may be beneficial in the detection of infarcts and inflammation of the myocardial tissue. However, the computed MTR range is smaller than expected, in comparison to the 30-50% reported for brain applications [3]. Possible sources of this discrepancy are low actual flip angles (25˚ – 41˚), low steady-state myocardial signals, and the limited TR range in bSSFP due to frequency responses, which can collectively contribute to the smaller range of MTR obtained in this work. Further investigations to fully explore the TR/RF scale combinations in achieving optimal MTR are still needed.

References: [1] Schar M, et al., MRM 2004;51:799-806. [2] Bieri O and Scheffler K. MRM 2006;56:1067-1074. [3] Bieri O and Scheffler K. MRM 2007;58:511-518. [4] Graham SJ and Henkelman RM. JMRI 1997;7:903-912. [5] Sung K and Nayak KS. ISMRM 2007, p355.