Experiment and Simulation-based Optimization of Blood-Myocardium CNR in Cardiac SSFP Imaging

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Introduction: Cardiac SSFP imaging provides high signal-to-noise ratio (SNR) and excellent blood-myocardium contrast [1]. In previous studies, imaging parameters such as flip-angle and slice profile have been chosen primarily based on simulations that assume: 1) on-resonance, 2) achieving the prescribed flip-angles, and 3) ideal slice profiles. In this work, we experimentally measure SNR and CNR in 3T cardiac SSFP scans over a range of imaging parameters using product sequences. SNR and CNR measurements are compared with simulations that include measured off-resonance, measured flip angle variations, and actual slice profiles.

Methods: Experiments were performed on a GE Signa EXCITE 3.0T system with gradients supporting 40 mT/m and 150 T/m/s. In-vivo experiments were performed on one healthy volunteer. Short-axis scan planes were localized using the I-drive real-time system. Field-maps were acquired in a single breath-hold, using a cardiac-gated spiral sequence with 0.4 ms TE. Flip angle maps were acquired in a single breath-hold using a cardiac-gated spiral SDAM sequence [2]. Cardiac SSFP cine loops were acquired using a product 2D FIESTA sequence with prescribed flip-angles from 15° to 45° with 2° increment. The following parameters were used; acquisition matrix = 224 x 224, FOV = 30 cm, slice thickness = 5mm, and TR of 3.2 ms to 3.8 ms. Bloch simulation and image analysis was performed in Matlab.

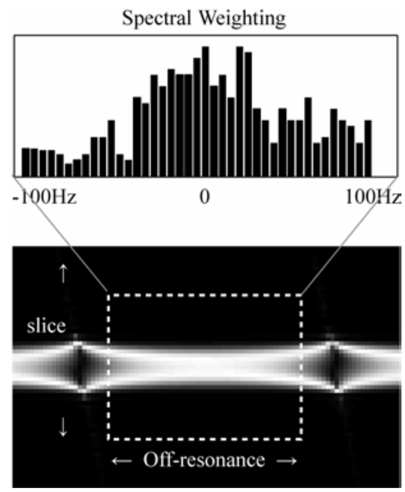

Figure 1: *(top) measured resonance frequency histogram and (bottom) simulated slice and spectral profile.*

Results and Discussion: The flip angle in SSFP is a critical factor in SNR and CNR optimization. To find the optimum flip-angle for blood-myocardium CNR, we considered both the spectral and slice profiles, and RF transmission non-uniformity. The 2D excitation profile (Fig. 1 – bottom) was simulated for all flip angles using Bloch simulation, using the actual RF pulse, and relaxation times T_1/T_2 = 1115/41 ms for muscle and T_1/T_2 = 1512/141 ms for blood [3]. The resonance frequency distribution (Fig 1 - top) was calculated from field map. Resonance offset over the left ventricle ranged from -99.0 Hz to 87.3 Hz. Measured flip-angles due to RF non-uniformity at 3T were 33.6% lower than the prescribed flip angle (31% lower for and 35% lower for muscle).

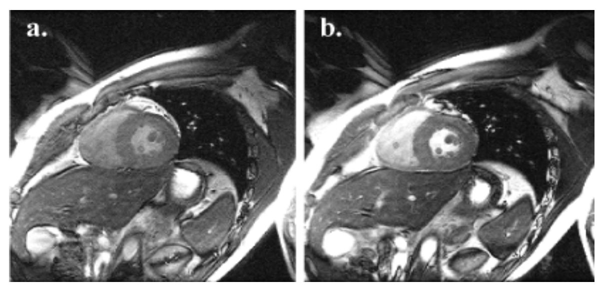

Figure 2: *Cardiac SSFP with actual flip angles of (a) 16.6° and (b) 30°*

Blood and myocardial signal intensities from SSFP images were calculated by averaging six segmented regions over the left ventricle. The standard deviation of noise was calculated by selecting a region of samples with no signals outside the body. Figure 2 contains the cardiac short-axis views in SSFP with different flip-angles. Prescribed flip-angles of (a) 25° and (b) 45° correspond to actual flip-angles (a) 16.6° and (b) 30°, based on the measured flip-angle maps. Figure 3 compares complete simulations with experimental measurements of SNR and CNR as a function of actual flip angle. Measurement and simulation (which includes off-resonance, actual flip angles, and actual slice profiles) are in good agreement. This comparison only spans actual flip angles from 10° to 30° because actual flip angles were lower than prescribed flip angles. Simulations suggest the optimal actual flip angle to be 45°.

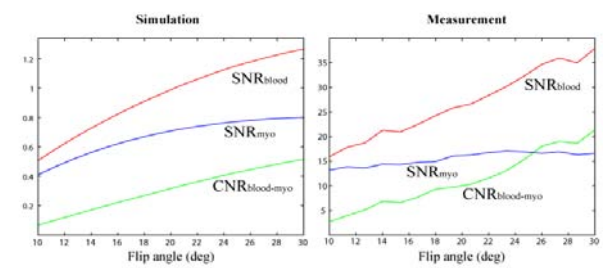

Figure 3: *Results from (left) simulation and (right) measurement: myocardial SNR (blue), blood SNR (red), blood-myocardium CNR (green), as a function of actual flip angle.*

Conclusion: SSFP has an important role in cardiac MRI. When optimizing scan parameters, we found that it is important to consider off-resonance, RF variations, and actual slice profiles. The greatest discrepancy between our detailed simulations and conventional simulation was the use of actual measured flip angles instead of prescribed flip angles. The difference can be 30% or more in cardiac imaging at 3 Tesla. We recommend using a localized pre-scan to calibrate the flip angles in regions of interest, or measurement of flip angle variation so that the prescribed flip angle can be set appropriately.

References

[1] Schar M., et al., MRM 2004:**51**:799-806. [2] Cunningham C., et al., MRM in rev. [3] Noeske R., et al., MRM 2000:**44**:978-982.