

## Optimal Flip Angle for balanced SSFP Cardiac Cine Imaging

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**INTRODUCTION:** Balanced SSFP (bSSFP) cardiac cine imaging is preferred to traditional spoiled GRE imaging<sup>1</sup> due to the high blood-myocardium contrast resulting from  $T_2/T_1$  differences for blood and myocardium. Previous literature<sup>2</sup> shows that the optimal FA for highest contrast between *stationary* blood and stationary myocardium at 1.5T is 54°. However, due to both inflow and out-of-slice flow effects in bSSFP, the flowing blood signal has a significantly different signal profile with respect to the FA compared to the stationary blood<sup>3</sup>. The **objective** of this work was to theoretically and experimentally determine the optimal flip angle for maximum blood-myocardium contrast in bSSFP cardiac cine imaging.

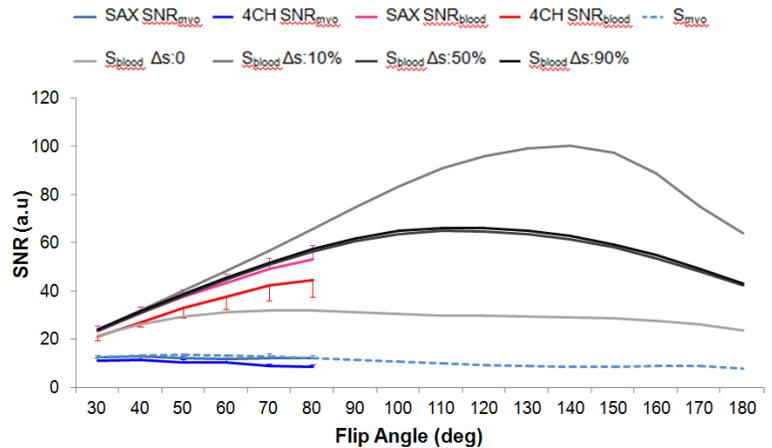
**METHODS:** Simulation: Bloch equation simulations were performed similar to Markl<sup>3</sup> et al. using MATLAB with imperfect slice profile (TBW: 2); 20 sub-slices ( $N_s$ ) for stationary myocardium ( $T_1/T_2$ : 867/57 ms), flowing blood ( $T_1/T_2$ : 1200/200 ms); with different percent spin replacement per TR ( $\Delta s$ ): 0-90%; and for different flip angles ranging from 30° to 180°. The other simulation parameters were out-of-slice effects ( $N_{os}$ ):  $4 \times \Delta s \times N_s \times T_2/TR$  for blood; measurements=3;  $N_{ky}=204$ ; and  $TR/TE=3.1/1.6$  ms. The spin density ( $M_0$ ) of the myocardium and blood was 0.7 and 0.95<sup>2</sup> respectively. Volunteer imaging: Five volunteers were imaged on a 1.5T MRI scanner (Siemens, Erlangen, Germany) using segmented bSSFP imaging with imaging parameters identical to the simulation (cardiac phases=25, resolution=1.5x1.5x5 mm, and BW= 1502 Hz/px;  $TR/TE=3.1/1.6$  ms and flip angles from 30° to the maximum flip angle limited by SAR ( $\leq 80^\circ$  at 1.5T)). Images were acquired in both short-axis and four chamber planes. Data analysis: The measured and simulated blood and myocardial signal were linearly scaled based on the linear regression analysis between the measured blood, myocardial SNR and simulated blood myocardial signal in the short axis. ROIs were drawn in the blood, myocardium, and background of the acquired diastolic images to measure the SNR and CNR of the blood and myocardium.

**RESULTS:** Fig.1 shows the simulated signal results for myocardium and blood with different  $\Delta s$  and a range of flip angles. The contrast between the simulated myocardium and stationary blood with imperfect slice profile is maximum between 130° and 150°. The contrast between simulated flowing blood and myocardium is maximum between 120° and 140° depending on  $\Delta s$ . Fig. 2 shows sample diastolic bSSFP images in SAX and 4CH planes with different flip angles and demonstrates that myocardial SNR remains relatively constant, blood SNR increases, and myocardial-blood CNR increase with increasing flip angle.

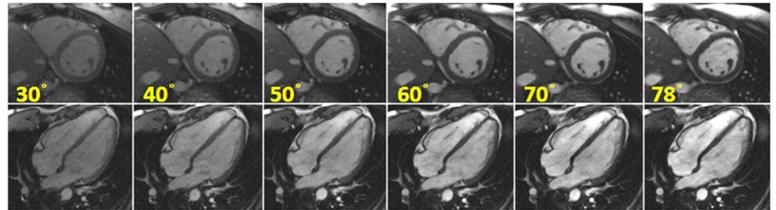
**DISCUSSION:** The simulated stationary myocardial signal agrees well with the measured SNR in both short-axis (SAX) and four chamber (4CH) views and shows limited flip angle dependence; the blood SNR increases with increasing FA up to a maximum that depends on  $\Delta s$ . The work of Markl *et al.*<sup>3</sup> and our simulations highlight the importance of considering imperfect slice profile and flowing blood to determine the blood-myocardium contrast for cardiac cine imaging. The measured blood signal, however, is likely different between the SAX and the 4CH planes due to differences in complex blood flow patterns. The achievable SNR and CNR for bSSFP cardiac cine imaging is currently SAR limited. Variable flip angle techniques should be able to achieve higher SNR and CNR without exceeding the SAR limit and should be explored further.

**CONCLUSION:** Cardiac cine bSSFP imaging should be performed with the maximum flip angle, subject to the SAR limitation, in order to achieve maximum blood-myocardium contrast.

**REFERENCES:** 1. Finn JP et al., *Radiology*. 2006;241(2):338-354. 2. Schär M et al., *MRM*. 2004;51(4):799-806. 3. Markl M et al., *JMRI*. 2004;20(4):697-705. **ACKNOWLEDGEMENTS:** The authors are grateful for research support from Siemens Medical Solutions.



**Figure 1: Simulation of the steady state signal of stationary myocardium and flowing blood with percent spin replacement per TR of 0 (no flow), 10%, 50%, and 90%. The experimental mean SNR values of the myocardium and blood signal measured from diastolic phase of short axis and four chamber view are also shown.**



**Figure 2: Short axis and four chamber view images for different FAs (30° - 78°). The blood myocardial contrast increases with increasing FA.**