

## Multiple Acquisition Fat-Saturated Balanced Steady State Free Precession Imaging

M. T. Alley<sup>1</sup>, S. S. Vasanawala<sup>1</sup>, R. J. Herfkens<sup>1</sup>, and B. A. Hargreaves<sup>1</sup>

<sup>1</sup>Radiology, Stanford University, Stanford, CA, United States

### INTRODUCTION

While balanced-SSFP (bSSFP) imaging is advantageous in its ability to produce high SNR in short imaging times, its clinical application has been limited due to several well-known shortcomings. The bright signal from fat is typically unwanted, and the short repetition times (TRs) required to avoid banding artifacts lead to limitations in the achievable resolution. This is especially true at higher field strengths where SAR considerations begin to limit the minimum possible TRs. To address these problems previous methods have combined multiple bSSFP acquisitions with different linearly-increasing excitation phases to either reduce signal variations with frequency (dark bands) or suppress fat [1]. Here we propose the addition of fat suppression to a multiple phase-cycled, 3D bSSFP acquisition to address both issues simultaneously.

### MATERIALS AND METHODS:

The most common approach to including fat suppression in bSSFP imaging uses the "alpha/2 - TR/2" transition to steady state [2]. Because a period of TR/2 is used the approach is effective only over every second signal pass band. The use of ramped [3] or Kaiser-window-based ramp pulses [4] separated by TR suppresses oscillations for *all* pass bands, which is critical for this application. Typically 4 TR intervals are used after every suppression block to establish steady state before imaging begins over the course of several TRs. The specific number of imaging TRs depends on the type of phase encoding used. For sequential ordering this is usually the number of phase encodings done in the slice direction.

Fat suppression is carried out using an inversion pulse with a flip angle calculated to minimize the signal from tissues with a specific T1 (in this case, fat) when the center of k-space is acquired. This allows the technique to work effectively with both centric and sequential phase encode orderings. In order to suppress the dark bands that result from the stop bands of the bSSFP, the acquisition is repeated with the RF excitation phase cycled by 180°. The two resulting data sets are then combined using a maximum intensity projection algorithm.

All imaging was done at 3.0T on a Signa HDx scanner (GE Healthcare, Milwaukee, WI, USA). Imaging was done in the axial plane with an eight channel cardiac coil (GE Healthcare, Milwaukee, WI, USA). A typical imaging volume consists of approximately 24, 3 mm thick slices. The in-plane matrix was set to 384 points in the readout direction and 192 phase encodes. The repetition and echo times (TR/TE) were 5.7 ms and 2.8 ms, respectively. These times had been lengthened to avoid exceeding SAR limits. Auto-calibrated parallel imaging [5] with a reduction factor of 2 was done in the in-plane phase encoding direction, and further time savings were gained by not acquiring the corners of  $k_y$ - $k_z$  space. Scan times for each phase cycle were thus 15 seconds.

### RESULTS

Figure 1 shows representative images from a single phase acquisition and the proposed, two phase-cycled technique. Because of the longer TR the single phase acquisition shows the dark banding in the liver that is a typical manifestation of off-resonance effects. These bands are eliminated using the proposed two-phase cycled approach. In addition, the alpha/2-TR transition to steady state in conjunction with the Kaiser-windowed ramped pulses provides excellent fat suppression throughout the entire image.

### CONCLUSION

We have demonstrated that it is possible to obtain a high quality fat suppressed bSSFP images in reasonable scan times. At higher field strengths the flip angles required for bSSFP imaging often require stretched RF pulses and thus longer TRs in order to avoid SAR limitations. Longer TRs are also needed when high resolution imaging is desired. In the presence of off-resonance effects the resulting signal voids can easily make the resulting images diagnostically unusable. With the proper approach to interrupting and restoring the steady state, phase cycling makes it possible to eliminate these banding artifacts. Although this approach necessitates two acquisitions, parallel imaging techniques make it possible to complete an exam in a reasonable breath-hold.

### REFERENCES

- [1]: Vasanawala SS, Pauly JM, Nishimura DG. *Linear combination steady-state free precession MRI*. Magn. Reson. Med. 2000; **43**:82-90.
- [2]: Deimling M, Heid O. *Magnetization prepared True FISP imaging*. In: Proceedings of the 2nd Annual Meeting of SMR, San Francisco, 1994, p. 495.
- [3]: Nishimura DG, Vasanawala SS. *Analysis and reduction of the transient response in SSFP imaging*. In: Proceedings of the 8th Annual Meeting of ISMRM, Denver, 2000, p. 301.
- [4]: Le Roux P. *Simplified model and stabilization of SSFP sequences*. J. Magn. Reson. 2003; **163**:23-37.
- [5]: P. Beatty, et al., *A Method for Autocalibrating 2D-Accelerated Volumetric Parallel Imaging with Clinically Practical Reconstruction Times*. ISMRM-ESMRMB, 2007; Berlin, p. 1749.

Research funded in part by NIH RR009784-11 and NIH EB009055-01

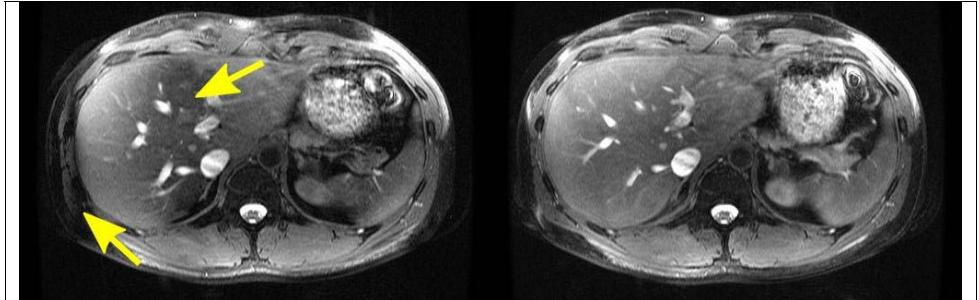


Figure 1: A sample image from a single-cycle fat-suppressed bSSFP acquisition (left) and the same location imaged using the proposed two-cycle technique (right). The multiple phase-cycled approach eliminates the banding artifacts from off-resonance effects (arrows).