Eddy Current Minimization in Selective Flow Suppression bSSFP Sequences

K. Dara[1], M. A. Griswold[1], J. J. Derakhshan[1], J. L. Sunshine[2], and J. L. Duerk[1]
[1]Department of Biomedical Engineering, Case Western Reserve University, Cleveland, Ohio, United States, [2]Department of Radiology, University Hospitals of Cleveland, Cleveland, Ohio, United States

Introduction: bSSFP sequences rely on a perfectly compensated zeroth gradient moment in each TR making them very sensitive to magnetic field inhomogeneities and changing eddy current patterns. Eddy current artifacts are emphasized when phase encoding (PE) gradient ordering schemes are not linear (1). Changes in eddy currents can give rise to abrupt deviations from the dynamic equilibrium and cause image artifacts. bSSFP sequences with additional preparatory schemes like diffusion weighting, T2 weighting, or selective flow suppression as seen in HEFEWEIZEN (2) are readily subjected to these artifacts since the sequence structure changes periodically. Beiri et. al. (3) have previously demonstrated some methods for eddy current minimization in bSSFP. Unfortunately, some of these earlier methods disrupt the bSSFP steady state due to imbalanced zeroth gradient moment in each TR and change image contrast when compared to bSSFP. In this work, we present a technique for eddy current minimization in bSSFP with selective flow suppression while retaining the bSSFP contrast. This is achieved by generating a continuous yet dynamically switching gradient pattern along the entire PE axis. This prevents changing eddy currents from being generated in subsequent TRs and minimizes the large deviations in PE gradient amplitude near the centre of k-space thereby reducing the eddy current artifact intensity.

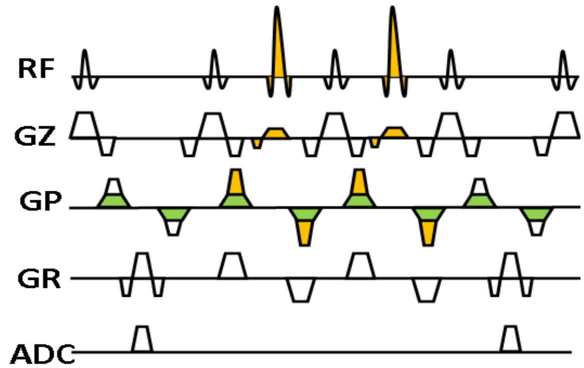

Fig 1: Sequence diagram of eddy current minimized selective flow suppression bSSFP sequence. Constant bipolar offset gradients (in green) are applied in each TR with preselected constant ramp times. Yellow RF pulses and gradients offer slice selective saturation to inflowing blood signal.

Methods: The selective flow suppression HEFEWEIZEN sequence (2) and an eddy current minimized version of it (fig 1) are used. The eddy current minimized sequence is obtained using the aforementioned dynamic switching pattern. This is employed using constant positive and negative gradients (called the bipolar offset gradients) with constant ramp times added to all regular gradients and/or spoilers in each TR on the PE axis (shown in green). The moments of these bipolar gradients cancel themselves in every TR. After obtaining IRB approval, both sequences were implemented and tested with similar parameters on a 1.5 T scanner (Siemens Espree, Germany) using the head and neck coils. Magnetization was prepared into steady state using an $\alpha/2$ pulse and TR/2 interval. In human volunteers imaging parameters included: TR=6.2ms, TE=3.1ms, base resolution=256, bandwidth=500Hz/Px, FA=50^{o}, averages=8 and linear reordering. Every six readouts spoiler gradients are used to selectively suppress incoming blood flow (not shown). The images obtained were reconstructed offline using Matlab. Artifact power was calculated as a percentage for all images respective to bSSFP images acquired without and with the use of the gradient switching patterns.

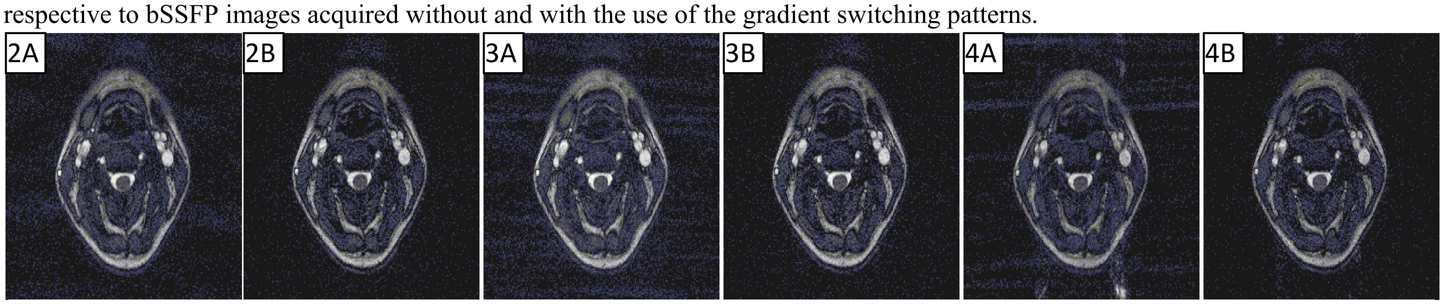

Fig 2A and 2B: bSSFP sequences without and with the use of bipolar switching gradients respectively. Fig 3A and 3B: Selective flow suppression bSSFP sequences without and with constant gradient switching. No flow spoiling gradients are used. Fig 4A and 4B: Selective flow suppression bSSFP sequences without and with constant gradient switching. Flow spoiling gradients are used on RE and PE axes.

Results: Fig 2A and 2B are bSSFP images without and with gradient switching patterns applied to each TR of the sequence. Periodically, no PE or RE gradients are employed for two TRs in figure 3A and 3B (extensions of fig 2A and 2B) thereby disrupting the steady state of the bSSFP sequence. This region acts a preparatory module in selective flow suppression bSSFP sequences. Figure 4A and 4B (extensions of fig 3A and 3B) have both PE and RE spoilers enabled. Artifact power is calculated using fig 2A and fig 4A is 26% and fig 2B and fig 4B is 22%.

Discussion: It is visually and quantitatively evident that eddy current artifacts are reduced to a greater degree in fig 4B (with dynamic gradient switching) as compared to fig 4A (without switching). Also there is no change in bSSFP image contrast in fig 4B. Ramp times of the various gradients and the amplitude, area and shape of the bipolar offset gradient used can be optimized.

Acknowledgements: This work was supported by Siemens Medical Solutions and in part by NIH F30HL094002 (JJD).

References: (1) Jung BA; MRM 2002;48:921–925 (2) Derakhshan JJ; MRM 2009; 29:1163-1174 (3) Bieri O; MRM 2005; 54:129–137