Fast Susceptibility Weighted Imaging (SWI) with an Echo-Shifted FLASH Sequence

J. Leupold[1], K. Zhong[1], and O. Speck[1,2]
[1]Dept. of Diagnostic Radiology, Medical Physics, University Hospital Freiburg, Freiburg, Germany, [2]Dept. of Biomedical Magnetic Resonance, Otto-von-Guericke University, Magdeburg, Germany

Introduction: With susceptibility weighted imaging (SWI), contrast between veins and surrounding brain tissue can be generated based on the low T_2* of deoxygenated blood [1]. We present a fast method to obtain SWI contrast with an echo-shifted FLASH sequence. The method is compared to FLASH with respect to scan time, arterial inflow enhancement, and vein detection sensitivity.

Method: Two sequences were compared for SWI: 1) 3D FLASH, provided as a product sequence on the scanner; 2) custom 3D echo-shifted FLASH (ES-FLASH) which allows shifting the gradient echo by one TR cycle enabling echo times longer than the RF-pulse spacing TR [2]. Both sequences employ RF-spoiling. The sequence diagram of ES-FLASH is shown in Fig. 1, incorporation of the shaded gradients shifts the echo by one TR cycle. To improve spoiling performance, the additional gradients were not only switched in slice selection direction as depicted but in phase encoding direction as well. The susceptibility difference leads to a frequency shift of 0.05 ppm between brain tissue and venous blood. SWI contrast is achieved by reduced T_2* and a signal phase difference leading to partial signal cancellation between deoxygenated blood and brain tissue. Imaging parameters for both sequences were: matrix size 320*256*88, resolution 0.7*0.7*0.7 mm^3. FOV 224*179*62 mm^3, k-space elliptically reordered, 10% slice oversampling. Parameters for FLASH: TR=32 ms, TE=25 ms, flip angle α=15°, readout bandwidth = 110Hz/px, 10:16 min scan time. Parameters for ES-FLASH: TR=17.15 ms, TE=25.05 ms, α=10°, readout bandwidth = 109Hz/px, 5:30 min scan time. The steady state of ES-FLASH with an echo-shift of one TR cycle is given by:

$$M_{Trans} = M_0 \sin\alpha \frac{1-\exp(-TR/T_1)}{1-\cos\alpha\exp(-TR/T_1)} \exp(-TE_0/T_2^*) \cdot \cos^2(\alpha/2)\exp(-TR/T_2^*) \qquad [1]$$

The steady state of FLASH is identical except of the last expression being dropped out (i.e., $\cos^2(\alpha/2)\exp(-TR/T_2^*)=1$). TE_0=TE for FLASH and TE_0=TE-TR for ES-FLASH.

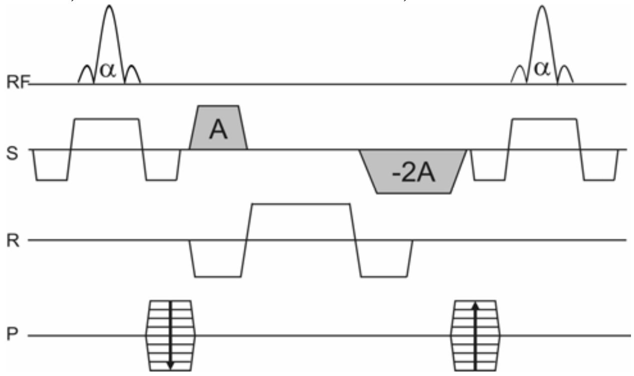

Fig. 1: Diagram of ES-FLASH for an echo shift of one cycle by means of additional gradients shaded) with a moment ratio of A/-2A. The same gradient pair was played out in phase encoding direction (not shown). 3D encoding is achieved by an additional phase encoding gradient table in slice direction (not shown).

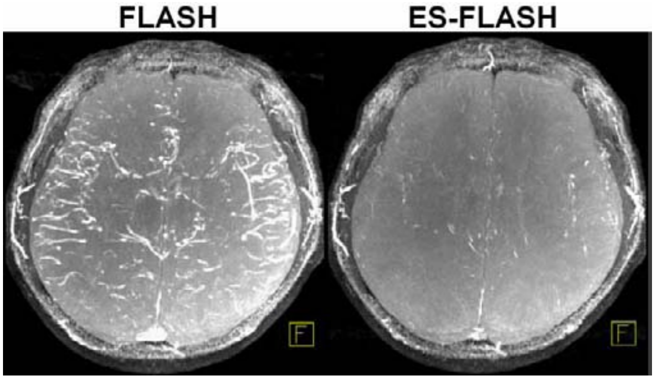

Fig. 2: MIPs for FLASH (left) and ES-FLASH. Note the reduced inflow enhancement for ES-FLASH.

Results: Images were taken on the brain of a healthy volunteer with a 3T Siemens Trio Scanner equipped with an 8-channel head-coil. Figure 2 displays Maximum Intensity Projection (MIP) over 88 slices for FLASH and ES-FLASH. Fig. 3 shows Minimum Intensity Projections (minIP) of two different 10 mm slabs consisting of 14 partitions each. Note the attenuated in-flow enhancement in the MIP for ES-FLASH (Fig. 2), which leads to enhanced contrast between brain tissue and veins in the minIPs (Fig. 3). The SNR of the images is in compliance with Eq. 1 (with T_1/T_2^* set to 1200ms/40ms). Eq. 1 gives an SNR ratio of 1.35 for FLASH/ES-FLASH, while an ROI analysis in the central slice of the 3D data results in a ratio of 1.49. A valuable advantage of ES-FLASH is the reduced acquisition time due to shorter TR compared to FLASH. Data can be acquired nearly twice as fast with ES-FLASH (acquisition time 5:30 min in contrast to 10:16 min for FLASH).

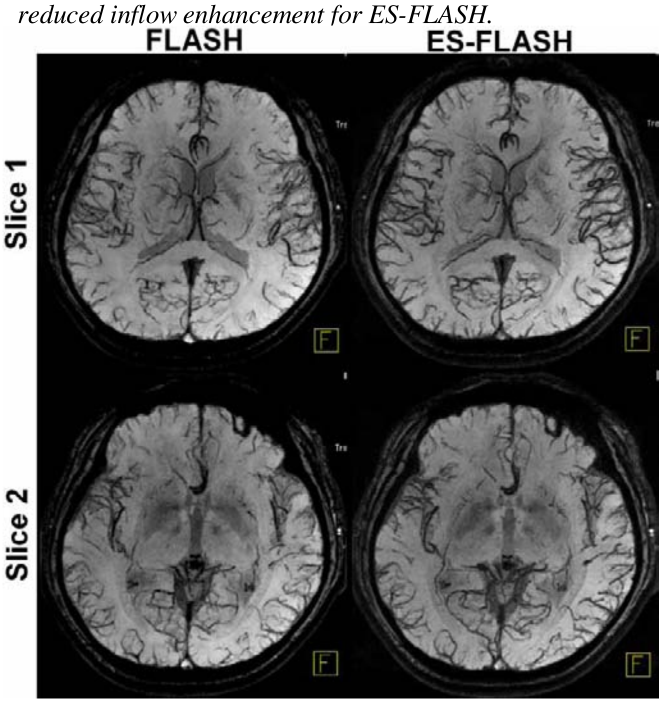

Fig. 3: Comparison of minIPs for FLASH (left) and ES-FLASH (right) at two different z-positions.

Discussion: With ES-FLASH it is possible to achieve susceptibility weighted contrast. The delineation of veins is improved over standard FLASH despite the reduced SNR. This is attributed to the fact that ES-FLASH shows significantly reduced inflow artefacts compared to FLASH. In addition, ES-FLASH allows a scan time reduction by a factor of two compared to FLASH.

References: [1] Haacke et al. MRM 52:612-618(2004). [2] Duyn et al. MRM 32:150-155(1994). [3] Chung and Duerk, MRM 42:864-877(1999).