Reducing EPI Distortion with Gradient Slew Rate of 700 T/m/s in Human Brain Imaging

Ek T Tan[1], Seung-Kyun Lee[1], Dominic Graziani[1], Matt A Bernstein[2], John Huston[2], Yunhong Shu[2], Paul T Weavers[2], Shengzhen Tao[3], Joshua D Trzasko[3], Jean-Baptiste Mathieu[4], Christopher J Hardy[1], John F Schenck[1], and Thomas KF Foo[1]

[1]GE Global Research, Niskayuna, NY, United States, [2]Radiology, Mayo Clinic, Rochester, MN, United States, [3]Biomedical Engineering, Mayo Clinic, Rochester, MN, United States, [4]GE Healthcare, Florence, SC, United States

Target Audience: Neuroradiologists, MR physicists.

Purpose: Recent work on a dedicated head-only gradient coil demonstrated maximum gradient amplitude of 80 mT/m and a 500 T/m/s slew rate (SR) [1]. Peripheral nerve stimulation (PNS) studies indicated no significant PNS in volunteers using a train of trapezoidal waveforms. A second iteration of the head-gradient coil has recently been completed allowing a SR up to 700 T/m/s. Such SR has hitherto been possible only in small-bore animal scanners, but is now available for in-vivo brain imaging. We are exploring the advantages of using high SR up to 700 T/m/s to improve the quality of echo planar imaging (EPI). Specifically, a high SR can reduce EPI echo spacing, which consequently reduces both spatial distortion and signal loss due to magnetic susceptibility [2, 3]. In preparation for imaging tests and in-vivo validation, we explore simulations to understand the extent of improvements to EPI at SR ranging from 200 T/m/s (attainable in whole-body MRI scanners) to 700 T/m/s (as in our dedicated head-only gradient coil).

Slew Rate (T/m/s)	ESP (μs)	Right Temoral Lobe: Mean/s.d. shift (mm)	Right Temoral Lobe: Mean/s.d. intensity	Left Temporal Lobe: Mean/s.d. shift (mm)	Left Temporal Lobe: Mean/s.d. intensity
200*	724*	-5.7/3.2	0.76/0.14	-11.5/1.2	0.63/0.19
200	588	-4.6/2.7	0.82/0.13	-9.3/1.1	0.67/0.19
300	475	-3.7/2.2	0.88/0.12	-7.5/0.9	0.71/0.18
500	375	-2.8/1.7	0.93/0.10	-5.9/0.7	0.76/0.17
700	344	-2.6/1.6	0.95/0.09	-5.4/0.7	0.79/0.17

Table 1. The tested gradient slew rates, the resulting EPI echo spacing (ESP), shifts in the phase-encoding direction, and normalized intensity changes in the right and left temporal lobes. With the exception of (*), whole-body PNS limits on gradient waveforms were disabled.

Methods: A T2-weighted FSE scan (FOV = 24 cm, TR/TE=0.1/10 s, 256×256 sampling in-plane, slice thickness=3mm) was acquired as a reference, in two normal subjects (under an IRB-approved protocol) using a conventional 3T MRI (GE MR750) with a 32-channel brain coil (Nova Medical, Wilmington MA). A 3D multi-echo gradient-echo acquisition with identical spatial sampling was used to obtain the B0-map needed to simulate EPI effects. The echo spacing was determined on the scanner without imaging by increasing SR from 200 T/m/s to 700 T/m/s (keeping maximum gradient amplitude at 50 mT/m), using a standard spin-echo EPI protocol for diffusion imaging, where the phase-encoding direction was in the anterior-posterior direction (FOV = 24 cm, TR/TE = 0.06/5 s, 128×128, slice thickness = 3 mm, parallel imaging R = 2). A spin-echo EPI image was also acquired at SR = 200 T/m/s (ESP = 724 μs) to compare the simulated EPI-distortion on the T2-FSE image. Spatial distortion and signal loss were simulated by applying the inverse of EPI-correction in k-space [5,6] on the T2 FSE reference. Spatial shift (distortion) and the normalized signal level in a 1 cm^2 ROI in the temporal lobe of the brain were recorded.

Results: Table 1 summarizes the results of ESP, spatial distortion and signal loss vs. the gradient SR. The disabling of the PNS model alone reduced ESP by 19%. The final ESP at SR=700T/m/s was less than half that achieved in conventional whole-body MRI. The improvement in shift (distortion) in the phase-encoding direction was also approximately proportional to the improvements in ESP. There was improvement in the intensity values with ESP, but these were not proportional to the ESP. Fig. 1 compares the T2-FSE reference against the acquired spin-echo EPI image and the EPI simulations on one subject. The extent of spatial distortion and signal loss in the image are visibly reduced in the SR700 result compared to the SR200 result. The differences between SR500 and SR700 were subtle.

Discussion and Conclusion: The dedicated head-only gradient system is predicted to provide a feasible means for low-distortion EPI at 3T. These simulation results will be validated experimentally over the next few months. The high SR capability will benefit complementary approaches to improve EPI quality, such as image distorion correction [3,5,6] and multi-shot EPI [7]. Whereas high gradient amplitudes primarily provide reduced echo times in diffusion MRI [8], a higher SR benefits EPI, as well as other pulse sequences such as spiral.

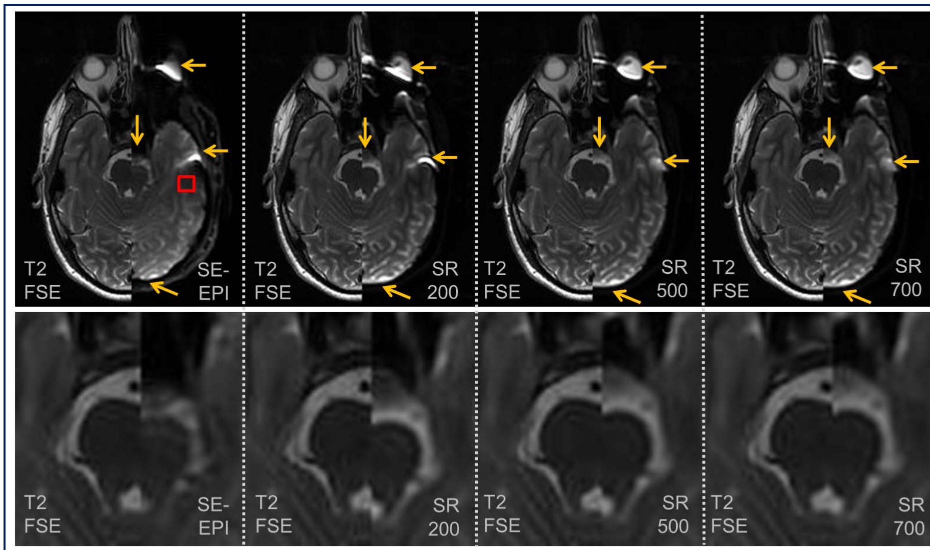

Fig.1. Horizontally-stitched images of the T2-FSE reference against the SE-EPI, SR200-700 simulated images, showing reduced distortion effects (arrows). The red box indicates an ROI used in the analysis. The top row shows images at the full FOV, while the bottom row magnifies the cortical-spinal region.

Acknowledgment: This work was supported in part by NIH 5R01EB010065. The views herein do not necessarily represent those of NIH.

References: [1] Lee SK, ISMRM '14;310. [2] Farzaneh F, MRM '90; 14:123-129. [3] Jezzard P, MRM '95;34:65-73. [4] Chronik BA, MRM '00;44:955-963. [5] Weisskoff RM, SMRM '93;411. [6] Munger P, IEEE TMI '00;19:681-689. [7] Skare S, MRM '07;57:881-90. [8] Ugurbil K, Neuroimage '13;80:80-104.