Highly Accelerated Single-Slab 3D GRASE with Phase-Independent Image Reconstruction

Hahnsung Kim[1], Dong-Hyun Kim[1], and Jaeseok Park[2]

[1]Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, Republic of, [2]Brain and Cognitive Engineering, Korea University, Seoul, Korea, Republic of

Introduction: Single-slab 3D turbo/fast spin echo (SE) imaging (1) with short non-selective pulses and variable flip angles in the refocusing pulse train has been recently introduced to increase echo train length and thus enhance imaging efficiency. It has been efforts to further prolong echo train length for high-resolution 3D brain imaging (2). However, this approach is highly energy-intensive and drops out signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) within permissible ranges of specific absorption rate (SAR). To enhance imaging efficiency while retaining SAR limit at high field, in this work we develop highly efficient single-slab 3D GRASE imaging, incorporating: 1) multiple echo planar imaging (EPI) readouts into a framework of turbo/fast SE imaging and thereby reducing the number of refocusing pulses and 2) parallel imaging assisted phase-independent image reconstruction to remove phase discontinuity related artifacts.

Sequence design and Reconstruction: The proposed single-slab 3D GRASE pulse sequence for very long echo train is shown in Fig.1, consisting of short non-selective excitation radio-frequency (RF) pulse followed by non-selective refocusing pulses trains with variable flip angles, EPI readout gradients and interleaved partition encoding gradient. Variable flip angles are calculated using exponential-flat-exponential prescribed signal evolution specific to gray matter (GM). EPI readout gradients are incorporated to collect multiple phase encoding signals. Multiple phase encoding signals for each RF pulse are denoted using the subscripts of refocusing pulse number and EPI echo number. Multiple echoes for each RF pulse are grouped (e.g., e_{11}, e_{12}, e_{13} for the 1st refocusing RF pulse and three EPI echoes) and then linearly phase-encoded in k-space with interleaved partition encoding for very long echo train. As a result, full k-space is evenly distributed into multiple echoes and whole k-space is under-sampled by an EPI factor. Interleaved acquisition along the partition direction denoted by superscription in Fig.1 (e.g., e^1, e^2), mitigates the signal difference between neighbor slice. Since phase encoding signals are reordered linearly, amplitude modulations along the phase encoding direction are smooth while phase modulations the same direction has discontinuities, potentially resulting in ghosting artifacts. To tackle the phase discontinuity induced problems, phase-independent image reconstruction is performed, in which each echo image is regenerated by SENSE-like parallel imaging technique and then averaged to retain SNR efficiency.

Materials and Methods: Numerical simulation of the Bloch equation is performed to investigate signal evolution along the long echo train in the proposed pulse sequence. Brain data is acquired in a healthy volunteer at 3T whole-body MR scanner (MAGNETOM Trio, Siemens Medical solutions) using both conventional single-slab 3D turbo SE imaging (1) and the proposed single-slab 3D GRASE for comparison. The imaging parameters of the proposed imaging were: TR/TE = 3000/416ms; FOV = 256x201x160 mm^3; resolution = 1x1x1mm^3; echo train length (ETL) = 67; EPI factor = 3; slice turbo factor = 2; echo spacing (ESP) = 6.22 ms; bandwidth = 1085Hz/Pix; imaging time = 4 min. The imaging parameters specific to conventional imaging were: TE = 330ms; no EPI factor; ESP = 3.3ms; bandwidth = 781Hz/Pix; and imaging time = 8min. For SENSE-like reconstruction, coil sensitivity is obtained from low resolution T2w reference scan. The imaging parameters: resolution = 4x4x4 mm^3; slice turbo factor = 4; and imaging time = 32sec.

Result: Numerical simulations in Fig.2 show that proposed sequence needs less refocusing pulses and shorter echo train duration as compared with 3D turbo SE imaging with slice turbo factor 2 due to the EPI readout gradient. Thus, the signal evolution level is scaled up, then, is evenly distributed to the interleaved slice. Fig.3 shows that comparison of SNR considering data acquisition time. In Fig.3 (c), phase-independent image reconstruction resolves severe periodic phase discontinuity leading to ghosting artifacts. Averaged each echo image retains SNR as compared with 3D turbo SE imaging with slice turbo factor 2. Proposed pulse sequence shortens data acquisition time rather than 3D turbo SE imaging, and also maintains contrast rather than 3D turbo SE imaging with slice turbo factor.

Conclusion: The proposed variable-flip-angle single-slab 3D GRASE with long echo train has been successfully demonstrated with phase-independent image reconstruction, enhancing imaging time efficiency with no apparent loss of signal and image contrast. Since the proposed method generates T2- and T2*-weighted images simultaneously, the averaged image might not appear a pure T2 contrast.

Acknowledgments: Mid-career Researcher Program (2011-0016116) and World Class University (WCU) (R31-10008) through National Research Foundation of Korea (NRF), the Ministry of Education, Science, Technology

References: 1. Mugler et.al, Proc ISMRM, p203; 2003; 2. Mugler et. al, Proc ISMRM, p2106; 2004

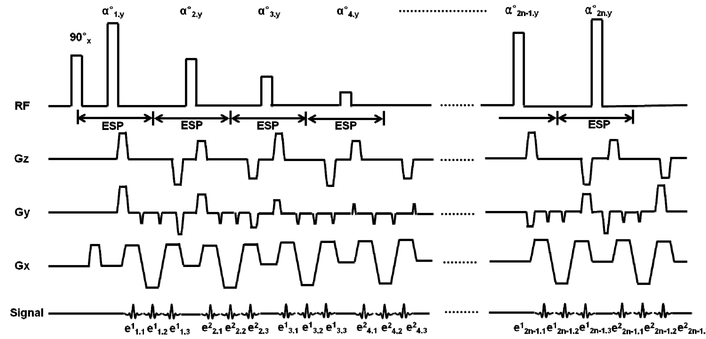

Fig. 1. Timing diagram of the proposed Single-slab 3D GRASE pulse sequence

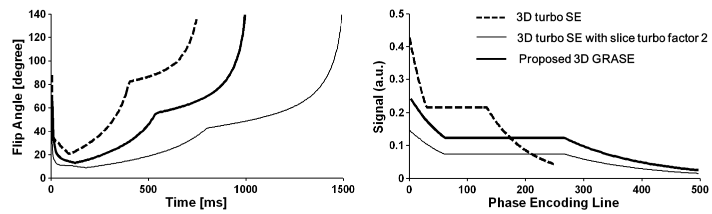

Fig. 2. Variable refocusing flip angles (a), corresponding signal evolution of GM in each case.

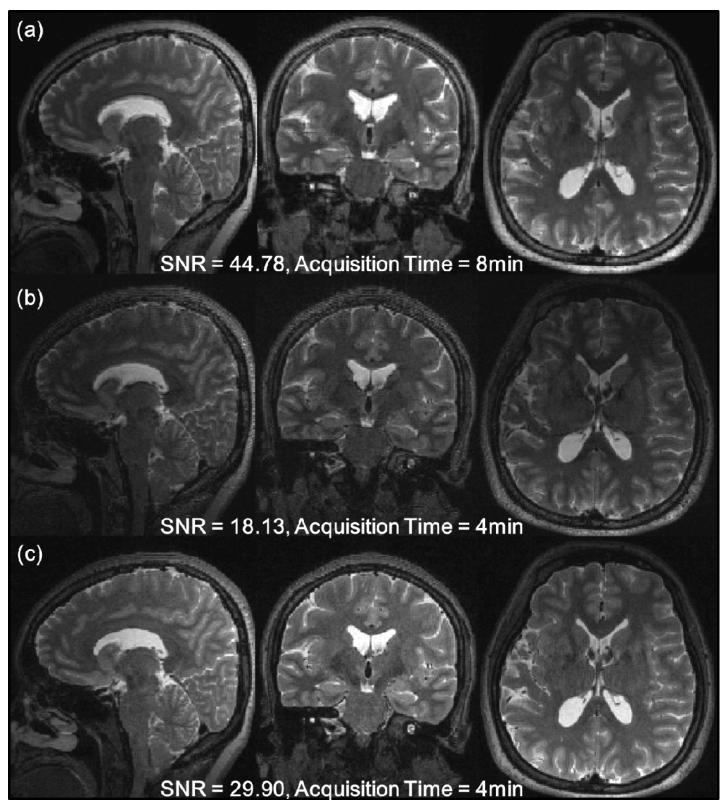

Fig. 3. T2-weighted image: 3D turbo SE imaging (a), 3D turbo SE imaging with slice turbo factor 2 (b), proposed pulse sequence (c).