A modified variable fip angle using a predefiend slice profile in a consecutive interleaved EPI

Dae-Hun Kang[1], Jun-Young Chung[1], Da-Eun Kim[1], Young-Bo Kim[1], and Zang-Hee Cho[1]

[1]*Neuroscience Research Institute, Gachon University of Medicine and Science, Incheon, Korea, Republic of*

Introduction. Variable flip angles (VFA) have been used to induce pseudo steady-state of transverse magnetizations in rapid imaging such as multi-shot echo planar imaging (EPI) sequence with minimal intersegment delay [1,2]. The use of progressively increasing flip angles yields a constant transverse magnetization after each RF pulse. For simply calculating the flip angles, the equation of $tan\,\theta_{i-1} = sin\,\theta_i\, for\ i = 2, \dots n$ and the last flip angle $\theta_n = 90°$ was used without considering T_1 recovery of longitudinal magnetization and slice profile, namely a typical VFA. In the previous study, the calculation considering T1 recovery was introduced [2]. In case of the shorter imaging time compared with T_1, the value of T_1 becomes a minor component in calculation of VFA. A calculation considering slice excitation profile was proposed, in which a RF pulse shape was progressively changed with VFA to maintain the observed slice profiles [3]. In this paper, we re-calculated a VFA considering a predefined slice excitation profile without changing RF excitation pulse by a computer simulation. By applying a modified VFA to consecutive interleaved multi-shot EPI (ciEPI) schemes [4], a intersegment magnitude variation was reduced and a SNR of images was improved.

Methods. (Theory) Theoretically, a typical VFA yields the same transverse magnetization after each RF excitation in a case of a slice excitation profile having a ideal rectangular shape. In practive, the various flip angles are applied to an excitation region in portion to a non-ideal slice profile for a single flip angle, namely effective flip angle $\theta(z)$. Then, the *n*-th transverse magnetization S_n can be calculated by the following: $S_n = \int_{-\infty}^{+\infty} \rho_0 \prod_{i=1}^{n-1} cos(\theta_i(z))\, sin(\theta_n(z))\, dz$, where $\theta_i(z)$ denotes a slice profile of an effective flip angle excited by the *i*-th flip angle of variable flip angles. Under the condition of $S_n = S_{n-1}$ meaning a constant transverse magnetization, two solutions are derived. The one solution is $tan\,\theta_{i-1}(z) = sin\,\theta_i(z)\ for\ all\ position\ z$ which is trivial in an ideal case. The other solution is directly derived by a computer simulation under the given conditions of the number of shots and the predefined slice profile.

(Computer simulation) To find a modified VFA, the distribution of magnetization was assumed to be uniform in a simulation. The slice excitation pulse was predefined as a sinc function weighted by Hanning filter with duration of 3840μs, samples of 768 and bandwidth-time-product of 4.2. Fig. 1 shows the shape of RF pulse and its excitation profile. In a simulation, the variable flip angles were found to equalize the transverse magnetizations in every shot, to maximize the transverse magnetization and to set the last flip angle to 90˚. In respect to the various numbers of shots, modified VFAs were calculated by simulations and compared with typical VFAs as plotted in Fig. 2.

(Data acquisition) To validate the effect of modified VFA, data was obtained by ciEPI with 8 segments in 7T magnetic field (MAGNETOM, SIEMENS, Erlangen). The flip angles of 27.0˚, 29.2˚, 31.9˚, 35.5˚, 40.5˚, 47.9˚, 60.6˚ & 90.0˚ were used as a modified VFA, while 20.7˚, 22.2˚, 24.1˚, 26.6˚, 30.0˚, 35.3˚, 45.0˚ & 90.0˚ as a typical VFA. The followings are common parameters: FOV 220mm^2, matrix 220x220, partial Fourier factor 6/8, In-plane resolution 1x1mm^2, Sl.thick.=1mm, TE=16ms, TR=3sec.

(SNR analysis) For determining SNR in images, the difference method was used, which is based on the evaluation of a difference image of two repeated (identical) acquisitions [5]. The ROI was chosen by a 64 x 64 square at the center of images.

Results. In Fig. 3, the images were obtained by using a typical or a modified VFA. A modified VFA led to reduce ghost artifacts due to the reduction of intersegment magnitude variations. For artifact-free images, the magnitude correction [6] was still needed. As illustrated in Fig.3e, tendency of navigators' energies showed that transverse magnetizations with a modified VFA had less variations compared to ones with a typical VFA. As shown in Table 1, SNR was calculated in each slice. A modified VFA yielded more than 14% of a SNR improvement as compared to a typical VFA.

Discussions and conclusions. The present work demonstrates a modified VFA considering a predefined RF pulse for establishing a pseudo steady-state within the limited number of excitations. By using a modified VFA, intersegment magnitude variations decreased and it resulted in reducing ghost artifacts in images. This product, however, was insufficient to eliminate ghost artifacts completely. Nevertheless, a modified VFA increases a SNR of images by improving the segments having the low transverse magnetizations in a typical VFA. Since white noise level is assumed to be constant, an upward equalization of magnitudes of transverse magnetizations will provide a better SNR in an image. On the other hand, the observed profile was changed since magnetization was gradually depleted by subsequent RF pulses. The variations of the observed profile can be problematical when a slice thickness is large because of including various types of tissues. In our experiment, a slice thickness of 1mm was considered to be small enough. We believe that the proposed method will support ciEPI schemes to measure brain activity with a higher SNR in high-resolution fMRI.

Table 1 SNR comparison between a typical and a modified VFA

SNR	typical VFA	modified VFA	Gain (%)
Slice #1	28.5±0.5	32.6±0.5	14.5
Slice #2	27.9±0.1	32.7±0.3	17.1
Slice #3	27.7±0.1	32.5±0.4	17.2
Slice #4	25.8±0.2	30.8±0.4	19.4
Slice #5	24.6±0.5	29.5±0.1	19.7

References. [1] S. G. Kim et al., Magn. Reson. Med. 35:895-902(1996) [2] D. N. Guilfoyle et al., NMR Biomed. 19:108-115(2006) [3] M.H.Deppe et al., J. Magn. Reson. 202:180-189(2010) [4] D-H. Kang et al., Proc. ISMRM, 2012;20:3244 (submitted) [5] Dietrich O. et al, J. Magn. Reson. Im. 26(2):375-385(2007) [6] D-H. Kang et al., Proc. ISMRM, 2011;19:2368 **Acknowledgement.** This research was supported by Basic Science Research Program through the National Research Foundation (NRF) funded by the Ministry of Education, Science and Technology (20110030089).

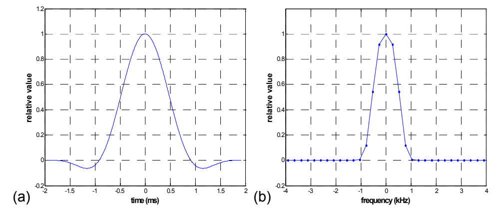

Fig. 1 (a) RF pulse used for a slice excitation and (b) the following slice profile

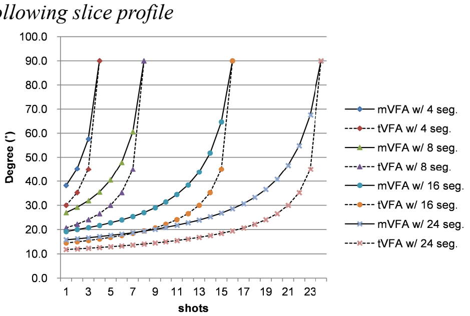

Fig. 2 The modified VFAs obtained by a simulation in cases of the various number of shots (n = 4, 8, 16 & 24). The dotted lines indicate the typical VFAs in the same cases.

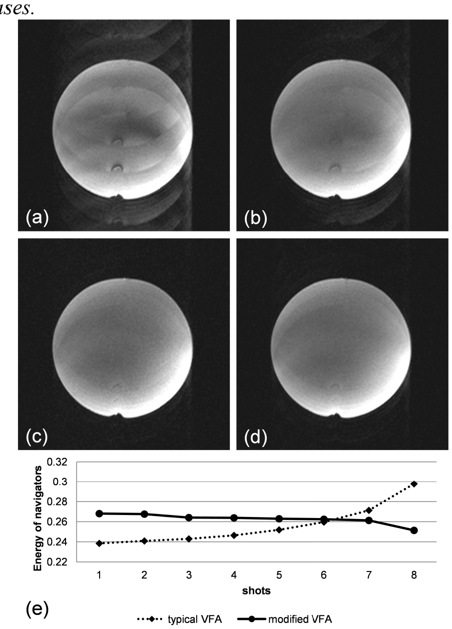

Fig. 3 The images were obtained by a ciEPI scheme with VFAs. The image (a) and (b) were obtained by using a typical and a modified VFA, respectively. The image (a) showed more artifacts than (b). Eliminating the ghost artifacts by intersegment magnitude correction, the image (c) and (d) were obtained. The graph (e) showed values of root square of energy of navigators of data (a) and (b).