Combination of consecutive interleaved EPI schemes and parallel imaging technique

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Introduction. Single-shot echo planar imaging (ssEPI) has widely been used to gather k-space data rapidly, which is sensitive to field inhomogeneity and local susceptibility. In contrast to ssEPI, interleaved multi-shot EPI (iEPI) is able to provide the short echo time and the short echo train length, which lead to reduce geometric distortions. iEPI with a minimum intersegment delay was presented for reducing motion artifacts by imaging like ssEPI [1,2], namely consecutive interleaved EPI (ciEPI). In this paper, we propose the combination between ciEPI and parallel imaging, which is able to provide some benefits.

Methods. (Pulse sequence) In contrast to ssEPI, the echo train length was divided by the number of segments in a case of iEPI. A ciEPI scheme was implemented by minimizing intersegment delay as illustrated in Fig.1. To achieve a pseudo steady-state during several excitations, variable flip angles were employed. The flip angle of the *i*-th segment was calculated by using $tan\,\alpha_{i-1} = sin\,\alpha_i\; for\; i = 2, \ldots n$ and the last flip angle $\alpha_n = 90°$. By fusing parallel imaging technique, the number of segment to be acquired decreased. When a ciEPI scheme with 6 segments and R=2 was applied, it is necessary to measure only 3 segments. In this case, the used flip angles were 35˚, 45˚ and 90˚ in order. As well, echo time shift technique was applied for reducing intersegment phase discontinuities.

(*k*-space trajectory) An example of a conventional trajectory of iEPI schemes with 6 segments was described in Fig. 2a. By choosing 1st, 3rd and 5th segment or the others (2nd, 4th and 6th segment) among 6 segments, the effective reduction factor R=2 was achieved in a case of iEPI as illustrated in Fig. 2b. Fig. 2c shows an example of iEPI schemes with 6 segments and R=3.

(Reconstruction) Since the technique of variable flip angles caused intersegment magnitude variations, a correction using navigator was applied to all data obtained from ciEPI schemes [3]. For R>1, the missing lines were estimated by GRAPPA technique [4]. Auto-calibrating signal (ACS) lines were obtained by additional acquisitions. For example, when one k-space with missing lines was composed of 1st, 3rd and 5th segment among 6 segments, other k-space consisted of 2nd, 4th and 6th segment was additionally obtained once. A full k-space was obtained by combining two different k-spaces, which was used as ACS lines.

(Data acquisition) To validate ciEPI with parallel imaging, data were acquired using ciEPI with 6 segments and R=1, 2 and 3 and with 8 segments and R=1, 2 and 4 in 7T magnetic field (MAGNETOM, SIEMENS, Erlangen). The followings are common parameters: FOV 220mm^2, matrix 220x220, partial Fourier factor 6/8, In-plane resolution 1x1mm^2, Sl.thick.=1mm, TE=20ms, TR=2000ms. For a rapid high-resolution imaging, a ciEPI scheme with 24 segments and R=4 was used having the following imaging parameters: FOV 220mm^2, matrix 220x220, partial Fourier factor 6/8, In-plane resolution 0.6x0.6mm^2, Sl.thick.=1mm, TE=19ms, TR=3000ms, T_β=460ms, average=5. The number of segments was chosen for setting the echo train length of a segment to be below 23ms, which is smaller than T_2^* of gray and white matters in 7T [5]. Fat-saturation pulses were used in all acquisitions.

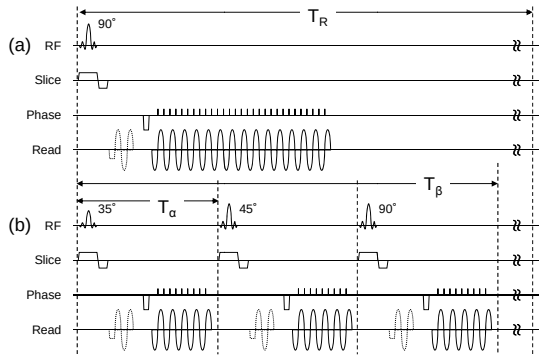

Fig. 1 Pulse sequence diagrams of (a) ss-EPI and (b) ci-EPI having 3 segments

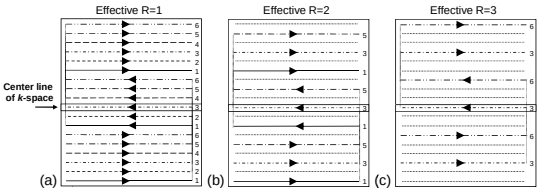

Fig. 2 k-space trajectories of ci-EPI with 6 segments and (a) R=1, (b) R=2 and (c) R=3

Results. The images in Fig. 3 were obtained by various ciEPI schemes. As increasing the effective reduction factor, the data collecting time T_β was reduced. In contrast to ssEPI, the shorten TE could be applied to all schemes and distortions of the images were almost same regardless of a reduction factor. As shown in Fig.4, the image with 0.6mm in-plane resolution was compared to the image with 1.0mm. A short TE and a short echo train length due to ciEPI scheme with parallel imaging led to reduce distortions in a high-resolution image.

Discussions and conclusions. The present work demonstrates the combination of ciEPI schemes and parallel imaging technique. The ciEPI schemes were presented in the previous studies [1,2], which provides a chance to reduce motion-related artifacts. A large number of segments leads a short TE, a short echo train length, and finally less-distorted images. Simultaneously it causes a low SNR, a long data collecting time and a small coverage for a limited TR. By combining ciEPI schemes with parallel imaging, the transverse magnetization given for each segment can be increased by reducing the number of segments which should be measured. Simultaneously, the data collecting time also reduce as small as the reduced number of segments. Although a g-factor may affect SNR of images on reconstruction of parallel imaging, these lead to improve SNR efficiency with maintaining less-distortions of images. We believe that it will be possible to measure high-resolution fMRI images using the proposed.

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] D-H. Kang et al., Proc. ISMRM, 2011;19:2368 [4] Griswold MA, MRM. 47(6):1202-1210(2002) [5] A.M. Peters et al., Magn. Reson. Imaging. 25:748-753 (2007)

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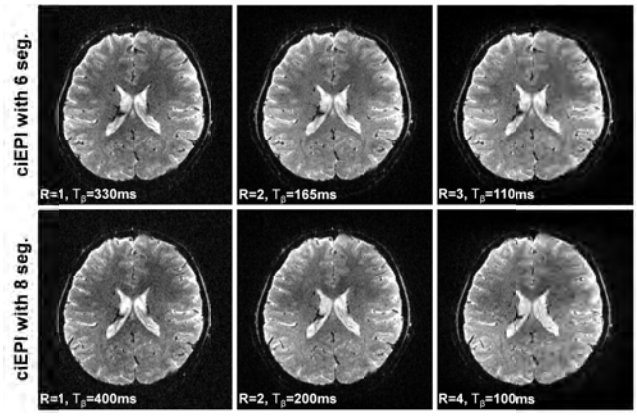

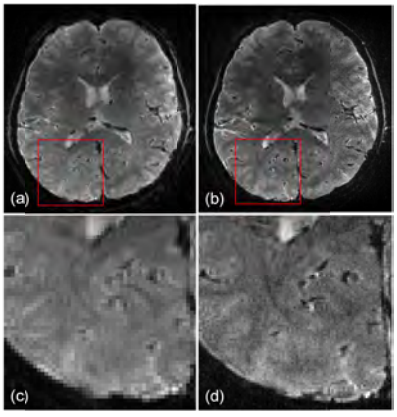

(Left)*Fig. 3 The images obtained by ciEPI schemes with 6 or 8 segments and R=1,2 and 3 (or 4 in case of having 8 segments). The images having similar qualities are shown regardless of reduction factors.*

(Right)*Fig. 4 High resolution imaging using ciEPI schemes, in which images have (a) 1.0 mm and (b) 0.6 mm in-plane resolution. The images were averaged with 5 repetitions. The images of (c) and (d) are magnifying views of the regions of a red box in (a) and (b), respectively.*