Utilizing 3D spatiotemporally encoded imaging from a different perspective

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Target Audience : MR physicists and radiologists

Purpose: New type of ultrafast imaging techniques have recently been proposed using spatiotemporal encoding (SPEN) (1,2). In SPEN-based imaging, a quadratic phase produced by a frequency-modulated pulse like a chirp pulse sequentially localizes a signal in time and space at the same time along the SPEN direction, thereby not requiring Fourier transform along that direction. Hence, Nyquist ghostings in SPEN-based imaging is weaker than in echo-planar imaging(EPI). However, SPEN has an inherently low spatial resolution because of signal localization based on a quadratic phase. A super-resolved(SR) image reconstruction method has been developed that improves the spatial resolution of SPEN imaging with an acceptable SNR (3,4). Despite several works on SPEN imaging so far, discontinuous signal variation seems to exist between adjacent pixels and signal overlapping from nearby pixels used to take place along the SPEN direction in the original SPEN imaging. In this study, we show that there is an effective way to *circumvent* this problem in the original SPEN imaging scheme with no special reconstruction technique like SR reconstruction if we employ a 3D imaging scheme for SPEN imaging. The guideline for parameter setup not to meet the overlapping artifacts was also discussed. The proposed method was demonstrated by theory and phantom imaging.

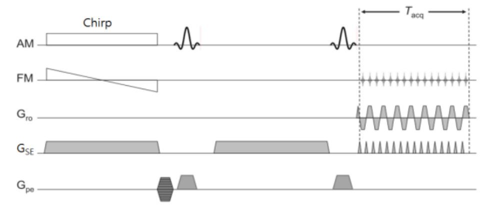

Fig. 1. 3D RASER sequence diagram. $\boldsymbol{G_{ro}}$(Read-out gradient), $\boldsymbol{G_{SE}}$(SPEN gradient), $\boldsymbol{G_{pe}}$(Phase-encoding gradient)

Theory and Methods: The idea of our new strategy is simple, that is, to use the SPEN for spatial encoding in the slab-selective(SS) direction, not in one of the two directions in the principal plane, in 3D SPEN imaging. With this strategy, we have a couple of advantages: First, we can benefit from 3D SPEN imaging in terms of SNR because the peak echo amplitude is reduced due to the quadratic phase existing in the SPEN direction and, thus, can maintain the SNR by reducing the quantization error when the dynamic range is limiting (5). Second, if we set the SPEN to be performed in the SS direction, the number of sampling points in the SPEN direction (N_{SPEN}) is not necessarily large enough to cover as broad as area possible, as is usually needed in the axes of the principal plane. If we can take a relatively small N_{SPEN}, image blurring due to T_2-decay along the readout(RO) direction can also be reduced because the total acquisition time (T_{acq} in Fig.1) is reduced. Even when we set the SPEN direction to be the SS direction, signal overlapping from nearby slices can happen unless some parameters are properly set up. The effective spatial resolution (Δz) in SPEN is given by (3): $\Delta z = FOV_e/\sqrt{R}$ [1], where FOV_e is the length of excited FOV and R = Pulse bandwidth×length. If Δz is the same as the nominal resolution, $N_{SPEN} = FOV_e/\Delta z$. Accordingly, based on Eq.[1], the number of sampling points corresponding to Δz is given by: $N_{eff} = N_{SPEN}/\mathrm{sqrt}(R)$ [2]. Since signal overlapping begins to appear when $N_{eff} > 1$ in principle, R has to be no less than $(N_{SPEN})^2$. For example, if we set N_{SPEN} to be 20, the R value of the RF pulse has to be at least 400. To confirm the condition for avoiding signal overlapping and evaluate the performance of the proposed method, ACR phantom imaging was performed at 3T (Siemens Magnetom Trio, Erlangen, Germany) with a 4-channel volume coil. For 3D SPEN imaging, 3D RASER sequence (2) was used with the scan parameters as follows: TE/shot-TR = 150/250 ms, FOV = RO(240)×SPEN(60/120)×PE(240) mm^3, FA = 38.8°(Ernst's angle), R-value (pulse bandwidth×length) = 512/128, matrix size = RO(80)×SPEN(20/40)×PE(80), isotropic resolution = 3mm^3. Reference image was acquired using 3D GRE imaging with GRAPPA. Scan parameters were: TE/TR = 3.53/7.6ms, FOV = 384 mm^2, FA = 9°, matrix size = 128×128, isotropic resolution = 3mm^3, total scan time = 46s.

Results and Discussion: Figure 2 show the axial slices of phantom images obtained from 3D RASER imaging by using the new strategy, i.e., by setting the SPEN to be in the SS direction, except for Fig.2E that was the 3D reference GRE image. The SPEN direction was the SS direction through the plane. Figures 2A and B were acquired with R = 512, and Figs.2C and D with R = 128. The number of sample points in Figs. 2A and C was 20 in the SPEN direction. It was 40 in Figs. 2B and D. According to Eq.[2], N_{eff} was calculated to be 0.88 (A), 1.77 (B), 1.77 (C), and 3.54 (D). As expected, signal overlapping from other slices was more apparent when R was small and N_{SPEN} is large, i.e., N_{eff} was more apart from 1. Figure 3 shows the comparison of our new strategy (Fig.3A) and the original strategy (Fig.3B) in the principal plane. Thus, the two axes of the principal image were PE and RO in Fig.3A, having SPEN in the through-plane direction, and SPEN and RO in Fig.3B, respectively. The image quality of Fig.3A was clearly better than that of Fig.3B, especially in terms of the discontinuous signal variation existing pixel by pixel, which was mentioned in Purpose. Signal overlapping observed in Fig.2 are also seen in Fig.3B because N_{eff} = 1.5 (R = 256, N_{SPEN} = 24).

Conclusion: We here suggested a simple strategy of using the SPEN direction as s slab-selective direction in a 3D SPEN imaging scheme. In this way, we make the two axes of the principal plane to be the readout and phase-encoding axes, avoiding SPEN-related image artifacts in the principal plane. We also proposed the proper experimental condition for not meeting signal-overlapping artifacts that is one of the SPEN-related artifacts. The proposed methods were well confirmed by phantom experiment.

Reference: [1] Ben-Eliezer N, Shrot Y, Frydman L. High-definition, single-scan 2D MRI in inhomogeneous fields using spatial encoding methods. Mag Reson Imaging 2010;28:77-86. [2] Camberlain R, J-Y Park, Garwood M, et al. RASER : A new ultrafast magnetic resonance imaging method, Mag Reson Med 2007;58:794-799. [3] Chen Y, Li J, et al. Partial fourier transform reconstruction for single-shot MRI linear frequency-swept excitation, Mag Reson Med 2012. [4] Seginer A, Schmidt R, et al. Referenceless reconstruction of spatiotemporally encoded imaging data: principles and applications to real-time MRI. [5]CADIZ ET, MUNOZ C, Quantization error in magnetic resonance imaging, Concepts in Magnetic Resonance Part A, 2014;Vol.43A(3):79-89.

Acknowledgment: This work was supported by IBS-R015-D1-2014-a00.

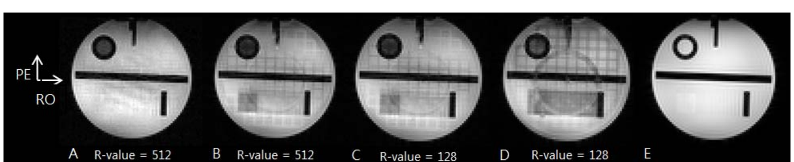

Fig. 2 Axial slices of ACR phantom images obtained by using the new strategy. The SPEN direction as a SS direction is through the plane. A and B are acquired with R-value of 512 and C and D with R-value of 128. E is the reference image obtained from 3D GRE imaging. In A and C, 20 sample points were set up in the SPEN direction. In B and D, 40 sample points in the SPEN direction. Signal overlapping from other slices is more apparent when R-value is small and the number of sample points in the SPEN direction is large.

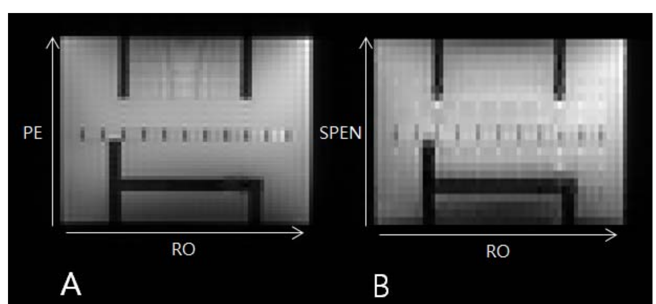

Fig. 3 Coronal slices of ACR phantom images. (A) was obtained by using the new strategy, i.e, by setting the SPEN to be in the slab-selective direction. Thus, the two axes of the image are PE and RO. (B) was obtained by using the original strategy. The two axes of the image are SPEN and RO. The SS direction is through the plane. R = 256. N_{SPEN} = 24.