Parallel Line-scan Echo-planar Spectroscopic Imaging

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Introduction

Line-scan echo-planar spectroscopic imaging (LSEPSI) has advantages in rapid water-fat discrimination for temperature mapping, motion insensitive metabolite mapping, and localized metabolite mapping with no aliasing artifacts in the line-scan direction [1, 2]. However, it has a disadvantage in that it is difficult to improve the number of lines, spectral resolution, and scan speed simultaneously. That is, if the number of lines during TR is increased, then the data acquisition time should be shortened, which results in a decrease in spectral resolution, and vice versa. In this paper, we present parallel LSEPSI (PLSEPSI) to overcome this limitation. This technique employs a parallel line-scan technique proposed for diffusion imaging [3]. The parallel line-scan technique uses simultaneous excitation of multiple lines and data processing to discriminate these lines by using the sensitivity difference among multiple receive coils. And it has an interesting feature on the signal-to-noise ratio (SNR); it preserves the SNR under certain condition, and this is very different from the conventional parallel imaging that reduces the number of phase encoding. The PLSEPSI technique obviously overcomes the limitation about the LSEPSI because the multiple lines are acquired simultaneously. The most interesting point is what condition the PLSEPSI preserves the SNR. The precise SNR analysis of PLSEPSI when a 2-channel array coil and 2-line excitation is used is described, and the acquisition of spectroscopic images is demonstrated by applying PLSEPSI to a phantom.

Methods

The developed PLSEPSI method uses a line-scan technique of which π/2-pulse and π-pulse excite multiple slices to acquire x-spatial information, and an echo-planar technique to acquire y-spatial information and spectral information simultaneously (Fig. 1). A typical configuration of a 2-ch array coil and two excited parallel slices are shown in Fig. 2. The two gray lines of the four excited lines are suppressed in the pre-pulses part since the number of lines should be less than the number of channels. The SNRs of PLSEPSI and non-parallel LSEPSI per measurement time are calculated (Fig. 3). The α:1-α denotes the sensitivity ratio between ch. 1 to ch. 2 at point x_a, and β:1-β denotes the sensitivity ratio between ch. 1 to ch. 2 at point x_b, which is the aliased point of x_a. The signal intensities at x_a and x_b are assumed to be the same, and T1 is sufficiently small for simplicity. The blue plane shows the averaged SNR at x_a and x_b using non-parallel LSEPSI. Each SNR at x_a and x_b is calculated by weighted averaging in which the weight is α:1-α and β:1-β, respectively. The red plane shows the averaged SNR at x_a and x_b using PLSEPSI. The number of acquisitions was set at two as the measurement time is half that of LSEPSI. Thus, SNR_a and SNR_b at x_a and x_b are reciprocals of g-factors g_a and g_b at x_a and x_b multiplied by √2 for the accumulation, which is represented by the following equations:

$$SNR_a = \sqrt{2}/g_a = \sqrt{2(\alpha-\beta)^2/\left(\beta^2+(1-\beta)^2\right)},\ SNR_b = \sqrt{2}/g_b = \sqrt{2(\alpha-\beta)^2/\left(\alpha^2+(1-\alpha)^2\right)}\ .$$

Interestingly, the SNR of PLSEPSI around ($\alpha = 0$ and $\beta = 1$) or ($\alpha = 1$ and $\beta = 0$) is higher than the SNR of LSEPSI. This condition occurs if one line is primarily detected by one coil and the other is primarily detected by the other coil. We compared PLSEPSI to LSEPSI on a 7-T MRI for a small animal study using a phantom. A transmit and receive volume coil and a 2-ch receive array coil were used. The sensitivity map of each receive coil was calculated as the ratio between the gradient echo images acquired by the receive coil and the volume coil. The measurement parameters of PLSEPSI and LSEPSI were a TE of 136 ms, spectral bandwidth of 7.24 ppm (128 points), FOV of 32 mm (16 pixels), slice thickness of 2 mm, and the number of acquisitions was 1. The TR was 2000 ms for PLSEPSI and 4000 ms for LSEPSI. Cosine-modulated sinc waves, which were adjusted to excite parallel slices 2-mm wide and with a 16-mm interval each for π/2-pulse and π-pulse, were used for PLSEPSI. Averaging with sensitivity correction was used to process LSEPSI data, and unfolding the aliased image with sensitivity maps was used to process PLSEPSI data.

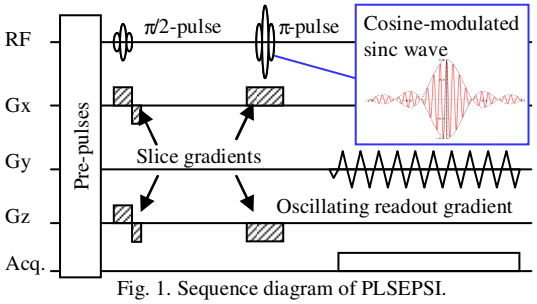


Fig. 1. Sequence diagram of PLSEPSI.

Results and Discussion

PLSEPSI enabled spectroscopic imaging with no aliasing in half the measurement time of LSEPSI (Fig. 4). Obtained SNRs were close to the theoretical values (Fig. 5). At the non-aliased red region, the SNR increased because the acquired signal intensities using PLSEPSI and LSEPSI per shot were the same. At the aliased blue and green regions, the SNRs decreased with the ratios similar to the theoretical values, and this means that the SNR of PLSEPSI may increase if the condition of the red region shown in Fig. 3 is satisfied.

Conclusion

We developed PLSEPSI to improve the number of lines, spectral resolution and scan speed. Analysis of the SNR suggests that this technique can increase the SNR under certain conditions, which will be important in measuring low concentrations of metabolites.

References

[1] Oshio et al. MRM 2000;44:521. [2] Bito et al. ISMRM 1998:1235. [3] Chu et al. ISMRM 2008:761.

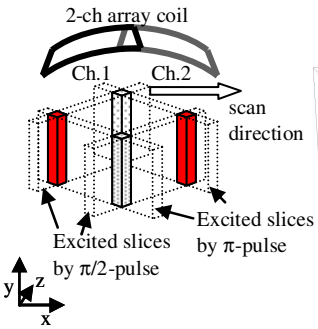


Fig. 2. Schematic diagram of array coil and lines excited by PLSEPSI.

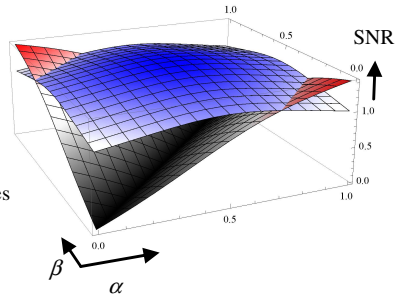


Fig. 3. SNRs of LSEPSI (blue plane) and PLSEPSI (red plane) per measurement time.

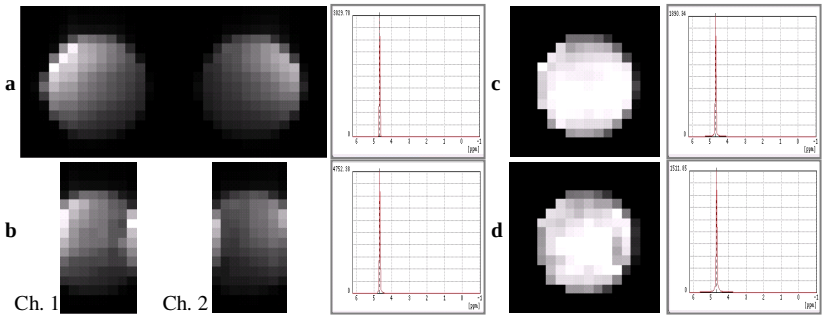
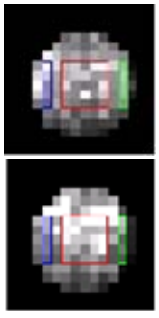


Fig. 4. Spectroscopic images of phantom using (a) LSEPSI and (b) PLSEPSI. (c) Averaged and sensitivity-corrected image using LSEPSI, and (d) unfolded image using PLSEPSI.



Region	red	blue	green
SNR of LSEPSI	2627	2689	2734
SNR of PLSEPSI x √2	3324	2193	2080
Ratio of SNRs	1.27	0.82	0.76
Theoretical ratio	1.41	0.81	0.67

Theoretical ratio at red region is √2 because no aliasing occurs. Theoretical ratios at blue and green regions are calculated using $\alpha = 0.82$ and $\beta = 0.29$.

Fig. 5. SNR map of (a) LSEPSI and (b) PLSEPSI. SNRs of experimental and theoretical values show good agreement.