Slice-direction SENSE: A Sensitive Acquisition Method for Detecting Neuronal Current MRI Signal Induced by Epilepsy

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Introduction

A recent study[1] reported a successful detection of neuronal currents generated by epiletiform spikes (interictal discharges) using MRI in human brain. This indicates that the neuronal current MRI (ncMRI) technique can be potentially used in epilepsy studies. Nevertheless, interictal spikes are brief events that last only 20-200 ms. To capture the interictal events, it is necessary to utilize a very short TR (~ tens of ms) to achieve high temporal resolution in the MRI acquisition. However, when acquiring the images of multiple slices, such a TR is too short to be achieved by the conventional pulse sequence used in ncMRI studies (gradient-echo spiral/EPI). To overcome this limitation, here we propose a simultaneous multislice acquisition method, Slice-direction SENSE (Sl-SENSE), to be used for detecting the ncMRI signal induced by interictal discharges. By exciting and acquiring multiple slices simultaneously, Sl-SENSE is able to reduce the minimum achievable TR and improve the temporal resolution by a factor of two or larger. In this study, we performed a simulation experiment to evaluate the detection sensitivity of Sl-SENSE to brief interictal spikes. Our experimental results are designed to provide convincing evidence for the feasibility of using Sl-SENSE to detect the epilepsy induced ncMRI signal.

Methods

Theory: The principle of Sl-SENSE has been described by Larkman et al.[2]. Briefly, a multifrequency RF pulse is used to excite multiple slices simultaneously, and the MRI signal is measured using multicoil arrays. The total signal measured by coil *i* (y_i) is given by:

$$y_i = C_{i1}S_1 + C_{i2}S_2 + C_{i3}S_3 + ... + C_{im}S_m \qquad [1]$$

where C_{ij} is the sensitivity of coil *i* to slice *j*, and S_j is the signal from slice *j*. Eq. [1] can be expressed by matrix multiplication: $y = CS$. Then the signals from individual slices (*S*) can be obtained with the following relationship:

$$S = (C^T C)^{-1} C^T y \qquad [2]$$

Simulation experiment: A simulation experiment was performed to demonstrate the feasibility of using Sl-SENSE to detect epileptic ncMRI signal. In the experiment, an electrical pulse coil (20 mm diameter) was attached to the head of a healthy human subject. Brief rectangular electrical pulses were generated by the coil to simulate the interictal discharges. The stimulation paradigm consisted of two pulse trains separated by 2 s resting period (no pulse was delivered). Each pulse train included 20 pulses with 400 ms inter-pulse interval. The duration of each pulse was 50 and 100 ms in the first and second pulse train, respectively. To detect the MRI signal change induced by the electrical pulses, MR images were acquired using Sl-SENSE and also the conventional spiral sequence with an 8-channel head coil at 3 T. Four 8-mm thick slices with 4-mm gap were selected to cover the brain areas near the pulse coil. The minimum available TR (= 140 ms) was used in the conventional sequence. The TR was shortened to 70 ms in the Sl-SENSE acquisition by simultaneously acquiring two interleaved slices (slices 1&3, then 2&4). In the both sequences, TE = 20 ms, matrix size = 54 x 54, and the corresponding Ernst angle was used as the flip angle.

Data analysis: Firstly, a regressor was created by sampling the waveform of the pulse trains with sampling interval = TR, and then the correlation coefficient maps for phase images were calculated by correlating the voxel time courses with the regressor. The corresponding t-maps were obtained by converting the correlation coefficients to t-values. The activated voxels corresponding to both positive and negative phase changes were identified by thresholding the t-maps with t > 4.0. To evaluate the detection sensitivity of the Sl-SENSE and the conventional spiral sequence, the total number of activated voxels in the four slices and their average t-value were calculated and compared between these two acquisition methods.

Results

Fig. 1 shows the t-maps of phase signal overlaid on anatomical images. It is found that the electrical pulses induced significant activation in all the four slices acquired by the Sl-SENSE sequence. In contrast, slice 1 and 2 of the conventional sequence did not show any activated voxels. In the Sl-SENSE t-maps, a total of 573 voxels were activated, and this is much larger than the number of activated voxels (147 voxels) in the conventional t-maps. In addition, the average t-value in the Sl-SENSE t-maps (= 4.6) is higher than that in the conventional t-maps (= 6.1). This suggests that Sl-SENSE is more sensitive to the MRI signal change induced by the transient magnetic field.

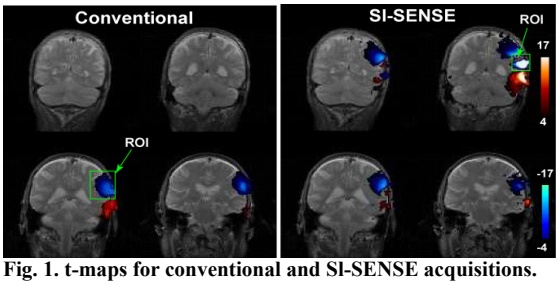

Fig. 1. t-maps for conventional and Sl-SENSE acquisitions.

The averaged time courses in the region-of-interest (indicated by the green rectangle in Fig. 1) were illustrated in Fig. 2. It can be seen that due to its relatively long TR (140 ms), the conventional acquisition method can only capture 8 of the 20 electrical pulses with 50 ms duration. Compared to the conventional method, the Sl-SENSE has much shorter TR (70 ms) and was able to detect all the pulses. Thus, the Sl-SENSE method shows better capability of detecting brief events than the conventional sequence.

Conclusions and Discussion

Our results demonstrated the ability of Sl-SENSE to acquire multiple image slices with high temporal resolution (~ 70 ms), and also showed that Sl-SENSE provides superior detection sensitivity to brief electrical pulses than the conventional spiral acquisition. These results suggest that Sl-SENSE is a sensitive and promising acquisition method for detecting the ncMRI signal produced by epileptiform spikes.

In this study, two slices were simultaneously acquired using Sl-SENSE. This method can be extended to the simultaneous excitation and acquisition of more than two slices, but the acceleration R depends on the coil g-factor, as in conventional SENSE. Here we were limited to 2 subslices by noise propagation but expect R of 3 or 4 with a 32 channel coil. In this way, the TR can be further shortened and a higher temporal resolution will be achieved in the image acquisition

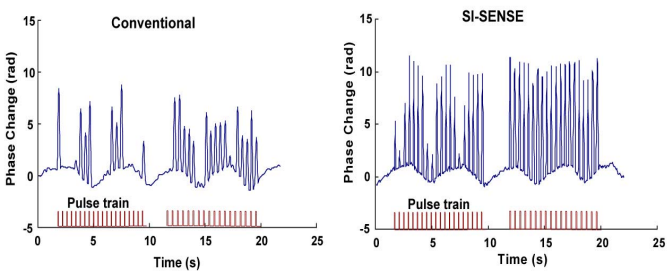

Fig. 2. ROI-averaged time courses in the phase images acquired with the conventional and Sl-SENSE pulse sequences.

References

1. Sundaram et al., Magn Reson Med 2010 (in press). 2. Larkman et al., J Magn Reson Imag 2001; 13:313–317.

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