Synchronized Detection of Minute Randomly Oriented Electrical Currents with MRI using Lorentz Effect Imaging

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Introduction

The BOLD effect is the most commonly used contrast mechanism in fMRI because of its relatively high spatial resolution, sensitivity, and ease of implementation. However, its ability to accurately localize neuronal activation in time is limited by delays and dispersions resulting from the hemodynamic modulation. It is thus of interest to develop alternative methods that can detect neuronal electrical activity directly. Song *et al.* [1] developed a technique called Lorentz effect imaging (LEI) that allows detection of minute electrical activity in a strong magnetic field. It is based on the fact that a current-carrying conductor placed in a magnetic field and surrounded by an elastic material experiences a Lorentz force given by the cross product of the current and the magnetic field that induces a spatial displacement of adjacent voxels. This incoherent displacement in turn results in an intravoxel dephasing and signal loss, which can be detected by applying equal but opposite encoding and decoding magnetic field gradients and turning on the current only during the former. In this work, we extend the LEI technique by applying successive cycles of encoding/decoding gradients in multiple directions, and demonstrate its feasibility for detecting minute randomly oriented electrical currents in a gel phantom.

Methods

Unlike in previous work, we developed a pulse sequence based on a gradient echo sequence where encoding and decoding gradients are applied as a series of bipolar gradients between excitation and data acquisition (Fig. 1). The current is turned on only during the encoding gradients (positive lobes). Successive cycles of encoding/decoding gradients are used to increase the sensitivity of the technique, and such gradients can be applied on multiple axes depending on the slice orientation to allow detection of currents flowing in any direction. There is however no need to apply them along the main magnetic field since no displacement occurs in that direction.

We studied two phantoms consisting of a copper wire immersed in a 3% gelatin solution with an elasticity similar to that of brain tissue. The first phantom contained a straight soft stranded copper wire (2×0.25 mm cross-section), whereas the second one contained a thinner insulated copper wire (0.25 mm diameter) oriented in random directions to simulate neuronal currents in the brain. For both phantoms, the wire was connected via a twisted-pair cable and a 1 or 10 kΩ resistor in series to a square wave pulse generator triggered by the encoding gradients.

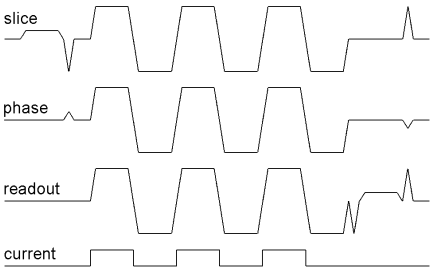

Fig. 1: LEI pulse sequence with three cycles of encoding and decoding gradients on all axes.

The studies were performed on a GE (Milwaukee, WI) 4 T whole-body MRI scanner using a quadrature birdcage head coil. Axial images were acquired using TR 1000 ms, TE 80 ms, flip angle 60°, FOV 10 cm, matrix size 256, slice thickness 10 or 3 mm for the first and second phantom respectively, and 3 cycles of encoding/decoding gradients with an amplitude of 4 G/cm and a duration of 10 ms for each lobe. For the first phantom, the wire was orthogonal to the main magnetic field and the frequency direction along the wire, so the encoding/decoding gradients were applied only in the phase direction, whereas for the second phantom, they were applied along both the readout and phase directions. To evaluate the sensitivity of the technique, the current was varied from 0 to 500 µA, thus covering the range of values found in biological systems.

Results and Discussion

Figs. 2 and 3 show the results for the first phantom. The central signal loss at 0 µA is due to the presence of the wire, whereas the progressive widening with increasing current levels is caused by the increasing intravoxel dephasing resulting from the Lorentz force-induced spatial displacement. This widening occurs in the posterior direction, as expected for a current flowing from right to left, and reaches up to 400 µm for a current level of 300 µA.

Fig. 4 shows the results for the second phantom. In that case, multiple currents flowing in random directions within a single voxel can result in a larger intravoxel dephasing and overall signal loss, which again becomes more pronounced with increasing current levels. There are also some regions of signal increase, which could be due to a local density increase resulting from a compression of the gel.

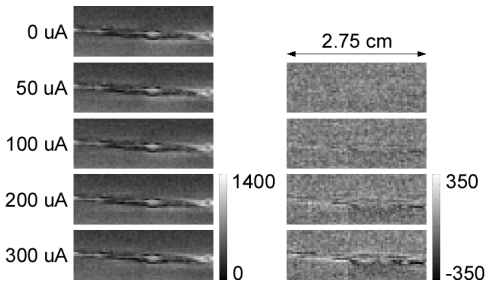

Fig. 2: Cropped axial images of the first phantom for different current levels (first column) and corresponding difference images with the image at 0 µA (second column).

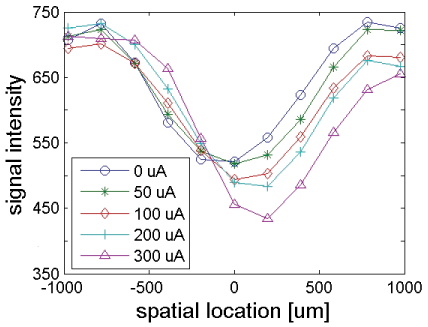

Fig. 3: Signal intensity profile across the wire averaged over an 8 mm section and interpolated to a resolution of 0.2 mm.

Conclusion

Although further studies are needed to improve the sensitivity of the technique, these initial results clearly demonstrate its feasibility for detecting minute randomly oriented electrical currents in a strong magnetic field. This constitutes a promising step towards the development of direct non-invasive imaging of neuronal electrical activity *in vivo*.

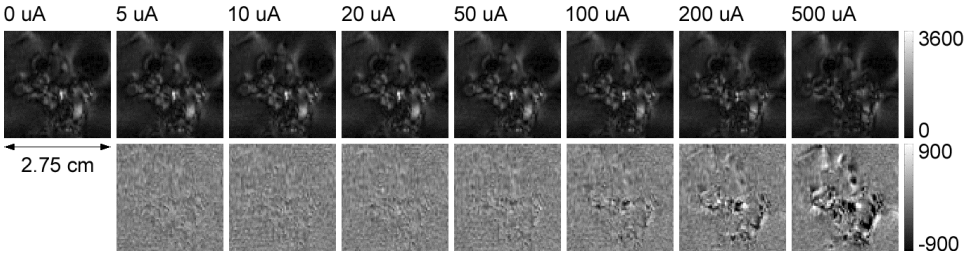

Fig. 4: Cropped axial images of the second phantom for different current levels (first row) and corresponding difference images with the image at 0 µA (second row).

References and Acknowledgments

1. Song AW *et al.* Magn Reson Imaging 2001; 19:763–767.
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