Off-resonance Artifact Reduction Methods for Imaging with Electrodes

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Introduction

Acquisition of neurological signals directly from brain is important in many clinical and neuroscience studies. Methods such as deep brain stimulation (DBS) or electroencephalogram (EEG) are popular in measuring brain activities. Such technologies may be coupled with magnetic resonance imaging (MRI) for acquisitions of high-resolution anatomical and neurological information. However, electrodes of DBS or EEG often cause artifacts due to its off-resonance characteristics in MRI. This artifact could be reduced by recent metal artifact reduction techniques such as spectrally-resolved fully phase encoded 3-dimensional fast spin-echo (SR-FPE) [1] imaging. However, SR-FPE is not suitable for reducing artifacts from small objects because SR-FPE uses 3-dimensional (3D) phase encoding that requires too much data for a high resolution image. Another method, echo-time encoding [2], [3], could be the most appropriate technique for this case because of its flexibility in the choice of spectral and spatial resolution. This work proposes effective methods that reduces the off-resonance artifacts caused by small objects such as electrodes using echo-time encoding for a high resolution image.

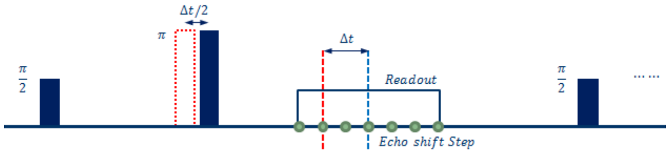

Fig.1 Sequence diagram of the echo-time encoding. Shifting π rf pulse makes the echo shift from the center of readout.

Methods

The artifact caused by off-resonance spin makes 3D geometric distortion. Some proper post processing methods using spectral data resolved by echo-time encoding (**Fig.1**) could reduce the artifact. In this paper, two different imaging methods are proposed to reduce the 3D geometric artifact by combining phase encoding and post processing using echo-time encoding.

Method 1 uses the 3D echo-time encoding sequence. This method reduces the artifact in 2D by using 2D phase encoding and the artifact in the other dimension by using post processing in frequency direction. **Method 2** uses the 2D echo-time encoding sequence. This method reduces the artifact in 1D by using 1D phase encoding and the artifact in 2D by using post processing in frequency and slice select direction. The post processing methods in frequency and slice select direction are described in the following paragraphs in detail.

In the case of frequency encoding direction in **Method 1** and **Method 2**, off-resonance spin causes the shift artifact in frequency encoding. Echo-time encoding could reduce this artifact by simple post processing [2]. If frequency encoding is performed in x direction, frequency encoding related shift is given by following equations,

$$S(t,\Delta t) = \int\int\int\int dxdydzd\omega_k\, \rho(x,y,z,\omega_k)\, exp\big(i(\omega_k \Delta t + \gamma x G_x t)\big),$$

$$\mathcal{F}\big(S(t,\Delta t)\big) = c \cdot \rho\left(x - \frac{\omega_k}{\gamma G_x}, y, z, \omega_k\right),$$

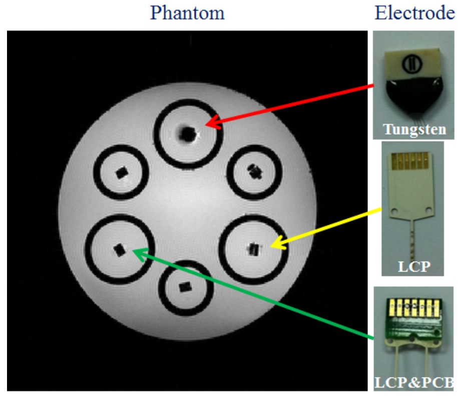

Fig.2 3D spin echo image and three different kind of electrode composed of tungsten, liquid crystal polymer (LCP), and printed circuit board (PCB).

where S is a measured signal, $\mathcal{F}$ is 4D Fourier transform, t is the time at sample, Δt is echo shift from readout center, ρ is proton density, ω_k is frequency offset from water, γ is gyromagnetic ratio, G_x is x direction gradient, and c is a constant coefficient. After acquisition of echo-time encoding data, shifting the spectral images or adding the phase in Fourier domain of spectral data should be performed according to offset-resonance in order to compensate the shift artifact.

In the case of slice select direction in **Method 2**, off-resonance spin causes the distorted slice profiles by RF pulses selecting the spins of the near slices. The spins that has ω_k off-frequency are detected with an offset of $\frac{\omega_k}{\gamma G_{ss}}$ away from the original slice where G_{ss} is the slice select gradient. In order to reduce this artifact, several near slices should be scanned to obtain signals from the spins of originally selected. The original location of spins could be estimated by using spectral data resolved by echo time encoding.

The phantom is designed that two acrylic bars in cylinder hold an electrode by pressing both side of electrode (**Fig. 2**). Three cylinders in the phantom contain three different kind of the electrodes. Experiments using **Method 1** were conducted on a clinical 3.0T scanner (Siemens Verio, Germany) with following imaging parameters: FOV = $256 \times 256 \times 36$ mm^3, matrix = $256 \times 256 \times 12$, voxel size = $1.0 \times 1.0 \times 3.0$ mm^3, TR = 50 ms, TE = 20 ms, G_x= 12.23 mT/m, 9 echo-time encoding step, spectral coverage of $\pm$2.5kHz, and total scan time is 23 min 2 sec. Experiments using **Method 2** were conducted on a clinical 3.0T scanner (ISOL Forte, Korea) with following imaging parameters: FOV = 256×256mm^2, slice thickness = 5mm, matrix = 256×256, voxel size = 1.0×1.0 mm^2, TR = 100 ms, TE = 38 ms, G_x= 0.4753 Gauss/cm, 25 slices, 25 echo-time encoding step, spectral coverage of $\pm$2.5kHz, and total scan time is 4 hr 26 min 40 sec.

Results

Figure 2 shows the conventional 2D spin-echo image of phantom. **Figures 3 a ~ c** show 2D spin-echo images in various slices with the artifact. **Figures 3 d ~ e** show the artifact-reduced images of **Figures 3 a ~ b** from **Method 1**. **Figure 3 f** shows the artifact-reduced images of **Figure 3 c** from **Method 2**.

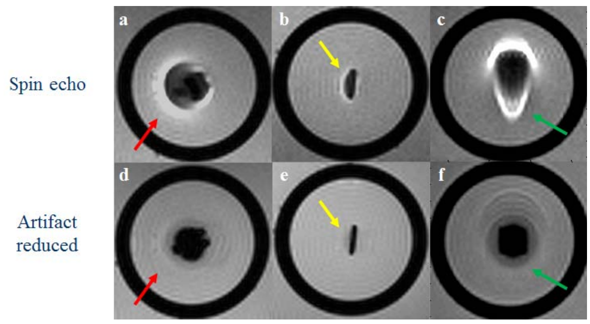

Fig.3 a ~ c is 2D spin-echo images in various slices. **d** and **e** are the artifact reduced images using **Method 1**. **f** is the artifact reduced images using **Method 2**.

Conclusions and Discussion

The preliminary results in this work show that off-resonance artifact from electrodes in high resolution images could be reduced by using the proposed imaging methods. Further studies could be conducted in order to reduce the overall processing time. One possible area of improvement is to enhance the scan time using faster acquisition sequences such as fast spin-echo sequence. Another possible area of improvement is to reduce the acquisition data using accelerating technique such as parallel imaging, compressed sensing, and partial Fourier acquisition.

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References

[1] Artz et al. MRM 2013 [2] Cho et al. MRM 1985;3:253~261 [3] Park et al. MRM 1986;3:448~453