MREIT conductivity imaging of canine head using multi-echo pulse sequence

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Abstract. In magnetic resonance electrical impedance tomography (MREIT), we measure induced magnetic flux densities subject to multiple injection currents to reconstruct cross-sectional conductivity images. Spin echo pulse sequence has been widely used in MREIT and produce postmortem and in vivo conductivity images of animal and human subjects. The image quality depends on the SNR of the measured magnetic flux density image. In order to reduce the scan time and current amplitude while keeping the image quality, we have developed a multi-echo pulse sequence for MREIT. In this study, we show results of canine head MREIT imaging experiments using the multi-echo pulse sequence. Compared to the injection current nonlinear encoding (ICNE) pulse sequence, it provides a higher SNR of MR magnitude images by combining multiple echo signals. Noise in measured magnetic flux density data is significantly reduced due to an increased current injection time over multiple echo signals. These allow us to significantly decrease the total scan time. Reconstructed conductivity images of a canine head show enhanced conductivity contrast between gray and white matter using the multi-echo pulse sequence. In our future work, we will focus on in vivo human and disease model animal experiments using the new MREIT pulse sequence.

Keywords: MREIT, conductivity image, multi-echo pulse sequence

1. Introduction

Magnetic resonance electrical impedance tomography (MREIT) utilizes an MRI scanner as a tool to measure a magnetic flux density distribution inside an imaging object induced by an externally injected current [1-4]. The quality of a measured magnetic flux density data is closely related with the adopted MR pulse sequence. The injection current nonlinear encoding (ICNE) pulse sequence, which has been widely used in MREIT, can produce in vivo conductivity images of human and animal subjects using imaging currents of 9 mA or less [5-8]. However, in performing in vivo human and disease model animal experiments, a long scan time and high injection current are still required to enhance the SNR. To improve the quality of a measured magnetic flux density data so that we can reduce the scan time, we developed a new multi-echo pulse sequence for MREIT.

In this study, we will show the results of canine head MREIT imaging experiments using the new multi-echo pulse sequence for MREIT. Comparing its performance with the conventional spin echo pulse sequence, we analyze advantages and limitations of the proposed sequence.
2. Methods

2.1. Animal preparation

To prevent dribbling during experiments, we injected 0.1 mg/kg of atropine sulfate. Ten minutes later, we anesthetized the animal with intramuscular injection of 0.2 ml/kg Tiletamine and Zolazepam (Zoletil 50, Virbac, France) and then sacrificed it by an intravenous injection of 2 mmol/kg KCl (KCl-40 inj, Daihan Pharmacy, Korea). After clipping hair at four locations (dorsal, ventral and bilateral surfaces) on the head, we attached four carbon-hydrogel electrodes and placed the animal inside the bore of our 3 T MRI scanner (Magnum3, Medinus, Korea). The experimental protocol was approved by the Institutional Animal Care and Use Committee (IACUC) of Konkuk University, Seoul, Korea.

2.2. Imaging experiment

Using our custom-designed MREIT current source, we injected 20 mA currents as the first current $I_1$ between one opposing pair of electrodes. Both spin echo and multi-echo (3 echos) pulse sequences were used for imaging experiments. Imaging parameters were as follows: TR/TE = 900/30 ms, FOV = 180x180 mm$^2$, slice thickness = 4 mm, NEX = 24, matrix size = 128x128, number of slices = 8 and total imaging time = 100 min. Figure 1 shows the current injection scheme used in spin echo and multi-echo sequences. Details of the multi-echo pulse sequence will be described elsewhere. The current injection intervals are denoted by $T_{c1}$ and $T_{c2}$ and TE is the echo time. After acquiring the first magnetic flux density ($B_z$) data set for $I_1$ in 8 axial slices, the second injection current $I_2$ with the same amplitude and pulse width was injected through the other pair of opposing electrodes to obtain the second $B_z$ data set.

2.3. Conductivity image reconstruction

We used CoReHA (conductivity reconstructor using harmonic algorithms), which is an integrated software package for MREIT [9]. It provides GUI-based functions for all data processing routines needed to produce conductivity images from measured $k$-space data sets. We used the single-step harmonic $B_z$ algorithm implemented in CoReHA for multi-slice conductivity image reconstructions [10]. All conductivity images presented in this paper should be interpreted as equivalent isotropic scaled conductivity images providing only conductivity-based contrast information. Interpretation of these images should be pursued in future work.

![Figure 1. Current injection for MREIT experiment. (a) Spin echo and (b) multi-echo pulse sequences.](image-url)
3. Results

Figure 2. (a), (b) and (c) are MR magnitude, magnetic flux density and conductivity images, respectively, of a canine head using the spin echo pulse sequence. (d), (e) and (f) are images of the same canine head using the multi-echo pulse sequence.

Figure 3. MR magnitude images (a, b, c) and conductivity images (d, e, f) using the multi-echo pulse sequence with 3 different echo spacing of 15, 20 and 30 ms, respectively.

Figure 2(a), (b) and (c) are MR magnitude, $B_z$ and conductivity images of a canine head using the spin echo pulse sequence. Figure 2(d), (e) and (f) are images using the multi-echo pulse sequence. Both the SNR of MR magnitude images and noise level in $B_z$ images were significantly enhanced in the multi-echo pulse sequence. Conductivity images using the multi-echo pulse sequence show a better conductivity contrast between gray and white matter. Figure 3 are MR magnitude images (a, b, c) and conductivity images (c, d, e) using multi-echo pulse sequences with different echo spacing of 15, 20 and 30 ms, respectively. Though the magnitude image SNR of 30 ms case was poor, the conductivity
image shows an improved contrast between gray and white matter due to its prolonged current injection time. The semi-automatic boundary extraction method implemented in CoReHA often resulted in somewhat distorted shape of the outermost boundary in conductivity images. This minor geometrical distortion has negligible effects in reconstructed conductivity images since the harmonic $B_z$ algorithm is insensitive to geometrical errors.

4. Discussion

We found that the multi-echo pulse sequence outperforms the spin echo pulse sequence. Compared to the spin echo pulse sequence, multi-echo sequence provides a higher magnitude image SNR by combining multiple echo signals. The noise level in measured magnetic flux density data is significantly reduced due to a prolonged current injection time over multiple echo signals, which allows a more phase accumulation. Conductivity images of a canine head show enhanced contrast between gray and white matter using the multi-echo pulse sequence. These will allow us to decrease the total scan time. We expect the multi-echo pulse sequence be useful in experimental MREIT studies where a short scan time is required. In our future work, we will focus on in vivo human and disease model animal experiments using the multi-echo pulse sequence.

Acknowledgments

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