Monitoring of electric field distribution in biological tissue by means of magnetic resonance electrical impedance tomography L9

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Duration of the experiment: day 1: 90 min
Max. number of participants: 4
Location: MRI Laboratory (Jožef Stefan Institute)
Level: Basic

PREREQUISITES

Participants should be familiar with Laboratory safety (S1). No other specific knowledge is required for this laboratory practice.

THEORETICAL BACKGROUND

A method capable of determining electric field distribution during the pulse delivery has a practical value as it can potentially enable monitoring of the outcome of electroporation which strongly depends on the local electric field. Measurement of electric field distribution enables detection of insufficient electric field coverage before the end of either reversible or irreversible electroporation treatment, thus enabling corrections of field coverage during the treatment and consequently increasing and assuring its effectiveness. As there are no available approaches for measurement of electric field distribution *in situ*, an indirect approach using magnetic resonance techniques was suggested. Magnetic resonance electrical impedance tomography (MREIT) enables reconstruction of electric field distribution by measurement of electric current density distribution, first, and calculation of electrical conductivity of the treated subject during application of electric pulses using MRI data as an input to numerical algorithms, second. This method enables determination of electric field distribution *in situ* also accounting for changes that occur in the tissue due to electroporation.
MREIT is a relatively new medical imaging modality based on numerical reconstruction of electrical conductivity inside a tissue by means of current density distribution measured by current density imaging (CDI) sequence. The MREIT algorithm applied for reconstruction of electrical conductivity of the tissue is based on solving Laplace’s equation through iterative calculation. Electrical conductivity is updated after each iteration (k+1):

$$\sigma^{k+1} = \frac{|\mathbf{J}_{\mathrm{CDI}}|}{|\nabla u^k|}.$$

where $\mathbf{J}_{\mathrm{CDI}}$ is current density obtained by CDI and u^k is electric potential obtained as a solution of Laplace’s equation. When difference between two successive conductivities falls below certain value electric field distribution can be calculated using:

$$\mathbf{E} = \frac{\mathbf{J}_{\mathrm{CDI}}}{\sigma}.$$

The aim of this laboratory practice is to demonstrate monitoring of electric field distribution in a biological tissue using MREIT.

EXPERIMENT

We will monitor current density distribution and electric field distribution in biological tissue exposed to electric pulses by means of MREIT. We will then compare measured current density distribution and reconstructed electric field distribution with simulation results obtained by a numerical model of the tissue.

Protocol

The experiment will be performed on biological tissue (chicken liver) sliced in a disc-like sample measuring 21 mm in diameter and 2 mm in height (Fig. 1a). Electric pulses will be delivered via two cylindrically shaped electrodes inserted into the sample. After the insertion, the electrodes will be connected to an electric pulse generator connected to an MRI spectrometer. The sample will be placed in a 25 mm MR microscopy RF probe (Fig. 1b) inside a horizontal-bore superconducting MRI magnet (Fig. 1c). Electroporation treatment of the sample will be performed by applying two sequences of four high voltage electric pulses with a duration of 100 µs, a pulse repetition frequency of 5 kHz and with an amplitude of 500 V and 1000 V.

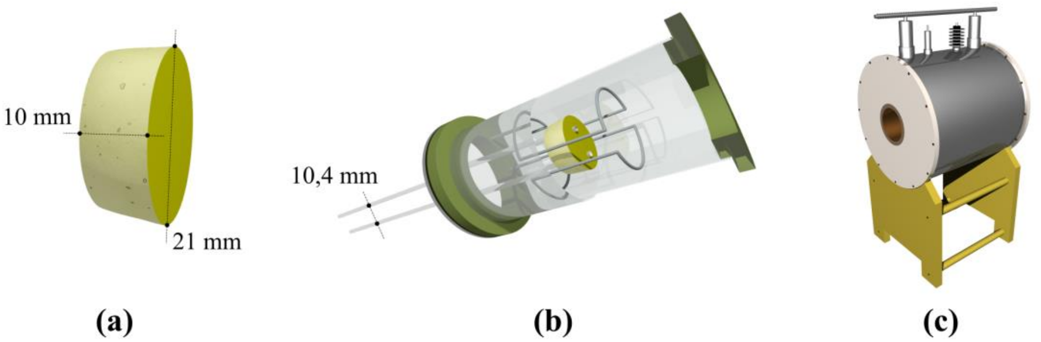

Figure 1: Biological sample (a) placed in a MR microscopy probe (b) inside a horizontal MRI magnet (c).

MR imaging will be performed on a MRI scanner consisting of a 2.35 T (100 MHz proton frequency) horizontal bore superconducting magnet (Oxford Instruments, Abingdon, United Kingdom) equipped with a Bruker micro-imaging system (Bruker, Ettlingen, Germany) for MR microscopy with a maximum imaging gradient of 300 mT/m and a Tecmag Apollo spectrometer (Tecmag, Houston TX, USA). Monitoring of electric field is enabled by CDI, which is an MRI method that enables imaging of current density distribution inside conductive sample. We will apply two-shot RARE version of the CDI sequence (Fig. 2).

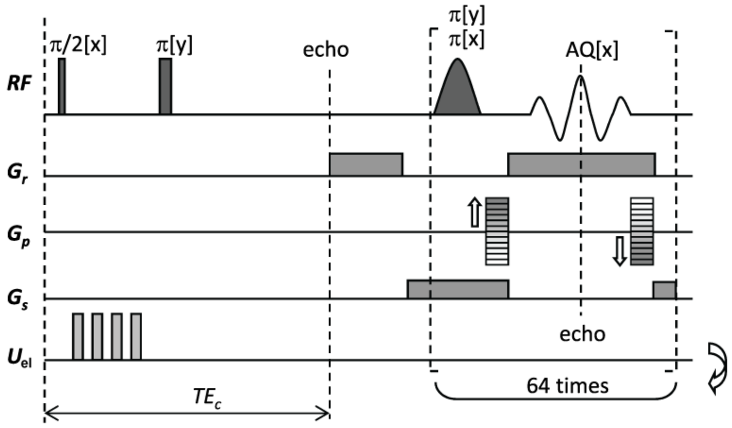

Figure 2: Two-shot RARE pulse sequence used for acquisition of current density distribution. The sequence consists of a current encoding part with a short (100 µs long) high-voltage electroporation pulse (U_{el}) delivered immediately after the nonselective 90° radiofrequency (RF) excitation pulse. In the second part of the sequence signal acquisition is performed using the single-shot RARE signal acquisition scheme that includes standard execution of readout (G_r), phase-encoding (G_p) and slice-selection (G_s) magnetic field gradients. Due to

auxiliary phase encoding induced by the electric pulse, the RARE sequence is repeated twice, each time with a different phase of the refocusing pulses (0°and 90°), and the corresponding signals are co-added.

Electric field distribution in the sample will be reconstructed by iteratively solving Laplace's equation using J-substitution mathematical algorithm and finite element method with the numerical computational environment MATLAB on a desktop PC. We will compare measured current density distribution obtained by means of CDI and reconstructed electric field distribution obtained by means of MREIT in the sample with simulation results obtained by a numerical model of the sample.

FURTHER READING

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NOTES & RESULTS