Impedance measurement of bipolar stimulation electrodes immersed in medium

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***Abstract*—We measured the impedance of bipolar stimulation electrode immersed in two media of interest for electrostimulation: extracellular fluid (ECF), and cerebrospinal fluid (CSF). Using a convenient method, the impedance magnitude and phase were measured within a frequency range from 10 Hz to 20 kHz. The impedance magnitudes were in 1 kΩ range, having capacitive character, a strong frequency dependence, and observable dependence on temperature and medium layer thickness.**

Keywords*—bipolar electrodes impedance measurement; medium conductivity; extracellular fluid (ECF); artificial cerebrospinal fluid (CSF); COST EMF-MED

I. Introduction

Bipolar electrodes are commonly used for neural electrostimulation, either in clinical applications (e.g. spinal cord stimulation [1]), or in research (e.g. animal studies of electrostimulation [2]). The electric field gradient, efficiently created between the two contacts of a bipolar electrode, is responsible for nerve excitation [3]. When designing stimulation circuits and systems for various purposes, the impedance of the electrode loading the stimulator circuit is an important design parameter to produce a stable stimulus of sufficient amplitude, given the system voltage and current requirements. Implantable stimulation systems are even more restrictive in terms of available voltage and current, therefore a special attention should be paid to electrode impedance as a key parameter of an implanted stimulator design. Implanted electrodes, depending on the location and purpose, partly or fully touch different types of tissues, but can also be considered to be touching, or even immersed in, the fluids found in and around tissue, which should correspond to two typical cases: extracellular fluid (ECF), and cerebrospinal fluid (CSF). Therefore, it is interesting and indicative to measure the impedance of bipolar electrodes immersed in ECF and CSF media, which can be done *in vitro*. The aim of this study is to perform such measurements with a bipolar electrode, in order to observe the behavior of such impedance in the frequency range of interest, and at different temperatures (room temperature compared to the physiological temperature).

II. Materials and Methods

The bipolar electrode of interest for these measurements consisted of two coplanar circular pads with diameter of 1 mm, separated by a distance of 2 mm (Fig. 1). The contact material was platinum-iridium alloy coated by iridium-oxide. This particular electrode was produced to be used in animal experiments, i.e. to be subsequently implanted in rats within the study of pain treatment by stimulation of dorsal root ganglion neurons [4].

The electrode was fixed to the bottom of the 100-mm Petri dish, contacts facing upwards, to be immersed in the various media (Fig. 1). The effect of medium layer thickness on the measured impedance was examined by setting the depth of the medium in the Petri dish to 2 mm and to 4 mm, for each medium.

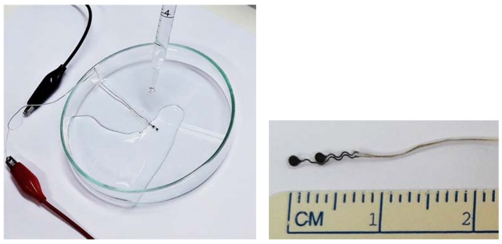

Fig. 1. Left: Medium being pipetted in the Petri dish with the electrode fixed to its bottom; right: the electrode size

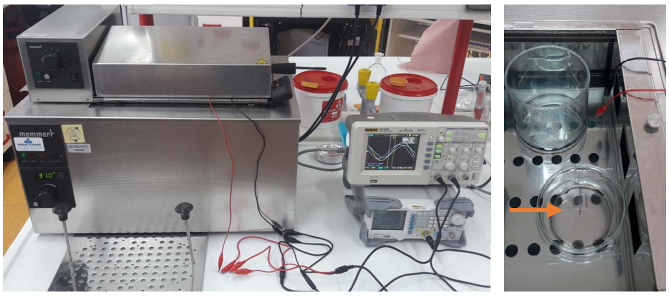

Fig. 2. Left: Measurement setup with Petri dish placed in the water bath at 37°C; right: Petri dish in the water bath, arrow pointing to the electrode

The two media of interest were the ECF and CSF. ECF was prepared as the Ringer's solution containing (in mM): NaCl 140, KCl 4, MgCl2 1, CaCl2 2, HEPES 10, NaOH 4.54, glucose 5, and the pH was adjusted to 7.4 with HCl. The artificial CSF was prepared as a solution containing (in mM): NaCl 128, KCl 3.5, MgCl2 1.2, CaCl2 2.3, NaH2PO4 1.2, NaHCO3 24, glucose 11, and the pH was adjusted to 7.4 with HCl. The effect of temperature was examined by performing the measurements at room temperature of 25°C, and at the physiologically relevant temperature, achieved by placing the Petri dish in the laboratory water bath heated to 37°C.

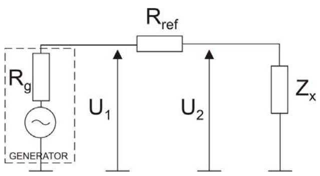

Fig. 3. Impedance measurement setup: Z_x is the unknown impedance connected in series with a reference resistor R_{ref} of a known preselected value. The complex voltages (i.e. amplitudes and phase difference) of U_1 and U_2 were measured by oscilloscope.

The impedance was measured using setup in Fig. 3. Z_x can be determined by:

$$Z_x = R_{ref} \frac{U_2}{U_1 - U_2} \quad (1)$$

The best results in terms of accuracy are achieved by setting the R_{ref} at the similar value or at least at the same order of magnitude as Z_x, therefore it is necessary to initially estimate this value, or to perform measurements in several iterations, converging to the most accurate measurements.

III. Results and Discussion

The impedances of the bipolar electrode immersed in ECF and CSF media are very similar, as shown in Fig. 4.

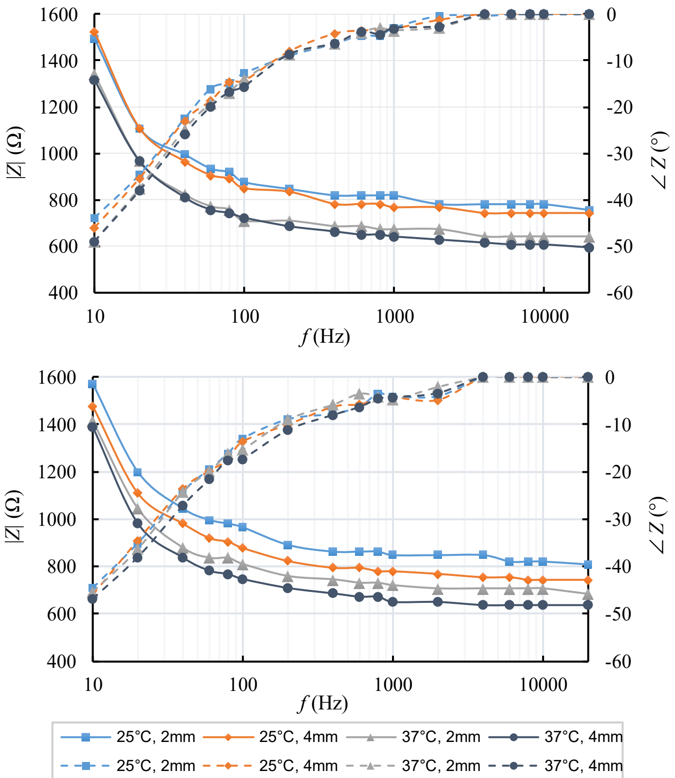

Fig. 4. Impedance of bipolar electrode immersed in ECF (top) and CSF (bottom): magnitude (solid lines) and phase (dashed lines)

There is a significant dependence on frequency for both magnitude and phase of the impedance. Impedance magnitude is noticeably inversely proportional with temperature, the observation is in line with [5], due to ionic conductivity being inversely proportional with viscosity, which decreases with temperature. The magnitude is also inversely proportional to the fluid layer thickness, this being less significant for the ECF than for CSF. Impedance phase has no significant variations with any of these parameters. Magnitudes are comparable to the values usually encountered in the literature (e.g. [6] gives the medians of 351Ω and 547Ω for cervical and thoracic spinal cord stimulation bipolar leads, respectively), taking into account that the geometry of this electrode is different, according to the different purpose (rat vs. human use). Additionally, the lack of measurement frequency, often also the impedance phase, is unfortunately a common occurrence in literature (in [6] as well), restricting further straightforward comparisons.

IV. Conclusions

The bipolar electrode impedance measurement in media provided illustrative results to be used for stimulator design based on bipolar electrodes. The method was conveniently implemented in a wider frequency range, which is a major contribution of this study with respect to the results available in literature, concerning the variability of the frequencies used in modern electrostimulation protocols. As a future extension of this study, we aim to measure the impedance of the implanted electrodes in vivo, and to test the setup for measuring the unknown conductivity of the media, by comparison with the standard solutions of known conductivity.

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