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Skin impedance measurements by means of novel gold sensors fabricated by direct writing

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Abstract

In this paper impedance sensors designed for measurement of skin impedance are described. The design of our sensors is simple and efficient. Thanks to their geometry accurate results average impedance measurements over the skin surface was obtained. Measurements were performed in KCl water solution and at the surface of human skin. RC equivalent circuit model was developed and fitted to measurements data. Different types of sensors (6 types) make possible to tune measurement set-up for specific properties of the skin (e.g. low or high skin impedance which differs among persons). Based on the proposed RC equivalent circuits including Warburg impedance element, the most universal skin model was elaborated.

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Keywords: impedance sensor; spiral geometry; impedance measurements; human skin impedance; RC equivalent model.

1. Introduction

Measurements of impedance is very convenient characterization method of various materials including human skin [1-3]. These measurements can be made *in vivo* and in real time without any unpleasant feeling or pain by patients. Skin impedance is very valuable parameter which can be used for the body stress evaluation [4,5]. The skin is composed of different layers of living and dead cells. This natural construction may be compared to electrical circuit consisting of capacitors and resistors connected either in series or parallel. Some of these layers have very high resistivity and they might be considered as natural barrier for relatively low potentials. These barriers are *stratum corneum* and the lipid layer. Because of these some parts of the skin play a role of capacitors, the rest - highly hydrated layers of the skin may be considered as resistors. But a simple RC equivalent circuit as a skin model is not enough adequate to reflect skin properties [6]. For this reason as well as for better fit of theoretical model to experimental data, an extended RC models with Warburg impedance element representing the impedance of semi-infinite diffusion, are applied [7].

There are many various types of impedance sensors for human skin measurements and their type depends on the location of the electrodes on the body surface [8-11]. Theoretical field analysis and experimental demonstration

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performed with impedance sensors provide results helpful in design of geometry of electric field line between the electrodes and optimization of sensors parameters such as sensitivity, which increases for multi-electrodes sensors [12]. Taking into account theoretical investigations, the design of our sensors are two electrode type. Because of circular geometry of electrodes, the sensors have sensitivity similar to the multi-electrode sensors. The sensor's construction covers a large area of the skin providing a very good contact with the skin and also averaging of the impedance over the contact area. The averaging improves measurements since natural living skin is not an uniform structure.

2. Materials and methods

The potentiostat „Bio-Logic SA VMP2" with build-in impedance analyzer was used for impedance measurements. The device operates with Princeton Applied Research EC-Lab v 6.93 software. For data analysis and RC circuit simulations version 9.30 of the software was used. In experiments the following substances: KCl 99,9% (POCH), deionized water 18.2 MΩ·cmwere used.

3. Impedance sensors

Six different types of impedance sensors (shown in Fig. 1) were fabricated and tested. The sensors electrodes were designed in a form of two parallel spirals. The electrodes made of gold polymer paste were fabricated by direct writing with use of the microdosing robot Ultra TT EFD on polyester foil. The sensors types differ from each other by number of coils and gap width between the two spiral electrodes. Such geometry of sensors enables to collect signals from relatively large skin area and average impedance measurements.

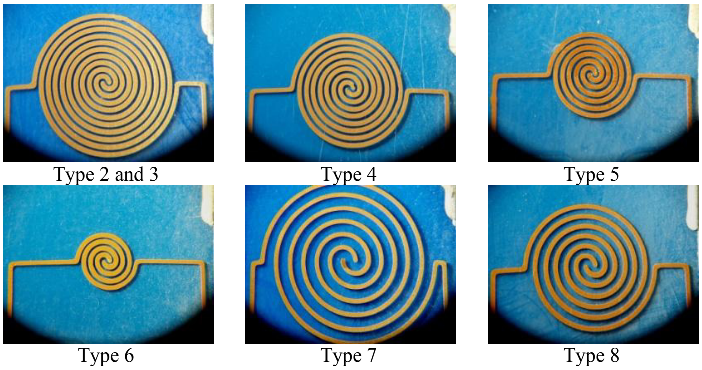

Fig 1. Types of impedance sensors.

4. Impedance measurements

Two types of impedance measurements were performed: in water solutions of KCl at concentrations of 1, 10 and 100 mM and on the human skin. The electrodes were polarized with potentials (E): 0.0 V and 0.1 V with overlapped peak-to-peak sinusoidal wave (V_{pp}): 100, 200, 400, and 1000 mV. In the case of skin measurements frequencies for measurements were from 100 kHz to 10 kHz with 10 kHz step and electrodes were polarized with potential E: 0.0V and V_{pp}: 1000 mV.

The measurement results are presented in two groups (Fig. 2a) - for measurements carried out directly after fixing the sensor on the skin surface and after one hour of wearing. It can be seen that skin impedance after 1 hour is typically much lower than at the beginning of measurements due to sweating. Impedance measurements performed by the sensors type 7 at time 0 and by the sensors type 2 and 3 are similar. The difference becomes visible after 1 hour of measurements. The sensors of type 7 give typically higher impedance values (Fig. 2b and Fig. 3a).

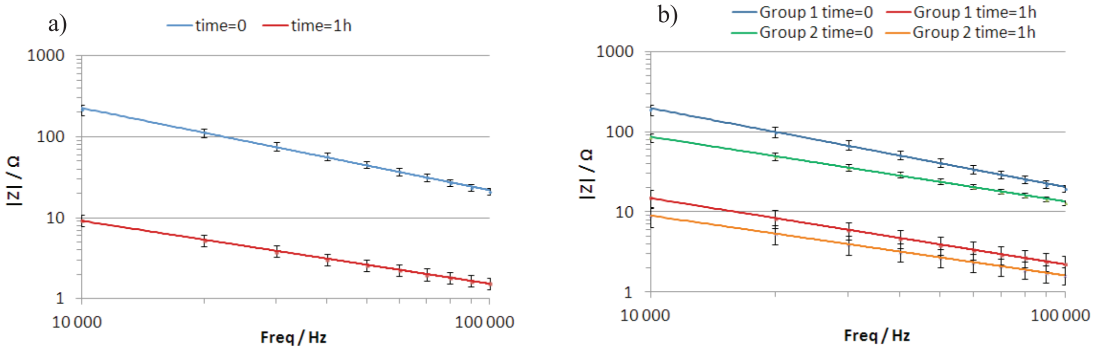

Fig. 2. Impedance measurements of persons with different skin type, frequencies: 100 - 10 kHz, E: 0.0 V; V_{pp}: 1000 mV. Sensors type 2, blue line - time 0, red line - after 1h(a), and sensors type 7, blue and green lines - time 0, red and orange lines - after 1h, groups 1 and 2 are for people with different electrical properties of the skin (b).

The sensors of type 7 are more suitable for persons with dry skin of very low impedance (Fig. 3b). In the case of sensor type 2 and 3, skin impedance drops slightly below 200 Ω at 10 kHz after 1 h of measurements. Low impedance measurements (below 1000 Ω) are hardly implemented in mobile equipment [13]. But when the same sweaty skin was measured by the sensor type 7 then the obtained impedance value was above 1 kΩ for frequency of 10 kHz. Therefore sensor geometry may be used to tune for specific properties of the skin and conditions.

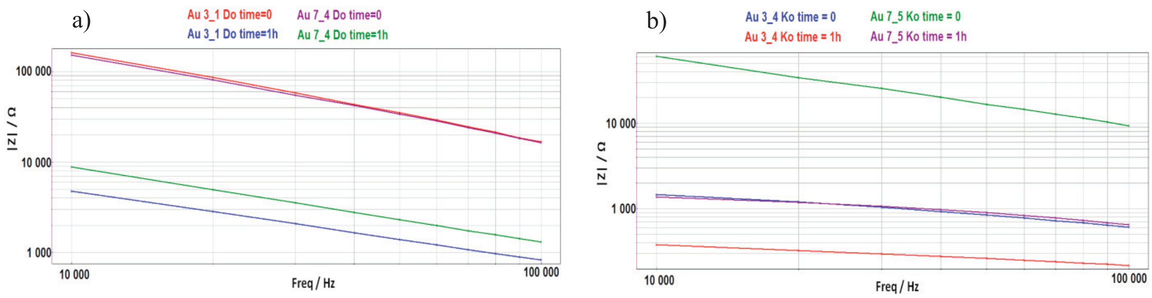

Fig. 3. Comparison of impedance measurements performed with sensors type 2(3) and 7, exemplary results for a person with typical skin (a), and very low skin impedance (b).

5. RC equivalent circuits - models of human skin

The skin impedance measurement were performed with the following parameters: frequency range from 200 kHz to 5 Hz, potential E: 0.0 V, voltage V_{pp}: 1000 mV. For these measurements the sensors of type 2 were used.

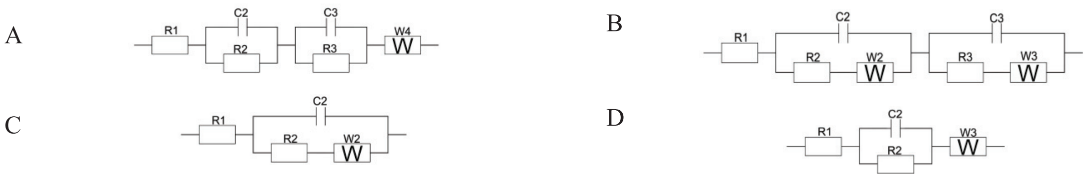

Fig. 4. Four RC equivalent circuits representing models of the human skin (A, B, C and D).

There were considered four RC models of the skin (Fig. 4). For each RC model the simulation results were compared with experimental data. The comparison is presented in Fig. 5. For the persons with very low skin impedance, good results were obtained for models A and B, while for the persons with typical skin, only model A has a good fit to the experimental data.

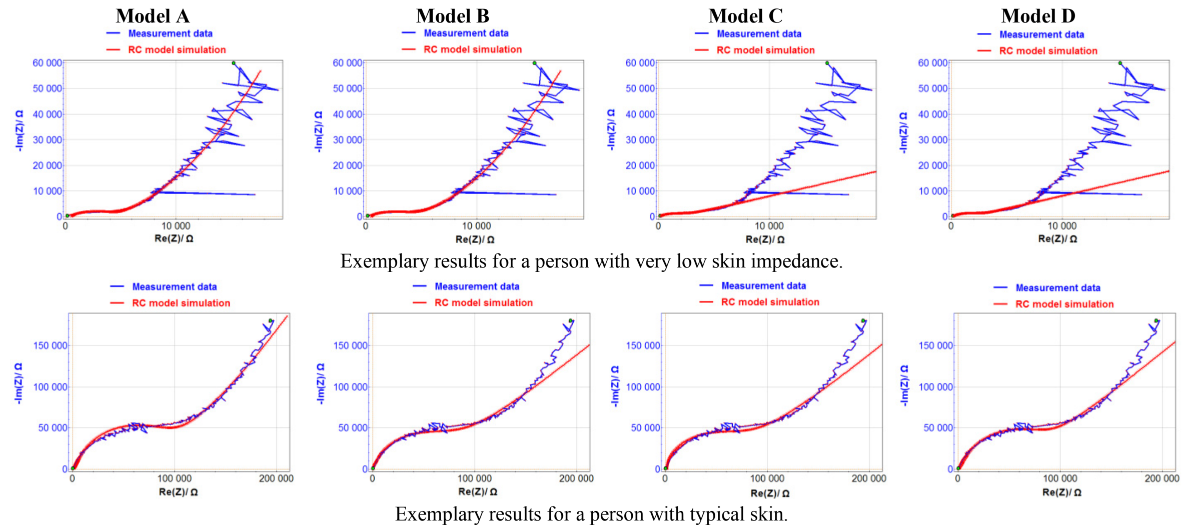

Fig. 5. Comparison between four different RC models (A, B, C and D) of the human skin for a person with very low skin impedance (top panel) and with typical skin (bottom panel).

Summarizing, based on the measurements performed in KCl water solutions and at the surface of human skin, as well as on fitting data to the proposed RC equivalent circuit representing human skin model, it was stated that the most universal is model A and it can properly describe electrical properties of different types of the human skin.

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