”Assessment of Skin Impedance in Radiofrequency Therapy: A Study Utilizing Unique Electrode Form for Cutaneous Leishmaniasis Treatment”

1st Ian C. Rodrigues Husler
Institute of Computational Physics
Zurich University of Applied Sciences
Winterthur, Switzerland
halu@zhaw.ch

2nd Davide Paparo
Institute of Computational Physics
Zurich University of Applied Sciences
Winterthur, Switzerland
papr@zhaw.ch

3rd Daniel Fehr
Institute of Computational Physics
Zurich University of Applied Sciences
Winterthur, Switzerland
fehd@zhaw.ch

4th Raphael Hagen
Institute of Computational Physics
Zurich University of Applied Sciences
Winterthur, Switzerland
hagp@zhaw.ch

5th Marta S. Velez Mestre
Zurich, Switzerland
m.velezmestre@gmail.com

6th Mathias Bonmarin
Institute of Computational Physics
Zurich University of Applied Sciences
Winterthur, Switzerland
bmat@zhaw.ch

***Abstract*—This study aims to investigate the impact of electrode shape and positioning on skin impedance measurements, with a focus on a specific radiofrequency therapy device developed in-house for treating cutaneous Leishmaniasis. The study involved 22 volunteers of mixed genders, whose skin impedance was measured in the frequency range of 1 MHz to 10 MHz using the device’s uniquely shaped, dry-applied electrodes. Additional measurements were conducted to record skin moisture, surface temperature, and personal parameters of the subjects, which were later used in correlation analysis. While the resistivity values from this study were found to be in alignment with those reported in the existing literature, it is positioning of the electrodes that significantly impacted the skin impedance measurements. Correlations were identified between the skin moisture and average phase shift in facial and forearm measurements and between the average magnitude and phase shift depending on the measurement site. Furthermore, a correlation was observed between the Cole series resistances of the facial and forearm skin. The study does not find a significant influence of gender, age, skin color, ethnicity, or Body Mass Index on the impedance measurements within the tested frequency range. This research enhances our understanding of skin impedance measurements using unique electrode designs and contributes to refining the design of radiofrequency therapy systems.**

***Index Terms*—1. Skin Impedance, Radiofrequency Therapy, Electrode Shape, Correlation Analysis, Bioimpedance Measurements, Cutaneous Leishmaniasis**

I. Introduction

Radiofrequency therapy is utilized in the treatment of various skin diseases, including cutaneous Leishmaniasis, basal cell carcinoma and Mycobacterium infections [1], [2], [3]. The scope of this modality further extends to handling diverse dermatological conditions, from allergic reactions to different forms of skin cancer, as well as dermatological manifestations associated with diabetes among others [4], [5], [6]. To precisely design and develop therapeutic devices utilizing radiofrequency, information on skin impedance is crucial. While a wealth of skin impedance data already exists [7], [8], the impedance values can vary with the electrode shape used in the respective devices. This variability makes it challenging for developers working with devices that employ unusual electrode forms to base their designs on existing data.

An example of a device with an unusual electrode form is a radiofrequency therapy system developed at Zurich University of Applied Sciences. This system is designed to treat the neglected skin disease cutaneous Leishmaniasis and features dry-applied electrodes with a unique shape. This design aspect makes it difficult to characterize the system’s operational parameters, given the lack of available data on skin impedance for such a setup.

The primary objective of this study is to measure skin impedance in the frequency range of 1 MHz to 10 MHz using the electrodes installed on this device. The gathered data can subsequently be used to refine the design of this and other similar systems. The secondary objective is to determine whether correlations between skin and personal parameters can be identified with such an electrode setup. By accomplishing these objectives, we can contribute to the advancement of humanitarian technologies by improving the efficiency and effectiveness of radiofrequency therapy for skin diseases.

II. Materials and Methods

Skin impedance measurements were conducted on 22 volunteers of mixed genders. Two different body locations were measured for each individual. One measurement was taken on the proximal side of the inner right forearm, while the other was taken on the left cheek in the parotideo-masseterica region. To reduce measurement inaccuracies, each measurement was performed five times. The measurements were carried out

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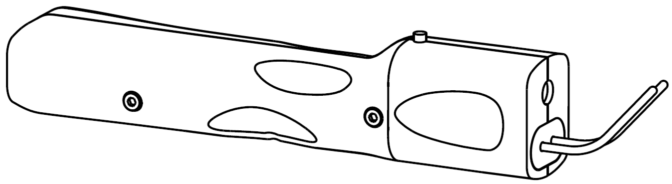

Fig. 1. Diagram of the device's handset showcasing the inserted electrodes at the tip, encompassing an area of 120mm^2.

using the 4192A LF Impedance Analyzer by Hewlett Packard within the frequency range of 1 MHz to 10 MHz. The utilized handset shown in Fig. 1, to which the electrodes were attached, was connected to the aforementioned device using an Ethernet cable. A two-electrode setup was employed, which is used in the treatment of various skin conditions, including cutaneous Leishmaniasis. The electrodes made contact with the skin over a length of 20 mm, with their centers positioned 6 mm apart, resulting in a measurement area of 120 mm^2. Both electrodes had a radius of 1 mm.

In addition, measurements of skin moisture were performed using the Corneometer CM 825 by Courage Katzakha, and surface temperature measurements were conducted using the Optris Xi 400. Furthermore, the weight, age, gender, height, and skin color of the volunteers were recorded. These parameters were subsequently utilized in the correlation analysis together with average calculations of the magnitude and phase of the signals over the measured range. For mapping skin color, the Fitzpatrick scale was used in this study.

The obtained impedance curves were processed as follows: first, the measurement cable and the handset, along with the electrodes, were calibrated. For this purpose, additional short- and open-circuit impedance measurements were performed, which allows to compute actual raw skin impedance by de-embedding the impedances of the cable and the electrodes, i.e., moving the calibrating plane to the electrode-skin interface. Subsequently, the impedance spectra were smoothed using a third-order Butterworth filter. The data was then fitted, employing the frequently used Cole-Cole model for bioimpedance measurements [8], [9], represented by (1). The parameters obtained from the fits were utilized in the correlation analysis.

$$Z_{Cole} = R_\infty + \frac{R_0 - R_\infty}{(1 + j\omega\tau)^\alpha} \tag{1}$$

R_∞ represents resistance at infinite frequency, accounting for non-electrochemical processes or high-frequency effects. R_0 is the resistance at zero frequency (DC resistance), related to bulk conductivity or ionic mobility. τ is the relaxation time, characterizing the system's response rate to frequency changes. α is the Cole-Cole parameter, controlling impedance spectrum shape and asymmetry.

III. Results

As seen in Fig. 2, with an increase in frequency, the magnitude of impedance decreases. This trend is observable in both the standard deviation and the average value of the amplitude course. During the forearm measurements, the average standard deviation of the amplitude course was 553 Ω, whereas the facial measurements yielded 152 Ω on average. Both amplitude plots, face and forearm, show a decrease in standard deviation. However, the course of the curve remains similar across both measurement locations.

Phase responses demonstrate a decrease in phase shift as the frequency increases. The standard deviations for the facial and forearm measurements are almost the same, with values of 14.58 and 14.52, respectively. However, the average phase shift is greater in the forearm measurements.

Based on the results of the correlation analysis, statistically significant associations were identified for all variables examined. The following correlations demonstrated statistical significance, as indicated by a p-value below 0.05 and a correlation value exceeding 0.5.

A correlation was found between the average phase shift and the moisture content of facial skin (r = 0.68, $p < 0.016$). For the forearm measurements, a stronger correlation was observed (r = 0.7, $p < 0.01$), as illustrated in Fig. 3. This correlation shows a dependency of the impedance measurement's phase shift on skin moisture content in facial and forearm measurements.

An additional noteworthy correlation emerged between the average magnitude and phase shift depending on the measurement site (r = 0.67, $p < 0.01$), see Fig. 5. This correlation confirms the variations in skin impedance between different body locations, specifically the face and forearm in this study. Moreover, there was a correlation between the R_∞ values of facial and forearm skin (r = 0.58, $p < .01$) as shown in Fig. 4. R_∞, a parameter in the Cole-Cole model, signifies the high-frequency resistance.

Finally, no strong correlations were detected with gender, age, skin color, ethnicity, or Body Mass Index in relation to the impedance measurements within the frequency range of 1 MHz to 10 MHz.

IV. Discussion

The resistivity values measured in this study are consistent with the range reported in the existing literature [7]. It is important to acknowledge that dry electrodes were used. This particular factor impacts the overall measurement as dry electrodes, compared to wet electrodes, typically exhibit a higher capacitive interaction with skin [10].

It is well-established that skin moisture significantly affects the measured skin impedance [11]. This property is exploited in conducting skin moisture measurements. However, the shape of the electrodes plays again a vital role [12]. Interdigitated electrodes in skin moisture measurement devices are designed such that the electrical field does not penetrate deeply into the skin, making the system highly responsive to the skin's uppermost layers. The electrodes used in our study were not designed with this specificity in mind, resulting in the electrical field penetrating deeper into the skin. Moreover, it's critical to underscore that this penetration depth is notably impacted by the frequency of the applied signal. Hence, as

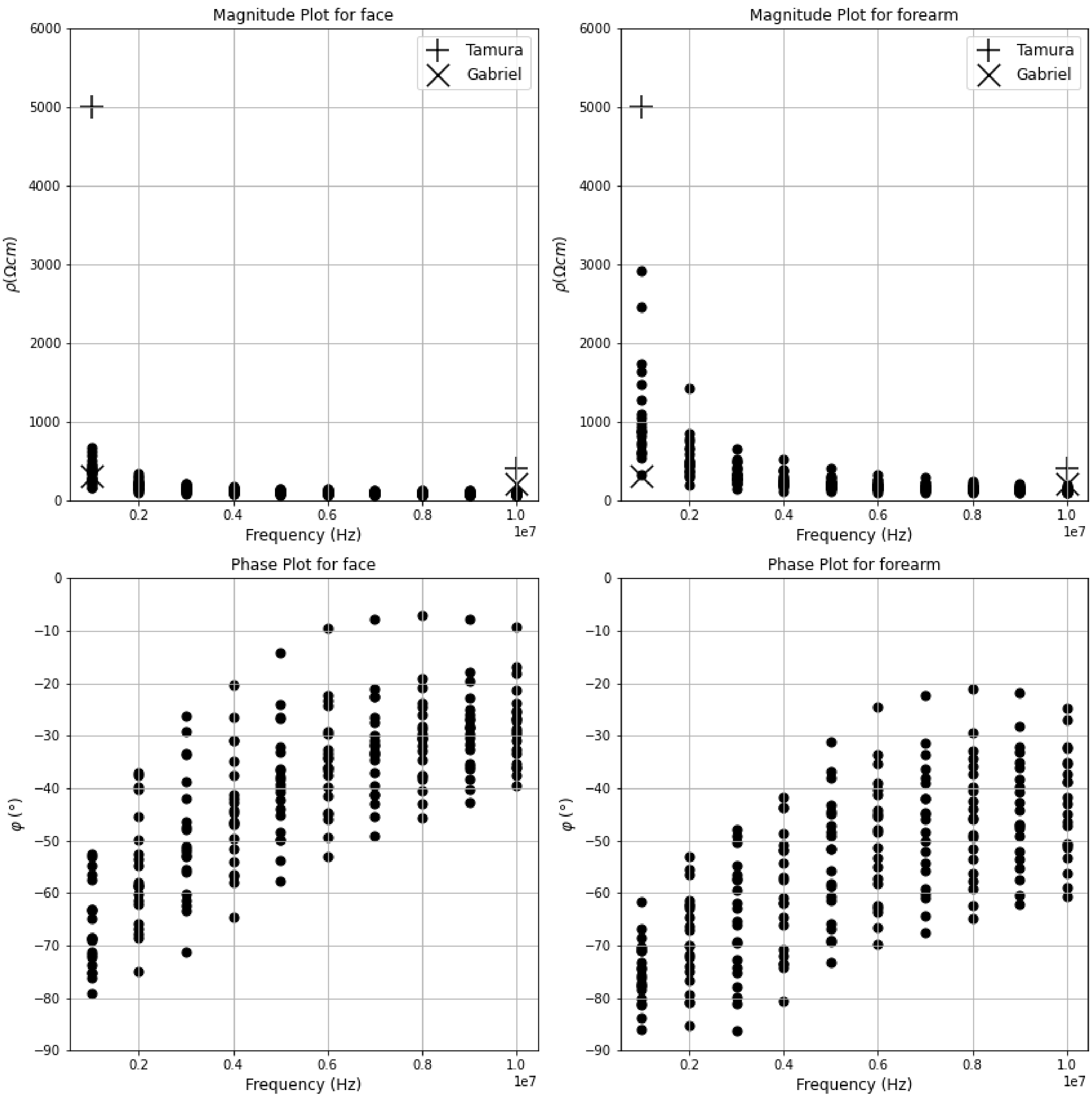

Fig. 2. Graph depicting amplitude and phase responses derived from impedance measurements, with each point representing the average value of a single subject at each frequency. Frequencies are analyzed at a resolution of 125 kHz. Comparative data from Gabriel and Tamura's research is included in the magnitude graphs for reference. [7]

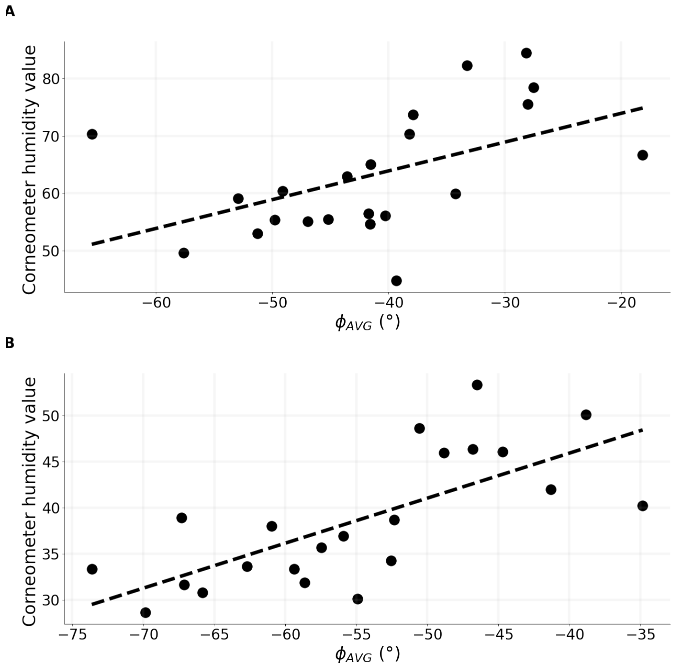

Fig. 3. Correlation between average phase shift and skin moisture levels on facial (A) and forearm (B) skin. Facial skin shows a positive correlation (r = 0.68, p = 0.016), while forearm skin reveals a stronger correlation (r = 0.7, p $<$ 0.01).

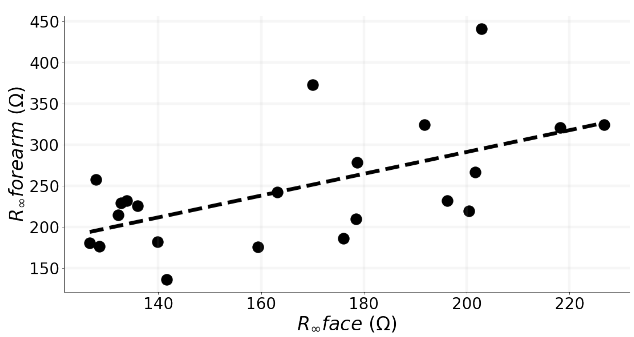

Fig. 4. The correlation between R_∞ values for forearm skin and facial skin is demonstrated. The Pearson's correlation coefficient stands at 0.58 with a p-value < 0.01

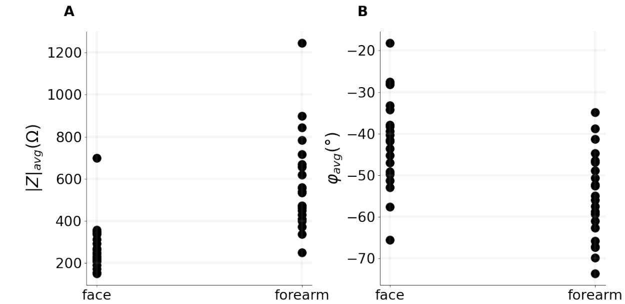

Fig. 5. Representation of the average values of the impedance amplitude and phase shift at the measurement site revealed a Pearson's correlation coefficient of 0.67 with a p-value $<$ 0.01.

the frequency increases, the influence of the skin's uppermost layers on the measurements decreases[8], [12].

The observed correlation between the measurement site and the average impedance magnitude and phases is not surprising as key parameters such as skin thickness, hydration, and composition vary from one body site to another [8], [13].

This study did not show that gender, age, skin color, ethnicity, or Body Mass Index exerted either a high or moderate influence on the impedance measurements in the frequency range of 1 MHz to 10 MHz.

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