Impedance analysis of acupuncture points and pathways

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Abstract. Investigation of impedance characteristics of acupuncture points from acoustic to radio frequency range is addressed. Discrimination and localization of acupuncture points in initial single subject study was unsuccessfully attempted by impedance map technique. Vector impedance analyses determined possible resonant zones in MHz region.

1. Introduction

In acupuncture and related fields it is assumed that there are special pathways in the body called meridians which are connected to main body systems, such as cardio-vascular, respiratory, digestive, etc. In this concept the pathways are exposed to the surface of human body in so called acupuncture points localized on skin surface. Although use of acupuncture is relatively well established in Western medicine as a complementary diagnostic and therapeutic tool, its physical and medical characterization is still largely unknown.

According to Zhang [1] within human body there is an invisible dissipative structure of EM field which in mainly composed of an interference patterns of standing waves in the resonance cavity of human body under the condition of permanent support of energy in an open system. This invisible structure may correspond to some extent to the mysterious acupuncture system and is closely related to different modalities of energetic medicine.

With noninvasive skin measurements typical values of impedance are around the range 100 kΩ and capacitance elements around fractions of μF. Some of the previous studies showed that electrical characteristics like impedance and capacitance at acupuncture points may show distinct values in comparison to values obtained from surrounding non-acupuncture points. Acupuncture sites were found to possess lower impedance and higher capacitance. However, some studies found no distinction from surrounding tissues. According to the review by Ahn et al. [2] preliminary evidence supports these findings however it is still impossible to determine whether acupuncture structures possess distinct electrical characteristics until better quality studies are performed.
Segments of human body may be modelled by electrical circuits. Complex electronic circuitry consists of conductors, capacitors and inductances. Resistive component reflects mainly proportion of liquids comprised in the tissue together with liquid properties of current conductance depending on concentration of different ions. Capacitive component reveals integrity of cell membranes. Phase angle is in bioelectrical impedance analysis used as an indicator for disease, hydration and nutritional status. Better overall health status should correspond with higher phase angle. Fukumoto [3] suggested a new approach for acupuncture point determination by constructing a ratio of imaginary and real part of complex impedance.

Within wide frequency range it may be beneficial to focus on the question whether resonant behavior may occur in systems of interest. Focus is directed to frequency windows with values of impedance modulus and/or phase angle different from values at surrounding frequencies. Basic resonance phenomena is often demonstrated on simple serial RLC circuits where inductance component is vitally needed in order to compensate capacitive part. Resonance should occur when phase angle vanishes. In biological systems inductance appears to play no significant role. However, also circuits with only resistive and capacitive components may possess resonant behaviour. Reichmanis et al. showed in [4] such an example: Infinite transmission line consisting of elements built from serial resistance with another resistance in parallel with capacitance (figure 7, model B) and terminated by its characteristic impedance.

Aim of the initial part of our study was to prepare methodology for several types of impedance measurements in order to study resonant behaviour of acupuncture system. Our investigation was focused on critical assessment of electrical properties of single acupuncture points and properties of meridians measured between two acupuncture points of the same meridian. In the first step we attempted to localize acupuncture points from impedance modulus maps. Then followed investigation of electrical properties of acupuncture system by vector impedance analysis in acoustic and radiofrequency range.

2. Methods

All data were measured from single healthy subject (corresponding author, male, 36 years old). Acupuncture points were chosen according to their accessibility – left arm, diversity of acupuncture pathways and significance regarded to therapeutic use in acupuncture medical system. The following points were used: Large intestine LI-4 and LI-11, heart HT-3 and HT-7, lungs LU-5 and LU-7, pericardium PC-6 and PC-3, and triple warmer TW-3, TW-8, and TW-9. Experienced clinical acupuncturist localized all the points and afterwards they were labeled by marker and photographed. Control points were taken several centimeters apart from acupuncture points, namely in LI-4 and HT-3 area.

For the first part, impedance maps were measured with a grid of 64 brass telescopic needle electrodes (figure 1). Their telescopic tips maintained balanced pressure across measured area with side length 17.5 mm. Distance between neighbouring tips was 2.5 mm. Monopolar arrangement was applied with clamp reference electrode on the opposite arm (surface 6 cm²). Frequency of probing current was 1 kHz. Unique recording system was controlled from Matlab environment via USB port. Prototype comprised microprocessor (Atmel ATmega16) with serial port and eight A/D converters with 10-bit resolution. The device measured voltage difference between active and passive electrodes based on spike detectors. Consequently, off-line transformation from voltage into impedance was performed based on interpolation of voltage data corresponding to known resistances.

For the second and the third experimental setup adhesive disposable Ag/AgCl ECG electrodes (Ambu Blue Sensor P) with measuring area 154 mm² and PUR sponge with highly conductive wet gel were used (figure 2). Electrode polarization effect was minimized by Ag/AgCl coating [5]. These active electrodes were placed on acupuncture point of the left arm.
3. Results and discussion

3.1. Impedance maps

We have found only one study depicting impedance/conductance maps of acupuncture point. Becker et al. [6] found higher conductance in the centre of acupuncture point surrounded by roughly circular equiconductance pattern (figure 3).
Impedance maps from 11 acupuncture points did not consistently support any map structure with similar characteristics and pattern. In most of the cases distinctive minima surrounded by circular patterns were not found. In many maps there was no isolated depression in impedance modulus (figure 4). To show one of the most resembling map, there is local extreme in a form of minima at the upper left picture of figure 4 with certain indication of surrounding pattern. Control maps showed similar structures: irregular extremities spread across the measured skin surface, often with considerable variations within mm distance: Readings from neighbouring electrode sites differed up to the one order of magnitude. We found that repeatability of the same map was valid only under very restricted conditions – with immediate repetition and without removing the electrode grid from the skin. As a next step we plan to localize acupuncture points more precisely into the centre of the map and test different pressure levels of telescopic needles.

Figure 3: Sample of conductance map on acupuncture point LI-4 from study of Becker et al. [6].
3.2. Impedance in acoustic frequency range

For impedance measurement in acoustic frequency range Tesla BM 595 RLCG meter was used. Copper reference electrode in a shape of cylinder was placed under the right thigh. Supported frequency range was 100 – 20 000 Hz.

No distinction of acupuncture points from control points was obtained. On the contrary to expectations (e.g. [7]), control points had not higher impedance modulus (figure 5) in comparison to acupuncture points. While in impedance modulus all the curves were slightly decreasing, phase angle curves (figure 6) did not exhibit monotonous behaviour for most of the cases.
From obtained data it is possible to fit impedance $|Z(f)|$ according to simple circuit models depicted in figure 7. John et al. [7] successfully fitted their data according to model from scheme A of figure 7. Resulted estimates of one resistive and two capacitive components represented electrical elements based on skin layers: epidermis on the surface with dry tissue of stratum corneum (parallel $R$ with $C$) together with serial $R$ representing dermis. Their estimates agreed with distinction of acupuncture points as to be sites with smaller resistance and larger capacitance.
Figure 7: Electrical equivalent circuits from [2]: Model A was proposed by Johng et al. [7], model B by Rosendal [8].

Preliminary fitting of our data based on models from figure 7 was not appropriate, as the regression error was too large. In the next step we plan to build more complex model with more circuit elements. Also, relatively large surface of active electrode (1.5 cm$^2$) could cause that the largest current density flowed at electrodes’ periphery and thus could avoid active points.

3.3. Impedance in radio frequency range

Depth of penetration into the skin is determined by AC frequency of measurement. Direct and low-frequency currents penetrates mainly only into the epidermis dominated by the dead stratum corneum. Moreover, at low frequencies (typically below several hundred kilohertz), the conductivity of the tissue is dominated by conduction in the electrolytes in the extracellular space. In order to investigate properties of deeper tissue structures and intracellular space as well, experimental setup with radio frequency impedance analyzer was prepared.

At radio frequencies, the tissue exhibits the beta dispersion, centered in the range 0.1 to 10 MHz, due to the charging of cell membranes through the intracellular and extracellular media. Above the beta dispersion, the cell membranes have negligible impedance, and the current passes through both the extracellular and intracellular media. On the other hand ionic flow is diminishing as relatively heavy ions are not able to adjust to rapid change of current direction.

Tomco TE1000 radio frequency impedance analyzer was applied with ECG active electrodes placed at acupuncture points and copper cylinder reference electrode hold in the right palm. The measurements were realized in the electromagnetically shielded room. Frequency from 0.5 – 150 MHz range was scanned with 1.5 MHz step.

The variations in impedance values across the whole frequency range were at the level of 1-2 orders of the magnitude (figure 8). Observed lower impedance zones around 50 and 70 MHz could point to the zone with improved information transmission in the studied tissues. Moreover, both zones bear another distinct property - zero phase angle (figure 9). These are the characteristics of resonant behaviour. Resonant properties may be demonstrated by either negative or positive impedance peaks. Different acupuncture subsystems differ from each other in resonant frequency around 50 MHz up to 10 MHz. A few another null angle zones appeared in the figure 8 while not binding to impedance extremities.
Acupuncture in comparison to control points seems to exhibit higher variations in impedance. Also, the main impedance minima at 50 MHz is for acupuncture points shifted to higher frequencies. The same holds for null angle characterizing resonant frequency around 50 MHz. The only acupuncture pathway measured between two acupuncture points exhibits distinct behaviour: sharper extremities and higher number of zero phase crossing.

Overall, the preliminary results require more data accumulation and further analysis. Experiences with measurement techniques confirm the fact that results may be heavily dependent on some of the
following measurement characteristics: skin surface, presence of sweat glands, electrode geometry and polarizability, contact pressure, time fluctuation of electrical properties, etc. Impedance analysis of acupuncture system deserves further attention along the need for improved understanding of physical mechanisms behind basic functioning of this relatively broadly used medical modality.

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