For Proofreading

Bioelectrical Impedance Of Meridians Using Low Frequency Electro-Acupuncture

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Abstract
The purpose of this research project was to investigate the bioelectrical behaviour of meridians in comparison with surrounding tissues in male volunteers using a stimulation frequency in the range of 2 Hz to 2000 Hz. Subjects were needled using a 4-electrodes needle insertion technique. Componential impedance values of meridian segments showed a marked difference compared to non-meridians, specifically in frequencies just below 50 Hz.

Reference

Keywords
Acupuncture; complementary medicine; biological impedance; invasive current; electrodermal.

Introduction
According to eastern medicine, sometimes identified as traditional Chinese medicine (TCM), meridians are biological pathways bridging special points named acupuncture points (APs). Results of recent tests by various researchers have allegedly shown differences in the bioelectric properties of meridians versus their peripheral tissues, with some tests indicating that the impedance of needled points precisely over a meridian is lower than in neighbouring non-meridian points.

TCM uses acupuncture to alleviate pain, as well as decrease and remedy disease, as has been documented in eastern medicine literature. The clinical practice of acupuncture originated in East Asia and is the most well-known complementary medicine modality(1,2). Since the spread of evidence-based western medicine, a good deal of research has been undertaken to establish the effectiveness of complementary medicine using western-based science.

In keeping with TCM theory, meridians are conduits for the flow of vital energy, also called Qi, in the body. The name of each meridian is based on the vital organ that a meridian passes through, such as kidney meridian (K) or small intestine meridian (SI). At the centre of TCM’s Qi flow theory is the assertion that pains and diseases related to these vital organs can be treated by applying acupuncture to specific points on meridians. These points have different biological properties.

Our study was aimed at investigating the differences in the bioelectrical properties of selected points on specific meridians and an equal number of non-meridian points in the same vicinity. One study of cardiovascular patients showed that thermal energy density was higher on the skin route along the heart meridian. Furthermore, tungsten light passing between two APs of the pericardium meridian was 20% brighter than on a similar off-route in peripheral tissues ie, non-meridian(3,4).

Research has been previously conducted on the identification of APs and treatment of diseases concerning biological parameters, including bioelectrical impedances(5). Ahn et al’s review of past research reported lower surface impedance around APs compared with their peripheral points(6). Although most of the previous studies were non-invasive with only a few being invasive, the aggregate outcome only yielded more controversy(7). The issue yet to be resolved is firstly, whether different electrical properties exist between meridians and non-meridians and secondly, whether this difference can enhance the understanding of how acupuncture can be used to treat disease or assist patients with pain relief.

This experimental set-up was designed to enable replication in future studies. Its objective was to consider the complex electron interactions in biological elements along meridians that show electrical properties, and to illustrate how these might differ from non-meridians. These electric properties have the potential to contribute to bioelectric impedance.
Taking this approach, our study was planned to evaluate electrical impedances of a 4-electrodes invasive treatment strategy. The results obtained were recorded, plotted, tabulated and analysed and the outcome is presented in this paper.

Subjects And Methods

The procedures used in this study complied with the World Medical Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects. The criteria for acupuncture points and the experimental method were submitted to the appropriate authorities at Azad University, Tehran, Iran, to obtain permission to conduct this research on human subjects. The entire experiment was carried out in the Bioelectric Laboratory Building of the Biomedical Engineering Faculty of Azad University.

Careful consideration was given to the selection of candidates. To keep variables controlled, only healthy male subjects were selected. There were 40 tests conducted on eleven male subjects aged between 25 and 35-years-old. Preliminary screening was applied to exclude subjects with cardiac, stomach or digestive disease. Furthermore, any volunteers with a history of pain or surgery in the relevant meridian, or its peripheral, or corresponding non-meridian control sites, were excluded. Also, those volunteers with sensitivity to needle insertion were not included in this study.

The procedure commenced by removing hair from the subjects in the areas that were to be needled. These areas were sterilised using alcohol. Every subject was allowed to rest in a relaxed position for five to twenty minutes while the procedure was explained to them. Standard off-the-shelf disposable steel acupuncture needles were used. These needles also acted as the output voltage-recording probes. The duration of each test was approximately 24–30 minutes.

The impedances for meridian and non-meridian biological pathways were calculated using the data acquired after stimulating the points as detailed above. This method, also known as the frequency response method, has been in use since the early nineteenth century, hence it is universally acceptable among biomedical and electrical engineers as a reliable modus operandi. Our aim in using this method was that, by injecting an electrical current with a known and controlled frequency which measures output voltage, it would yield sufficient data for assessing the impedance.

The selection of test points considered: location and direction of the meridian route; ease of probing; relative spacing between points with respect to other meridians to minimise inter-meridian and intra-meridian inaccuracy; potential harm or side effects whilst needling; whether hair could be removed prior to probing if it existed; adequate clearance from peripheral; and the presence of different bio-matrices under the needling site for getting distinct biological conditions. Moreover, subjects were given a rest period of twenty minutes prior to needling in an attempt to settle any anxiety or fear in anticipation of the procedure.

Based on ease of access to the segments, as well as relative popularity in acupuncture practice, three meridians and their segments were chosen for this study. These meridians were pericardium (Ximen PC-4 to Daling PC-7), stomach (Zusanli ST-36 to Xiajuxu ST-39), and spleen (Chongmen SP-12 to Fuai SP-16). These were APs with distances between 1 Tsun and 3 Tsun on selected parts of meridians, and were quoted frequently in text books as effective points used in clinical practice.

Non-meridian needled points were located on a parallel line to the meridians in a position relative to the APs. These non-meridian points provided a comparison with the sample segments of meridians in different body locations: foot, hand and trunk. Each of these locations has different biological properties, electro-sensitivities, bioelectrical characteristics and impedance responses to stimulation.

The impedance was evaluated using Ohm’s Law applied to the 4-electrodes measurements. An electrical current was passed through two outer points, and the electric potential across the two inner points was measured (admittance evaluation).

An advantage of applying the 4-electrodes technique compared with the 2-electrodes technique was the uniformity of current flow at the receiving sites. Due to possible electro-chemical exchange between tissue and electrodes, this 4-electrodes technique was preferred. In this technique, entry and exit points of the electrical current were assumed as outer points that received voltage.

Since concurrent measurement of meridian and non-meridian voltages were conducted in this study, the 4-electrodes set-up had to be improved. After the needles were inserted in-vivo, the real-time measurement of current through the predicted routes and voltage read-outs were concurrently recorded. This was achieved by simultaneously using the 2-needle electrodes for current entry, and another 2-probed electrode points for measuring voltage on meridian APs and non-meridian control points.

The current was produced by a voltage regulator and placed 20 mm away from the midline of the path that linked the meridian and non-meridian routes. The current was limited to 60 µA in amplitude with 2 Hz to 2000 Hz stimulation frequency range. Currents and voltages were recorded non-sequentially in frequency multiples of two, five and ten to minimise the harmonic effect and adaptation of live reactivation and galvanic response.

The current passing through tissues and output voltage from needles was recorded using a data acquisition system (BIOPAC Systems, Inc., Santa Barbara, CA 93117 USA). The data was monitored on a computer in real-time and then passed through a software filter known as Hamming. This was used to enable computation of the impedance as well as observation of any phase change in the frequency response, otherwise known as Bode plots.

The results of all the tests ie, pericardium, stomach and spleen meridians from points PC-4 (Ximen) to PC-7 (Daling) on the arm, ST-36 (Zusanli) to ST-39 (Xiajuxu) on the leg, and SP-12 (Chongmen) to SP-16 (Fuai) on the trunk,
were recorded and saved. Non-meridian points were distanced no less than 10 mm alongside their parallel meridian points.

Figure 1 illustrates a typical arrangement of inserting needles at 3 Tsun from the stomach meridian and its parallel route as non-meridian at a distance of 10 mm. The insertion depth was 5–10 mm in depth for all needles in every case. Surface EMG electrode patches were used for applying the stimulation current.

There were six electrodes, including two for current entry and four for simultaneous voltage-recording of meridian and non-meridian points, as derived from the classic 4-electrodes technique. Using such a set-up allowed for a synchronous measurement of the impedance components for meridian and non-meridian pathways. The resulting data was filtered and stored ready for post-processing and further analysis.

To enhance signal:noise ratio and minimise any undesired interference effect on cell matrix and remote tissue, the sinusoidal current amplitude was set at 10–60 µA. This minute applied current created voltages in the surrounding tissue in the order of a millivolt range which was considered safe.

The recorded amplitude and phase of input and output signals were stored for computation of impedance using Ohm’s principles. Ohm’s law states that the amount of current through a medium is directly related to the electrical potential difference or voltage across the medium, and is inversely proportional to the resistance in between. The current and voltage peak amplitudes were measured and post-processed by applying a Hamming filter.

A sample of a signal recorded at a distance of 3 Tsun on the stomach meridian after passing the software filter is illustrated in Figure 2. The inserted current was 25 µA with a frequency of 5 Hz as signified in the top graph. The second and third graphs indicate voltages from the meridian and its pathway parallel non-meridian, respectively.

The values of recorded impedances at different frequencies were plotted on a Bode plot using MATLAB software Ver.7.0. Figure 3 shows a sample of a Bode plot for the tests conducted at various distances on meridian and non-meridian points on the foot, hand, and trunk on the pericardium, stomach, and spleen meridians. All the tests yielded similar pattern diagrams. The meridian and non-meridian impedance changes were analysed for frequencies from 2 Hz to 2000 Hz. The minimum impedance amplitude was observed to be in the 15–55 Hz frequency range. Furthermore, the focal phase changes were evident in this range.

Results

The results indicated that there was significant non-linearity between the distances and recorded values of two probed biological locations, even with measurements carried out on the same subject. Application of the Bode plot to the data allowed assessment of the meridian and non-meridian impedances to be compared within the 15–55 Hz frequency range.

Larger differences were evident at frequencies lower than 60 Hz. It was noted that meridian impedance was lower at some frequencies (resonant frequency), and the value of impedance was at its minimum when the meridian and non-meridian phase sign switched polarity.

The tests were of an invasive nature; hence stimulation and recordings were classified as in-vivo data. The invasive needling tests showed insignificant differences in impedances of meridian and non-meridian pathways at high frequencies. In contrast, a notable difference was evident for frequencies lower than about 55 Hz with mean differences as high as 40% with a minimum of at least 14%. The resonance frequency for meridians and non-meridians averaged 23–43 Hz (p<0.005).
The results showed that the maximum impedance difference between meridian and non-meridian pathways occurred at frequencies lower than 40 Hz. At the frequencies where impedance of meridians and non-meridians was at its lowest, i.e., resonance frequencies, test results indicated statistically significant differences in the recordings. This feature can be used to identify meridian and non-meridian pathways. Furthermore, the clear difference observed between meridians and non-meridians in the lower frequency range confirmed TCM practitioners’ assertion of lower frequencies yielding better outcomes. Similar findings were reported by other investigators.

This kind of practical methodology effectively permitted a real-time assessment of the biological impedance components at the probed sites; hence, a means of demonstrating differences in biological pathways in-vivo. The outcome of this study can be replicated using electro-acupuncture stimulation equipment as used by acupuncturists. Such devices are capable of generating selectable frequencies; however, the waveform shape needs consideration as it may also be important.

One practical issue when treating a patient with electro-acupuncture is the application of a safe level of electric current to APs. The safe level relates to both frequency and amplitude which is dependent on the waveforms. Figure 4 shows typical waveforms generated by commercial devices. Saw-tooth waveforms cover a greater frequency spectrum.

Fourier Transform technique, when applied to such waveforms, can demonstrate this characteristic. The Fourier Transform technique is a means of analysing a complex signal into its oscillatory components, thereby enabling the experimenter to calculate the fundamental frequency and the component frequencies. Conversely, the period of such types of treatment to waveforms in time domain contains two modes of high and low repeat frequencies.

According to practitioners’ anecdotal claims, the frequency of 5 Hz returns worsening and/or extended motor muscles. Accordingly, frequencies of 50–100 Hz have been applied by acupuncturists in eliminating anesthesia, senselessness, and related tenderness of muscle or muscle spasm. A combination of these frequencies has been used for relatively complicated treatments depending on the individual patients’ biological responses.

Furthermore, the 50–100 Hz frequency range has been applied to improve limb activities, tissue reproduction and digestion, as well as to decrease vein inflammation, swelling in muscles and joints, and clear vein or meridian clogging. For acute conditions, such as paralysis and similar syndromes, discrete repeated frequencies have been used.

Even the waveforms can have different types as shown in the sample waveforms used in practice in Figure 4. All the anecdotal evidence points to finer treatment responses to electro-acupuncture stimulation being achieved when frequencies lower than 100 Hz are used.

Our observations indicate that the main difference between meridians and non-meridians is restricted to frequencies lower than 50 Hz. Perhaps this could explain why an improved treatment response is experienced when lower frequency settings are applied in clinical practice. This western scientifically-designed study, with its unique approach using a biomedical engineering technique, conformed with the practical results of electro-acupuncture.

The observed higher resistance of non-meridian pathways, especially in lower frequencies when compared with meridians, could be accepted as the scientific rationale for observing lesser biological affectability when invasive electro-acupuncture is applied to the body for the purpose of treating health conditions.

**Discussion**

In this study, the electrical componential impedance of three meridians was evaluated and the values were compared with their neighbouring non-meridian impedances in the frequency range of 2 Hz to 2000 Hz. The similarities and differences observed in the result and graph patterns were analysed. The meridians and non-meridians had a resonant frequency of about 20 Hz and 45 Hz, respectively, and in frequencies lower than the resonance.

The major difference between the meridian and non-meridian impedance components was distinct. It is concluded that the functional operation range is in the lower than resonance frequencies which is quantified to be generally less than 50 Hz. These results were consistent with anecdotal claims from electro-acupuncture practitioners and their patients—that high period excitation is most effective for treatment.

The high period excitation is effectively low frequency stimulation. The devices used in practice have a frequency range up to 0.8 kHz, but frequencies far lower than that may be useful depending on the location of the meridian being needled. The treatment capacity of electro-acupuncture devices may be justified for certain categories of cases such as neural and musculo-skeletal pains if the results of this study relate to categories of bioelectrical pain signal pathways.

Different results with different meridians add to the complexity of scientific reasoning. Comparing our results of three meridians with different sub-neighbourhood tissues (arterial, neural, skeletal and adipose), revealed that there was no direct relationship between the characteristics of tissue matrices and meridian impedance parameters.

Any scientific explanation of differing biological results when needling and stimulating two locations on the body, even 1 Tsun apart, must relate to the natural constituents of the locale. The tissues can be nervous, muscular, epidermal or connective and have cell arrays. They are connected to peripheral tissues via connecting tissues and create cell matrices.
Some research revealed that the quantity of the mast cell was more concentrated under the meridian lines vis-à-vis their control areas (10, 11). Also, water molecule polarity could make a low impedance pathway (12). Therefore, a meridian pathway might have a different characteristic according to special streamlining of water molecular polarity along the trail.

On the other hand, grasp in needled APs has more momentum force in comparison to peripheral control points (13). The different biomechanical parameters can be due to structural differences of tissues in meridian and non-meridian pathways. More research at the sub-tissue level is needed to understand this phenomenon. In particular, further evidence is required to understand and explain the similarity in impedance of meridians and non-meridians at higher frequencies.

An analysis may be necessary to investigate the relationship of the low frequency range to the energy flow. This may create a means of understanding TCM theory of Qi conducted by meridians and not through non-meridian pathways, and the transfer of Qi between APs of the vital organs that the meridians have been named after. This study should assist with understanding human biology from an eastern medicine viewpoint as well as redefine the concept with western science-based theory. Ultimately, the two medicinal practices will complement each other in working towards improving health.

References


