



Original Article

Biopotential changes of acupuncture points by acupuncture stimulation



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ABSTRACT

Background: The energy flow at acupuncture point is important for understanding the mechanism of acupuncture treatment. However, there are few studies on energy at acupuncture point, and related studies have limitation in explaining the energy flow in all meridians. Thus, we aimed to understand the properties of electrical energy at acupuncture point in twelve meridians by measuring the biopotential at acupuncture and non-acupuncture points.

Methods: For each meridian, twenty subjects were participated, and biopotential was measured at five transport points and their adjacent non-acupuncture points. In each subject, both 'non-stimulation' and 'stimulation' experiments were conducted in random order. The data were analyzed in two parts: biopotential variability and biopotential difference between acupuncture and non-acupuncture points.

Results: The biopotential variability at acupuncture point was increased by acupuncture stimulation, and it was related to the activation of Qi flow by acupuncture stimulation. The biopotential difference between acupuncture and non-acupuncture points was formed in the direction related to the Qi flow theory, and this biopotential difference tended to decrease by acupuncture stimulation.

Conclusion: The study on biopotential can provide a foundation for research on energy flow mechanism of acupuncture stimulation, and it is expected to overcome limitation of qualitative explanation in traditional medicine.

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1. Introduction

Acupuncture treatment has been used for thousands of years in clinical practice and its efficacy has been objectively verified on various diseases including osteoarthritis,¹ chronic pain,²⁻⁵ fibromyalgia,⁶ headache,⁷ dysmenorrhea,⁸ xerophthalmia,⁹ and addiction.^{10,11} Despite such objective evidences of efficacy, acupuncture treatment is still controversial because its physiological mechanism is not clear.

Recently, some studies have attempted to understand the mechanisms of acupuncture treatment. Studies on the mechanism of acupuncture treatment are divided into 1) molecular biological studies based on animal experiments and 2) bio-imaging studies based on clinical trials. In molecular biological studies, biomolecule

changes are investigated after acupuncture treatment,¹²⁻¹⁵ but these studies have limitations that cannot be applied to humans. In bio-imaging studies, the changes of bio-indices such as fMRI^{16,17} and EEG^{18,19} are assessed after acupuncture stimulation. As such, many have tried to elucidate the mechanism of acupuncture treatment in various areas, but these are limited in that they focus only on signal transmission by acupuncture stimulation and cannot explain the energy transmission. Energy transmission is as important as signal transmission in explaining the mechanism of acupuncture treatment, thus this study focuses on energy change caused by acupuncture stimulation.

In Korean medicine, the concept of energy or Qi is so broad that it is difficult to define it in one or two sentences. The complicated explanation of Qi can be simplified to 'things that are invisible but have action', and the flow of Qi in the meridian is regarded as the flow of energy or a specific functional action.²⁰ In addition, the flow of Qi is activated by acupuncture stimulation.²¹ Due to the difficulty in defining or measuring Qi, few studies have been

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Table 1
Five transport and source points of twelve meridians.

Meridian	Five transport points					Source point
	Well	Brook	Stream	River	Sea	
Lung (LU)	LU11	LU10	LU9	LU8	LU5	LU9
Large Intestine (LI)	LI1	LI2	LI3	LI5	LI11	LI4
Stomach (ST)	ST45	ST44	ST43	ST41	ST36	ST42
Spleen (SP)	SP1	SP2	SP3	SP5	SP9	SP3
Heart (HT)	HT9	HT8	HT7	HT4	HT3	HT7
Small Intestine (SI)	SI1	SI2	SI3	SI5	SI8	SI4
Bladder (BL)	BL67	BL66	BL65	BL60	BL40	BL64
Kidney (KI)	KI1	KI2	KI3	KI7	KI10	KI3
Pericardium (PC)	PC9	PC8	PC7	PC5	PC3	PC7
Triple Energizer (TE)	TE1	TE2	TE3	TE6	TE10	TE4
Gall Bladder (GB)	GB44	GB43	GB41	GB38	GB34	GB40
Liver (LR)	LR1	LR2	LR3	LR4	LR8	LR3

conducted on the mechanism of Qi or energy flow by acupuncture treatment, and all related studies have focused on the electrical properties such as the conductivity of acupuncture points²²⁻²⁵ or measured biopotential changes only at some acupuncture points, not all meridians.²⁶⁻²⁸ Thus, we aimed to observe the changes in electrical energy and to compare the electrical potential between the acupuncture and non-acupuncture points in twelve meridians.

In the theory of Korean medicine, five acupuncture points wherein the energy flow is mostly activated in each meridian have been designated as five transport points (well, brook, stream, river, and sea points). The five transport points have a continuous flow of Qi between acupuncture points within a meridian, similar to the merging of waterways, and their properties change gradually.²⁹ Thus, it is considered suitable for observing the continuous change of the energy at acupuncture points. Based on this, we attempted to investigate the properties of biopotential at the five transport points and nearby non-acupuncture points of 12 meridians.

2. Methods

2.1. Subject

Two hundred forty healthy subjects (20 for each of the 12 meridians) were recruited to participate in this study. The subjects' mean age was 23.8 ± 2.5 (\pm SD) years. Individuals with asthma, atopy, inserted prosthesis, burns on the arms or legs, excessive sweating, skin diseases, metal allergy, surgery history within the previous year, or medication in the previous month were excluded. All subjects were fully informed about the experiment and signed the written consent form.

2.2. Biopotential recording

For each meridian, biopotential was measured at eight points; five acupuncture points (well, brook, stream, river, and sea) on the left side of the body and three non-acupuncture points 1 cm apart from brook, stream, and river points in the direction perpendicular to the meridian. Fig. 1A shows an example of the acupuncture and non-acupuncture points in the pericardium meridian used in this study, and Table 1 presents the five transport points, which were used for biopotential measurements, and the source points, which were used for acupuncture stimulation, in twelve meridians. The ground electrode was attached to the inside of the elbow for hand's meridian and to the inside of the knee for foot's meridian. The reference electrode was attached 1 cm apart from the ground electrode. The location of each acupuncture point followed the "WHO Standard Acupuncture Point Locations in the Western Pacific Region",³⁰ and locating the acupuncture and non-acupuncture points was performed by Korean medicine doctor. The

electrode, which is gold-plated and round-type with 0.25 cm diameter, was developed by the Korea Institute of Oriental Medicine (KIOM), and biopotential was recorded through a data collecting device (Bioscan Meridian) developed by KIOM.³¹ Bioscan Meridian can record 24 channels at the same time with a maximum sample rate of 5 kHz. Electrodes were attached to the skin with signal gel "Lectron II" (Pharmaceutical Innovations, Newark, NJ) to reduce the resistance between the electrode and skin. Data handling and statistical test were performed using "MATLAB 2015b" (Mathworks, Natick, MA).

2.3. Procedure

All subjects rested for 30 min for stabilization before starting the experiment. While a subject lay on the bed, the electrodes were attached, and then the subject rested for 30 min to reduce the noise. The measurement process is shown in Fig. 1B. After a 30-minute rest, biopotential was measured in a total of 4 sections (Sections 1, 2, 3 and 4) with an interval of 5 min, and each section was continuously measured for 10 min. In each subject, both 'non-stimulation' and 'stimulation' experiments were performed in random order, and the interval between the two experiments was set to be at least 3 days for minimizing the interference effect. For 'stimulation' experiment, the needle was inserted into the source point on the right side of the body after Section 1 and removed after Section 3. During the measurement, the subject was stationary and awake. The sample rate was set up at 100 Hz, and a notch filter was applied to eliminate the AC noise. The measurement was taken in a quiet place with steady lighting where was shielded from electromagnetic waves and maintained at 23~25 °C and 35~55% humidity.

2.4. Analysis

The recorded data were preprocessed through smoothing and normalizing. First, robust locally estimated scatterplot smoothing (RLOESS) with a window size of 100 s was performed to remove outlier data. Then, moving average with a window size of 100 s was performed twice for smoothing. Smoothed data were normalized based on the overall range (the difference between the maximum and minimum values) of the non-stimulation data for each subject. After preprocessing, the changes in biopotential variability and the comparison of the biopotential between the acupuncture and non-acupuncture points were examined.

The biopotential variability was analyzed by defining the variability using mean distance and standard deviation.

Mean Distance

$$MD = \frac{1}{T} \sum_{t=1}^T |x_t - x_{t-1}|.$$

Standard Deviation: $SD = \sqrt{\frac{1}{T} \sum_{t=0}^T (x_t - \bar{x})^2}$ where, \bar{x} is the mean of the samples.

Variability: $VA = MD \times SD$.

Many studies evaluate the variability using only the standard deviation, but standard deviation does not sufficiently express the variability because it contains only spatial distribution of the samples. Therefore, in this study, we estimated the variability by considering both standard deviation for the spatial distribution and mean distance for the temporal fluctuation (see Section 1 in Supplementary). Based on Section 1, the change of biopotential variability in each section was investigated. For the statistical analysis, one-way paired *t*-test was performed for non-stimulation and stimulation data in each section.

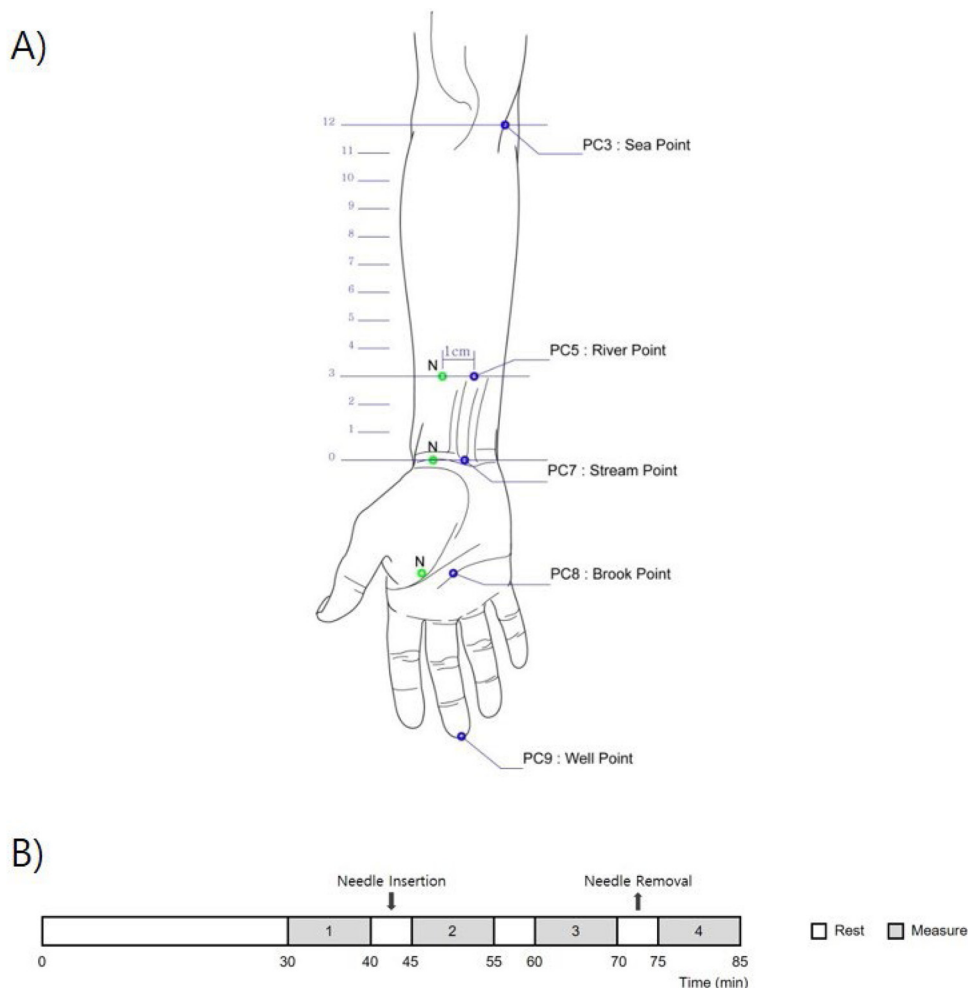


Fig. 1. Biopotential measurements.

A) An example of the acupuncture and non-acupuncture points in pericardium meridian for measuring biopotentials. PC9, PC8, PC7, PC5, and PC3 were used for the acupuncture points, and three non-acupuncture points were selected 1 cm apart from PC8, PC7, and PC5 in a direction perpendicular to the meridian. B) Biopotential recording procedure. After a 30-minute rest, biopotential was measured in a total of 4 sections (Sections 1, 2, 3 and 4) with an interval of 5 min, and each section was continuously measured for 10 min. For 'stimulation' experiment, the needle was inserted after Section 1 and removed after Section 3.

For the biopotential comparison between the acupuncture and non-acupuncture points, the mean of biopotentials for each section was obtained, and the difference in biopotentials between the acupuncture and non-acupuncture points was obtained as follows:

$$\Delta \bar{\Phi} = \bar{\Phi}_{ACU} - \bar{\Phi}_{NON},$$

where $\bar{\Phi}_{ACU}$ and $\bar{\Phi}_{NON}$ are the mean of biopotentials at the acupuncture point and nearby non-acupuncture point, respectively. Finally, one-way ANOVA was performed for the brook, stream, and river point groups at each meridian to assess the significance among groups.

3. Results

3.1. Biopotential variability

Fig. 2 shows the mean of biopotential variabilities of 12 meridians in each section at the five transport points. In the figure, the error bar is the standard error, and asterisk (*) indicates that the p-value is less than 0.05 by the paired t-test. The results show that the biopotential variability increases considerably after acupuncture stimulation at all five transport points.

3.2. Biopotential difference between acupuncture and non-acupuncture points

Fig. 3 shows the biopotential differences between the acupuncture and non-acupuncture points. Fig. 3A shows the mean and standard error of the biopotential differences at the brook, stream, and river points in twelve meridians. In the figure, asterisks indicate the significance by the ANOVA (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). The results show that the biopotential differences tend to increase in order of brook – stream – river in all meridians. There are significant differences in all meridians except the heart meridian (see Table S1 in Supplementary). Fig. 3B is the rearrangement of the results of Fig. 3A with respect to acupuncture points. In the results, the biopotential differences have negative values at the brook point but positive values at the river point. There are both negative and positive values at the stream point, but within a meridian, the value is between those of brook and river points. Fig. 3C is a histogram of all individual biopotential differences in twelve meridians with respect to acupuncture point. The results show that the biopotential differences are mostly distributed in negative at the brook point but mostly distributed in positive at the river point. Fig. 3D represents the ratio of the positive and negative values of biopotential differences. In the results, at the

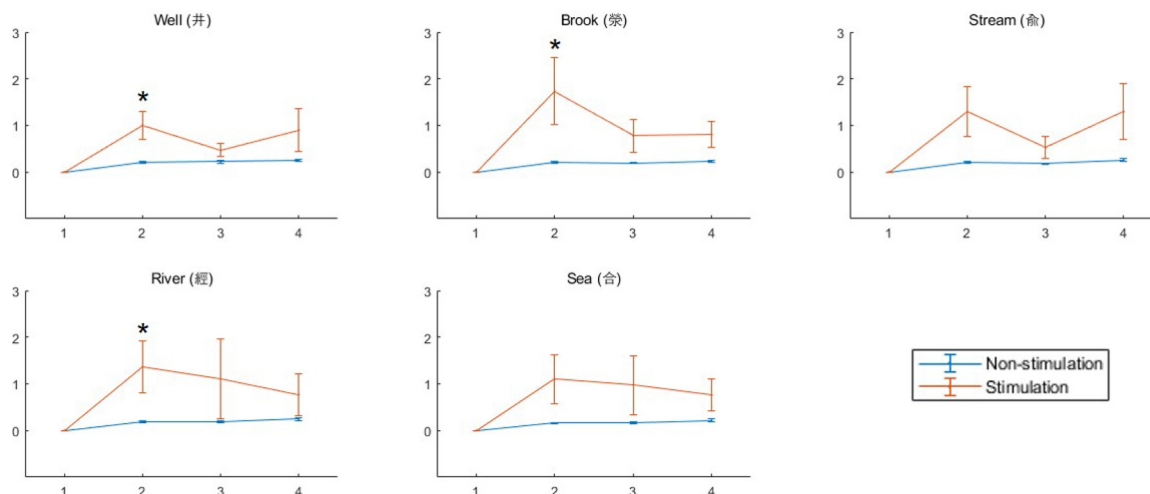


Fig. 2. Biopotential variability by acupuncture stimulation. The biopotential variability is increased by acupuncture stimulation at five transport points. The error bar is the standard error, and asterisk (*) indicates that the p-value is less than 0.05 by the paired t-test.

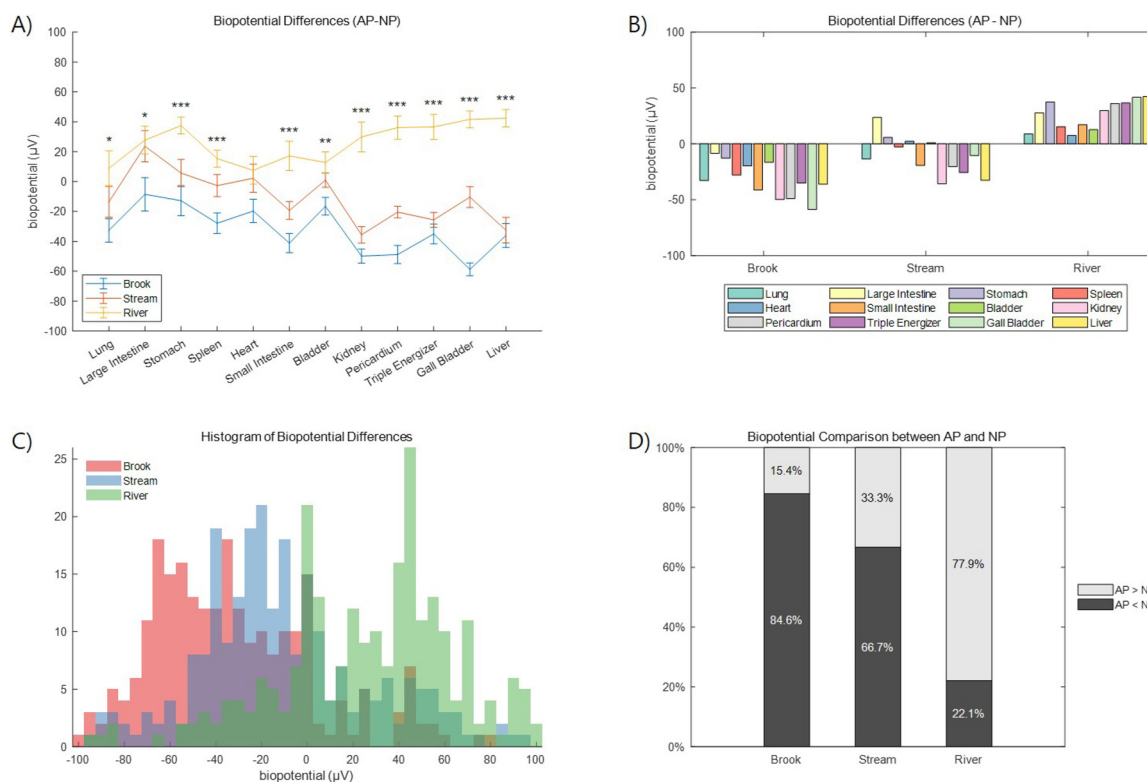


Fig. 3. Biopotential differences between the acupuncture and non-acupuncture points. A) The mean and standard error of biopotential differences between the acupuncture and non-acupuncture points at brook, stream, and river points in twelve meridians (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). The biopotential differences tends to increase in order of brook – stream – river in all meridians. B) Rearrangement of the biopotential differences according to the location of points. C) A histogram of all individual biopotential differences in twelve meridians. D) A ratio of positive to negative of all individual biopotential differences.

brook point, 37 out of 240 are positive and 203 are negative, so the biopotential of acupuncture point is generally lower than that of non-acupuncture point. On the contrary, at the river point, 187 are positive and 53 are negative, so the biopotential of acupuncture point is generally higher than that of non-acupuncture point. At the stream point, 80 are positive and 160 are negative, and the biopotential of acupuncture point tends to be lower than that of

non-acupuncture point, but this effect is weaker than the brook point.

Fig. 4 shows the changes in biopotential differences for non-stimulation (Fig. 4A) and acupuncture stimulation (Fig. 4B). For non-stimulation, there are small changes in biopotential differences, whereas acupuncture stimulation induces large changes. At the brook point, the changes in biopotential differences tend to be

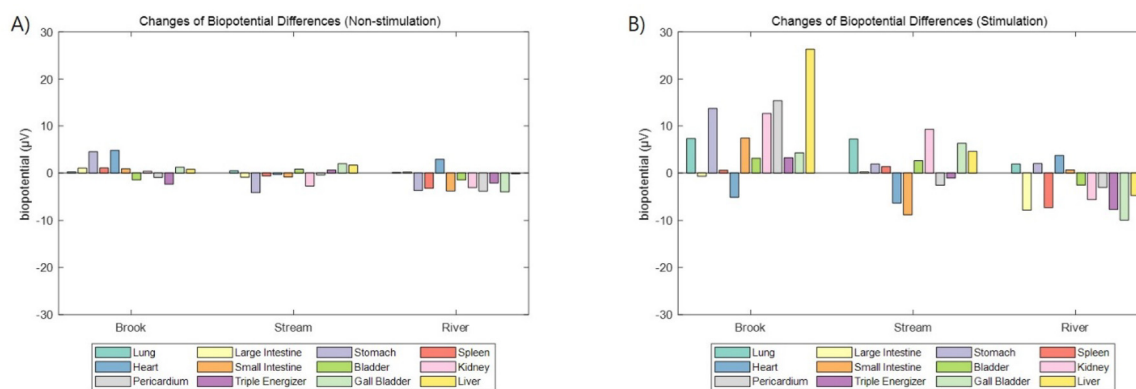


Fig. 4. Changes in biopotential differences between the acupuncture and non-acupuncture points by the acupuncture stimulation.

A) There are small changes in biopotential differences without acupuncture stimulation. B) There are relatively large changes in biopotential differences by acupuncture stimulation. The changes tend to be positive at brook point, but tend to be negative at river point.

positive, however, at the river point, the changes tend to be negative.

4. Discussion

4.1. Biopotential variability

This study observed the changes in biopotential variability by the acupuncture stimulation to investigate energy activity at acupuncture point. Gow et al. estimated the biopotential variability at LI4 and PC6 (with their corresponding adjacent controls) without stimulation using standard deviation and range (difference between maximum and minimum values), and they reported there was no significant difference in biopotential variability between acupuncture point and its adjacent control.²⁶ In the results of this study, biopotential variability did not change significantly for non-stimulation, which is natural that there is no factor that induces the change in stable state of the body. In addition, the standard deviation and range contain only spatial information, so that do not sufficiently represent the variability.

Thus, this study considered the biopotential variability that contains both spatial and temporal information, and compared changes in biopotential variability by acupuncture stimulation and non-stimulation.

In the results, the biopotential variabilities at five transport points were increased by acupuncture stimulation. The variability in this paper is an index of how large and how often the biopotential changes, and it is related to the activity of electrical energy. Thus, the results suggest that the energy activity at the acupuncture points increased by acupuncture stimulation. If the Qi is related with electrical energy, then the results are in line with Korean medicine theory that the flow of Qi is activated by acupuncture stimulation.²¹ Of course, it is not enough to conclude the relationship between Qi and electrical energy. However, it is meaningful to obtain results similar to the flow of Qi in terms of energy for the mechanism of acupuncture stimulation.

4.2. Biopotential difference between acupuncture and non-acupuncture points

This study compared the property of biopotential between acupuncture and non-acupuncture point to investigate energy flow at acupuncture point in meridian. Lee et al. measured the change in electric potential between ST37 and ST39 by acupuncture stimulation at ST36, and compared the cases of acupuncture stimulation with bare and shielded hands. They reported that bio-energy

was transferred from practitioner to receiver based on the potential change that occurred during bare handed acupuncture stimulation.²⁷ However, they could not show the energy flow in the body by acupuncture stimulation, and it was limited to stomach meridian. Spaulding et al. measured the change in bio-potential at PC4, PC6 and their adjacent control by acupuncture stimulation at PC4 or PC4's control. They found energy transfer phenomenon from the stimulus point (PC4) to a point farther away (PC6), and the transferred signal had an opposite polarity to the signal at the stimulus point²⁸. Their results are consistent with our results that the biopotentials at five transport points are changed by acupuncture stimulation at the source point and that the direction of energy flow can be differed depending on the location of acupuncture point. However, they could not explain why the direction of energy flow in PC4 and PC6 was opposite, and it was still limited to pericardium meridian. Thus, this study measured the biopotential difference between acupuncture and non-acupuncture points in twelve meridians.

In the results, there are significant biopotential differences between acupuncture and non-acupuncture points in most meridians, and the biopotential differences tend to increase in order of brook, stream, and river. Such a significant biopotential difference is caused by the following reasons: 1) A number of nerves and blood vessels exist in the subcutaneous area of acupuncture points, which may have different electrical properties from those of adjacent non-acupuncture points. 2) The nerves under acupuncture points release or reabsorb a large amount of electrolyte during action potential generation, and electric potential can be distinguished from surrounding tissues.³² Electric potential is formed by the distribution of electric charges, and the electric potential difference forms an electric field. The magnitude and direction of the electric field is determined by the negative gradient of the electric potential:

$$\vec{E} = -\nabla\Phi,$$

where \vec{E} is the electric field and Φ is the electric potential. At the brook point, the electric potential of acupuncture point was lower than that of non-acupuncture point, so the electric field was formed in the direction from non-acupuncture point to acupuncture point. On the other hand, at the river point, the electric field was formed in the opposite direction. In other words, the electric field was formed in the direction convergent to acupuncture point at the brook point but formed in the direction divergent from acupuncture point at the river point. In the electric field, the negative charge receives the electric force in the opposite direction of the electric field:

$$\vec{F} = q\vec{E}.$$

where F is the electric force and q is the signed electric charge. Considering the movement of negative charges at acupuncture point, they received the force in the direction divergent from acupuncture point at the brook point and in the direction convergent to acupuncture point at the river point. In other words, negative charges maintained the flow-out condition at the brook point and the flow-in condition at the river point. In Korean medicine theory, the flow of Qi at each of five transport points is compared to the flow of water. At the well point, Qi springs like water gushing from a well, and at the sea point, Qi is gathered like a river running into the sea. The phrase “Qi springs” means that Qi is divergent from acupuncture point, and the phrase “Qi is gathered” means that Qi is convergent to acupuncture point. Based on the tendency at the brook, stream, and river points, the biopotential of acupuncture point is expected to be lower than non-acupuncture point at the well point but higher at the sea point. Suppose that the electrical characteristic of Qi is the same as the negative charge, then Qi is trying to diverge from acupuncture point at the well point and to converge to acupuncture point at sea point. Thus, the results are consistent with Qi flow theory at five transport points.

In the results of changes in biopotential difference between acupuncture and non-acupuncture point by acupuncture stimulation, the changes tended to be positive at the brook point and to be negative at the river point. At the brook point, negative charges flowed out from acupuncture point, so that the biopotential differences tended to decrease—note that the biopotential differences at the brook point were negative. At the river point, the negative charges flowed into acupuncture point, so that the biopotential differences tended to decrease—note that the biopotential differences at the river point were positive.

In summary, the biopotential distribution and its changes by acupuncture stimulation at five transport points are related to the Qi flow theory in Korean medicine. Thus, the biopotential can provide a foundation for studying Qi flow in meridians. The observation and interpretation of Qi flow are expected to overcome limitation of qualitative explanations in traditional medicine and provide a ground for objective evidence. Of course, this study has limitations for understanding the effect of acupuncture stimulation on biopotential in the patient since this study was conducted with healthy subjects. Further study is needed to investigate the biopotential changes by acupuncture stimulation in specific patients.

Conflict of interest

None.

CRediT authorship contribution statement

Seong Jin Cho: Conceptualization, Investigation, Writing – original draft, Visualization, Project administration. **Kwang-Ho Choi:** Methodology, Software, Investigation, Resources. **Min Ji Kim:** Methodology, Validation, Investigation, Resources, Data curation. **O Sang Kwon:** Conceptualization, Formal analysis, Investigation. **Suk Yun Kang:** Writing – review & editing. **Su Yeon Seo:** Writing – review & editing. **Yeonhee Ryu:** Conceptualization, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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Ethical statement

This research was reviewed and approved by the institutional review board of Oriental Hospital of Daejeon University (registration number: djomc-61). Informed consent was obtained from all participants.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.imr.2022.100871.

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