Meridian study on the response current affected by electrical pulse and acupuncture

Yu-Chiang Hung, Wen-Chung Chen, Ting-Chang Chang, Hao-Xuan Zheng, Yan-Wen Liu, Yung-Fang Tan, Shih-Kai Lin, Ying-Hsin Lu, Wen-Long Hu, and Tsung-Ming Tsai

Abstract

Acupuncture and its meridians are important components of traditional Chinese medicine, and numerous opinions have been previously expressed regarding these meridians. This study aims to explore the phenomenon of meridians from the perspective of electronic physics by studying these meridians for the response current affected by electrical pulse and acupuncture. In this study, acupuncture which applies an electrical pulse was used to research the physical properties of the meridians. Different kinds of pulses were applied to the human body to realize abnormal electrical signals. Comparing these electrical measurement results with the isothermal transient ionic current (ITIC) theory, we found that the transmission of meridian messages may be related to ion conduction. The movement of ions induced by acupuncture and electrical stimulation can lead to drift and diffusion currents through the meridians. The ionic conduction of meridian hypothesis is proved in that the substances delivered by meridians are in fact ions.

Keywords: Acupuncture, Chinese medicine, Electrical pulse, Meridian theory, Ion current

Introduction

Acupuncture has been used for more than three thousand years. Now it is not only known as an important treatment instrument for musculoskeletal illness, but is also widely used to treat internal-medical diseases [1–4]. Though acupuncture is widely used for healing the disease in human body, better clarity is needed of the composition of meridians and their fundamental theory [5–7].

Meridian theory is a core component and foundation of acupuncture and tui-na massage. There are many different kinds of hypothesis on the nature of meridians [8]. They can be divided into four theoretical parts: those of nerve conduction theory [9, 10], body fluid circulation theory [11, 12], fascia and connective tissue structure doctrine [13, 14], and biological field (or energy) doctrine [15, 16]. Each hypothesis interprets the meridian essence of Chinese medicine from a different perspective, and these different hypotheses try to explore the essence of the meridian from individual reasonable points of view. However, each hypothesis can only explain part of the meridian essence and cannot provide a comprehensive interpretation of the meridian system. This study aims to explore the phenomenon of meridians from the perspective of electronic physics by comparing different kinds of pulses to explain an abnormal current, proving that the movement substance is ions.

Electroacupuncture involves the insertion of needles into acupoints and introducing an electrical current through that needle, thus combining electricity and the needle to enhance the stimulation and the effects of acupuncture. When choosing two or more meridians to use electroacupuncture, the acupoint and meridian act like electrodes and a current channel, such that the current

© The Author(s). 2020 Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.
passes through the meridians. By applying direct and alternating pulses into the *hegu* and *quchi* points in this work, the oscilloscope signal and responding current can be measured. This is very similar to the ITIC theory. For ions, it is very small substance moving to form the current [17–20]. In addition, many nanomaterials and devices used this theory to explain their model [21–24]. It is important to realize the transport mechanism in the ITIC theory. Moreover, by introducing the ion current model and comparing the difference in response current from direct and alternating pulses, the physical characteristics of meridians can be understood more clearly.

**Experimental Methods**

**Participant Selection**

This clinical trial was approved by the Institutional Review Board of Chang Gung Medical Foundation (IRB permit no. 201800392A3). Written informed consent was obtained from all participants before enrollment. After certain initial assessments, 30 volunteers who met the inclusion criteria mentioned below were recruited; they included 15 men and 15 women, aged between 20 and 30 years. They were all well informed about this project and signed the consent before the experiment. We chose healthy volunteers as subjects in this study and therefore did not target any particular acupoint. The positions were instead chosen for their common use and convenient location in order to observe the phenomenon of ion transport in meridians.

**Inclusion and Exclusion Criteria**

According to a prospective survey, despite its benefits, acupuncture can also lead to some side effects [25]. As an invasive treatment, it may sometimes induce either...
local or systemic adverse reactions [25–27]. Moreover, a systemic review shows that life-threatening events may also develop, albeit rarely. As a result, the exclusion criteria were very stringent. Bleeding and hematoma are the most common adverse reactions. Volunteers with bleeding tendencies (platelet counts less than 20,000 and/or thrombocytopenic purpura) were excluded. Volunteers with chronic medical conditions who were prescribed anti-coagulants were also excluded. In addition, pregnant women and volunteers with pacemakers were excluded.

**Acupuncture Needles**
The acupuncture needles used in this experiment were produced under the same conditions, in the same factory (Dong Bang Acupuncture Inc.), and on the same day, to minimize experimental error.

**Experiment Process**
In this experiment, the semiconductor measurement analyzer Agilent B1500A is used to input the human body meridian waveforms, and the flow directions of electrical signals are defined as remote electroacupuncture and near electroacupuncture, respectively, as shown in Fig. 1a. Remote electroacupuncture means that the electrical signals go through from limbs to body, and near electroacupuncture means that the electrical signals go through from body to limbs. The Chinese medicine treatment of electroacupuncture usually uses a square waveform. This is the reason we decided to use square waveforms, instead of triangle waveforms. In addition, when applying voltage, two different waveforms are given by alternating current (AC) and pulse, as shown in Fig. 1b. AC is a continuous square wave going back and forth between 0.5 and −0.5 V, and pulse is a continuous square wave starting from 0 to 0.5 V. Further, the
experiment uses AC and pulses of four frequencies (2, 4, 6, and 8 Hz). All data evaluations in this study were repeated thrice, which are presented as mean ± standard deviation.

**Result and Discussion**
First, we chose the LI meridian with remote and near electroacupuncture between *hegu* and *quchi* points to start the experiment and measured the responding current. For AC, as the voltage was 0.5 V, the response current was 13 μA, and the current was 26 μA at 0.5 V, as shown in Fig. 2a. In contrast, the current of the pulse waveform also read 10 μA when the voltage was at 0.5 V. However, there was an abnormal reverse current of about 8 μA at voltage of 0 V, as can be seen in Fig. 2b.

In order to analyze this abnormal current, the initial current value was defined as $I_1$, and the abnormal reverse current was defined as $I_2$. We divide $I_2$ by $I_1$ to find the difference between pulse and AC. The pulse ratio was close to 1, which indicates that the current is

---

![Fig. 4](image-url)

**Fig. 4** The model for explaining the phenomenon of the pulse electric feature: **a** drift current caused by voltage and **b** diffusion current caused by concentration gradient. For AC electric feature: **c** drift current caused by voltage; **d** reverse voltage generate the larger current than diffusion current of pulse.
negative at negative voltage, but will reverse back at the same amount without any voltage applied. However, in the AC ratio, the value was close to 2. This indicates a forward current at a negative voltage, but when reverse voltage is applied, the current will not only flow back but also increase with the response current. Therefore, the AC ratio becomes larger than the pulse ratio, as shown in Fig. 3a. Similarly, we change different frequencies and plot the ratio of $I_2/I_1$ against the frequency. In the pulse experiments, we found that the higher frequency showed a smaller ratio because there was not enough time for the compensation current in the higher frequency (shorter period) pulse, as shown in Fig. 3b. In addition, AC experiments with different frequencies demonstrate the same trend, as shown in Fig. 3c. The ratio decreased as the frequency increased in both pulse and AC experiments.

The $I$-$V$ curve was used to analyze the mechanism inside the meridians of the human body. In the beginning, the current increases sharply and gradually decreases and saturates after exceeding the peak maximum value. We found that this was similar to the isothermal transient ionic current (ITIC) mechanism [28–33]. In the ITIC theory, the anions and cations will move by electrical field to the two sides of the channel, resulting in the increase in current [34]. When the ions accumulate at the two sides, the current will gradually decrease because of the barrier from the space charge. Therefore, the way of conducting electricity in the human body is mainly through ions.

From the ITIC theory, the electrical signal transference in meridians is very similar to the ion current. As a result, following measurement results and the ITIC theory, for applied voltage of 0.5 V at initial, the ions will move by the electric field, leading to drift current, and will accumulate at the two sites, as shown in Fig. 4a. However, when the voltage was not applied, the abnormal current was read by the diffusion current of the different concentration of ions. Therefore, the current direction was opposite to that of the drift current, as shown in Fig. 4b. Similarly, in AC pulse conditions, 0.5 V was applied, leading to the drift current in Fig. 4c. However, when the voltage changed from 0.5 to −0.5 V, both diffusion current and drift current with the opposite electric field were formed, leading to a current twice than measured at initial, as shown in Fig. 4d.

According to this result, the same experiments were carried out in 12 meridians. In Table 1, the ratio of $I_2/I_1$ all show the same result. Pulse had an abnormal response current, and the ratio was close to 1, while the ratio in AC was about 2.

Our findings are similar to the body fluid circulation theory. Acupuncture on the meridian acupoint can induce ion passive diffusion. In body fluid circulation theory, the meridians consist of ions and neurotransmitters, because human tissue is a complex electrolyte electrical conductor composed of moisture, inorganic salts, and charged biocolloids. When a pulse is applied to the human body, the ions will move directionally, eliminating the polarization of the cell membrane. Consequently, the ion concentration and distribution shows significant variety, affecting human tissue function. It is also the basic electrophysiological element.

One limitation of this study is that diseases may negatively affect the signal transmission of the meridian. We enrolled 30 volunteers, but not patients, to participate in this research. Electronic signal response in acupuncture meridians of patients suffering a specific disease require future study.

Table 1 Average and standard deviation of $I_2/I_1$ ratio to AC and pulse for 12 meridians

| Meridians                  | AC          | Pulse       |
|----------------------------|-------------|-------------|
| Yangming large intestine meridian in hand (LI) | 1.57 ± 0.53 | 0.51 ± 0.18 |
| Taiyang small intestine meridian in hand (SI) | 1.66 ± 0.42 | 0.54 ± 0.14 |
| Shaoyang Sanjiao meridian in hand (SJ) | 1.57 ± 0.33 | 0.64 ± 0.11 |
| Shaoyin heart meridian in hand (HT) | 1.25 ± 0.38 | 0.73 ± 0.63 |
| Taijin lung meridian in hand (LU) | 1.59 ± 0.30 | 0.64 ± 0.12 |
| Jueyun pericardium meridian in hand (PC) | 1.60 ± 0.32 | 0.64 ± 0.15 |
| Taiyang bladder meridian in foot (BL) | 1.76 ± 0.46 | 0.77 ± 0.32 |
| Shaoyang gallbladder meridian in foot (GB) | 1.55 ± 0.42 | 0.64 ± 0.10 |
| Yangming stomach meridian in foot (ST) | 1.52 ± 0.46 | 0.53 ± 0.14 |
| Shaoyin kidney meridian in foot (KI) | 1.69 ± 0.46 | 0.63 ± 0.13 |
| Jueyun liver meridian in foot (LR) | 1.59 ± 0.38 | 0.50 ± 0.16 |
| Taijin spleen meridian in foot (SP) | 1.38 ± 0.50 | 0.58 ± 0.15 |

Conclusion
This study used different kinds of pulse (pulse and AC) to realize abnormal response current by the reverse voltage. This abnormal current can be explained via the ITIC theory, demonstrating that the movement of ions leads to the drift and diffusion currents. Therefore, the ions can be confirmed to be the substance transferred by the meridians.

Abbreviations
ITIC: Isothermal transient ionic current; AC: Alternating current; LI: Yangming large intestine meridian in hand; SI: Taiyang small intestine meridian in hand; SJ: Shaoyang Sanjiao meridian in hand; HT: Shaoyin heart meridian in hand; LU: Taijin lung meridian in hand; PC: Jueyun pericardium meridian in hand; BL: Taiyang bladder meridian in foot; GB: Shaoyang gallbladder meridian in foot; ST: Yangming stomach meridian in foot; KI: Shaoyin kidney meridian in foot; LR: Jueyun liver meridian in foot; SP: Taijin spleen meridian in foot

Acknowledgments
This study was supported by the Chang Gung Medical and National Sun Yat-sen University Research Fund (CMRPBG0331, CMRPBG0321). The authors would like to thank Chen-ting Dai for his help in this study.
Authors’ Contributions
Yu-Chiang Hung, Wen-Chung Chen, Hsao-Xuan Zheng, and Tsung-Ming Tsai performed the electrical measurements. Ting-Chang Chang and Yu-Chiang Hung were involved in the planning and supervised the work. Wen-Chung Chen, Yung-Fang Tan, Shih-Na Lin, and Ying-Hui Lu processed the experimental data, performed the analysis, drafted the manuscript, and designed the figures. Wen-Long Hu and Yan-Wen Liu performed the acupuncture. All authors discussed the results and commented on the manuscript. The author(s) read and approved the final manuscript.

Availability of Data and Materials
All data are fully available without restriction.

Competing Interests
The authors declare that they have no competing interests.

Author details
1 Department of Chinese Medicine, Kaohsiung Chang Gung Memorial Hospital, 123 Dap 1 Road, Kaohsiung 83301, Taiwan. 2 School of Chinese medicine, Chang Gung University College of Medicine, 259, Wenhua 1st Rd., Guishan Dist., Taoyuan 33302, Taiwan. 3 Department of Materials and Optoelectronic Science, National Sun Yat-Sen University, 70 Lienhai Rd., Kaohsiung 80424, Taiwan. 4 Department of Physics, National Sun Yat-Sen University, 70 Lien-Hai Road, Kaohsiung 80424, Taiwan. 5 The Center of Crystal Research; National Sun Yat-Sen University, Kaohsiung 804, Taiwan. 6 Institute of Electronics Engineering, National Tsing Hua University, Hsinchu 30013, Taiwan. 7 College of Nursing, Fooyin University, 151, Jinxue Rd, Kaohsiung 83102, Taiwan. 8 Kaohsiung Medical College of Medicine, 100, Shiquan 1st Rd., Kaohsiung 80708, Taiwan.

Received: 20 March 2020 Accepted: 23 June 2020

Published online: 10 July 2020

References
1. Jin L, Wu JS, Chen GB, Zhou LF (2017) Unforgettable ups and downs of acupuncture anesthesia in China. World Neurosurg 39(7):983–986
2. Ho RST, Chung VCH, Wong CHL, Wu JCY, Wong SYS, Wu IXY (2017) Acupuncture and related therapies used as add-on or alternative to prokinetics for functional dyspepsia: overview of systematic reviews and network meta-analysis. Sci Rep 7:10330
3. Wang Y, Chen J, Zhang Y, Zhang Y, He JH, Fang X (2019) Silicon-compatible photodetectors: trends to monolithically integrate photosensors with chip technology. Adv Funct Mater 29(18):1–17
4. Fu HC, Ramalingam V, Kim H, Lin CH, Fang X, Alshareef HN, He JH (2019) MXene-contacted silicon solar cells with 11.5% efficiency. Adv Energy Mater 9(2):1–9
5. Tang SY, Medina H, Yen YT, Chen CW, Yang TY, Wei KH, Chueh YL (2019) Enhanced photocarrier generation with selectable wavelengths by M-decorated-CuInS2 nanocrystals (M = Au and Pt) synthesized in a single surfactant process on MoS2 bilayers. Small 15(8):1–9
6. Lin LL, Wang YH, Lai CY, Chau CL, Su GC, Yang CY, Lou SY, Chen SK, Hsu KH, Lai YL, Wu WM, Huang JL, Liao CH, Juan HF (2012) Systems biology of meridians, acupoints, and Chinese herbs in disease. Evid Based Complement Alternat Med 327670
7. Yuan C, Xing F, Zheng Q, Zhang H, Li X, Ma X (2020) Factor analysis of the uniformity of the transfer current density in vanadium flow battery by an improved three-dimensional transient model. Energy 1941:16839
8. Yang W, Chen J, Zhang Y, Zhang Y, He JH, Fang X (2019) Silicon-compatible photodetectors: trends to monolithically integrate photosensors with chip technology. Adv Funct Mater 29(18):1–17
9. Fu HC, Ramalingam V, Kim H, Lin CH, Fang X, Alshareef HN, He JH (2019) MXene-contacted silicon solar cells with 11.5% efficiency. Adv Energy Mater 9(2):1–9
10. Tang SY, Medina H, Yen YT, Chen CW, Yang TY, Wei KH, Chueh YL (2019) Enhanced photocarrier generation with selectable wavelengths by M-decorated-CuInS2 nanocrystals (M = Au and Pt) synthesized in a single surfactant process on MoS2 bilayers. Small 15(8):1–9
11. Kim Y, Jung J, Yu H, Kim GT, Desser D, Passerini S (2020) Sodium biphosphoryl as anolyte for sodium–seawater batteries. Adv Funct Mater 2001249
12. Alamri AM, Leung S, Vaseem M, Shamim A, He JH (2019) Fully inkjet-printed photodetector using a graphene/perovskite/graphene heterostructure. IEEE Trans Electron Devices 66(6):2657–2661
13. Liu S, Zheng L, Yu P, Han S, Fang X (2016) Novel composites of α-Fe2O3 tetraaldaedachroand and graphene oxide as an effective photodetector with enhanced photocurrent performances. Adv Funct Mater 26(19):3331–3339
14. Lee S, Cho JY, Kim D, Park NK, Park J, Kim Y, Hong SY (2020) Redox-active functional electrolyte for high-performance seawater batteries. ChemSusChem 13(9):2220–2224
15. Yamashita H, Tsukayama H, Hori N, Kimura T, Tanno Y (2000) Incidence of adverse reactions associated with acupuncture. J Altern Complement Med 6(4):345–350
16. MacPherson H, Thomas K, Walters S, Fitter M (2001) A prospective survey of adverse events and treatment reactions following 34,000 consultations with professional acupuncturists. Acupunct Med 19(2):93–102
17. Ernst E (1997) Life-threatening adverse reactions after acupuncture? A systematic review. Pain 71(2):123–126
18. Greer R, Hooenders BJ (1984) Theoretical solution of the transient current equation for mobile ions in a dielectric film under the influence of a constant electric field. J Appl Phys 55(2):3371–3375
19. Gao N, Fang X (2015) Synthesis and development of graphene–inorganic semiconductor nanocomposites. Chem Rev 115(16):8343–8343
20. Frenning G, Strommea M (2001) Theoretical derivation of the isothermal transient ionic current in an ion conductor: migration, diffusion, and space–charge effects. J Appl 90(11):5570–5575
21. Ouyang W, Teng F, Fang X (2016) High performance BiOCl nanosheets/TiO2 nanotube arrays heterojunction UV photodetector: the influences of self–induced inner electric fields in the BiOCl nanosheets. Adv Funct Mater 23(16):1–13
22. Frenning G, Nilsson M, Westlinder J, Niki arsenal GA, Mattsson MS (2001) Dielectric and Li transport properties of electron conducting and non–conducting sputtered amorphous Ta2O5 films. Electrochim Acta 46(13–14):2041–2046
23. Watanabe M, Rikukawa W, Sanui K, Ogata N (1985) Evaluation of ionic mobility and transference number in a polymeric solid electrolyte by isothermal transient ionic current method. J Appl 58(2):735–740
24. Mattsson MS, Niki arsenal GA (1999) A frequency response and transient current study of β-Ta2O5 methods of estimating the dielectric constant, direct current conductivity, and ion mobility. J Appl 85(4):2185–2191

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.