ARTICLE IN PRESS

JID: JTCM [m5G;April 28, 2018;13:36]

Journal of Traditional Chinese Medicine 000 (2018) 1–9

Contents lists available at ScienceDirect

Journal of Traditional Chinese Medicine

journal homepage: www.elsevier.com/locate/jtcm
http://www.journaltcm.com

Low impedance nature of 12 acupoints on the limbs, and the unexpected dependence on limb angle☆,☆☆

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A R T I C L E I N F O

Article history:
Received 12 January 2017
Revised 15 March 2017
Accepted 2 July 2017
Available online xxx

Keywords:
Channel
Acupoint
Superficial collaterals
Electric impedance
Limb

A B S T R A C T

Objective: To better understand the working mechanism of acupuncture, we investigated the skin electrical impedance distribution around acupoints, and the impedance changes at 12 original acupoints bilaterally after bending the limbs.
Methods: We measured the skin electrical impedance in three study subjects in the frequency range of 40 to 10 kHz using the four-electrode method with a sharp probe and a large reference electrode. A measurement matrix of 7 mm × 7 mm with spacing of 2.0 (or 3.0) mm was measured to obtain 2D impedance mapping of acupoints. The impedance spectra of 12 original acupoints were measured at the 0° position and the 90° position.
Results: The electrical impedance of some acupoints, such as Yangchi (TE 4), was 16 times lower than that of the surrounding area, showing a recognizable small central area of low impedance with a diameter of less than 4 mm. In contrast, other acupoints, such as Laogong (PC 8), had an electrical impedance that was not significantly different from that of the surrounding area. When the limb was bent from a straight position (0°) to a vertical position (90°), the electrical impedance of the 12 original acupoints showed varied trends, either increasing or decreasing by a factor of up to 10 times, or remaining at the same level.
Conclusion: Not all acupoints tested show the property of low impedance, which might be related to the varied depth of the openings of superficial collaterals. The unexpected dependence of acupoint impedance on limb angle is a novel discovery, which implies that the channel paths are located in interstitial structures in the limbs. It might be possible to determine an optimized limb position for each particular acupuncture treatment in clinical practice.

1. Introduction

In recent years, complementary and alternative medicine has attracted more attention in clinical practice. One important type of complementary and alternative medicine is Traditional Chinese Medicine (TCM). As part of TCM, acupuncture is widely practiced worldwide, and the World Health Organization currently lists 43 diseases that can be treated or managed with acupuncture in 1979 [1,2]. The actual physiological basis and working mechanism of channels and acupoints have become interesting topics for many researchers. The location and physical nature of channels and acupoints have been investigated via a variety of biophysical, biochemical, and molecular biological methods applied in clinical experiments [3–6]. Biophysical studies have been conducted to investigate thermal characteristics [7–12], optical characteristics [13,14], migration of isotopes along channels [15,16], acoustic characteristics [17–22], magnetic characteristics [23–25], myoelectric activities [26], and electrical characteristics [27–30]. Some specific results regarding research into the channels and acupoints include: acupuncture treatment results in high temperature lines

☆ Supported by the National Natural Science Foundation of China (Nos. 11374016 and 91221202) and the Medicine-School of Electronics Engineering and Computer Science Joint Seed Fund 2016, Peking University.
☆☆ Peer review under responsibility of Traditional Chinese Medicine Periodical Press.
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https://doi.org/10.1016/j.jtcm.2018.03.005
0254-6272/

Please cite this article as: X. Jingjing et al., Low impedance nature of 12 acupoints on the limbs, and the unexpected dependence on limb angle, Journal of Traditional Chinese Medicine (2018), https://doi.org/10.1016/j.jtcm.2018.03.005

that emerge along the channels [9]; research into the luminous biophysical properties of channels and acupoints identified 14 high luminous lines on the body surface, which matched well with the locations of 14 regular channels recorded in the *Huang Di Nei Jing* [13]; injecting the isotope $^{99m}TcO_4^-$ into one low hydraulic resistance point results in movement of the isotope along channel lines in minipigs [16]. These studies provide supporting evidence for the existence of channels and acupoints, and their locations match well to those reported in TCM theory.

Some interesting physical characteristics of the acupoints along the channels have also been revealed. Sun *et al.* [20] evaluated the acoustic characteristics of acupoints and reported that the bidirectional conduction velocity was 6.2–10 cm/s, which is close to the velocity of propagated sensation along the channels. Most investigations into the magnetic characteristics of channels and acupoints have focused on functional magnetic resonance imaging technology [22]. Some studies showed that obvious myoelectric activity accompanied propagated sensation along the channels [26]. Early results on electrical characterization of channels and acupoints have demonstrated that channels and acupoints have low impedance and high capacitance [31–36]. However, other studies have not supported the low impedance nature of acupoints [27–30]. For example, Kramer and co-workers [27] recently measured the electrical impedance of 631 acupoints on the human body, and found that 25.9% of these acupoints showed low impedance, but 11.3% had higher impedance compared with non-acupoints in the surrounding area, and 62.8% showed no remarkable difference in impedance compared with the surrounding area.

These experimental results have led to varying theories on the actual nature and working mechanism of acupuncture. Yang [37] believed that the overlap between low impedance lines and regular channels in TCM was not incidental, and that the physiological basis of channels was the connective tissue, which had more interstitial fluid than the neighboring tissues. Fan *et al.* [38] discovered that there were more gap junctions in the subcutaneous tissue of acupoints compared with that of non-acupoints, and suggested that the gap junction was the structure foundation of low impedance.

Despite all these developments in acupuncture studies, there is still controversy regarding the physical properties of channels and acupoints. In the present study, we investigated the impedances spectra (40 to 10 kHz) of more than 10 acupoints on the hand and foot, and obtained detailed two-dimensional (2D) mapping of the impedance around acupoints. We also investigated whether the impedance at 12 original acupoints was dependent on limb position.

2. Materials and methods

We measured the skin electrical impedance in the frequency range from 40 to 10 kHz with the four-electrode method, using an Agilent 4294A Precision Impedance Analyzer (Agilent, Santa Clara, CA, USA). A 1.0 mm diameter probe was made with a copper wire, and a large reference electrode was made from a thick braided wire with a width of 2.0 cm. The reference electrode was firmly wrapped around the upper arm during investigation of acupoints on the hand (or the upper leg for acupoints on the foot), so that it caused a negligible amount of contact resistance during the measurements. Figs. 1A and B shows the tip of the testing probe, where the central part is the copper that was cleaned before each measurement, and the surrounding material was an insulator. Fig. 1C shows the positions of the testing probe, the reference electrode, and the measurement circuit.

During each measurement process, a heavy load of 200 g was mounted on the probe to create a constant pressure on the skin of around 6 atm (i.e., 60 N/cm^2) when the probe was pressed against the skin vertically. As a result, the skin at the location of the test points turned red (but did not bleed) and remained this way for a few hours (depending on individuals) after each measurement. This ensured that the repeat measurements were made at the same locations.

We obtained precise 2D maps of impedance distribution for the following eight acupoints: Zhongquan (EX-UE 3), Yangchi (TE 4), Yanglingquan (GB 34), Shangqiu (SP 5), Qiuxu (GB 40), Hegu (LI 4), Zhigou (TE 6), and Laogong (PC 8). We set a measurement matrix of 7×7 (49 points) around each acupoint, where the spacing between each two neighboring measurement points was 2.0 or 3.0 mm, leading to a pixel density of 34 or 15 points/cm^2. The original measurement results were calculated with a program written in Labview software (National Instruments, Austin, TX, USA), where the data for points between the testing points were calculated with a smooth interpolation algorithm [39,40].

We also measured the angle dependence of electrical impedance for the following 12 original acupoints: Yangchi (TE 4), Hegu (LI 4), Taiyuan (LU 9), Shenmen (HT 7), Daling (PC 7), and Wangu (SI 4) near the wrist, and Qiuxu (GB 40), Taichong (LR 3), Taibai (SP 3), Taixi (KI 3), Chongyang (ST 42), and Jinggu (BL 64) around the ankle. We obtained the impedance data for the 12 original acupoints on both the left and right limbs. We defined the 0° position as that in which the arm (or leg) was in full extension, and defined the 90° position as that in which the distal arm (or leg) was flexed by 90°. Three different 0° and 90° positions were used for the acupoints on the hand, as shown in Fig. 2. The positions shown in Fig. 2A were applied for Hegu (LI 4) and Yangchi (TE 4), the positions shown in Fig. 2B were used for Daling (PC 7), Taiyuan (LU 9), and Shenmen (HT 7), and the positions in Fig. 2C were used for Wansu (SI 4). For the acupoints on the foot, we used similar positions to those shown in Fig. 2B. For the acupoints Shenmen (HT 7), Taiyuan (LU 9), and Yangchi (TE 4) on both the left and right hands, we measured the change in the impedance spectrum by changing the bending angle of the front arm by 15° per step.

To limit the measurement error, we tested five different points within an area of 0.5 cm^2 at each acupoint and recorded the electrical impedance of each point. For each test point, the measurement was repeated three times, and the average was calculated. The lowest value among the five sets of testing data was taken as the representative impedance of the acupoint.

The study subjects were four healthy Chinese people; three were females aged 23–26 years (referred to as Alpha, Beta, and Gamma), while the other was a 50-year-old male (referred to as Delta). Unless otherwise mentioned, most of the data presented were taken from Alpha.

3. Results

3.1. Reliability and stability of the measurement system

We first checked the reliability and stability of our probe and measurement system. Using the measurement parameters and conditions described above, smooth measurement curves could be obtained for most testing points on dry skin. We found that maintaining constant pressure on the probe ensured repeatable measurement results. Fig. 3 presents a set of typical experimental data taken from Delta at three acupoints: Qiangu (SI 2), Juque (CV 14), and Laogong (PC 8); the measurement was repeated three times for each acupoint, and these three data curves are well-matched with each other.

In some cases, when the pressure on the testing point was changed a bit, a small jump in the measurement curve was recorded, but the relative change was small and the trend of the curve remained the same. As highlighted by the red circles in