Optically noninvasive measurement of the light transport properties of human meridians

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To confirm the existence and properties of human meridians, the optical transport properties along the pericardium meridian and tissues around the pericardium meridian are studied noninvasively on twenty healthy volunteers *in vivo* and then compared with each other. Our study shows that the light propagating along the meridian and non-meridian directions both conform to the Beer's exponential attenuation law. However, statistical analysis of the results suggests that the optical transport properties of human meridian differ from those of the surrounding tissues over a low modulated frequency range ($P < 0.01$), and light attenuation along the pericardium meridian is significantly less than that along the non-meridian direction. These findings not only indicate the existence of acupuncture meridian from the point of view of biomedical optics, but also shed new light on an approach to investigation of human meridians.

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Acupuncture has been around for many thousands of years in China and has achieved good clinical results. It has also begun to gain wide acceptance in the world[1]. The theory behind acupuncture is that the body has a system of meridians which channel some kind of substance, energy, or information that has been vaguely called "qi" in the traditional Chinese medical literatures. It is well known that when one dissects the human body, one does not find any substance that distinguishes the meridians from their surrounding tissues, unlike other human systems such as the nerve system or the blood system. There have been many efforts since 1950s to investigate human acupuncture and meridian system by use of modern scientific methods, such as electrical impedance measurement, infrared spectrum analysis, and functional magnetic resonance imaging etc. Among them, the electrical impedance technique is mostly used[2−6]. These methods can reveal the existence of human meridian and its properties to some extent. However, all of these methods are invasive, which limits the reproducibility on the same subject. To the best of our knowledge, there is no noninvasive study ever been reported that can reveal the physical properties of human meridian. Recently, the possibility of optical method for studying human meridian was tentatively proposed[7−9]. However, the proposed method is still quite coarse and requires further improvement, such as the accurate control on the measurement positions and statistical analysis of the results. Based on biomedical photonic technique[10−12], an improved scheme was proposed to study the existence and properties of human meridians by optical transport measurement on and around the meridian. The light propagation characteristics along the pericardium meridian and non-meridian directions were measured and compared. Compared with the conventional methods, this optical method is simple and noninvasive, and may perform on any of human meridians with good reproducibility.

Twenty healthy volunteers (12 females, 8 males) were recruited from different departments of Fujian Normal University (mean age ± SD, 20.0 ± 3.0 years). The subjects had no history of chronic diseases and were healthy at the time of enrolment. The experimental protocol was approved by the Key Laboratory of Optoelectronic Science and Technology for Medicine of Ministry of Education, Fujian Normal University and Fujian Normal University Hospital. All subjects agreed to participate in the study and gave written informed consent.

The experimental setup is shown in Fig. 1. The He-Ne laser (Melles Griot, USA) was modulated in 10 Hz by an optical chopper (SR540, Stanford Research Systems, USA). And then the modulated light was focused by a lens into the source fiber with 600-μm core diameter (Ocean Optics, USA), which was put in a small stainless-steel tube with about 2-mm inner diameter for easy

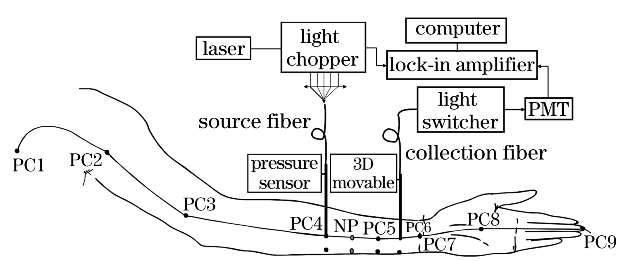

Fig. 1. Scheme for studying the light transport characteristics along the pericardium meridian.

controlling, and touched slightly with the skin surface. The collection fiber was a two-fiber probe containing two 600-μm-core diameter fibers (Ocean Optics) which were used to collect the emittance diffuse light from the meridian and non-meridian respectively. The light signals were then conducted to a photomultiplier tube (PMT, Oriel, USA). The PMT amplified the light signals and converted them into electronic current signals, which would be sent to a lock-in amplifier (SR850, Stanford Research Systems, USA). The lock-in amplifier finally selected the electronic current signals according to the frequency control signal. In this way, the signals from the meridian and non-meridian can be recorded, analyzed, and displayed in real time.

We selected the pericardium meridian as the meridian line in our study, while the non-meridian line was located 9 mm away on the inner side of the pericardium meridian. The determination of the pericardium meridian was under the National Standard of China (GB12346-90) and the traditional acupuncture chart with the help of an acupuncturist[13,14]. In order to reduce the influence of the detection probe remotion during the experimental measurement, we placed the two-fiber probe immovably on the *Neiguan* (PC6) acupoint and its reference point which is 9 mm off PC6 in this study, as shown in Fig. 1, while changing the laser irradiation points from the *Jianshi* (PC5) to *Ximen* (PC4). Five irradiation points were selected, including three non-acupoints between PC5 and PC4 on the pericardium meridian direction, which are called NP1, NP2, and NP3 for simplicity. The distances between these three non-acupoints and PC6 were 25, 35, and 40 mm, respectively. When the pericardium meridian and the laser irradiation points were determined, their corresponding reference points on the non-meridian direction can be determined easily and precisely by a patent device for human meridian study, as shown in Fig. 2. In short, we selected PC5, NP1, NP2, NP3, and PC4 totally five points on the pericardium meridian as laser irradiation points; accordingly, the five reference points on the non-meridian were named Ref1, Ref2, Ref3, Ref4, and Ref5, respectively.

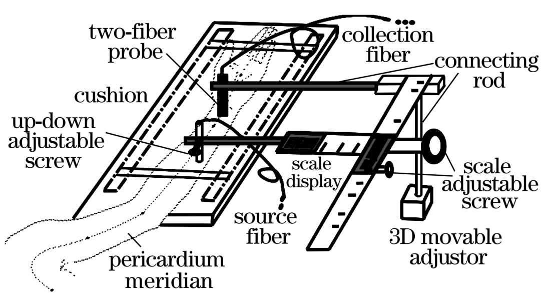

Fig. 2. A precise location device for studying human acupuncture and meridian.

The He-Ne laser was modulated by the optical chopper and firstly was conducted onto the *Jianshi* (PC5) acupuncture point on the pericardium meridian. After collecting the signal, an up-down adjustable screw and two scale adjustable screws shown in Fig. 2 were used to change the laser irradiation onto the reference point Ref1 and collect the signal also. Secondly, laser irradiated onto the NP1, NP2, and NP3 points on the pericardium meridian and their reference points respectively, and then the signals were collected. Finally, laser irradiated onto the *Ximen* (PC4) acupoint and its reference point Ref5, and the signals were collected. During all these measurements, the pressure status between the source fiber and the skin surface was kept under the same condition, which could be monitored by a pressure sensor device.

The experimental measurements were performed in a dark room, and the room temperature was kept about 25.0 °C during all the measurements. The laser irradiation points on the pericardium meridian and non-meridian were determined and labeled before the experiment with the help of an acupuncturist. In order to reduce the measurement error induced by the remotion of the subject's arm, the subjects laid on a special bed and put their arm under the comfortable condition during the experiment. We sampled continually the signals twelve times in one minute, and repeated for three times, and then obtained the average value as one measurement result.

Twenty healthy subjects were tested in this study. Signal differences between the five points (PC5, NP1, NP2, NP3, and PC4) on the pericardium meridian and their reference points (Ref1, Ref2, Ref3, Ref4, and Ref5) are shown in Table 1. Since the distances from PC5 to PC6 and from PC4 to PC6 varied for person to person, the differences between the meridian and non-meridian were compared by the relative ratio, namely $(S_{\rm meri} - S_{\rm non-meri})/S_{\rm meri} \times 100\%$, where $S_{\rm meri}$ and $S_{\rm non-meri}$ represent the signal values of the meridian and the non-meridian respectively.

Figure 3 shows the relative attenuation rates of light propagating along the pericardium meridian and

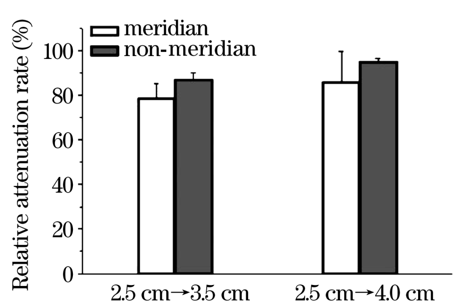

Fig. 3. Comparison of attenuation rate of light propagating along the meridian and non-meridian.

Table 1. Signal Differences between the Meridian Points and Their Reference Points

Points	PC5-Ref1	NP1-Ref2	NP2-Ref3	NP3-Ref4	PC4-Ref5
Difference Value (mV)	158.8 ± 86.6	88.7 ± 45.1	24.9 ± 14.6	12.0 ± 8.8	0.97 ± 1.1
Relative Ratio (%)	38.7 ± 19.6	59.1 ± 19.1	73.9 ± 12.7	74.7 ± 15.1	66.5 ± 20.9

Difference value is equal to the signal value on the meridian plus the corresponding signal value on the non-meridian. Values are mean ± SD. $n = 20$, $P < 0.01$.

non-meridian directions. We compare the attenuation rates from NP1 (2.5 cm away from PC6) to NP2 (3.5 cm away from PC6) and from NP2 to NP3 (4.0 cm away from PC6) on the pericardium meridian direction with the attenuation rates from Ref2 to Ref3 and from Ref2 to Ref4 on the non-meridian directions, respectively.

Figure 4 gives the optical transport characteristics of light propagating along the pericardium meridian and non-meridian direction. The relative amplitude is the mean value of twenty subjects, and shown in unitary format. Figure 5 shows the influence of optical chopped frequency on the signal values which were measured at the acupuncture point PC5 and its reference point Ref1.

To search for the specific constituents of human acupuncture and meridian has proven to be a failure or an elusive goal, because of the complexity of the human structure. Especially, one has not found any substance that distinguishes the meridians from their surrounding tissues till now[15]. Therefore, many scientists begin to study the physical properties of human acupuncture meridians *in vivo* in the viewpoint of their physiological functions[2,4−6], in which the electrical properties of acupuncture meridian have mostly been investigated. However, the electrical impedance technique has a lack of reproducibility other than its invasiveness. This study suggests that optical method is a non-invasive technique in contrast to other methods, which is suitable for studying human acupuncture meridians. Our experimental results agree with Choi's results[7].

From Table 1, one can see that diffuse reflectance signals from the pericardium meridian are stronger than those of the non-meridian for all the laser irradiation points. Statistical analysis shows that the light propagation difference has significant statistical difference

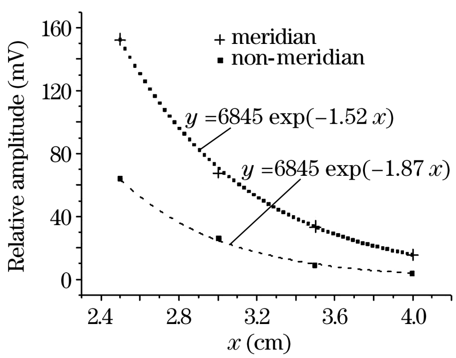

Fig. 4. Light propagation characteristics along the meridian and non-meridian directions.

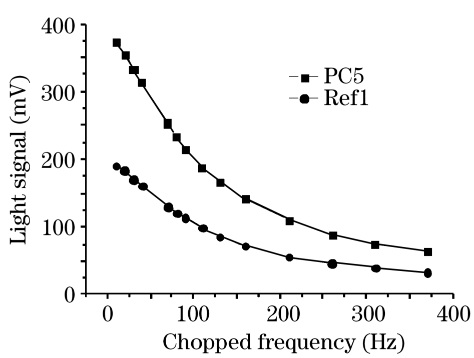

Fig. 5. Optical signal versus chopped frequency.

($P < 0.01$). The relative ratio of this difference can reach from 38.7% to 74.9% for different irradiation points. Furthermore, the difference of light propagation between meridian and non-meridian varies from person to person, which also can be found from the standard differences of the signals shown in Table 1. In order to analyze quantitatively the attenuation rate of light propagating along the meridian versus non-meridian direction, we compare the light attenuation from NP1 to NP2, and from NP2 to NP3 on the pericardium meridian direction with those of the non-meridian direction, as shown in Fig. 3. We can see that the relative light attenuations are about (78.8 ± 6.4)% in the 1.0-cm distance (2.5 cm → 3.5 cm), and (86.0 ± 13.9)% in the 1.5-cm distance (2.5 cm → 4.0 cm) along meridian direction, while the relative light attenuations of their reference points along non-meridian direction can reach (87.1 ± 3.0)% and (94.8 ± 1.7)%, respectively. In other words, Fig. 3 shows that light attenuates less along the meridian than along the non-meridian direction. In addition, one can also find that the light attenuations along meridian and non-meridian are exponential, which conform to the Beer's attenuation law.

The transport characteristics of He-Ne laser propagating along the pericardium meridian versus non-meridian direction can be expressed as $y = y_0 \exp(-1.52x)$ and $y = y_0 \exp(-1.87x)$ as shown in Fig. 4 by fitting the experimental data. Herein, y_0 is equal to 6845, representing the relative amplitude of light intensity, while the values −1.52 and −1.87 represent the light attenuation factors of the meridian and non-meridian. It should be noted that the correlation coefficient R in the fitting can reach 0.99, which denotes the expressions can well fit the experimental results. From Fig. 5, one can find that the signals decrease as the optical chopped frequency over the low frequency range within 400 Hz, whether light propagating along meridian or non-meridian direction.

In conclusion, a simple and noninvasive experimental technique has been used to measure the optical transport properties of light propagating along the pericardium meridian and non-meridian directions *in vivo*. Being noninvasive, this technique is feasible and the results are reproducible. Our study suggests that light in a certain wavelength may propagate better along pericardium meridian than along non-meridian direction, and this difference of light propagation has a significant statistical meaning ($P < 0.01$). Further investigation is required in order to ascertain the optical transport preferential pathway of human meridians and its wavelength and frequency dependences.

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