Front. Optoelectron. China 2011, 4(2): 223–227
DOI 10.1007/s12200-011-0129-x

RESEARCH ARTICLE

In vivo experimental study of optical characteristics of human acupuncture points

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Abstract Effective attenuation coefficients and diffuse reflectance spectra of acupuncture point and non-acupuncture point were measured *in vivo* before and after the brachial artery was constricted with a sphygmomanometer. Experimental results showed that the effective attenuation coefficient of acupuncture point was smaller than that of non-acupuncture point. When the brachial artery was constricted, the effective attenuation coefficients of acupuncture point and non-acupuncture point increased. Furthermore, the increasing amplitude of effective attenuation coefficient of acupuncture point was smaller than that of the non-acupuncture point. Diffuse reflectance of acupuncture point was lower than that of non-acupuncture point within the wavelength range of 470 to 600 nm. Both the diffuse reflectance of acupuncture point and non-acupuncture point decreased after the brachial artery was constricted. These experimental results indicated that the optical characteristics of acupuncture point tissues were correlated with the physiologic changes. Therefore, these optical characteristics of acupuncture points would be helpful to study the mechanism of acupuncture meridian.

Keywords effective attenuation coefficient, diffuse reflectance spectrum, acupuncture point, oxy-hemoglobin, brachial artery

1 Introduction

Acupuncture, an ancient form of healing, has been widely used in traditional Chinese medicine over centuries. To date, it has evolved and achieved much progress in clinics [1,2]. Acupuncture has been one of the main alternative and complementary therapies in the West due to its clinical effectiveness. The World Health Organization and the United States National Institutes of Health have stated that acupuncture can be effective in the treatment of neurological conditions and pain. Although the efficacy of acupuncture has been confirmed in clinical studies, its mechanism remains unclear.

To investigate the mechanism of acupuncture, many studies have been conducted since 50 years ago with modern scientific techniques [3–7], including electric impedance measurement, ultrasonic imaging, nuclear isotope trace, and magnetic resonance imaging. Shen et al. studied the volt-ampere (V-A) characteristics of human acupuncture points [8]. The experiment results showed that human acupuncture points had characteristics of nonlinear and inertia. The nonlinear characteristic reflected the complexities of physiology and behavior, while the inertia characteristic was related to the energy metabolism of acupuncture points. Hu et al. used the infrared radiation imaging technique to investigate the infrared radiant track along meridian course over human body surface [9]. The results demonstrated that it was a normal biologic phenomenon existing in human subjects. Zheng et al. utilized sound detecting technique to determine the superficial course of the Bladder Meridian of rabbits [10]. Despite the facts that these techniques have revealed some characteristics of acupuncture points to some degrees, their potential in revealing the mechanism of acupuncture meridian is limited because of the invasion or low resolution. Compared with these techniques, optical techniques are of great advantage with non-invasion and high resolution. Moreover, optical techniques can provide comprehensive information about the acupuncture point, which could be helpful to understand the mechanism of acupuncture.

Received November 15, 2010; accepted November 30, 2010

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A few explorations have been made to investigate the optical properties of acupuncture points. Choi and Yang et al. had studied respectively the propagation of light along the acupuncture meridian and found that light propagated better along the meridian than the reference path with more than 20 percent difference for all the subjects tested [11–14]. Zhong et al. used optical coherence tomography image to distinguish human acupuncture point from the non-acupuncture point [15]. These studies pioneer the use of optical techniques in discovering the mechanism of acupuncture meridian. However, their studies are confined to a certain aspect of acupuncture points, respectively.

In this study, we proposed an approach that combines an ultra weak light measurement system with a diffuse reflectance measurement system to investigate the optical characteristics of acupuncture point before and after the constriction of the brachial artery. *Neiguan* and *Jianshi* acupuncture points, which have a relationship with regulating effect on cardiac autonomic nerve [16], were selected as the study subjects. The experimental results show that there are significant differences between acupuncture point and non-acupuncture point in terms of optical characteristics.

2 Experiment study

2.1 Effective attenuation coefficients

An ultra weak light measurement system was utilized to measure the effective attenuation coefficients of acupuncture point and non-acupuncture point. As shown in Fig. 1, the ultra weak light measurement system consisted of an LD laser (Newport, USA), an optical chopper (SR540, Stanford Research Systems, USA), optical fibers (Ocean Optics, USA), a photomultiplier tube (Oriel, USA), and a lock-in amplifier (SR850, Stanford Research Systems, USA). The emitted laser light was modulated with the optical chopper and coupled into the source fiber with a lens. Another end of the source fiber was put on the *Jianshi* acupuncture point (PC5). The collection fibers were put on the *Neiguan* acupuncture point (PC6) and its reference point (REF2) for collecting photons diffusing from the irradiation point (PC5). These photons were detected with the photomultiplier tube and the lock-in amplifier. Refer to Ref. [12] for more details about the experimental setup. There were 10 healthy volunteers (6 male, 4 female), 23.6±1.2 years old, involved in this experiment.

Jianshi acupuncture point (PC5) and its reference point (REF1), which is 9 mm away from PC5, were respectively chosen as irradiation points. *Neiguan* acupuncture point (PC6) and its reference point (REF2) were selected as detection points. All of these acupuncture points and non-acupuncture points were determined and labeled with the help of an acupuncturist before the experiment. To reduce the influence of the probes remotion during the experimental measurement, the detection fibers were fixed on PC6 and its reference point.

The radial reflectance could be expressed in the form [17] as

$$R(\rho) = \frac{I(\rho)}{I_0} = \frac{C_1}{\rho^m}\exp(-C_2\rho), \tag{1}$$

where ρ is the radial distance from the light source, $I(\rho)$ and I_0 are the intensities of the incident and reflected light respectively, C_1 and C_2 are empirically determined parameters, and the parameter depends upon the range of

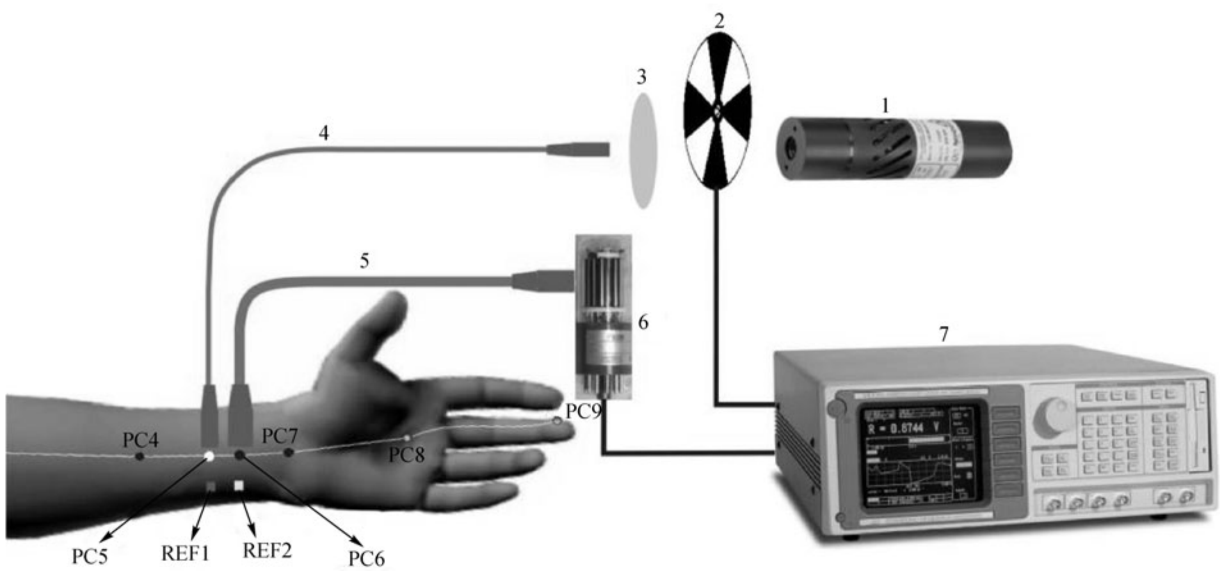

Fig. 1 Schematic of experimental setup (1: LD laser; 2: optical chopper; 3: lens; 4: source fiber; 5: collection fibers; 6: photomultiplier tube; 7: lock-in amplifier; PC5: *Jianshi* acupuncture point; PC6: *Neiguan* acupuncture point; REF1, REF2: reference points)

ρ and the scattering coefficient of the tissue. At large ρ, the parameter C_2 equals μ_{eff}, which is called the effective attenuation coefficient. Then, we could obtain the effective attenuation coefficient from Eq. (1) as

$$\mu_{\text{eff}} = -\frac{1}{\rho}\log_e\frac{I(\rho)\rho^m}{I_0C_1}. \quad (2)$$

Therefore, the differences between acupuncture point (PC5) and non-acupuncture point (Ref) in the effective attenuation coefficient could be expressed by

$$\Delta\mu_{\text{eff\_(Ref-PC5)}} = \mu_{\text{eff\_Ref}} - \mu_{\text{eff\_PC5}} = \frac{1}{\rho}\log_e\frac{I(\rho)_{\text{PC5}}}{I(\rho)_{\text{Ref}}}, \quad (3)$$

where $I(\rho)_{\text{PC5}}$ and $I(\rho)_{\text{Ref}}$ are the intensity of reflected light at the PC5 and Ref, respectively. The differences between acupuncture point and non-acupuncture point in effective attenuation coefficients were shown in Table 1.

To study the influence of blood flow on the effective attenuation coefficients of acupuncture point and non-acupuncture point, the effective attenuation coefficients were measured before and after the brachial artery were constricted with a sphygmomanometer. Figure 2 presented the variations of effective attenuation coefficients of acupuncture point and non-acupuncture point after the brachial artery was constricted with 13.3 kPa (100 mmHg) pressure.

2.2 Diffuse reflectance

The diffuse reflectance spectra of acupuncture point and non-acupuncture point were measured with an integrating sphere (Ocean Optics, ISP-REF) and a spectrometer (Ocean Optics, USB2000) before and after the brachial artery were constricted. The aperture sample port of the integrating sphere contacted the skin with the same pressure by putting the integrating sphere on the skin. Figure 3 showed the diffuse reflectance spectra of acupuncture point (PC6) and non-acupuncture point before the brachial artery was constricted.

To describe clearly the changes of diffuse reflectance spectra of acupuncture point and non-acupuncture point after the brachial artery was constricted, a coefficient, $K(\lambda)$, was introduced. It was defined as the diffuse reflectance spectrum after the brachial artery was constricted divided by the diffuse reflectance spectrum before the brachial artery was constricted:

$$K(\lambda) = \frac{R(\lambda)_{\text{aac}}}{R(\lambda)_{\text{bac}}}, \quad (4)$$

where $R(\lambda)_{\text{aac}}$ is the diffuse reflectance spectrum after the brachial artery was constricted, and $R(\lambda)_{\text{bac}}$ is the diffuse reflectance spectrum before the brachial artery was constricted. Figure 4 displayed the coefficients of acupuncture point and non-acupuncture point.

3 Discussion

The data in Table 1 show that the effective attenuation coefficient of acupuncture point is smaller than that of non-acupuncture point. One will find that both of the effective attenuation coefficients of the acupuncture point and non-acupuncture point increase after the brachial artery was constricted from Fig. 2. Moreover, the effective attenuation coefficient of non-acupuncture point increases more than that of acupuncture point (PC5). These results indicate that the constriction of the brachial artery would influence the non-acupuncture point more than acupuncture point ($p < 0.01$). Figure 3 presents that there are differences between acupuncture point and non-acupuncture point in diffuse reflectance within the wavelength range of 470 to 600 nm. Figure 4 displays the coefficients of acupuncture point and non-acupuncture point. The coefficients are smaller than 1 within the wavelength range of 480 to

Table 1 Differences between acupuncture point (PC5) and non-acupuncture point (Ref) in effective attenuation coefficients

subjects	$I(\rho)_{\text{PC5}}/I(\rho)_{\text{Ref}}$	ρ/cm	$\Delta\mu_{\text{eff\_(Ref-PC5)}}/\text{cm}^{-1}$
1	4.01	2.23	0.62
2	4.97	1.80	0.89
3	5.24	1.85	0.90
4	2.41	2.03	0.43
5	6.46	1.90	0.98
6	5.98	2.05	0.87
7	5.45	2.17	0.78
8	2.13	1.95	0.39
9	5.69	2.03	0.86
10	5.17	1.92	0.86
mean±SD	4.75±1.44	1.99±0.11	0.76±0.20

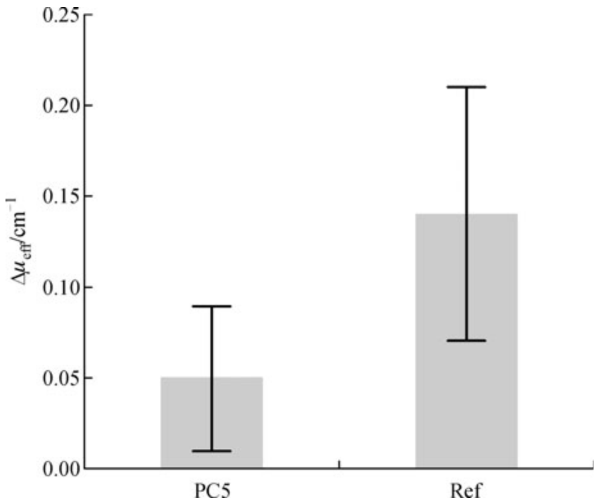

Fig. 2 Variations of effective attenuation coefficients of acupuncture point (PC5) and non-acupuncture point (Ref) after brachial artery was constricted ($p < 0.01$)

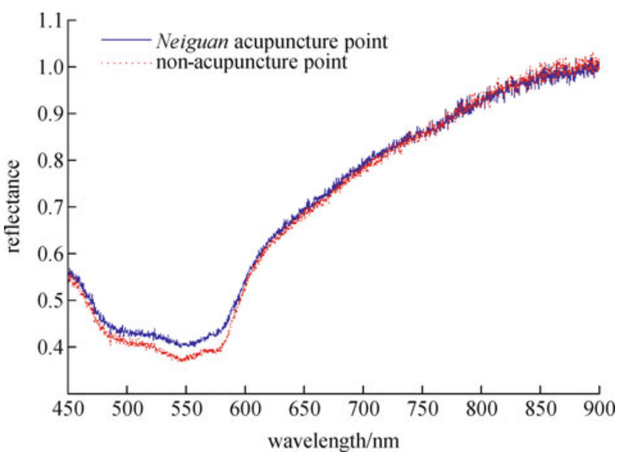

Fig. 3 Diffuse reflectance spectra of acupuncture point and non-acupuncture point before brachial artery was constricted

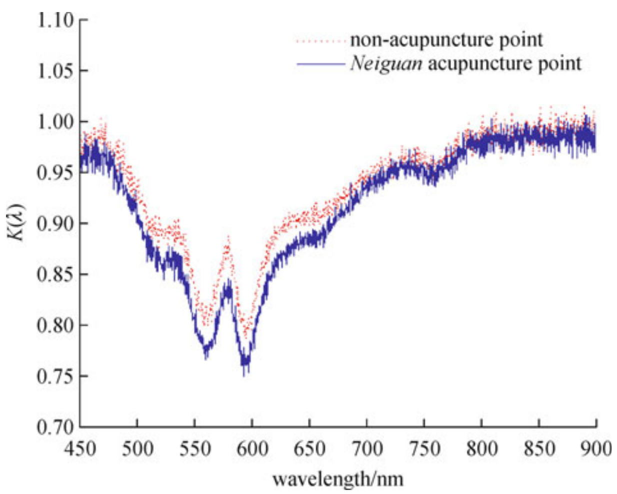

Fig. 4 Coefficients of *Neiguan* acupuncture point and non-acupuncture point, which represented changes of diffuse reflectance spectra after brachial artery was constricted

800 nm for both acupuncture point and non-acupuncture point, which indicates that the diffuse reflectance within this range decrease after the brachial artery is constricted. Furthermore, there are two pits between 500 and 600 nm. The two pits correspond to two peaks of molar extinction coefficient of oxy-hemoglobin [18] within the wavelength range of 500 to 600 nm. It means that the concentrations of oxy-hemoglobin at the acupuncture point and non-acupuncture point increase after the brachial artery is constricted.

4 Conclusion

The experiment results reveal that there are differences between acupuncture point and non-acupuncture point in the effective attenuation coefficients and diffuse reflectance spectra. The changes of effective attenuation coefficients and diffuse reflectance spectra after the brachial artery is constricted indicate that the blood flow change would influence the optical characteristics of acupuncture point and non-acupuncture point. In other words, the optical characteristics of acupuncture point and non-acupuncture point could present the physiologic change of tissues. Therefore, the optical characteristics of acupuncture point and non-acupuncture point might be utilized to study the mechanism of acupuncture meridian in further research.

Acknowledgements This work was supported by the National Basic Research Program of China (No. 2006CB504505), the National Natural Science Foundation of China (Grant No. 60978071), and the Nature Science Foundation of Fujian Province (No. 2010J01322).

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