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Brief Effect of Acupuncture on the Peripheral Arterial System of the Upper Limb and Systemic Hemodynamics in Humans

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Abstract

Background: Pulse diagnosis of the peripheral artery is an important technique in Traditional Chinese Medicine, where, in acupuncture therapy, the treatment is adjusted according to the observed changes of the pulse. We investigated the change of blood flow in the peripheral artery and the cardiac index during acupuncture treatment.
Objectives: The aim of this study is to explore the effect of acupuncture on radial and brachial artery blood flow volume and the cardiac index in healthy subjects.
Methods: Eighteen (18) healthy volunteers were enrolled. Acupuncture was performed bilaterally on LR-3 with manual rotation of the needles. The blood pressure and heart rate were measured at rest and 180 seconds after acupuncture. Radial and brachial artery blood flow volume was monitored continuously by an ultrasound with an echo-tracking system. Cardiac index was measured by impedance cardiography. The hemodynamic parameters were measured before, during, and 30, 60, 180 seconds after acupuncture.
Results: The peripheral artery blood flow volume decreased significantly during acupuncture (radial; $p < 0.01$, brachial; $p < 0.05$) but increased at 180 seconds after acupuncture (radial; $p < 0.05$, brachial; $p < 0.05$) compared with before acupuncture. The cardiac index did not change significantly after acupuncture, but systemic vascular resistance index significantly decreased ($p < 0.05$).
Conclusions: The present study showed that radial and brachial artery blood flow volume decreased immediately during acupuncture on LR-3 acupoint, but increased at 180 seconds after acupuncture. This reaction is attributed to the change in peripheral vascular resistance.

Introduction

Acupuncture has been widely applied to treat several conditions such as neck pain, shoulder pain, lumbar pain, headache, and hypertension in Asian and Western countries, and has also been found to be effective for a number of conditions in a number of randomized trials.[1–7] The evaluation of the radial pulse is an important diagnostic technique in Traditional Chinese Medicine (TCM). Radial, carotid, fibular, and posterotibial arteries have been used in pulse diagnosis. However, the radial pulse is more common in clinical pulse diagnosis. Acupuncture therapy is adjusted according to the observed alterations of the radial pulse, and is monitored through changes of the radial pulse pattern. There have been some reports about the hemodynamic influences of acupuncture using a single acupoint,[8–10] but its effects on the changes of blood flow volume in the peripheral artery have not been demonstrated. Furthermore, the relationship between peripheral artery blood flow and the cardiac index as related to acupuncture has not been studied in human subjects.

Liver in TCM is different from the Western medical liver organ. Liver has been thought to have the functions of

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storing blood, ensuring the smooth movement of *qi* throughout the body, controlling the sinews, manifesting in the nails, opening into the eyes, and housing the Ethereal Soul in TCM.[11] The acupoint of LR-3 is utilized for the acupuncture treatment of hypertension, headache, vertigo, and insomnia.[12] The point is the primary acupoint in the Liver meridian and is located on the foot at 1.5–2 units above the web, between the first and second toes on the Liver meridian.[12] The LR-3 has the functions of "soothing the Liver" and "regulating the blood." Thus, we hypothesized that LR-3 could affect blood flow volume in the peripheral artery and the cardiac index. The blood flow of radial artery is supplied from the heart through the brachial artery.

The aim of this study is to clarify the effect of acupuncture on blood flow volume of the radial and brachial artery and the cardiac index.

Subjects and Methods

Subjects

Eighteen (18) healthy volunteers who had a mean ± standard deviation (SD) age of 32 ± 5 years (range: 24–40 years; 14 males and 4 females) were enrolled in the study. They underwent the test on the radial artery first, followed by the test on brachial artery at 7-day intervals (Fig. 1). The study protocol was approved by the Ethics Committee of Tohoku University Graduate School of Medicine, and written informed consent to participation was given by all the subjects.

Setting

All the subjects took the test in the morning, after an overnight fast. They were placed in a quiet, air-conditioned room (temperature: 25°C–26°C), and were told to rest in the supine position. Three (3) monitoring electrocardiographic electrodes were attached to the anterior part of the chest while four electrodes for impedance cardiography (ICG) (BioZ ICG Module, Dash 3000®, GE Healthcare, U.S.A.) were placed at the base of the neck at the level of the xiphoid process in the midaxillary line. ICG is a noninvasive monitor that allows the measurement of the cardiac output based on the changes of thoracic resistance that result from variations in intrathoracic blood flow volume.[13,14] Blood pressure was measured with an oscillometer (BP-608 Evolution II®, Colin Healthcare Co., Ltd., Kyoto, Japan) on the left arm, and radial or brachial artery hemodynamics were evaluated with an ultrasound system (Prosound α10®, Aloka Co., Ltd., Tokyo, Japan) on the right arm. This system contained a high-resolution linear array transducer (13 MHz), and computer-assisted analysis software (e-Tracking system®, Aloka Co., Ltd.). The software could automatically detect the vessel edge and measure the vessel diameter and blood flow volume continuously.[15] The right arm was fixed and the right radial or brachial artery was scanned longitudinally where the vessel diameter and Doppler wave readings were stable. At the site where the clearest B-mode image of the anterior and posterior vessel wall was obtained, the transducer was fixed in a special probe holder (MP-PH0001, Aloka Co., Ltd.) (Fig. 2). The compression of the artery was carefully avoided. When the tracking gate was placed on the intima of the vessel, the radial or brachial artery diameter was monitored automatically. The waveform of the changes of vessel diameter over the cardiac cycle was displayed in real time using the e-Tracking system (Fig. 3). To obtain accurate measurements, a Doppler angle of 60 degrees or less was maintained.[16,17] Blood flow volume was calculated automatically as the Doppler flow velocity (corrected for the angle) multiplied by the heart rate and the vessel cross-sectional area.[16–18] To ensure that consistent images were obtained, the probe was kept at the same position throughout the test, using a special holder. The e-Tracking system can automatically measure changes of vessel diameter with a precision of 0.01 mm. The use of this system avoids operator bias, increases reproducibility, and improves accuracy. The system and software was developed for the measurement of flow mediated vasodilatation, which is usually measured at the brachial artery.[19,20] Although the vessel can be visualized easily without compression or mechanical distortion in the radial artery, the diameter is far smaller than that of the brachial artery. The correct assessment of hemodynamics is more difficult and requires some skills. Fixing the probe at

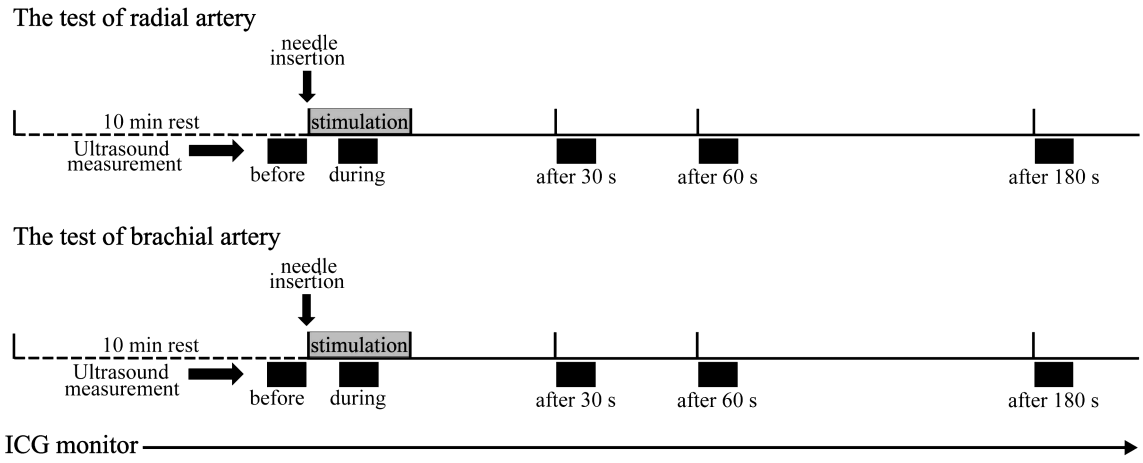

FIG. 1. Outline of the test. Ultrasound measurement was performed before, during, 30, 60, and 180 seconds after acupuncture. Acupuncture consists of needle insertion and stimulation. An impedance cardiography (ICG) monitor was used in the brachial artery test.

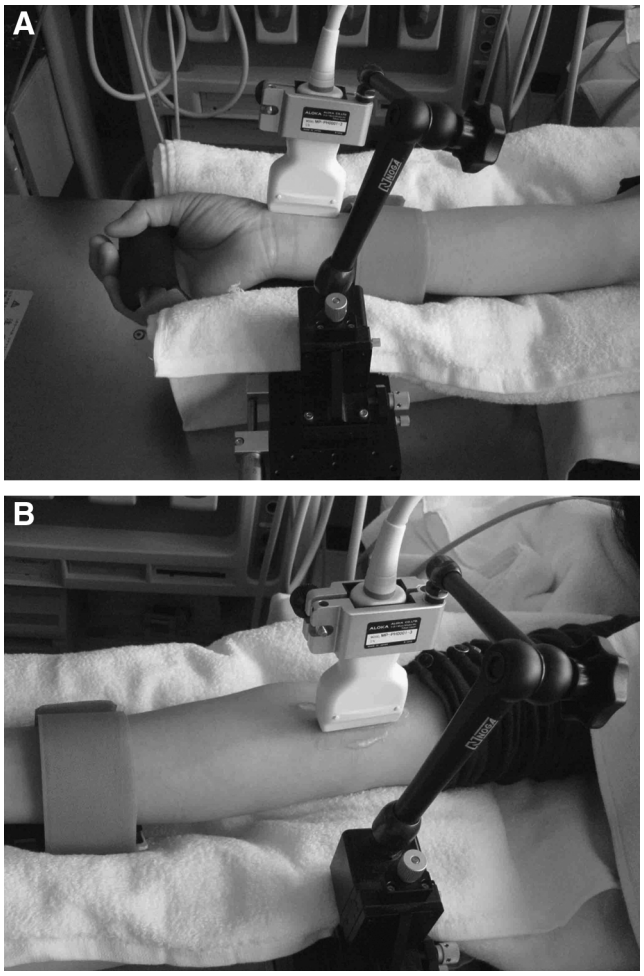

FIG. 2. Ultrasound measurement of radial or brachial artery with a special probe holder (MP-PH0001, Aloka Co., Ltd., Tokyo, Japan). (**A**) Radial artery measurement and (**B**) brachial measurement.

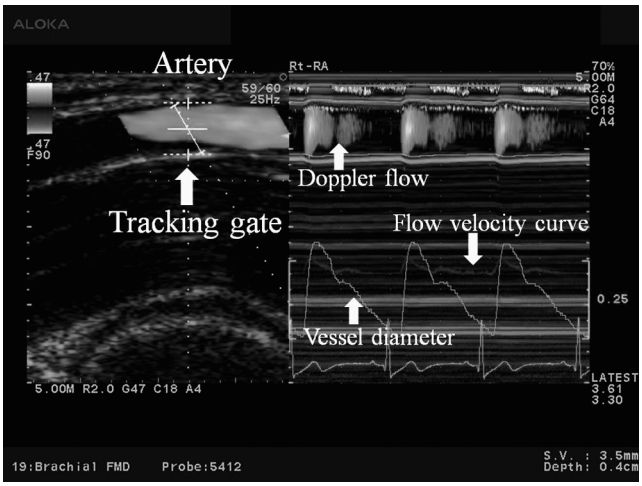

FIG. 3. Left image shows the vessel image and the position of the tracking gate of the artery. Right image shows the changes of the vessel diameter, Doppler flow, and flow velocity determined with an automated edge detection device and computer analysis software (e-Tracking system®, Aloka Co., Ltd., Tokyo, Japan).

the optimal position and avoiding movement of the upper limb are crucial.

The pulse Doppler ultrasound is a noninvasive method for evaluating blood flow velocity. Blood flow changes rapidly in the arteries of the extremities, especially in the peripheral arteries.[21] It is reported that changes of venous return due to respiration cause the oscillation of the stroke volume and blood pressure.[22] Thus, the arterial pulse should be modified by breathing.[23] Thus, the subjects were asked to breathe every 6 seconds during the test, and hemodynamic parameters were calculated as average values for each 6-second period to minimize the influence of respiration in the present study.

Study protocol

We performed acupuncture on LR-3 bilaterally and measured the hemodynamics of the radial artery or brachial artery from rest to 180 seconds after acupuncture. The cardiac index was measured and the test on brachial artery was performed at same time. The time course of the study is shown in Figure 1.

After 10 minutes of rest in the supine position, hemodynamic measurements of blood pressure, right radial, or brachial artery were started.[19,20] Acupuncture was performed by a licensed acupuncturist. A disposable fine stainless-steel needle (diameter: 0.16 mm; length: 40 mm; Seirin Co., Ltd., Shizuoka, Japan) was inserted on LR-3 bilaterally, and maintained at a depth of 10 mm during the test. After the needle was inserted, stimulation (rotating the needles manually within an angle of 90 degrees) was performed for 18 seconds. The needles were removed 200 seconds after acupuncture.

We measured radial or brachial artery hemodynamics before acupuncture, during acupuncture, and 30 seconds, 60 seconds, and 180 seconds after acupuncture (Fig. 1). The hemodynamic parameters, which include vessel diameter, blood flow volume, cardiac index, and heart rate, were recorded continuously. The values of the hemodynamic parameters were calculated as the average for each 6-second period. Blood pressure was measured under resting conditions and 180 seconds after acupuncture.

Statistical Analysis

Statistical analysis was performed with SPSS software (version 16.0, SPSS Japan Inc., Tokyo, Japan). Repeated-measure analysis of variance, followed by Dunnett's *post hoc* test, was used for statistical comparison between the measure points. Results are presented as the mean $\pm$ SD and $p < 0.05$ was taken to indicate significance for all statistical analysis.

Results

Hemodynamic parameters, including vessel diameter, blood flow volume in radial or brachial artery, cardiac index, heart rate, and blood pressure are summarized in Table 1.

Radial and brachial artery diameter

The systolic and diastolic diameter of the radial or brachial artery did not significantly change in the test (Table 1).

Table 1. Summary of Hemodynamic Parameters

Parameter		Acupuncture				
		Before	*During*	*30 s after*	*60 s after*	*180 s after*
Systolic vessel diameter (mm)	Radial	2.95 (0.46)	2.9 (0.46)	2.91 (0.46)	2.93 (0.47)	2.95 (0.44)
	Brachial	4.60 (0.61)	4.61 (0.62)	4.58 (0.61)	4.59 (0.61)	4.60 (0.63)
Diastolic vessel diameter (mm)	Radial	2.89 (0.45)	2.85 (0.45)	2.86 (0.45)	2.88 (0.47)	2.91 (0.43)
	Brachial	4.50 (0.61)	4.51 (0.62)	4.49 (0.61)	4.50 (0.60)	4.51 (0.63)
Blood flow volume ($mL/s/m^2$)	Radial	0.51 (0.31)	0.24 (0.23)**	0.54 (0.44)	0.62 (0.41)*	0.61 (0.31)*
	Brachial	0.73 (0.38)	0.56 (0.33)*	0.77 (0.41)	0.79 (0.44)	0.87 (0.36)*
Heart rate (beats/min)		67.3 (10.1)	64.2 (8.8)**	65.8 (9.3)	66.2 (9.3)	66.9 (9.6)
Systolic blood pressure (mmHg)		116.8 (10.1)				114.5 (12.3)
Diastolic blood pressure (mmHg)		87.3 (8.4)				65.8 (7.3)
Cardiac index ($l/min/m^{-2}$)		2.87 (0.41)				2.92 (0.39)
Systemic vascular resistance index (dyne sec/cm^5 m^2)		2387.4 (427.7)				2284.2 (388.8)*

Values represent the mean (standard deviation).
*$p < 0.05$; **$p < 0.01$ versus before acupuncture.

Radial and brachial artery blood flow volume

The blood flow volume was determined as milliliters per second per square meter and the percent change at each time was calculated in relation to before acupuncture. The blood flow volume in radial and brachial arteries is shown in Table 1. The blood flow volume in the radial artery decreased significantly during acupuncture (means ± SD; $0.24 \pm 0.23\,mL/s/m^2$, $p < 0.01$), but showed a significant increase at 60 seconds ($0.62 \pm 0.41\,mL/s/m^2$, $p < 0.05$) and 180 seconds after acupuncture ($0.61 \pm 0.31\,mL/s/m^2$, $p < 0.05$) compared with before acupuncture ($0.51 \pm 0.31\,mL/s/m^2$). In the brachial artery, the blood flow volume also decreased significantly during acupuncture ($0.56 \pm 0.33\,mL/s/m^2$, $p < 0.05$), and showed a significant increase at 180 seconds after acupuncture ($0.87 \pm 0.36\,mL/s/m^2$, $p < 0.05$) compared with before acupuncture ($0.73 \pm 0.38\,mL/s/m^2$). Figure 4A illustrates the profile of the percent changes in radial and brachial artery blood flow volume. The blood flow volume in the radial artery decreased significantly during acupuncture ($p < 0.01$), but showed a significant increase at 180 seconds after acupuncture ($p < 0.05$). In the brachial artery, the blood flow volume also showed a significant increase at 180 seconds after acupuncture ($p < 0.05$).

Cardiac index

The percent change of cardiac index did not significantly change during acupuncture, as well as at 30, 60, and 180 seconds after acupuncture, when compared with the values before acupuncture (Fig. 4B).

Heart rate

The heart rate significantly decreased during acupuncture relative to that before acupuncture ($p < 0.01$). However, 30 seconds after acupuncture, values returned to before acupuncture levels (Table 1).

Blood pressure

The systolic and diastolic blood pressure showed no significant change after acupuncture compared with before acupuncture (Table 1).

Systemic vascular resistance index

Systemic vascular resistance index was calculated by the cardiac index and the mean blood pressure. The percent change of systemic vascular resistance index decreased significantly after acupuncture, compared with before acupuncture ($p < 0.05$) (Fig. 4C).

Side-effects of acupuncture

There were no local complications such as bleeding, hematoma, or infection.

Discussion

Our result demonstrated that the radial and brachial artery blood flow volume decreased immediately during acupuncture on LR-3, and increased 180 seconds after acupuncture. While the cardiac index did not change significantly, the systemic vascular resistance index significantly decreased after acupuncture. The amount of upper limb blood flow is influenced by the systemic vascular resistance.

We showed a decrease in blood flow volume of the radial and brachial artery during acupuncture, and an increase in the volume 180 seconds after acupuncture. We believe that the response of acupuncture on peripheral artery hemodynamics during acupuncture was due to an increase in sympathetic tone as an extreme rapid response to the intervention caused by needle insertion. Elie and Guiheneuc reported that pain stimulation evokes a cutaneous sympathetic response,[24] which appears 1–3 seconds after the stimulus and is of short duration.[25–27] Vasomotor regulation and blood flow changes in the hand are entirely regulated by sympathetic nerves in contrast to other parts of the body.[27,28] Blood flow velocity is mainly influenced by distal resistance, so the marked variability of blood flow patterns is assumed to be related to changes of vasomotor activity. It has been reported that lumbar sympathectomy leads to an increase in forward flow and the disappearance of reverse flow in the femoral artery.[28] Therefore, the immediate response of the peripheral blood flow volume was presumably related to an increase in peripheral resistance due to the vasoconstrictor response to an instantaneous increase in sympathetic tone.

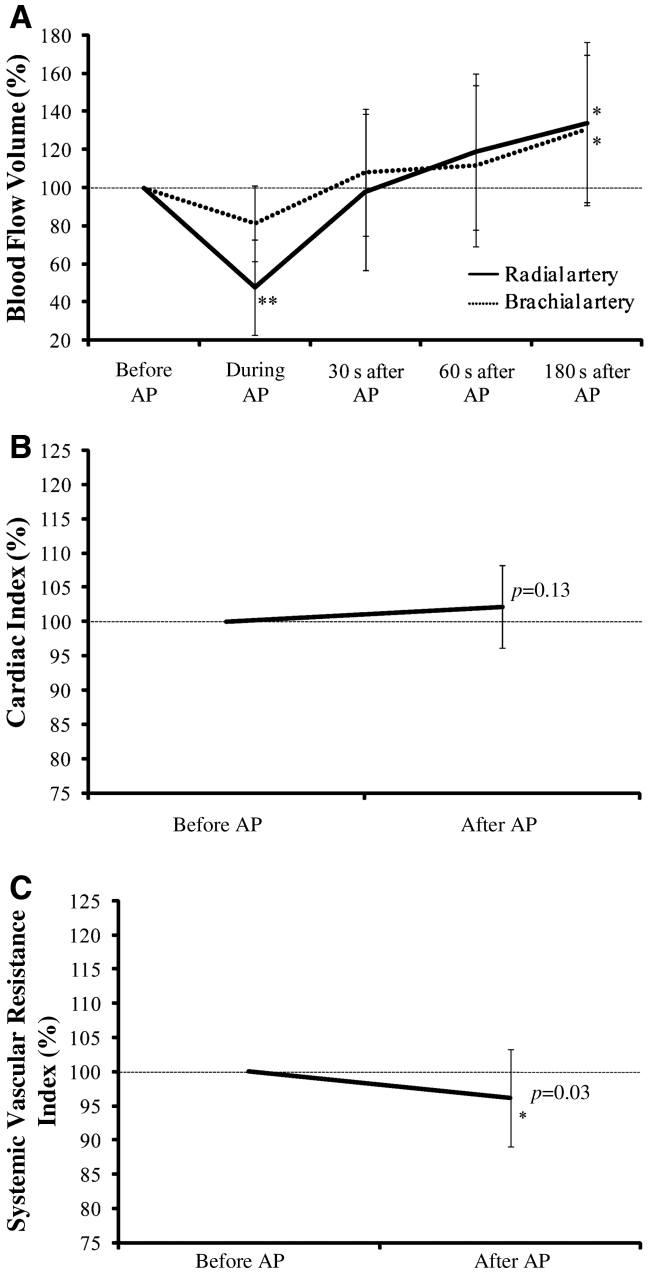

FIG. 4. (**A**) Percent change of blood flow volume in radial and brachial artery. Each variable is relative to the 6-second period before acupuncture. (**B**) Cardiac index. (**C**) Systemic vascular resistance index. Values represent the mean (SD). AP, acupuncture. $*p < 0.05$, $**p < 0.01$ versus before acupuncture.

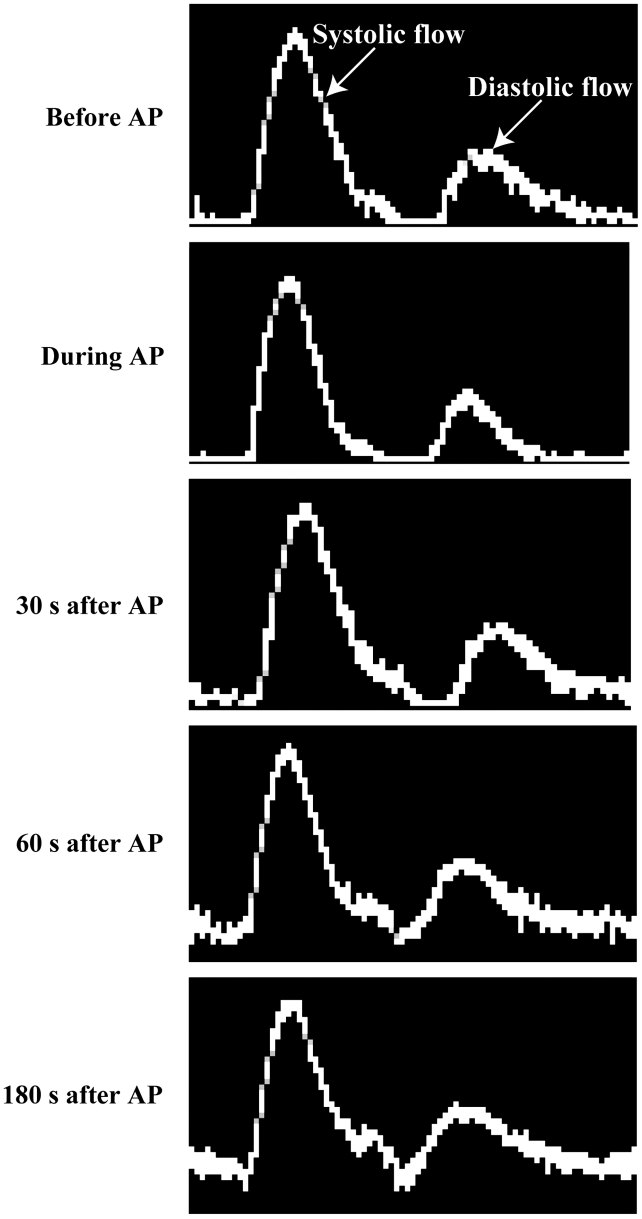

FIG. 5. Change of the blood flow velocity pattern. The pattern showed that diastolic flow velocity increased and the duration of forward flow was longer than before acupuncture. AP, acupuncture.

The increase in blood flow volume 180 seconds after acupuncture was also observed, along with an increase in the time velocity integral (which is the sum of the velocities) with no significant change in vessel diameter. The e-Tracking system cannot simultaneously show the pulsatility index or resistive index, which reveals distal vascular resistance. However, continuous recording with this system showed that the blood flow velocity pattern changed gradually from 60 seconds after acupuncture (Fig. 5). The pattern showed that diastolic flow velocity increased and the duration of forward flow was longer than before acupuncture. These changes of the blood flow pattern suggested that the increase in diastolic flow was due to a decrease in distal vascular resistance, which presumably decreased along with peripheral vasodilation secondary to a decrease in vascular tone. Omura reported similar peripheral circulatory changes after acupuncture by examining the fingernail bed using ultraminiature reflection-type photoelectric plethysmographic sensor. He also suggested that the consecutive changes after acupuncture could be divided into three phases, which were vasoconstriction, quasicontrol, and vasodilatation.[29]

The physiologic mechanism was supported by the change of systemic vascular resistance index. The index decreased

after acupuncture revealed decreased systemic vascular resistance in the present study. Therefore, the increase in blood flow volume 180 seconds after acupuncture was attributed to a decrease in peripheral vascular tone and vascular resistance. Uchida et al. suggested that the acupuncture affected the peripheral nerve and the skeletal muscle and caused blood flow increase in experimental animals.[30] The mechanism was supported with antidromic vasodilation by stimulation of unmyelinated C (or group IV) afferent fibers that are mediated by the release of calcitonin gene-related peptide. The decrease in vascular resistance may be caused by these physiologic mechanisms.

The present result showed no significant change in the cardiac index compared to before and after acupuncture. Tsuru and Kawakita suggested that acupuncture causes vasodilation and increases the blood flow of various organs by increasing the cardiac index and decreasing the total peripheral resistance via the central nervous system at the same time.[31] However, the cardiac index was not significantly changed by acupuncture in the present study. We suggest that the mechanism of increased blood flow by acupuncture is mainly due to decreased peripheral vascular resistance, not to an increase in the cardiac index.

In the present study, ICG was used as a noninvasive monitor of evaluating systemic hemodynamics. ICG utilizes four dual sensors on the neck and chest to apply low-amplitude, high-frequency, and alternating electrical current to the subject's thorax. Pulsatile changes of blood flow volume and velocity are measured as changes of impedance. Then it is synchronized with the electrocardiogram to automatically calculate hemodynamic parameters such as stroke volume and cardiac index.[32] The recent device of ICG (BioZ ICG Module, Dash 3000,® GE Healthcare, United States) provides highly reproducible and accurate data in a number of clinical settings, including heart failure.[33] We estimated the changes in the cardiac index using this device, and our findings show that the effect of acupuncture on LR-3 was not related to an increase in the cardiac index.

The LR-3 acupoint was selected for stimulation in this study because it is the primary acupoint on Liver meridian and is applied to treat cardiovascular disease in TCM.[12] To our knowledge, the present study is the first to provide physiologic evidence that acupuncture at only one acupoint has an effect on peripheral and systemic hemodynamics in human subjects. Our findings indicate that acupuncture at a single point increases peripheral blood flow without an increase in the cardiac index, suggesting that the acupuncture treatment can affect sympathetic tone on the upper limb.

The test duration was less than 15 minutes, which may seem insufficient to evaluate the effects of acupuncture. In a preliminary study, we attempted a longer test, but fixing the right upper limb for more than 15 minutes was difficult because of muscle strain and cramps.

The present findings suggest that acupuncture at a single acupoint can alter both radial and brachial artery hemodynamics in healthy subjects. The results should be treated with caution, given that this is a pilot study with no control intervention and with limited sample size. In another study, we intend to compare the changes in the peripheral blood flow volume and in the cardiac index with control conditions (e.g., another acupoint).

Conclusions

The study showed that radial and brachial artery blood flow volume decreased immediately during acupuncture on the LR-3 acupoint and increased 180 seconds after acupuncture, while the cardiac index did not significantly change. Changes in the peripheral vessel hemodynamics were accurately evaluated using the high-resolution ultrasound system with automated echo-tracking and central hemodynamics by ICG monitor.

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Disclosures

No competing financial interests exist.

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