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Basic Investigations

Correlation of the Cerebral Microvascular Blood Flow with Brain Temperature and Electro-Acupuncture Stimulation

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Objective: To investigate the relationship between the temperature and the microvascular blood flow of the cerebral cortex, and the influence of electro-acupuncture (EA) on the cortical microcirculation.

Methods: High temperature spots on the anterior ectosylvian and low temperature spots on the posterior suprasylvian on the cortical surface of 20 cats were identified using cortical infrared thermography (CIT); the blood flow in the microcirculation on these spots was measured with laser-Doppler flowmetry. EA was given at Zusanli (ST 36) and changes in the blood flow in the cerebral cortex microcirculation were detected.

Results: 1) The mean temperatures on the high (34.83±0.24°C) and low (32.28±0.27°C) temperature spots were significantly different (P<0.001); this was indicative of a temperature difference on the cortical surface; 2) The average blood flow in the microcirculation of the high (266.8±19.2 PU) and low (140.8±9.9 PU) temperature spots was significantly different (P<0.001). 3) On the cortical high temperature spots, the mean blood flow in the microcirculation significantly increased from 266.8±86.8 PU before EA, to 422.5±47.4 PU following 5 minutes of EA (58.35%; P<0.01), and 431.8±52.8 PU 5 minutes after ceasing EA (61.84%; P<0.01). 4) On the low temperature spots, there were no significant differences in blood flow following 5 minutes of EA (146.3±11.5 PU), and 5 minutes after ceasing EA (140.5±11.6 PU), when compared with that before acupuncture (140.8±9.9 PU; P>0.9).

Conclusion: The high temperature spots of the cortex are active functional regions of neurons with higher blood flow and a stronger response to EA. EA induces a significant increase in blood flow in the high temperature spots of the cortex.

Keywords: *cerebral cortex; brain temperature; micro-circulation perfusion; electro-acupuncture; infrared thermography; laser-Doppler technique*

The temperature of different parts of an organism varies: The core temperature is higher; the surface temperature is lower; the temperature on the head and face is higher; and that on the limbs is lower. The temperature difference on the cortical surface has been evaluated by cortical thermography and is thought to be related to the local blood circulation.[1] The authors used cortical infrared thermography (CIT) and laser-Doppler flowmetry (LDF) to explore the mechanisms responsible for the formation of high and low temperatures on the cortex, to understand the relationship between the cortical microcirculation and temperature, and to investigate the response of cortical micro-vessels to electro-acupuncture (EA) in the cat.

MATERIALS AND METHODS

Experimental Animals and Modeling Method

Experimental animals: Twenty cats, either male or female, weighing 2.5–3.0 kg, were supplied by the Center of Experimental Animals, China Academy of Chinese Medical Sciences.[1]

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Modeling Method

Cats were anesthetized with intraperitoneal injections of pentobarbital sodium (45 mg/kg). The skin, muscles, and cranial bone over the cerebral hemisphere of one side were removed, and the microcirculation of the exposed cerebral cortex was investigated using CIT (Fig. 1) and LDF before and after EA.

Experimental Instruments and Environment

Experimental Instruments: An infrared thermograph AGA Corp., Lidingo, Sweden) with a main processor temperature resolving power of 0.1°C was used to measure temperature; thermograms of the cerebral hemispheres were recorded with an infrared video camera; the thermogram processing program DISCO3.1 was used for storage of thermogram images and recording temperature data; and blood flow in the cortical microcirculations was continuously recorded with a Periflux-4001 laser-Doppler flowmeter and is expressed in perfusion units (PUs).

Experimental environment: Room temperature was 28.5–29.5°C; relative humidity was 50–60%; the fluctuation of the temperature before and after each experiment was ±0.5°C.

Cortical Temperature and Microcirculation

Measurement of cortical temperature: An infrared thermogram of the cerebral hemisphere on one side of the cat was recorded. An infrared video camera was used to record a temperature image of the lateral cortex and an infrared thermogram of the cortex was displayed. The high temperature spots within the anterior ectosylvian and the low spots within the posterior suprasylvian were identified. Temperature values were analyzed using the thermogram processing program (Figs. 1, 2).

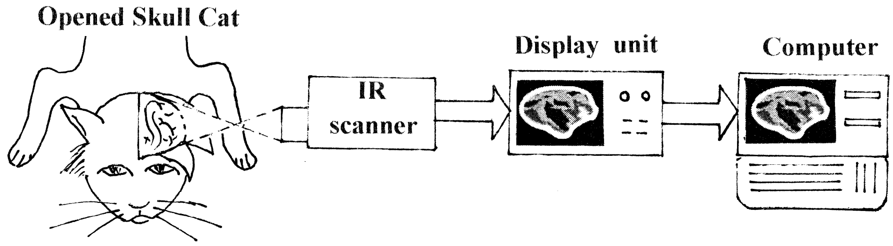

Figure 1. Infrared thermography was used to generate a temperature image of the cerebral cortex.

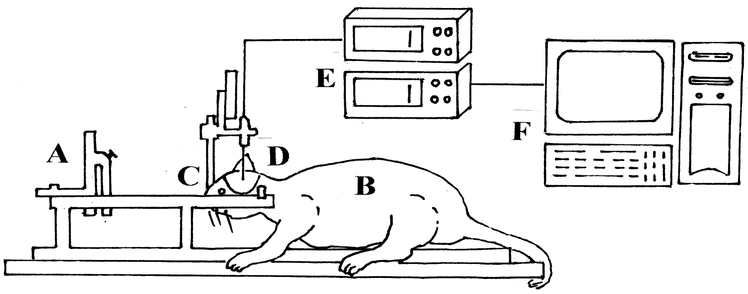

Figure 2. Laser-Doppler flowmetry for the measurement of blood flow in the cortical microcirculation.
A. Stereotaxic meter; B. Cat; C. Opened cortex; D. Laser-Doppler probe; E. Laser-Doppler flowmeter; F. Computer

Observations on the cortical microcirculation: After the cortical temperature was measured, animals were placed on a brain stereotaxic apparatus. The probe of the laser-Doppler flowmeter was fixed on the propeller of the brain stereotaxic apparatus (Fig. 2). The microvascular blood flow at the high and low temperature spots on the cortex were measured before EA, following 5 minutes of EA, and 5 minutes after ceasing EA.

Electro-acupuncture

Bilateral "Zusanli" (ST 36) were punctured with stainless steel needles connected to a WQ-10C EA instrument and stimulated once/second for 5 minutes, intensity 6V.

Statistical Analysis of Cortical Temperature and Blood Flow

The temperature values and the blood flow in the microcirculations in the high and low temperature spots of the cortex were statistically analyzed: 1) the mean temperatures between the high and low temperature spots were compared; 2) the mean blood flow in the microcirculations of the high and low temperature spots were compared; 3) the mean blood flow in the microcirculations of the high and low temperature spots following 5 minutes of EA and after ceasing EA were compared with those before EA. 4) The differences in blood flow in the cortical microcirculations of the high and low temperature spots, and the influence of EA on cortical blood flow were compared.

RESULTS

Selection of Cortical High and Low Temperature Spots and the Temperature Values

Cortical thermograms of the cerebral hemisphere of the cat were displayed as infrared thermographs, and cortical temperature distribution images were used to select high and low temperature spots (Fig. 3). These spots were marked and temperature values on the two regions were recorded and analyzed. There was a significant difference in mean temperature between the high and low temperature spots (difference, 2.5°C; n=20; P<0.001; Table 1).

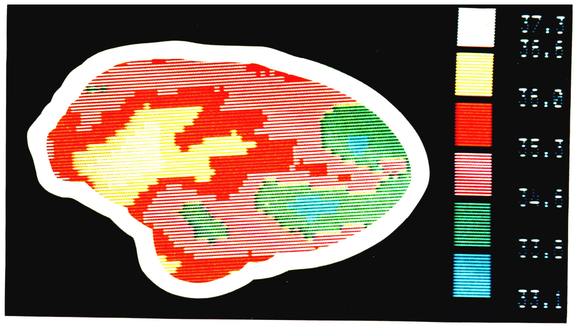

Figure 3. An infrared thermogram of the right cerebral cortex identifying high and low temperature spots.

Microcirculatory Blood Flow in Cortical High and Low Temperature Spots

The mean blood flow was significantly different (P< 0.001) between the high (266.8±19.2 (mean±standard error) PU) and low (140±9.9 PU) temperature spots (Table 1).

Table 1. Comparison of the temperatures and blood perfusion between the cortical high and low temperature spots ($\bar{x}\pm s$; n=20)

Group	Temperature (°C)	Blood perfusion (PU)
High temperature spot	34.83±0.24	266.8±19.2
Low temperature spot	32.28±0.27	140.8±9.9**

Notes: **P<0.01 compared with the high temperature spot.

Changes in Blood Flow in the Cortical High Temperature Spots Before and After EA

In the cortical high temperature spots, the mean microcirculatory blood flow was 266.8±19.2 PU before EA. It significantly increased by 58.35% to 422.5±47.4 PU (P<0.01) following 5 minutes of EA, and by 61.84% to 431.8±52.8 PU 5 minutes after ceasing EA (P<0.01) (Table 2).

Changes in Blood Flow in the Cortical Low Temperature Spots Before and After EA

In the cortical low temperature spots, the mean microcirculatory blood flow was 140.8±9.9 PU before EA, 146.3±11.5 following 5 minutes of EA, and 140.5±11.6 at 5 minutes after ceasing EA. These were not significantly different (P>0.9; Table 2).

Table 2. Blood perfusion of the cortical high and low temperature spots before and after EA ($\bar{x}\pm s$; n=20)

Groups	Before EA	5 min of EA	5 min after ceasing EA
High temperature spot	266.8±19.2	422.5±47.4**	431.8±52.8**
Low temperature spot	140.8±9.9	146.3±11.5	140.5±11.6

Notes: **P<0.01 statistically significant when compared with that before EA.

DISCUSSION

Cortical infrared thermography is a new neuro-thermo-imaging method which displays the temperature on the surface of an explored cortex as an image. CIT can be used to understand the temperature state on the cortex and study the functions and activities of the brain. CIT showed that the temperature on the anterior half of the cortex was higher than that of the posterior half. The high temperature area is part of the sensorimotor center and includes the anterior sylvian, anterior suprasylvian, and anterior ectosylvian. The low temperature region is not a main functional activity area and includes the posterior suprasylvian, posterior ectosylvian, and the posterior segment of the middle suprasylvian.[2] The objectives of the study were to compare the blood flow in the microcirculations of these different temperature regions before and after EA. The authors' hypothesis was that the high temperature region of the cortex is a more active area with a richer blood flow.

In this study the authors showed that the mean PU of the high temperature spots was significantly greater than that of the low temperature spots. These data indicate that there is a larger area of perfusion of the microcirculation and a denser distribution of microvessels in cortical high temperature regions. This results in a higher local temperature and suggests that cortical temperature is directly correlated with blood flow. These data are in accordance with previous results which indicated that the temperature and blood flow of the microcirculation influence each other and interact as both cause and effect. A study reporting on the relationship between changes in infrared radiation on the skull surface and the cortical microcirculation found that the local temperature of the cortex changed with alterations in the cortical microcirculation.[3] Other investigators found that under different temperatures, or due to an increase in body temperature induced by prostaglandin E_2, the micro-vascular diastolic-contractive state was changed causing an increase or decrease in the blood flow of the cortical microcirculation.[4,5] Furthermore, a decrease in body temperature can reduce cerebral microcirculation.[6,7] In some diseases of the brain, decreased cerebral temperatures reduced damage to neurons and protected brain tissues.[8,9]

An increase in blood flow is a direct response to increased neuron activity. Shirane et al. found that the amplitudes of electroencephalograms (EEG) in cerebral ischemia decreased, indicating that a decreased blood supply to the brain results in weaker neuronal activity. Administration of 6-aminonicotinamide in cats caused a synchronous decrease in the cortical microcirculation, the metabolism of the brain cells (oxygen content and the use rate of glucose), and the ratio of the α-2 rhythm of the EEG. This suggests that there is a close relationship between the blood circulation, electrical activity, and the metabolism of brain cells.[10,11] These data indicate that the high and low temperatures on the cortex are induced by the local blood circulation which is determined by the excitatory state of the cortical neurons. Therefore, the authors' method for recording cortical temperature distribution images using CIT may be indicative of the excitability of neurons. Future studies are required to confirm this.

EA is known to induce temperature increases on certain parts of the cortex.[12] The authors believe that EA increases cortical neuron activity which elevates local metabolism and blood flow. Therefore, the response of the cortex to EA probably reflects the excitatory and inhibitory states of the neurons. A number of investigations indicated that EA can induce micro-circulatory perfusion of the skin on the limbs by mechanisms that included increasing capillary permeability, eliminating the spasticity of micro-arteries, changing the automotive fluctuations of the microc-irculation, activating the fibrinolysis system, and decreasing blood viscosity and platelet aggregation.[13–16] EA also increased perfusion of the cortical micro-circulation, and may promote the healing of lesions in patients with cerebral ischemia.[17,18]

Zusanli (ST 36) is a commonly-used acupoint with many functions; it has a regulative action on visceral smooth muscle and a diastolic action on vascular smooth muscle. Positron emission tomography indicated that acupuncture at Zusanli (ST 36) increased glyco-metabolism in the inferior part of the optic thalamus, the head of the caudate nucleus, the temporal lobe, the cerebellum, the post-central gyrus, and the brain stem.[19] Functional magnetic resonance imaging (fMRI) showed that acupuncture at Zusanli (ST 36) and Sanyinjiao (SP 6) activated primary and secondary sensory areas, the insula, the ventral thalamus, the temporal lobe, and the cerebellum.[20] Positron emission tomography indicated that EA at acupoints on the limbs of healthy people and the paralytic limbs of stroke patients induced an obvious increase in glucose metabolism in the brain, and the motor and sensory areas.[21] Acupuncture or EA at Zusanli (ST 36) has a wide action on the central nerve system. In the present study, EA at Zusanli (ST 36) induced a significant increase in blood perfusion in the cortical high temperature regions.

The results in this study confirmed that EA increases cortical blood perfusion, and indicate that this occurs in a region specific manner. After EA with the same parameters, the blood flow in the cortical high temperature spots (anterior ectosylvian) increased by 60%, while that of the low temperature spots (posterior suprasylvian) increased by only 1.4%. This suggests that the blood flow in different parts of the cortex is not the same, and that EA induced increased perfusion of the cortical microcirculation shows regional specificity. The authors suggest that the neurons in different functional areas of the cortex show different responses to EA stimulation. The neurons in the high temperature region have a sensitive response to EA; they react with strong excitability and an increase in tissue metabolism and blood flow. The neurons in the low temperature region are not in an excitatory state, have no obvious nervous activity, and are not influenced by EA. These assumptions are supported by a study in rats in which EA induced obvious discharge in the somatosensory area, but the cortical functional areas had different responses to stimulation of different peripheral parts. These data support the results and indicate that EA affects the whole cortex and the somatosensory area differently.[22]

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