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Effects of Electrical Stimulation Applied to Paraspinal Tissues on Peripheral Blood Circulation.

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To investigate effects of electrical stimulation on the peripheral blood circulation being remote from the stimulated site, human paraspinal tissues were stimulated, and finger skin temperature, acceleration plethymogram (APG) in finger, and finger blood flow (estimate by vein width) were examined. With some appropriate electrical stimuli (1Hz strong, 3Hz strong, 5Hz soft) at the paraspinal tissues of 7th cervical vertebral level, skin temperature, the value of APG b/a (blood vessel distensibility) and APG amplitude (magnitude of acceleration plethysmogram) in finger significantly rose, and with 3Hz strong stimuli, finger vein width significantly increased, but any effect was not found with 10Hz soft or 30Hz soft stimuli. The thermograph imaging showed that the skin temperature of hand and ulnar forearm rose during the stimuli at 7th cervical vertebral level, but not at 3rd thoracic vertebral level. These findings suggest that through somato-sympathetic reflex, appropriate electrical stimuli to the paraspinal tissues improved peripheral blood circulation of the same dermatome region being remote from the stimulated site. Besides, even with stimuli conditions that none of the subject experienced any pain or discomfort, electrical stimuli could improve the local peripheral blood circulation being remote from the stimulated site. The similar methods to the electrical stimuli examined in the present study might be useful as a clinical measure, especially at the acute stages of clinical cases in which the direct approaches to injury site are difficult due to a pain with inflammation or insertion of cast brace.

Key words

Somato-sympathetic reflex, Peripheral blood circulation, Sympathetic rhythm, Electrical stimulation, Human.

Introduction

Blood supply is one of the important factors

that could affect the wound healing and tissue regeneration following injury^{1,2)}. It has been widely accepted that the improvement of the local blood circulation reduces the secondary disorder, such as edema, tissue atrophy and chronic pain. Therefore, some therapeutic approaches to improve the peripheral blood circulation from the early stages of injury might be useful in many clinical cases. But, the direct approaches to the injury site are often difficult due to a pain with inflammation or insertion of cast brace, especially at the early stages of injury. Indeed, the previous clinical research reported that the unsatisfactory results such as joint contracture were strongly as-

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sociated with the periods of prolonged immobilization after injury³⁾. Thus, the procedure which could start as early as possible after injury should be developed in clinical cases from a point of view that would prevent the secondary disorder.

It was reported that electrical, mechanical and chemical stimulation to the lumbar paraspinal tissues evoked a muscle contraction not only in the paraspinal muscles but also in the leg muscles innervated by the spinal nerve arising from the same spinal segment⁴⁻⁶⁾, and the electrical stimulation to the dorsal branch of the spinal nerve innervating the paraspinal tissues evoked a compound action potential in the dorsal branches arising from one or two adjacent spinal cord segments⁷⁾. These findings suggest that the electrical stimuli would be able to affect the various tissues being remote from the stimulated site through some polysynaptic reflex arches. The somato-sympathetic reflex might play an important role for modulation of the peripheral blood circulation in the experimental animals⁸⁻¹⁰⁾. However, the role of the somato-sympathetic reflex for modulation of the peripheral blood circulation in human has not yet been practically studied, because human experiments would be impossible to carry out with invasive methods that are used in animal experiments. Besides, in clinical

cases, it is important to reduce patient's tolerance with pain by therapeutic approaches. Our preliminary experiments showed that under certain conditions, electrical stimuli didn't induce any pain or discomfort to subjects during the stimulation. In the present study, therefore, the human paraspinal tissues at the lower cervical vertebral levels were electrically stimulated, and the changes of the blood circulation in finger were examined to reveal the possible role of the somato-sympathetic reflex with some non-invasive methods.

Materials and Methods

General protocol

Subjects wore the experimental uniform, and the portions to be electrically stimulated (2cm×2cm, 1.5 cm bilaterally from the posterior median line at 7th cervical or 3rd thoracic vertebral level) were shaved. They kept a supine position on the bed at least for 30 minutes before the experiment.

At 5 minutes before the experiment, subjects changed to a lateral decubitus position without any neck rotation, and a pair of stimuli electrodes were placed bilaterally on the skin covering the paraspinal tissues at 7th cervical or 3rd thoracic vertebral levels (Fig. 1, 2). Each experiment was composed of a rest



Fig. 1. The position of subject during electrical stimulation

Subjects relaxed themselves with a lateral decubitus position except for keeping their hands still during the experiments.

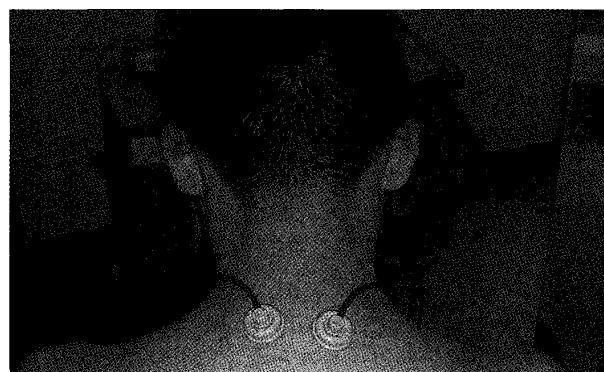


Fig. 2. Experimental set-up for placing stimulus electrodes

Subjects were electrically stimulated at 1.5 cm bilaterally from the posterior median line at 7th cervical or 3rd thoracic vertebral level.

phase for 30 minutes and a stimulating phase for 20 minutes. During the experiments, subjects relaxed themselves on the bed except for keeping their hands still. All experiments were carried out in a silent room where room temperature (24 ± 1 °C), humidity ($52.5 \pm 2.5\%$), and brightness (only room illumination without any natural light) were kept constant, between 3 p.m. and 6 p.m. to minimize the circadian variability of the biological signs, such as blood pressure and pulse rate.

Subjects

All experiments were carried out in healthy young volunteers aging 18-27 years old (20.03 ± 2.52 years; mean $\pm$ standard deviation). Some subjects were tested more than once in different experiments. Each subject was informed the purpose and protocol of the experiments and gave their consent to participate. During each experiment, subjects were comfortably on the bed, and none of the subject experienced any pain or discomfort.

Electrical stimulation

Electrical stimuli were applied to the paraspinal tissues by using an electrical stimulator (AIDEX α 303, Aich Electric Inc., Nagoya, Japan) that has been popularly used for clinical physical therapy. The output of this stimulator was mainly controlled by degrees of stimuli intensity and frequency. Stimuli were square-wave electrical pulses (duration 85μ sec) delivered by the stimuli electrodes.

To determine the appropriate electrical stimuli condition, the stimuli intensity and frequency are very important factors. The stimuli should not induce any pain or discomfort, because unpleasant stimuli such as vibration and noise decrease peripheral skin blood circulation¹¹⁾. As to the stimuli frequency, it was reported that the relationship between the evoked local cerebral blood flow and the field potential induced by somatosensory activation was depend on stimuli frequency, and the stim-

uli frequency of 5Hz exhibited the maximal evoked local cerebral blood flow¹²⁾. In this experiment, therefore, we chose 1, 3, 5, 10 and 30Hz for trial frequencies among a range of low frequency (1-30Hz) in consideration of difference between human and animal. And the maximal degree of stimuli intensity without any pain at these frequencies was determined by using randomly extracted 20 subjects. Under the constant voltage and electrical resistance, if the stimuli frequency is higher, current per second would increase, and being easy to induce a pain or discomfort. Accordingly, the maximal degree of stimuli intensity without any pain at 10Hz is stronger than that at 30Hz. Thus, in the present study, the maximal degree of stimuli intensity without any pain at 10Hz are referred as "strong" and that at 30Hz, as "soft". Current per pulse of strong stimuli was 28μ A and that of soft stimuli was 20μ A. Electrical stimuli of both intensity degrees arrived to skin, hypodermal tissue and superficial skeletal muscles of stimuli site. Each sham study was performed by the same methods except for setting the electrical output intensity to zero.

Test 1: Difference in effects with different frequencies of the electrical stimuli

This test was carried out to know the effective frequencies in the same current per pulse of the electrical stimuli. Finger skin temperature, blood pressure and pulse rate were examined in 50 subjects divided into 5 groups of 10. They were kept with a left lateral decubitus position during the electrical stimulation. A thermistor (Digi-Temper, Tsuruga Electric Works Ltd, Tokyo, Japan) was placed at the tip of the right middle finger, and sphygmomanometer (HEM-770A, Omuron, Tokyo, Japan) at their left brachium. The electrical stimuli at different frequencies with soft intensity were applied to the paraspinal tissues at 7th cervical vertebral level, and finger skin temperature,

blood pressure and pulse rate were recorded at every one minute during the stimulation.

Test 2: Thermograph imaging during the stimulation at different levels

To observe substantially the effects of the electrical stimuli applied to the paraspinal tissues on the peripheral blood circulation in the region being remote from the stimulated site, changes of the skin surface temperature were examined by using a thermograph imaging (Fujitsu, Inc., Tokyo, Japan) in 6 subjects divided into 2 groups of 3. The electrical stimuli were applied to 7th cervical or 3rd thoracic vertebral level with 5Hz soft. During stimulation, the subjects were kept with a lateral decubitus position, but a thermograph imaging was recorded with an anatomical neutral position at every 5 minutes. To minimize influence of changing position, an assistant helped subjects' motion.

Test 3: Differences in effects with different intensities in the same frequency of the electrical stimuli

This test was carried out to know the effective intensities in the same frequency of the electrical stimuli. Acceleration plethysmogram (APG) was examined in 70 subjects divided into 7 groups of 10. They were kept with a right lateral decubitus position being symmetry to the position of Test 1 in order to compare laterality. The probe of photoelectric plethysmography (Nihon Kohden, Tokyo, Japan) was placed at the tip of their left middle finger, and the thermistor, at the tip of their left ring finger. The electrical stimuli at the same frequency with different intensities were applied to the paraspinal tissues at 7th cervical vertebral level, and APG and finger skin temperature were recorded every 5 minutes during the stimulation. The signals of the photoelectric plethysmography were amplified, filtered, digitized with A-to-D converter and sampled (sampling rate 1000Hz), analyzed and stored

on a personal computer with a dedicated software package (Saluse APG 0.70, Tokyo, Japan). The value of APG amplitude was to observe the change of arterial blood flow, and the value of APG b/a was to evaluate blood vessel distensibility. The value of APG b/a has been widely used for an index of elasticity or destensibility of peripheral blood vessel clinically. It has been generally said that with the decline of blood vessel distensibility, the value of the APG b/a will increase, and the value of the APG b/a will be gradually rising with age¹³⁾.

Test 4: Changes in the finger blood flow during the stimuli

Finger blood flow was non-invasively monitored in 20 subjects divided into 2 groups of 10, by using finger vein width as parameters. Stimuli electrodes were placed at 7th cervical vertebral level and the electrical stimuli were applied to the paraspinal tissues with 3Hz strong. To measure the vein width, a non-invasive optical anemia analyzer (Astrim SU, Sysmex, Kobe, Japan) was used¹⁴⁾. A camera was placed on the ventral surface of the left middle finger, and the light emitting diode radiating near-infrared light was placed on the dorsal surface of the finger. With this method, veins

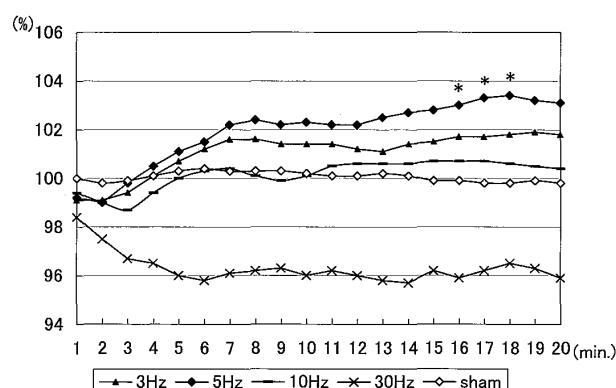


Fig. 3. Changes in skin temperature in Test 1
Changes in skin temperature during electrical stimuli at different frequencies with soft intensity. Values were normalized to the pre-stimulus value. *: $p < 0.05$ (compared with the rest phase value).

running near the skin of the ventral surface of the finger can be examined. Finger vein width obtained by analyzing the transmitted imaging was recorded at every 1 minute.

Statistical analysis

Data were expressed as mean $\pm$ standard deviation. The percentage value for each individual was normalized to the rest phase value (the normalized value (%) = the obtained data / the rest phase value $\times$ 100). The rest phase value was provided with calculating average for 3 minutes of finger temperature, blood pressure, pulse rate, and finger vein width. The results for all tests were evaluated significance of difference from the rest phase value by one-way factorial analysis of variance (ANOVA) according to the Bonferroni's multiple comparison. Statistical significance was seen when the p value was less than 0.05.

Results

Test 1: Changes in the finger skin temperature, blood pressure and pulse rate during the stimulation with different frequencies

Changes in finger skin temperature during the soft stimulation with different frequencies are shown in Fig. 3. The finger skin temperature gradually rose during the stimuli with 3Hz and 5Hz. The temperature significantly rose at 17th, 18th and 19th minutes of the stimuli with 5Hz, whereas any significant changes were not observed with 10Hz or 30Hz. No significant change was observed in blood pressure or pulse rate with any frequencies examined in the present study (data not shown).

Test 2: Changes in thermograph imaging during the stimulation at different levels

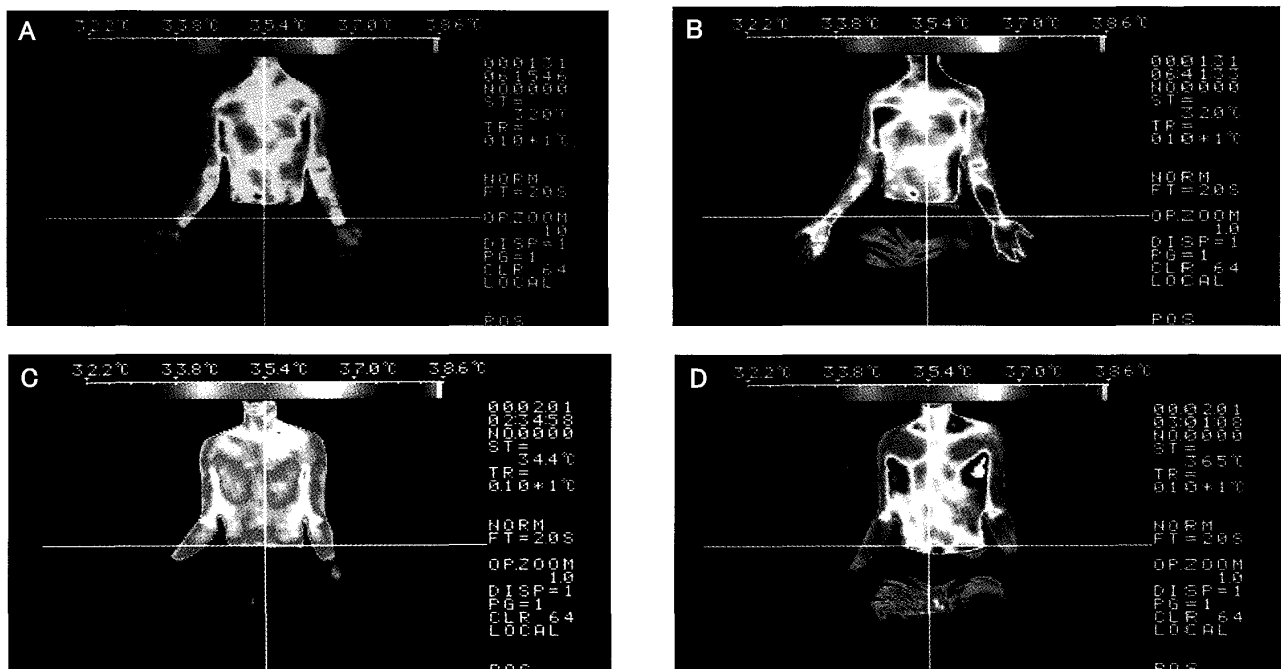


Fig. 4. Thermograph imaging in Test 2

Changes in skin temperature induced by electrical stimuli applied to 7th cervical (before stimuli: A, 20 minutes after stimuli: B) and 3rd thoracic vertebral level (before stimuli: C, 20 minutes after stimuli: D) with 5 Hz soft respectively.

The thermograph imagings are shown in Fig. 4. The skin temperature of fingers, palm and ulnar forearm gradually rose during the stimulation at 7th cervical vertebral level. During the stimulation at 3rd thoracic vertebral level, though skin temperature rose in the upper chest, no change was found anywhere in the upper limb. Similar results were obtained in each group.

Test 3: Changes in APG and the finger skin temperature during the

stimulation with different intensities

As shown in the Test 1, since the skin temperature rose during the stimulation with lower frequencies, the effect of stimuli with different intensities were examined at 1, 3 and 5Hz. The changes in the finger skin temperature are shown in Table 1, and the changes in the value of APG b/a are shown in Table 2, respectively. Under the conditions showing significant rising of the skin temperature, the APG b/a appeared to increase, especially at

Table 1. Changes in skin temperature in Test 3

frequency	1Hz		3Hz		5Hz		sham
output degree	soft	strong	soft	strong	soft	strong	zero
5min	100.2±0.92	100.9±1.17	100.9±1.10	101.2±1.11	101.6±1.74	100.6±1.07	100.0±0.72
10min	100.0±2.24	101.5±1.38	101.9±1.66	102.0±1.71	101.8±1.36	100.8±1.16	98.1±6.18
15min	100.0±2.82	102.1±1.77*	101.9±1.97	102.8±1.93*	102.4±1.89*	101.1±0.91	99.8±0.89
20min	99.6±2.78	102.0±1.65*	101.7±2.46	103.0±2.16*	102.5±2.11*	100.9±1.06	99.8±1.13

Changes in skin temperature during electrical stimuli at the same frequency with different intensities on normalized value. *: p<0.05.

Table 2. Changes in APG b/a in Test 3

frequency	1Hz		3Hz		5Hz		sham
output degree	soft	strong	soft	strong	soft	strong	zero
5min	111.0±21.99	114.7±15.59	99.3± 7.27	120.3±14.46	113.7±23.13	101.6±13.95	97.3± 6.82
10min	103.9± 9.85	115.3±17.70	101.8±11.04	124.0±25.73*	113.8±19.76	104.3± 9.97	95.4± 5.30
15min	99.0±11.67	95.9±13.00	103.1±10.07	112.4±16.19	102.9± 8.68	93.5±14.11	97.8±11.31
20min	104.5± 6.72	97.1±11.19	105.1± 9.11	111.1±12.19	109.0± 8.91	103.9±12.36	98.2± 7.98

Changes in APG b/a during electrical stimuli at the same frequency with different intensities on normalized value. *: p<0.05.

Table 3. Changes in APG amplitude in Test 3

frequency	1Hz		3Hz		5Hz		sham
output degree	soft	strong	soft	strong	soft	strong	zero
5min	117.1±91.83	277.1±178.61*	161.7±111.52	275.3±133.46*	206.2±101.82	158.5±127.81	114.0±29.04
10min	94.5±50.89	272.2±140.01*	168.8±156.22	256.7±173.41*	222.2±165.21*	147.4±117.69	126.3±32.62
15min	82.1±40.04	124.9± 93.01	152.4±126.06	148.4±114.14	99.4± 48.99	151.7±217.23	122.6±28.12
20min	67.7±37.77	79.9± 48.05	126.6± 79.82	98.8± 70.76	71.7± 43.68	81.2± 66.49	106.1±20.26

Changes in APG amplitude during electrical stimuli at the same frequency with different intensities on normalized value. *: p<0.05.

the 10th minutes of the stimulation with 3Hz strong (statistically significant), suggesting that the compliance of artery was improved during these stimuli.

The changes in the value of APG amplitude are shown in Table 3. The value of APG amplitude significantly increased with strong stimuli of 1 and 3Hz at the 5th and 10th minutes, and with soft stimuli of 5Hz at the 10th minutes. The significant increase of the APG amplitude was followed by the significant rising of the finger skin temperature.

Test 4: Changes in finger blood flow

Judging from the skin temperature, the value of APG b/a and APG amplitude, 3Hz strong stimuli appeared to be most effective for modulation of the blood circulation in these examinations. In this test, therefore, changes in finger vein width during the stimulation with 3Hz strong were examined as a parameter indicating blood flow, and were compared with sham control group. As shown in Table 4, finger vein width significantly increased at 10th, 14th, 15th, 16th, 17th, 18th, 19th and 20th minutes of the stimuli with 3Hz strong.

Discussion

In the present study, effects of the electrical stimulation applied to the paraspinal tissues on the peripheral blood circulation being remote from the stimulated site were examined in human, by measuring changes of some physiological indexes non-invasively. Electrical stimuli used in the present study did not induce any pain or discomfort. With 1Hz strong, 3Hz strong and 5Hz soft electrical stimuli applied to 7th cervical vertebral level, the finger skin temperature, the value of APG b/a, APG amplitude significantly rose, and with 3 Hz strong stimuli, finger vein width were significantly increased. The thermograph imaging clearly showed that during the electric stimuli applied to 7th cervical vertebral level,

the skin temperature in the finger, palm and ulnar forearm rose. During the stimuli at 3rd thoracic vertebral level, the skin temperature rose in the upper chest, but not any portion in the upper limb. These findings suggest that suitable electrical stimuli without any pain or discomfort could locally improve peripheral blood circulation being remote from the stimulated site, probably through some polysynaptic reflex arches.

During the early phase of stimuli (by 10 minutes), the value of APG b/a and APG amplitude in finger first increased, and thereafter the finger skin temperature rose. Since the

Table 4. Changes in finger vein width in Test 4

frequency degree	3Hz strong	sham zero
1min	103.6±2.78	102.4±5.23
2min	104.9±3.19	101.7±6.09
3min	105.9±3.80	101.1±6.57
4min	107.4±4.23	101.7±7.18
5min	107.9±4.93	101.1±6.44
6min	106.4±4.68	100.4±7.87
7min	109.4±5.51	100.2±7.55
8min	107.7±4.73	98.4±8.94
9min	109.1±4.71	101.6±7.44
10min	110.6±6.24*	99.2±6.20
11min	109.5±6.73	99.3±6.92
12min	108.9±3.53	100.4±7.32
13min	108.9±4.81	100.1±7.92
14min	111.4±7.10*	100.6±7.04
15min	112.0±6.50*	100.9±7.81
16min	113.2±6.57*	101.0±5.28
17min	112.0±6.42*	98.7±8.34
18min	111.1±7.35*	101.5±7.97
19min	115.4±10.89*	98.8±9.31
20min	115.7±8.56*	102.9±8.58

Changes in finger vein width during electrical stimuli with 3 Hz strong or zero on normalized value. *: p<0.05.

value of APG b/a and of APG amplitude in finger reflect compliance of arteries and the magnitude of acceleration plethysmogram in finger, respectively, the increase of the value of APG b/a and APG amplitude in finger can be regarded as the increase of elasticity of arteries and arterial blood flow in finger. In addition, the increase of finger vein width can also be regarded as a maker representing the increase of the finger venous return volume. The findings of the present study suggest that the rising of the finger skin temperature might be resulted from the increase of the elasticity of the artery and finger blood flow, and also that the increase of the elasticity of finger arteries might be very important for the improvement of the finger blood circulation.

It was reported that some of the postganglionic sympathetic nerve fibers innervating the blood vessel wall (vasomotor nerves) exhibited a dominant rhythm, named as T-rhythm¹⁵⁾. Several authors speculated that the T-rhythm might be generated in the central nervous system¹⁶⁾, and modulated in elsewhere including the sympathetic ganglia¹⁷⁻¹⁹⁾. Another several authors suggested that the discharge of sympathetic neurons gradually became to synchronize with the entraining forces, such as activities of the phrenic nerve or given somatic inputs^{10, 16, 20)}. In addition, even when the somatic inputs rhythm was higher than the T-rhythm of the vasomotor nerve, if the somatic input rhythm was 1:2 or 1:3 to the T-rhythm, the constriction of the blood vessels could synchronize with the stimuli²⁰⁾. Therefore, it is important that the somatic inputs rhythm has constant stable relations with the sympathetic rhythm. In the present study, the value of the APG b/a and APG amplitude in finger increased during some appropriate electric stimuli, suggesting that the constriction and dilatation of the finger arteries might be modulated through some somato-sympathetic

reflex. That is to say, these findings present possibility that improvement of local blood circulation would be induced by the stimuli synchronizing with T- rhythm.

With the soft stimuli of 5Hz, the skin temperature and the value of APG amplitude in finger significantly rose, while the significant changes were not noted with the strong stimuli of 5Hz. These findings suggest that even if the stimuli synchronized with their sympathetic rhythm, the stimuli intensity might be also very important for the improvement of the local blood flow, even if any pain or discomfort were not induced.

It is widely accepted that the improvement of the local blood circulation reduces the secondary disorder, such as edema, tissue atrophy and chronic pain following injury, and promotes the repair and regeneration of injured tissues. Thus, the improvement of the blood circulation might be very useful as one of the measures for many clinical cases in physical therapy. In the present study, some appropriate electrical stimuli applied to the paraspinal tissues improved the peripheral blood circulation in the different regions being remote from the stimulated site, without any pain or discomfort. In addition, these electrical stimuli did not directly affect the general circulatory functions, such as blood pressure or pulse rate. Therefore, the electrical stimuli described in the present study might be very useful, especially at the early stages of the clinical cases in which the direct approaches to injury sites are difficult due to a pain with inflammation or insertion of cast brace. In addition, it is expected that these methods would be applied in clinical rehabilitation for acute stage of cerebrovascular accident as well as an injury disorder. Further experiments are necessary to determine the most effective frequency and intensity for clinical application.

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