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Postcontraction hyperemia after electrical stimulation: potential utility in rehabilitation of patients with upper extremity paralysis

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ABSTRACT

The purpose of this study was to compare postcontraction hyperemia after electrical stimulation between patients with upper extremity paralysis caused by upper motor neuron diseases and healthy controls. Thirteen healthy controls and eleven patients with upper extremity paralysis were enrolled. The blood flow in the basilic vein was measured by ultrasound before the electrical stimulation of the biceps brachii muscle and 30 s after the stimulation. The stimulation was performed at 10 mA and at a frequency of 70 Hz for 20 s. The mean blood flow in the healthy control group and in upper extremity paralysis group before the electrical stimulation was 60 ± 20 mL/min (mean ± SD) and 48 ± 25 mL/min, respectively. After the stimulation, blood flow in both groups increased to 117 ± 23 mL/min and 81 ± 41 mL/min, respectively. We show that it is possible to measure postcontraction hyperemia using an ultrasound system. In addition, blood flow in both groups increased after the electrical stimulation because of postcontraction hyperemia. These findings suggest that evaluating post contraction hyperemia in patients with upper extremity paralysis can assess rehabilitation effects.

Local and acute increases in blood flow, which occur just after the contraction of skeletal muscles, is related to the elevation of intramuscular pressure, and then block blood flow to the muscles. The postcontraction hyperemia, which continues for a relatively long time after each contraction, proportionally increases along with the strength and length of the contraction. This is believed to be caused by metabolic products that are generated during muscle contraction (2). Until recently, the study of postcontraction hyperemia has only been conducted in animals. Techniques for measuring blood flow in humans have been quite invasive, for example, the thermocouple inspection method, which requires a needle to be inserted into the muscle. Nowadays, the noninvasive Doppler ultrasound system is being used to evaluate blood flow. Thus, we used this system to evaluate postcontraction hyperemia in humans. It is reported that blood flow of the paretic limb is significantly reduced compared with the unaffected limb (10). Therefore, we hypothesized that this phenomenon will also decrease in upper limb paralysis patients compared with the healthy controls or the unaffected limb.

Patients with upper extremity paralysis caused by upper motor neuron diseases who were admitted to the department of rehabilitation medicine, Akita University Hospital for rehabilitation from December 2013 to May 2014 and healthy controls were included in the study. A full explanation was given to the patients before taking part in this study, and informed consent was obtained. The present trials excluded patients with cardiac pacemakers; uncontrolled

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Fig. 1 A demonstration of a blood flow measurement using the Doppler ultrasound system.

seizure disorders; preexistent functional limitations of the upper limbs; serious contractures of the shoulder, elbow, or wrist; severe dementia; severe skin problems of the arm; metal implants in the upper limb; no reaction to the test stimulus; or intensive electrical stimulation treatment before this trial.

An electro-stimulation device (DM-2500; Minato Medical Science Co. Ltd., Japan) was used to provide the stimulation. The blood flow in the basilic vein in both the upper extremity paralysis group and healthy control group was measured at rest in a supine position using a Doppler ultrasound system (SSA-680A; TOSHIBA Medical Systems Corp., Japan). To measure the amount of blood flow (mL/min), the area of the vessel (cm^2) and the speed of the blood flow (m/s) were measured. Then, a surface electrode was placed on the biceps brachii muscle (Fig. 1). The strength of the electrical stimulation was 10 mA, the frequency was 70 Hz, and the stimulation was performed for 20 s. The blood flow was measured again 30 s after the electrical stimulation. A paired *t*-test was performed to test whether there was a significant difference in the blood flow before and after the electrical stimulation. For patients in the upper extremity paralysis group who had previously experienced a stroke, we also compared postcontraction hyperemia between the affected upper extremity and the affected arm. In addition, we evaluated postcontraction hyperemia by changing the strength of the stimulus (10 mA, 15 mA, and 20 mA) in healthy controls. Differences in these parameters between the healthy control group and upper extremity paralysis group were compared. Data were analyzed using SPSS version 9.67 for Windows (Department of Environmental Health Sciences, Akita University Graduate School of Medicine, Japan). Significance thresholds were set at $P < 0.05$.

Table 1 *Causes of the upper limb paralysis among the patients*

	n
Stroke	3
Cervical spine disc herniation	3
Cervical myelopathy	2
Central cord syndrome	1
Ossification of the posterior longitudinal ligament	1
Epidural abscess of the cervical spine	1

In total, 13 healthy controls and 11 patients with upper extremity paralysis were enrolled. Three had experienced stroke, three had cervical spine disc herniation, two had cervical myelopathy (after operation), one had central cord syndrome, one had ossification of the posterior longitudinal ligament, and one had an epidural abscess of the cervical spine (Table 1). The mean blood flow before the stimulation in healthy controls was 60 ± 20 mL/min, and in patients with upper extremity paralysis, it was 48 ± 25 mL/min. After the stimulation at 10 mA, the blood flow in both healthy controls and patients with upper extremity paralysis increased to 117 ± 23 mL/min and 81 ± 41 mL/min, respectively ($P < 0.05$; Fig. 2). The mean blood flow before the electrical stimulation in patients with stroke was 53 ± 21 mL/min for the unaffected arm and 37 ± 17 mL/min for the affected arm, and after the stimulation, the mean blood flow was 83 ± 9 mL/min and 60 ± 16 mL/min, respectively (Fig. 3). The mean blood flow in the unaffected arm was significantly higher than the paralyzed arm both before and after the electrical stimulation. The mean blood flow in healthy controls after the stimulation at 15 mA was 116 ± 25 mL/min and after the stimulation at 20 mA was 120 ± 19 mL/min. There was no significant difference in postcontraction hyperemia when the strength of the electrical stimulation was modulated.

There are many ways to measure the blood flow. Plethysmography, a technique used to measure changes in volume, is one of the earliest methods developed to measure the blood flow in humans.

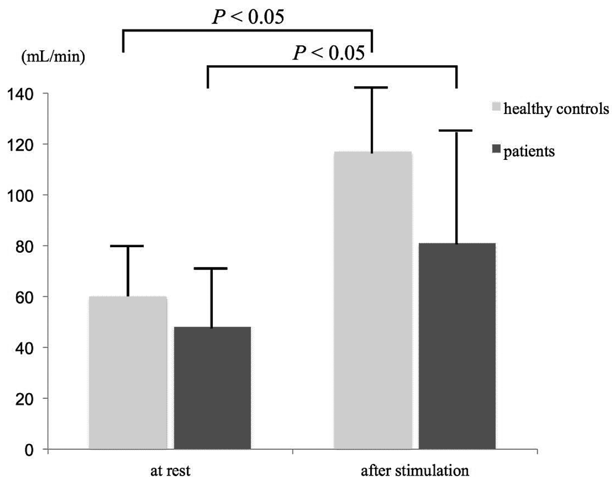

Fig. 2 Blood flow in healthy controls and patients with upper extremity paralysis at rest and after stimulation.

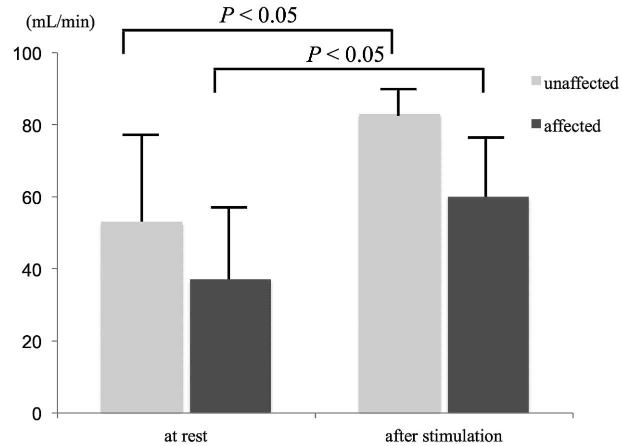

Fig. 3 Blood flow in the unaffected side and the affected side in patients with stroke.

This method is non-invasive and inexpensive, but can only be used under resting conditions (8). The heated-thermocouple technique is another method, but it requires the insertion of a needle-type probe into the muscle, making it quite an invasive technique (2). Recently, the utility of Doppler ultrasound systems, which are noninvasive, has been evaluated for measuring blood flow.

There have been few reports about blood flow after contraction or exercise in humans as measured by the Doppler ultrasound system. Hoelting *at al*. (7) measured the blood flow in the femoral artery using this method before and after a knee extension exercise. Griffin *et al*. (6) assessed the efficacy of electrical stimulation to the calf muscle and demonstrated the utility of ultrasound systems in measuring venous blood flow and finding deep vein thrombosis. Billinger *et al*. (3) reported that single-limb exercise of the affected side in patients with post-stroke improved the blood flow in the femoral artery in the affected extremity. Finally, Parker *et al*. (12) evaluated the sex difference in the vasodilatory response after a knee extension exercise and concluded that it was greater in young women compared with men. However, there had been no reported studies comparing postcontraction hyperemia between healthy control subjects and patients with upper extremity paralysis caused by upper motor neuron diseases.

Fundamental research on postcontraction hyperemia was performed by Abe *et al*. (1) who showed that postcontraction hyperemia is maximized when the frequency of the electrical stimulation is more than 67 Hz and measured 30 s after the stimulation; our research is based on this study. Igarashi *et al*. also reported that postcontraction hyperemia of the quadriceps femoris muscle decreased after cutting the femoral nerve of rabbits (9). Nishi *et al*. dosed phentolamine (α-adrenergic blocker) to rabbits and reported that postcontraction hyperemia significantly increased because it suppressed vessel vasoconstriction (11). These reports indicate that there is some connection between the autonomic nervous system and postcontraction hyperemia. The dysfunction of the autonomic nervous system occurs in patients with stroke (4). In our study, we compared postcontraction hyperemia between healthy controls and patients with stroke and observed that the blood flow increased significantly in healthy controls. Thus, our study supports the idea that there is a relationship between postcontraction hyperemia and the autonomic nervous system. Recently, the assessment of stroke patients was done mainly by physical performance such as the Fugl-Meyer Assessment (5, 13). Our results suggest that evaluation of postcontraction hyperemia will help assess the physiological function of stroke patients.

Previous studies about postcontraction hyperemia have been reported only in animals. To our knowledge, this is the first report studying postcontraction hyperemia in humans using a non-invasive ultrasound approach. However, our study is limited by its small sample size, and further studies should be performed on large number of patients, particularly, with stroke. Furthermore, inter-examiner reliability was not assessed in the present study.

In conclusion, we show that it is possible to evaluate postcontraction hyperemia in humans using a Doppler ultrasound system. Furthermore, we find that the blood flow in both healthy control group and upper extremity paralysis group caused by upper motor neuron diseases increased because of postcontraction hyperemia. The findings of this study may be useful for evaluating the effects of rehabilitation in patients with upper extremity paralysis.

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