Relation between muscle fiber conduction velocity and exerted dynamic characteristics of muscular tension in patients with hemiplegia caused by stroke

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Abstract. [Purpose] The aim of this study was to clarify the relationships among muscle fiber conduction velocity, time-force characteristics of muscle force production, and voluntary movement in patients with hemiplegia. [Subjects and Methods] The participants in the present study were 13 patients with hemiplegia. Muscle fiber conduction velocity, deep temperature of muscles and muscle thickness were measured for the tibialis anterior, and a time force curve was obtained from dorsiflexion of the ankle and lower thigh girth (maximum, minimum) for both sides. The maximum torque rate of change and maximum torque were calculated from the force-time curve. In addition, Brunnstrom Recovery Stage was used to evaluate the function of the hemiplegic side. [Results] In all the measurement items, significant differences were observed between the hemiplegic side and the healthy side. The maximum torque rate of change and Brunnstrom Recovery Stage showed a high degree of correlation. The muscle fiber conduction velocity and maximum torque rate of change or maximum torque showed a medium degree of correlation. However, muscle fiber conduction velocity was not significantly correlated with Brunnstrom Recovery Stage. [Conclusion] Brunnstrom Recovery Stage was good as a determination factor for the maximum torque rate of change. In addition, in patients with hemiplegia, it became clear that relationship is between muscle fiber conduction velocity and time-force characteristics of muscle force production as in healthy persons.

Key words: Hemiplegia, Muscle fiber conduction velocity, Dynamic characteristics of muscular tension

INTRODUCTION

Human motion control is known to be associated with various physical uncertainties. One factor is the muscle fiber conduction velocity (MFCV), which is affected by the type of muscle fiber, environment, and measurement methods1–8). Consequently, it is difficult to specify the reference value for MFCV, but it is reportedly about 3–5 m s⁻¹ at room temperature for healthy adults7, 8). Earlier studies have examined various factors, relations of conduction velocity to healthy adults, clinical conditions including muscular disease, and muscular atrophy. Additionally, particularly addressing motion control or contraction characteristics, the maximum torque rate of change of the time curve representing the response time by MFCV’s changes have been examined, as have dynamic characteristics (muscular dynamic characteristics) of exerted muscular ten-
sion. Based on such studies and the results of evoked electromyogram electromyogram examinations, positive correlation between voluntary muscle contraction and single contraction has been reported. This correlation suggests that response times in the force–time curve or force-peak time are extended as a result of a delayed muscle contraction time attributable to decreased MFCV and reduced motion accuracy or speed caused by the decreased maximum torque rate of change. However, if MFCV increases, then muscle motion characteristics might improve, thereby improving the motion performance.

We know empirically that motion control systems are degraded in patients with hemiplegia caused by stroke. Additionally, studies have shown that the motion control system is associated with different factors such as decreased muscle strength and reduced balance ability. Additional related studies are now being conducted as well. However, most studies measure such things as walking speed. The basic factors remain unknown. MFCV studies in patients with hemiplegia caused by stroke report that reduced muscle cross-sectional areas degrade the motion control system. MFCV has been identified as the index that enables evaluation of the muscle atrophy state. However, MFCV and muscle cross-sectional area are not the only factors that are decreased; voluntariness and muscular tension are also decreased. The correlations among these factors have not been reported in the relevant literature.

This study, specifying the MFCV and dynamic characteristics of exerted muscular tension in patients with hemiplegia caused by stroke, suggests one factor of reduced motion control systems in patients with hemiplegia caused by stroke, which might be contributory to understanding clinical conditions and expanding the scope of treatment intervention.

For the reasons and motivations stated above, we sought to specify the relationships among MFCV and dynamic characteristics of exerted muscular tension in patients with hemiplegia caused by stroke.

**SUBJECTS AND METHODS**

The subjects were 13 patients with hemiplegia caused by stroke (8 male, 5 female, aged 65.5 ± 10.8 years old, 21.0 ± 14.9 days since onset), with 10 having left hemiplegia and 3 having right hemiplegia. In addition, their Brunstrom Recovery Stages were between III and V.

The exclusion criteria were patients with a subtentorial lesion caused by stroke and higher brain dysfunction, which is an obstacle to performing measurements. The subjects did not include any patient with diagnosis of orthopedic disease.

The legs on both the hemiplegic and non-hemiplegic sides were targeted in this investigation. The measurement items were the MFCV of the tibialis anterior muscle and force-time curve of ankle dorsiflexion (isometric contraction). Additionally, lower leg maximum circumference, deep temperature of the tibialis anterior muscle, and muscle thickness were measured as basic physical information of the subjects.

The index of muscle temperature was the deep temperature of the right tibialis anterior muscle. Measurements were performed in a room with the room temperature set at 23–26 °C.

Deep temperature was measured using a deep temperature monitor (Coretemp CM-210, Terumo Corp., Tokyo, Japan) and a deep temperature probe (PD-1, Terumo Corp., Tokyo, Japan). The measurement principles were the zero-heat-flow method and thermistor method. The measurement range was 0–50 °C, and the measurement depth was 10 mm. The temperature precision of the deep temperature probe was ±0.1 °C at 30–40 °C, ±0.2 °C at 0–30 °C, and ±0.2 °C at 40–50 °C.

To measure deep temperature, the location of the tibialis anterior muscle was confirmed using ultrasonography (LOGIQ a100, WIPRO GE, Bangalore, India). Then the probes were set on the measurement sites. The measurement value obtained was the stabilized temperature after 20 min of bed rest. The measurement location was the proximal one-third of the lower thigh.

MFCV measurement values were recorded using noninvasive methods by surface electrical stimulation.

The surface electrical stimulation sites in tibialis anterior muscle were the most distal sites where twitching resulted from electrical stimulation. Furthermore, for electrical stimulation, a square wave with a duration of 0.2 ms was used. The stimulation frequency was 1 Hz, the stimulation intensity was the intensity (10–50 mA) that produced a waveform with a positive peak showing phase shifting at regular latency intervals in 2–4 channels.

The recording electrodes used were array electrodes, i.e., eight silver chloride electrodes (1 mm in diameter, 10 mm long) arrayed in parallel and at regular intervals of 10 mm on a transparent sheet of silicon (TOG 206–152, Unique Medical Co., Ltd., Tokyo, Japan). The positions for application of the array electrodes were 2 cm proximal from the stimulated site and along the right tibialis anterior muscle.

The MFCV was recorded using evoked potential electromyography (Neuropack Σ, Nihon Kohden Corp., Tokyo, Japan). The waveform produced by conducting continuous surface electronic stimulation at a frequency of 1 Hz to the target sites was recorded simultaneously via seven channels with bipolar leads of array electrodes that lay mutually adjacent. Furthermore, the recorded waveform was averaged 10 times through 10–5,000 Hz filter. Thereafter, selecting the channel shoeing clear positive peaks in the waveform, the distance between channels was divided by the difference between peaks to obtain the MFCV. Two trials were conducted.

The subjects were fixed to the ankle dorsiflexion muscle measurement device at 90 degrees of knee flexion and 0 degrees of ankle joint plantar flexion. In addition, the dorsiflexion muscle strength was converted into an electrical signal by a load cell and amplified with the dynamic strain measurement device (LUR-A-SA1, Kyowa Electronic Instruments Co. Ltd., Tokyo, Japan). For the measurement setup, as a skin treatment for the measurement site, the hair over the right tibialis
anterior muscle was shaved; layers of dead skin were removed using a skin preparation treatment agent for a biological signal monitor (Skinpure, Nihon Kohden Corp., Tokyo, Japan). Sebum was reduced by wiping around the measurement area with alcohol-soaked cotton. Subjects were asked to dorsiflex as rapidly as possible and with maximum muscle strength immediately after an auditory cue. The exercise was conducted twice. The signal was A/D converted at 1,000 Hz with a 16-bit AD converter (PowerLab, ADInstruments Pty Ltd., Castle Hill, NSW, Australia) and was recorded on a personal computer. After the obtained force–time curve data were processed through a high-pass filter of 6 Hz, the maximum torque rate of change and maximum torque were calculated.

For comparison of individual measurement items on the hemiplegic and non-hemiplegic sides (deep temperature, MFCV, maximum torque rate of change, and maximum torque), the paired t-test was used. Additionally, to assess correlation between deep temperature and other measurement items (MFCV, maximum torque rate of change, and maximum torque), partial correlation analysis (with deep temperature as the control variable) was used; for correlation between Brunnstrom Recovery Stage and other measurement items (MFCV, maximum torque rate of change, and maximum torque), Spearman’s rank correlation coefficient was used. The level of statistical significance was set at 5%. For statistical processing, all analyses were conducted using software (R 2.8.1).

After approval by the institutional review board of each principal researcher’s institute, we conducted this interventional research in accordance with the ethical research principles of the Declaration of Helsinki.

RESULTS

The results showed that the MFCV was $1.71 \pm 0.66$ m•s$^{-1}$ on the hemiplegic side and $2.88 \pm 0.85$ m•s$^{-1}$ on the non-hemiplegic side. The maximum torque rates of change were $298.0 \pm 229.0$ Nm•s$^{-1}$ on the hemiplegic side and $658.2 \pm 362.6$ Nm•s$^{-1}$ on the non-hemiplegic side. The deep temperature was $33.6 \pm 0.93$ °C on the hemiplegic side and $34.9 \pm 0.74$ °C on the non-hemiplegic side (Table 1).

Significant differences were found between the hemiplegic side and non-hemiplegic side for all the measurement items (MFCV, maximum torque rate of change, maximum torque, and deep temperature) ($p<0.05$).

Moderate positive correlation was found between MFCV and maximum torque rate of change, maximum torque, and deep temperature on the hemiplegic side (maximum torque rate of change, $r=0.65$, $p<0.05$; maximum torque, $r=0.63$, $p<0.05$). In contrast, no significant differences were found between them on the non-hemiplegic side (maximum torque rate of change, $r=0.03$, not significant; maximum torque, $r=0.20$, not significant) (Table 2).

Weak positive correlation was found between MFCV and Brunnstrom Recovery Stage on the hemiplegic side ($r=0.35$, not significant). Strong positive correlation was also found between the Brunnstrom Recovery Stage and the maximum torque rate of change and maximum torque ($r=0.70$, $p<0.05$, and $r=0.83$, $p<0.05$, respectively) (Table 3).

DISCUSSION

Significant differences were found between the hemiplegic side and non-hemiplegic side in each measurement item (deep temperature, MFCV, maximum torque rate of change, and maximum torque). Patients with hemiplegia caused by stroke, who are forced to rest after acute onset, are known to often manifest disuse syndrome on both the hemiplegic and non-hemiplegic

### Table 1. Measurement data of patients with hemiplegia caused by stroke

|                     | Hemiplegic side | Non-hemiplegic side |
|---------------------|-----------------|---------------------|
| MFCV (m•s$^{-1}$)   | $1.71 \pm 0.66$ | $2.88 \pm 0.85$ *   |
| Maximum torque rate of change | $298.0 \pm 229.0$ | $658.2 \pm 362.6$ * |
| Maximum torque (Nm) | $73.1 \pm 53.0$ | $160.3 \pm 79.9$ *   |
| Deep temperature (°C) | $33.6 \pm 0.9$ | $34.9 \pm 0.7$ *   |

Mean ± standard deviation. *$p<0.05$ (hemiplegic side vs. non-hemiplegic side)

### Table 2. Correlation of MFCV within maximum torque rate of change and maximum torque

|                     | Hemiplegic side | Non-hemiplegic side |
|---------------------|-----------------|---------------------|
| Maximum torque rate of change | 0.65 *          | 0.03                |
| Maximum torque (Nm) | 0.63 *          | −0.20               |

Spearman’s rank correlation coefficient. *$p<0.05$

### Table 3. Correlation of the Brunnstrom Recovery Stage within MFCV, maximum torque rate of change and maximum torque

|                     | Hemiplegic side |
|---------------------|-----------------|
| MFCV (m•s$^{-1}$)   | 0.35            |
| Maximum torque rate of change | 0.70 *          |
| Maximum torque (Nm) | 0.83 *          |

Spearman’s rank correlation coefficient. *$p<0.05$
In this research, the significant decrease in each measurement item on the hemiplegic side was attributed to poor circulation and muscle atrophy, which were strongly affected by immobility caused by motor paralysis.

Moderate correlation was the MFCV and maximum torque rate of change on the hemiplegic side; no correlation was found on the non-hemiplegic side. The results for the maximum torque rate of change on the hemiplegic side were the same as those of previous studies with healthy adults (with voluntary contraction, r=0.44, p<0.05; with twitch, r=0.78, p<0.05)8). It was suggested that a decrease of MFCV on the hemiplegic side results from a decrease in transmission velocity between the muscle and joint, caused by a decrease in deep temperature and muscle atrophy. Consequently, this should engender a decrease in maximum torque rate of change and make it difficult to produce contraction within short time. This is regarded as a decrease in the dynamic characteristics of muscles developing motor paralysis in patients with hemiplegia caused by stroke, suggesting that it might be an obstacle to rapid and coordinated motion or movement performance.

Weak correlation (r=0.35, not significant) was found between the Brunnstrom Recovery Stage used for evaluation of the function of the hemiplegic side and MFCV; strong correlation (maximum torque rate of change, r=0.70, p<0.05; maximum torque, r=0.83, p<0.05) was observed between the Brunnstrom Recovery Stage and maximum torque rate of change and maximum torque, which suggests that the Brunnstrom Recovery Stage reflects maximum torque not as a dynamic characteristic but instead as a static characteristic of muscles. The Brunnstrom Recovery Stage is regarded as an index to stage recovery based on evaluation of movement and the level of spasm16). However, it is difficult to evaluate movement and spasm quantitatively, which probably weakens the correlation between MFCV and maximum torque rate of change. Furthermore, the strong correlation between the Brunnstrom Recovery Stage and maximum torque suggests that the Brunnstrom Recovery Stage reflects simultaneously improving muscles.

This study found no correlation between MFCV and maximum torque rate of change on the non-hemiplegic side. Although previous studies showed moderate correlation of MFCV with maximum torque rate of change in healthy adults, their results and predictions differed from ours. It is difficult to infer findings logically, so this remains a challenge to be examined in the future.

Like that in healthy people, a relation was found between MFCV and dynamic characteristics of exerted muscle tension in patients with hemiplegia caused by stroke. Additionally, the Brunnstrom Recovery stage was found to be a factor determining both dynamic and static characteristics of exerted muscle tension strength. The results from this research suggest that the relation between MFCV and dynamic characteristics might be strong not only in healthy people but also in patients with hemiplegia caused by stroke and that MFCV might not only serve as a means for diagnostic evaluation in healthy people but also as an index to evaluate the motion function in patients with hemiplegia caused by stroke.

The results of this study suggest that in addition to the relation between MFCV and dynamic characteristics in muscle, which we have reported in healthy people, tension occurring in muscle fiber might be altered by a change in the condition velocity of action potentials in patients with hemiplegia caused by stroke. In future studies, we intend to use the results of this study as basic data to examine whether the effects of physical therapy (hyperthermia) can improve MFCV and dynamic characteristics of muscle. In doing so, we should elucidate the contribution of the physical therapy to improved performance and the position control system in patients with hemiplegia caused by stroke, which might reduce risks of falling and the need for more applied training.

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