

A New Analysis Method of F-Waves to
Obtain “F-Wave Waveform Values”Toshiaki Suzuki^{1,2*}, Yoshibumi Bunno^{1,2}, Makiko Tani^{1,2}, Chieko Onigata², Yuuki Fukumoto¹, Marina Todo², Hirofumi Watanabe³, Toshihiro Ohnuma^{1,2,3} and Naoko Komatsu³¹Graduate School of Health Sciences, Graduate School of Kansai University of Health Sciences, Japan²Clinical Physical Therapy Laboratory, Faculty of Health Sciences, Kansai University of Health Sciences, Japan³Department of Rehabilitation, Rokujizo General Hospital, Japan

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Keywords F-wave; F-wave waveform values

Abbreviations CVD: Cerebro Vascular Disease; MVC: Maximum Voluntary Contraction

Abstract

From the observation of different F-wave waveforms, we introduce a new method of differentiating these waveforms, by assigning each with an “F-wave waveform value”, which can be used in the clinic to evaluate the effects of rehabilitation. F-wave waveform values were determined by creating a window from minimum onset latency to maximum onset latency in measurable waveforms. We then calculated the correlation coefficient of each waveform, using Microsoft Excel, and identified F-waves as those with a correlation coefficient of greater than 0.9 or equal to 1.0. The number of different F-wave waveforms types was determined from the number of identified waveforms. We applied F-wave waveform values to evaluate neurophysiological change and the effects of rehabilitation following hemiplegia. In the future, F-wave waveform values should be considered as an important tool when assessing the effects of rehabilitation on impaired neurological responses.

Introduction

The F-wave results from the backfiring of the α -motor neuron after antidromic invasion of the propagating impulse across the axon hillock [1]. Its occurrence reflects excitability changes in the spinal motor neurons as reported in patients with spasticity [2] and in healthy subjects during isometric contraction [3].

It is well documented that the H-reflex could be evoked with supramaximal stimulation in patients with Cerebro Vascular Disease (CVD). In our previous study, we investigated the relationship between the characteristic appearance of the H-reflex and F-wave with increasing stimulus intensity and the concomitant changes in other neurological responses [4].

We examined changes in the H-reflex and F-wave of the affected arm, with increasing stimulus intensity, during muscle relaxation in 31 patients, mean age of 56.0 years, with hemiplegia caused by CVD. The H-reflex and F-wave were recorded from the *opponens* pollicis muscle in patients with CVD, following stimulation of the median nerve at the wrist with increasing intensity. The appearance pattern of the H-reflex and F-wave were separated into the following four types.

Type 1: Only the F-wave appeared with increasing stimulus intensity (no H-reflex).

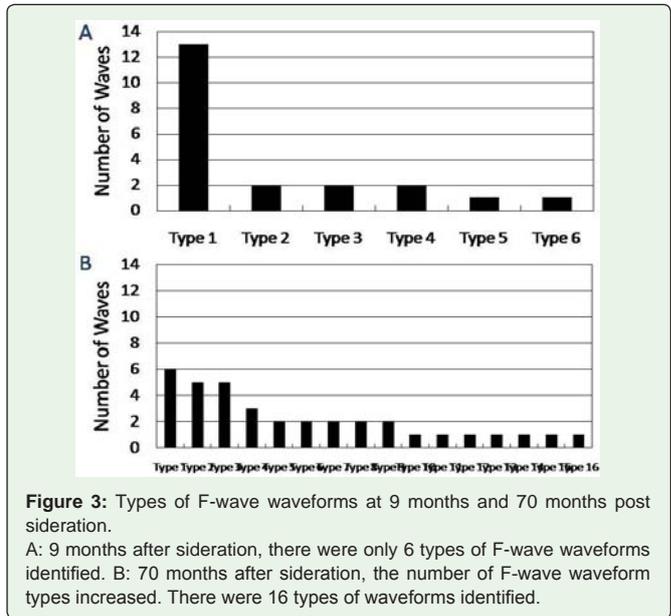
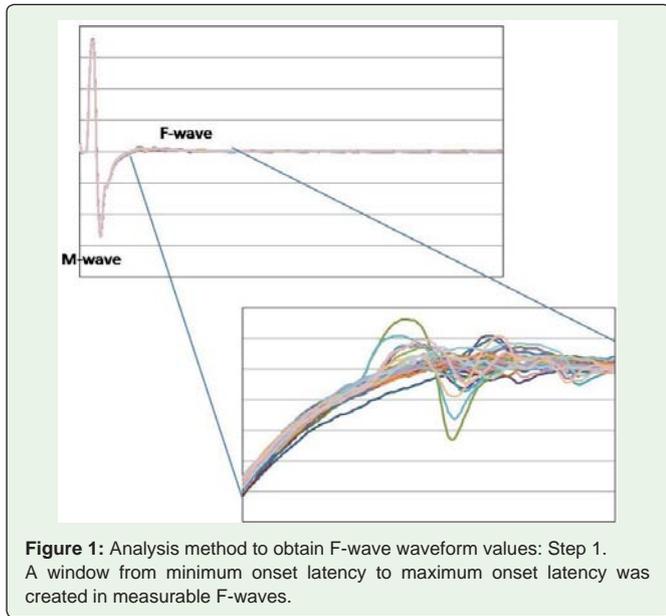
Type 2: Both the H-reflex and F-wave appeared with increasing stimulus intensity; with the F wave appearing as the H-reflex disappeared.

Type 3: Both the H-reflex and F-wave appeared with increasing stimulus intensity, with the F-wave appearing during the H-reflex.

Type 4: Only the H-reflex appeared with increasing stimulus intensity (no F-wave).

Neurological assessment of muscle tone and tendon reflex was also included and classified into increased (markedly, moderately and slightly), normal, or decreased. The appearance pattern of the H-reflex and F-wave, with increasing stimulus intensity, in patients with markedly increased muscle tone and tendon reflex was almost always classified as Type 4.

It has been stated that the current stimulus intensity needed to evoke the F-wave is 20% of the supramaximal stimulation required to evoke the M-wave since only the F-wave, not the H-reflex, appears in healthy subjects. Our previous study reported that only the H-reflex, not the F-wave, appeared in patients with CVD. Therefore, we wanted to understand whether the presence of the H-reflex in the Type 4-appearance pattern was genuine since collision between the H-reflex and antidromic impulse of an α -motor neuron might occur during supramaximal stimulation of the peripheral nerve. In this study, we observed F-wave waveforms and introduced a new analysis method to acquire “F-wave waveform values”, which can be used to monitor the effects of clinical rehabilitation on neurological responses in patients with CVD.



Analysis Method of Waveforms to Obtain F-Wave Waveform Values

F-wave waveform values were determined according to the following steps.

1. A window from minimum onset latency to maximum onset latency was created in measurable waveforms (Figure 1).
2. The correlation coefficient of each waveform was calculated using Microsoft Excel, and F-waves were identified as having a correlation coefficient of either greater than 0.9 or equal to 1.0 (Figure 2).
3. The number of different F-wave waveforms types was determined from the number of identified waveforms.

Clinical use of F-wave waveform values

Increase in F-wave waveform values seen with improved voluntary movement in a patient with cerebro vascular disease: We measured F-waves from affected thenar muscles after stimulating the affected median nerve at the wrist in a left hemiplegia patient (female, 60 years old) with CVD. The patient underwent physical therapy twice a week, with each session lasting 20 minutes. F-waves were measured three times at 9 and 70 months after sideration. We analyzed the F/M amplitude ratio and obtained F-wave waveform values from 30 trials. The F/M amplitude ratio gradually decreased and the number of F-wave waveform types gradually increased. Nine months after sideration, there were only 6 types of F-wave waveforms (Figure 3A), while at 70 months, the number of different waveforms increased to

Wave number

| | w1 | w2 | w3 | w4 | w5 | w6 | w7 | w8 | w9 | w10 | w11 | w12 | w13 | w14 | w15 | w16 | w17 | w18 | w19 | w20 | w21 | w22 | w23 | w24 | w25 | w26 | w27 | w28 | w29 | w30 |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| w1 | 1.00 | 0.98 | 0.95 | 0.96 | 0.99 | 0.99 | 0.98 | 0.79 | 0.96 | 0.99 | 0.99 | 0.98 | 1.00 | 0.98 | 1.00 | 0.95 | 0.99 | 0.99 | 0.99 | 1.00 | 0.97 | 0.97 | 0.99 | 0.99 | 0.95 | 0.99 | 1.00 | 0.97 | 0.93 | 0.99 |
| w2 | 1.00 | 1.00 | 0.93 | 0.97 | 0.96 | 0.97 | 0.98 | 0.76 | 0.97 | 0.97 | 0.97 | 0.99 | 0.97 | 0.97 | 0.97 | 0.93 | 0.98 | 0.97 | 0.98 | 0.97 | 0.98 | 0.93 | 0.98 | 0.97 | 0.92 | 0.96 | 0.95 | 0.99 | 0.94 | 0.95 |
| w3 | 1.00 | 1.00 | 1.00 | 0.89 | 0.93 | 0.94 | 0.91 | 0.90 | 0.88 | 0.93 | 0.95 | 0.91 | 0.96 | 0.97 | 0.95 | 0.97 | 0.91 | 0.95 | 0.93 | 0.96 | 0.90 | 0.94 | 0.91 | 0.93 | 0.99 | 0.95 | 0.96 | 0.98 | 0.92 | 0.96 |
| w4 | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 | 0.98 | 0.97 | 0.70 | 1.00 | 0.96 | 0.98 | 0.97 | 0.96 | 0.95 | 0.96 | 0.90 | 0.97 | 0.98 | 0.96 | 0.97 | 0.98 | 0.78 | 0.99 | 0.97 | 0.92 | 0.94 | 0.96 | 0.98 | 0.93 | 0.96 |
| w5 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.99 | 0.74 | 0.96 | 0.99 | 0.98 | 0.97 | 0.98 | 0.95 | 0.99 | 0.91 | 0.99 | 0.99 | 0.98 | 0.99 | 0.96 | 0.83 | 0.98 | 0.99 | 0.93 | 0.98 | 0.99 | 0.96 | 0.91 | 0.98 |
| w6 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.76 | 0.97 | 0.98 | 1.00 | 0.98 | 0.99 | 0.98 | 0.99 | 0.94 | 0.98 | 1.00 | 0.98 | 0.99 | 0.98 | 0.83 | 0.99 | 0.98 | 0.97 | 0.98 | 0.99 | 0.98 | 0.93 | 0.99 |
| w7 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.73 | 0.97 | 0.99 | 0.98 | 0.99 | 0.97 | 0.96 | 0.99 | 0.91 | 1.00 | 0.98 | 0.99 | 0.97 | 0.98 | 0.81 | 0.98 | 0.99 | 0.93 | 0.98 | 0.97 | 0.97 | 0.92 | 0.96 |
| w8 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.72 | 0.77 | 0.77 | 0.75 | 0.81 | 0.86 | 0.79 | 0.88 | 0.74 | 0.78 | 0.77 | 0.79 | 0.73 | 0.99 | 0.74 | 0.79 | 0.86 | 0.77 | 0.80 | 0.72 | 0.87 | 0.77 | |
| w9 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 | 0.96 | 0.97 | 0.96 | 0.95 | 0.96 | 0.90 | 0.97 | 0.97 | 0.96 | 0.96 | 0.98 | 0.79 | 0.99 | 0.97 | 0.92 | 0.93 | 0.95 | 0.97 | 0.95 | 0.95 | | |
| w10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.99 | 0.96 | 1.00 | 0.93 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.97 | 0.95 | 0.98 | 1.00 | 0.94 | 0.98 | 0.99 | 0.96 | 0.99 | 0.94 | 0.95 | |
| w11 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.98 | 0.98 | 0.99 | 0.95 | 0.98 | 1.00 | 0.98 | 0.99 | 0.98 | 0.98 | 0.99 | 0.98 | 0.95 | 0.98 | 0.98 | 0.99 | 0.98 | 0.99 | 0.98 | 0.94 | 0.99 | |
| w12 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.97 | 0.97 | 0.98 | 0.94 | 0.98 | 0.98 | 0.99 | 0.97 | 1.00 | 0.83 | 0.99 | 0.98 | 0.93 | 0.97 | 0.97 | 0.97 | 0.98 | 0.94 | 0.97 | 0.98 | 0.94 | 0.97 | |
| w13 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.99 | 0.96 | 0.98 | 0.99 | 0.98 | 1.00 | 0.97 | 0.89 | 0.98 | 0.99 | 0.97 | 0.98 | 1.00 | 0.97 | 0.98 | 1.00 | 0.97 | 0.94 | 0.99 | 0.94 | 0.99 | |
| w14 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.97 | 0.97 | 0.98 | 0.94 | 0.98 | 0.98 | 0.97 | 0.98 | 0.96 | 0.91 | 0.97 | 0.97 | 0.98 | 0.97 | 0.98 | 0.97 | 0.98 | 0.96 | 0.96 | 0.98 | 0.96 | 0.98 | |
| w15 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.94 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.97 | 0.97 | 0.98 | 1.00 | 0.95 | 0.98 | 0.99 | 0.97 | 0.98 | 0.99 | 0.97 | 0.94 | 0.98 | 0.98 | 0.98 | |
| w16 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.91 | 0.95 | 0.94 | 0.95 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.94 | 0.95 | 0.93 | 0.94 | 0.95 | |
| w17 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | |
| w18 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 |
| w19 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| w20 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| w21 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.87 | 0.99 | 0.98 | 0.97 | 0.98 | 1.00 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| w22 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.82 | 0.86 | 0.91 | 0.84 | 0.88 | 0.80 | 0.90 | 0.85 | 0.92 | 0.93 | 0.96 | 0.97 | 0.93 | 0.96 | 0.97 | 0.93 | 0.96 | 0.97 | 0.93 | 0.94 | 0.97 | 0.93 | 0.94 |
| w23 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.94 | 0.97 | 0.98 | 0.99 | 0.93 | 0.98 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 | 0.93 | 0.92 |
| w24 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.94 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 |
| w25 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| w26 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 | 0.96 |
| w27 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 | 0.97 |
| w28 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 |
| w29 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 |
| w30 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 |

Figure 2: Analysis method to obtain F-wave waveform values: Step 2. We calculated the correlation coefficient of each waveforms using Microsoft Excel, and F-waves were identified as having a correlation coefficient or greater than 0.9 or equal to 1.0. The pink column is the calculated correlation coefficient from identical waveforms, which equals 1.0.

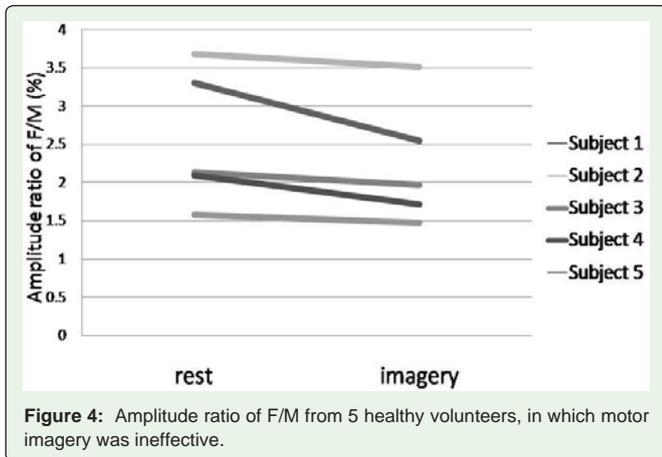


Figure 4: Amplitude ratio of F/M from 5 healthy volunteers, in which motor imagery was ineffective.

16 types (Figure 3B). Muscle tone and voluntary movement of the affected arm also gradually improved with physical therapy.

The effect of motor imagery on F-wave waveform values: In our previous study [5], we used motor imagery to determine whether mental simulation without actual muscle contraction associated with motion can increase the excitability of spinal neurons. We analyzed the F-wave evoked from thenar muscles after stimulating the median nerve in subjects that were not holding the sensor of a pinch meter. In this previous study, 11 healthy volunteers (mean age, 34 years) participated after providing informed consent. We examined the F-wave evoked from the left thenar muscles after stimulating the left median nerve at the wrist at rest and under holding or motor imagery conditions. During motor imagery, the subjects were asked to imagine using 50% of their *Maximum Voluntary Contraction* (MVC) during isometric contraction, while not holding the sensor. The persistence and amplitude of the F/M ratio during motor imagery was greater than that during rest. However, F-wave data, especially amplitude ratio of F/M from 5 healthy volunteers, in which motor imagery was ineffective (Figure 4) was analyzed to produce F-wave waveform values. The number of different waveforms during motor imagery was increased compared to the number of waveforms during rest (Figure 5).

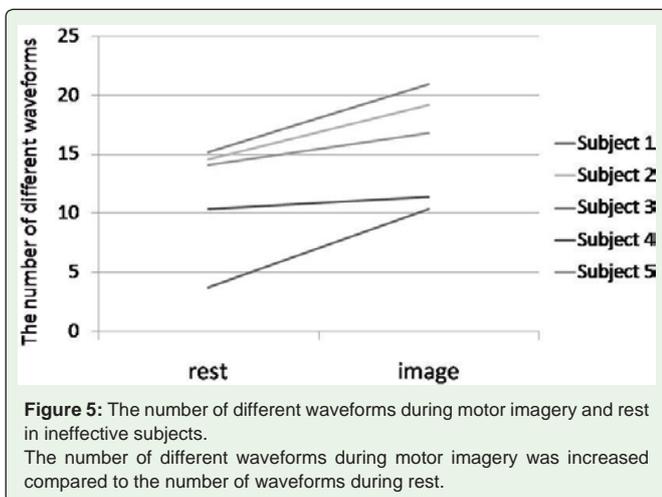


Figure 5: The number of different waveforms during motor imagery and rest in ineffective subjects. The number of different waveforms during motor imagery was increased compared to the number of waveforms during rest.

Discussion

It is generally accepted that the current stimulus intensity used to evoke the F-wave is 20% of the supramaximal stimulation required to evoke the M-wave since only the F-wave, not the H-reflex, appears in healthy subjects. The characteristics of each F-wave waveform are different because a different population of anterior horn cells is activated following each stimulus.

In our previous study [4], we investigated spinal neuron function using the appearance pattern of the H-reflex and F-wave with increasing stimulus intensity in patients with CVD. We analyzed the relationship between the characteristic appearance of the H-reflex and F-wave with increasing stimulus intensity and other neurological responses in patients with CVD. In healthy subjects, F-waves from thenar muscles appeared with increasing stimulus intensity, but there was no H-reflex (Type 1). The appearance pattern of the H-reflex and F-wave with increasing stimulus intensity in patients with almost normal muscle tone and tendon reflex was similar to that in healthy subjects. The appearance pattern of the H-reflex and F-wave with increasing stimulus intensity in patients with moderately or markedly increased muscle tone and tendon reflex could be classified as Type 3 (mixed pattern with the appearance of both the H-reflex and F-wave) or Type 4 (Only the H-reflex). From this result, we can conclude that the F-wave disappeared with supramaximal stimulation in patients with increased spinal neuron excitability.

In the first part of this clinical study, we observed that F-wave waveform values were increased in patients with CVD who showed improved voluntary movement. Almost all of the F-waves measured 9 months after sideration were similar in waveform to the H-reflex, suggesting that the population of anterior horn cells activated to produce the F-waves was also similar. However, 70 months after sideration, the F-wave waveforms changed as voluntary movement improved. This suggests that the number of active anterior horn cells was increasing with improved voluntary movement. When considering both our previous [4] and current clinical study, it is possible to conclude that only the H-reflex with supramaximal stimulation is F-wave to excite typical anterior horn cell.

In the second part of this clinical study, we observed that F-wave waveform values during motor imagery were increased in ineffective cases where the amplitude the F/M ratio during motor imagery did not increase. The amplitude of the F/M ratio is an index of the excitability of spinal neurons, particularly the excitability of anterior horn cells. The number of different waveforms during motor imagery was increased compared to that during rest, suggesting that the number of anterior horn cells activated by supramaximal stimulation increased during motor imagery, but that the excitability of individual anterior horn cells was not changed.

One limitation of this study was that the appropriateness of using the correlation coefficient of each waveform to assign the number of different F-wave types was not determined. In the future, we would like to continue to research the use of the correlation coefficient in determining F-wave waveform values. We propose that this new analysis method of F-waves to obtain “F-wave waveform values” will be an important tool when evaluating progress in clinical neurophysiology and rehabilitation.

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