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REPORT

Excitability of Spinal Motor Neuron Function after the Transcutaneous Electrical Stimulation (TES) in Healthy Subjects —F-wave Study—

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Abstract. To clarify the excitability of spinal motor neuron function after transcutaneous electrical stimulation (TES), we investigated the F-wave before and after TES. Fourteen healthy volunteers with a mean age of 23.4 years were studied. TES was applied to the flexor hallucis brevis (FHB) for 15 minutes. F-wave and M-wave were recorded from the FHB after tibial nerve stimulation at the ankle before TES, just after TES, 10, 20 and 30 minutes after TES. TES evoked full flexion of the great toe. F-wave was analyzed for the amplitude ratio of F/M, latency and duration. The amplitude ratio of F/M was 3.1% before TES, 1.4% just after TES, 1.6% 10 minutes after, 1.9% 20 minutes after and 1.7% 30 minutes after TES. Each amplitude ratio of F/M after TES was significantly lower than that before TES ($p<0.05$). There was no statistically significant difference in the latency and the duration. These results suggest that the excitability of spinal motor neuron function after TES to muscles under this condition was reduced in healthy subjects.

Key words: transcutaneous electrical stimulation (TES), spinal motor neuron function, F-wave

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Spasticity is a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyper-excitability of the stretch reflex, as one component of upper motorneuron syndrome.

Physical treatments for spasticity are designed to reduce the muscle tone, maintain or improve the range of motion and mobility. The transcutaneous electrical stimulation (TES) is a useful method of improving spasticity in cases of cerebrovascular disease[1)2)]. Treating the spasiticity is a common effect of TES, but the neuro-physiological mechanism of this effect has not been obvious. Goulet *et al.*[3)] found that there was a definite tendency towards inhibition of the H-reflex after TES evoked a mild tingling sensation without muscle contraction in healthy subjects. Hardy *et al.*[4)] found that H-reflex amplitudes increased following TES at sensory threshold in healthy subjects, whereas H-reflex amplitudes did not change following TES at 1.5 times motor threshold. In those studies, the level of TES was mild.

F waves are small compound muscle action potentials recorded from muscle fibers of a single or small number of motor units activated by antidromic action potentials ascending in motor axons to the anterior horn cell. Usually only a small proportion of motor units are activated antidromically with supramaximal stimulus[5)]. The amplitude of the F-wave provides a measure of motorneuron excitability[6)7)]. However as F-wave amplitude was variability, the amplitude ratio of F/M was used for the index of a measure of motorneuron excitability[8)]. F-wave latencies measure the conduction in motor axons. F-wave duration can be modified by the number of motor units and the conduction property of the motor axons, which depends on central excitability[8)].

In the present study, we investigated the excitability of spinal motor neuron function by analyzing the F-wave recorded before TES, 10, 20 and 30 minutes after TES with high-intensity that evoked full flexion of the great toe in

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healthy subjects, as a first step in the attempt to clarify neurophysiological mechanisms of the effect of TES.

Material and Methods

Subjects

Fourteen healthy volunteers (11 males and 3 females) between the ages of 19 and 30 years (mean 23.4; SD 2.5) with no known musculoskeletal or neurological dysfunction agree to participate in this study. All subjects gave informed to participation in consent for the study before the experiment.

Conditions for testing the F-wave before and after TES

We recorded the M-wave and F-wave before and after TES. Subjects received TES of the right flexor hallucis brevis (FHB) using bipolar surface electrodes (Fig. 1). The stimulus pulse was a biphasic square-waveform, pulse width of 0.3 msec, frequency 30 Hz, and the current amplitude was the high-intensity necessary to evoke full flexion of the great toe. TES was applied with a duty cycle of 4 seconds on and 4 seconds off for 15 minutes.

M-wave and F-wave were recorded before TES, just after TES, 10, 20 and 30 minutes after TES. The active surface electrode (10 mm diameter) was placed over the motor point of the FHB, with the reference electrode at the base of the proximal phalanx. M-wave and F-wave were recorded from the FHB after stimulation of the right posterior tibial nerve at the ankle in a prone position. The intensity of constant current stimulation was supra-maximum with stimulation a frequency of 0.5 Hz and a duration of 0.2 msec. Stimulation was administered 15 times in each trial.

The F-wave was analyzed for the amplitude ratio of F/M, latency and duration. The sensitivity was set at 5mV/div for the M-wave and 0.2 mV/div for the F-wave. Peak-to-peak amplitudes of F- and M-waves were measured and the amplitude ratio of F/M was expressed as the ratio of F-amplitude and the maximal amplitude of M-wave. Latency was the time from stimulation to onset of F-wave. Duration was the time from the take off to return to the baseline. When we defined the start and end of the response, the evoked potential of more than 0.02 mV was considered a component of F-wave[8)9)]. These were determined as the mean values of the measurable F-wave (Fig. 2).

Data analysis

Means and standard deviations for quantitative components were calculated for this study. Statistical analyses of differences between four groups were performed using one-way analysis of variance (ANOVA), followed by post hoc Tukey's tests. $p<0.05$ was considered statistically significant. All results are shown as mean ± S.D.

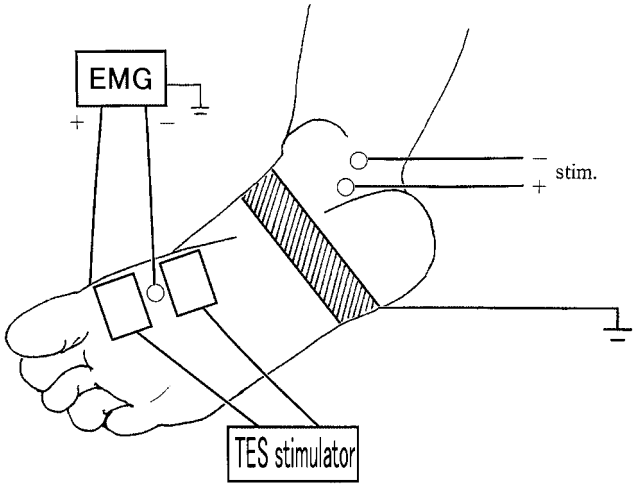

Fig. 1. The setting of TES stimulator and EMG. Subjects received TES of the right flexor hallucis brevis (FHB) using bipolar surface electrodes. We recorded M-wave and F-wave before and after TES.

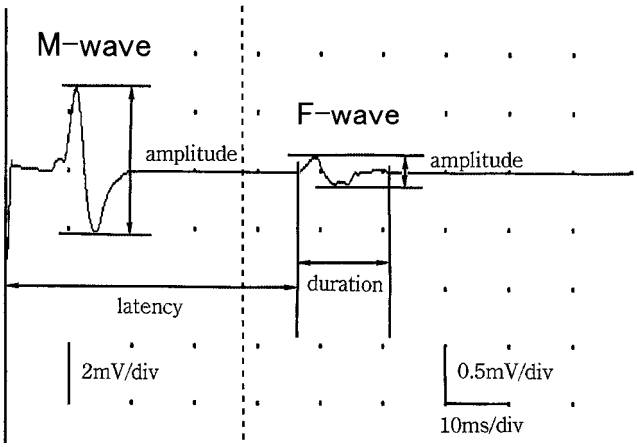

Fig. 2. M-wave and F-wave analysis. Amplitude ratio of F/M, latency and duration. Amplitude ratio of F/M was the ratio of F-amplitudes and maximal amplitude of M-wave. Latency was the time from stimulation to onset of F-wave. Duration was the time from onset to end of F-wave.

Results

The occurrence rate of F-waves was 83.7 ± 17.6 %.

Amplitude ratio of F/M(%)

Amplitude ratio of F/M before TES was 3.1 ± 1.5%. Amplitude ratio just after TES was 1.4 ± 0.6%, 10 minutes after TES was 1.6 ± 0.9%, 20 minutes after TES was 1.9 ± 1.0% and 30 minutes after TES was 1.7 ± 0.6%.

Each amplitude ratio of F/M after TES was significantly lower ($p<0.05$) than that before TES (Table 1).

Latency (msec)

Latency before TES was 46.5 ± 2.9 msec. Latency just after TES was 47.4 ± 2.4 msec, 10 minutes after TES was 47.4 ± 2.7 msec, 20 minutes after TES was 47.5 ± 2.7% and 30 minutes after TES was 47.5 ± 2.4 msec.

There was no significant difference in the latency (Table 1).

Duration (msec)

Duration before TES was 13.5 ± 2.7 msec. Duration just after TES was 13.5 ± 2.5 msec, 10 minutes after TES was 13.5 ± 1.9 msec, 20 minutes after TES was 13.6 ± 1.8 msec and 30 minutes after TES was 13.4 ± 1.5 msec.

There was no significant difference in the duration (Table 1).

Discussion

TES has been reported to reduce clinical spasticity[1)10)11)], as well as to improve motor dysfunctions in patients with spastic hemiparesis[12)]. Although TES may be a promising modality for the treatment of spasticity, the mechanism underling the effects of TES using the evoked EMG remains unclear[3)].

In the present study, we investigated the excitability of spinal motor neuron function using M-wave and F-wave from the FHB after applying TES to the FHB at an intensity that evoked full flexion of the great toe in healthy volunteers. In our results, amplitude ratios of F/M were significantly decreased just after TES, 10, 20 and 30 minutes after TES in normal subjects. These findings indicate decreased motor neuron excitability after applying TES to the muscles with high-intensity at a level that evoked full flexion of the great toe in healthy subjects.

In other studies, Goulet *et al.*[3)] reported that there was a definite tendency towards inhibition of the H-reflex after TES evoked a mild tingling sensation without pain or muscle contraction in healthy subjects. Hardy *et al.*[4)] reported that TES at a sensory threshold increases H-reflex amplitudes in subjects without neuromuscular disease, whereas H-reflex amplitudes did not change following TES at 1.5 times motor threshold. In those studies, the level of TES was at the sensory threshold or 1.5 times motor threshold.

In our study, the method used to administer the TES differed in regard to the stimulation intensity. In our study, the current amplitude was applied at an intensity that evoked full flexion of the great toe. It was suggested that TES with high-intensity decrease the motor neuron excitability in healthy subjects. The result suggested that TES might have an inhibitory effect on both the sensory and motor systems[13)]. It is probable that TES with low-intensity resulted primarily in the depolarization of low-threshold cutaneous afferents[4)]. However, with high-intensity stimulation, high-threshold deep afferents also were likely recruited[4)]. The results of our study suggested that afferents that have different thresholds for electrical stimulation exert differential effects on spinal motor neuron excitability, with high-threshold deep afferents possibly serving in a more inhibitory capacity. Furthermore, the decrease in motor neuron excitability continued for 30 minutes after TES. This phenomenon is called a "carry-over" effect[14)15)] when they are not using the stimulator after TES. The mechanism of a 'carry-over' effect might be explained by reorganization of the central nervous system (CNS)[16)].

Conclusions

To investigate the excitability of spinal motor neuron function before TES, just after TES, 10, 20 and 30 minutes after TES at evoked full flexion of great-toe TES to the right flexor hallucis brevis in healthy subjects, M-wave and

Table 1. F-wave analysis data (latency, duration and amplitude ratio F/M) recorded before TES, just after TES, 10, 20 and 30 minutes after TES (n=14)

	Before TES	After TES			
		0 min	10 min	20 min	30 min
Latency (msec)					
Mean	46.5	47.4	47.4	47.5	47.5
SD	2.9	2.4	2.7	2.7	2.4
Duration (msec)					
Mean	13.5	13.5	13.5	13.6	13.4
SD	2.7	2.5	1.9	1.8	1.5
Amplitude ratio*					
Mean	3.1	1.4	1.6	1.9	1.7
SD	1.5	0.6	0.9	1.0	0.6

*: $p<0.05$ (ANOVA, followed by post hoc Turkey's tests).

F-wave from the muscle after stimulation of the right posterior tibial nerve was analyzed.

The amplitude ratio of F/M after TES was significantly lower than that before TES. There was no significant difference in the latency and the duration. These findings suggest that the excitability of spinal motor neuron function after TES to the muscles under the conditions of this study was reduced in healthy subjects.

In the near future, we will investigate the spinal motorneuron function in the patients with CVD.

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