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F WAVE CHANGE BY DECREASED MOTONEURONAL EXCITABILITY: A SLEEP STUDY

BY

Tadashi ICHIKAWA and Takanori YOKOTA*

ABSTRACT

To clarify the effect of the change in motoneuronal excitability on the F wave, we studied the persistence, mean size, and minimum latency of the F wave in nine normal subjects while awake and asleep. Recordings were made from the abductor pollicis brevis muscle by stimulating the median nerve at the wrist. The persistence and size of the F wave markedly decreased during sleep, especially in stage REM. The mean size in stage REM was less than 5% of that in stage W in most subjects, and the F wave entirely disappeared in one subject. The minimum latency during sleep was longer than during wakefulness. Prolongation was within 2.0 ms when the persistence was more than 10%. A decrease in the number of motoneurons that elicit the F wave may be the major cause of prolongation.

We conclude that the decreased motoneuronal excitability can cause the F wave to disappear without conduction block in the peripheral motor nerve and that the prolongation of the F wave for more than 2 ms provides a marker for proximal conduction delay in the clinical nerve conduction studies.

Key words: F wave, Motoneuronal excitability, Minimum latency, Persistence, Sleep

INTRODUCTION

The F wave is a late response subsequent to the stimulation of the peripheral nerve. It originally was described as a reflex wave recorded from the foot muscle (Magladery [1]). The mechanism that elicit the F wave has been regarded as the recurrent discharge of the motoneurons (Eccles [2]; Fisher [3]; Guiloff and Sadeghi [4]; MacLeod and Wray [15]; Mayer and Feldman [6]). But, strict analysis of the potentials of the motoneurons after the antidromic stimulation suggests that the F wave is elicited by the electrical synaptic potentials of the motoneurons (Arasaki et al. [7]).

Although clinically the F wave is used to evaluate the proximal motor nerve conduction in the peripheral neuropathies (Fisher [3]; Fraser and Olney [8]; Kimura [9]; Shahani et al. [10]), it is known to be affected by the change in the supraspinal condition. The change in the latency of the F wave because of decreased motoneuronal excitability, however, has not been studied. Many experiments on animals have been done during sleep to find the motoneurons suppressed by supraspinal inhibition (Chandler et al. [11]; Chandler et al. [12]; Chase and Morales [13]; Morales and Chase [14]). To clarify what effect the change in motoneuronal excitability has on the F wave in humans, we studied the F wave during sleep.

* 市川　忠，横田隆徳：Department of Neurology (Associate Prof. T. YUASA), Faculty of Medicine, Tokyo Medical and Dental University (Tokyo Ika Shika Daigaku)

Methods

I. Subjects

Nine healthy subjects (five men and four women, mean age 35.4 years) and a 19-year-old patient who had suffered complete cervical cord transection were examined. This patient showed complete loss of sensation for all modality and paralysis below the C4 level. Informed consent for testing was obtained from each subject. The subjects were tested while supine with the arm and hand in a neutral position. The skin temperature of the forearm was monitored with a thermistor (Electrical Thermometer, Top Surgical MFG. Co., Tokyo) equipped with a surface thermic sensor. Testing was done when the skin temperature of the forearm was more than 34.0°C. The temperature in the room was maintained over 25°C with an air conditioner.

II. Polysomnography

To determine the sleep stage, polysomnography comprised recording the electroencephalography (EEG), electrooculography, and chin-electromyography. The EEG was recorded from the unilateral central and parietal leads (scalp-to-ear derivations) with Ag-AgCl surface electrodes. The sleep stage classifications were W, wakefulness; stages 1, 2, and 3&4, non-REM sleep; and stage REM, REM sleep on the basis of Rechtshaffen's criteria (Rechtshaffen and Kales [15]).

III. F-wave measurement

M and F waves were recorded from the abductor pollicis brevis muscle by using an electromyography (Neuropack 4, Nihon Kohden Medical Co., Tokyo) with Ag-AgCl surface electrodes. The electrodes were fixed on the skin with collodion according to the belly-tendon method. The band pass was set at 10 to 3 kHz. Pulse electrical stimulation of 0.2-ms duration was delivered percutaneously on the median nerve at the wrist at an intensity of 20% more than the maximum motor threshold. The stimulating electrodes also were fixed with collodion. The frequency of stimulation was 0.5 Hz and the number of stimuli given was 200 in each stage. The latency of the F wave was measured at the onset of the first deflection of the late response. The F-wave size was measured from the peak to peak amplitude, in waves for which the deflection from the baseline was clear and the amplitude of 40 μV or more. The mean F-wave size was calculated using the formula: Sum of F-wave amplitudes/recording times. The ratio of the mean F-wave size was calculated as the mean F-wave size in each stage divided by the mean F-wave size in stage W. The prolongation of the minimum latency of the F wave was the difference in the values for minimum latency in individual sleep stages and in wakefulness. The analysis of variance with repeated measures was used for the statistical analysis.

IV. Single motor unit potentials of F wave

The stimulation at an intensity of 50% of the maximum motor threshold was also given to find the single motor unit potentials. Single motor unit potentials were accepted only when the configuration and amplitude of the waves were identical. It is difficult to accurately determine the latency because of the shift in the baseline when the low cut filter was set at 10 Hz. To ensure that the baseline was flat at the F-wave onset, the band pass was set at 100 to 3 kHz because the baseline of the EMG was not shifted by the stimulation at this setting.

Results

I. F wave in normal subjects during sleep

The test was done on nine subjects in stage W; eight in stage 1; seven in stage 2; four in stage 3&4; and seven in stage REM. Both the persistence and the size of the F wave were markedly suppressed during sleep. The mean persistence (SD) was 75.3 (12.0)% in stage W; 34.9 (15.9)% in stage 1; 18.0 (11.1)% in stage 2; 14.2 (12.6%) in stage 3&4; and 7.1 (6.4)% in stage REM. The persistences in non-REM sleep and REM sleep were significantlty ($p<0.001$) lower than the persistence in stage W. For the non-REM sleep stages, the persistence decreased significantly ($p<0.01$) with the change from stage 1 to 2. The persistence in the REM stage was less than 20% in each subject, significantly ($p<0.001$) lower than in the non-REM stages. The mean F-wave size during sleep also significantly ($p<0.001$) decreased. The mean ratio (SD) of the mean F-wave size was 0.423 (0.195) in stage 1; 0.157 (0.107) in stage 2; 0.132 (0.111) in stage 3&4; and 0.047 (0.056) in stage REM. The ratios of the mean F-wave size in non-REM and REM sleep were less than 1.0. For the non-REM stages, the ratio of the mean F-wave size decreased significantly ($p<0.01$) when the stage changed from 1 to 2. The ratio of the mean F-wave size in stage REM was less than 0.05 in six of seven subjects in whom the test was done in stage REM and significantly ($P<0.01$) lower than in the non-REM stages. In one subject, the F wave disappeared in stage REM. (Figure 1, 2A, 2B).

The minimum latency of the F wave during sleep was longer than in stage W, but the minimum latency was not significantly different between the individual stages. The relationship of the minimum latency to the persistence showed that the prolongation of latency was as much as 2 ms when the persistence was more than 10%. When the persistence was less than 10%, the prolongation increased. The minimum latency of the F wave was prolonged a maximum of 4.2 ms during sleep. (Figure 3A, 3B)

II. Single motor unit potentials of the F wave

Two single motor unit potentials of the F wave were recorded in stages W and 1 in two subjects. The skin temperature of the forearm during the recording of the F wave was between 34.8 and 35.2°C in stage W and between 35.2 and 35.4°C in stage 1 in one of these subjects. In the other subject, the skin temperature was between 34.4 and 34.6°C in stage W and between 34.5 and 34.8°C in stage 1. The mean latency (SD) of the single motor unit potentials of the F wave was 24.24 (0.05) ms in stage W and 24.4 (0.06) ms in stage 1 in one of these two subjects and 28.41 (0.07) in stage W and 28.60 (0.06) in stage 1 in the other subject. The prolongation of the single motor unit potentials was significant ($P<0.01$). (Figure 4)

III. F wave during sleep in patient with complete transection of cervical cord

There was no suppression of persistence and size of the F wave in the patient with complete transection of the cervical cord during sleep (Figure 5). The persistence and the mean size of the F wave were 34.3% and 49.7 μV in stage W; 47.5% and 54 μV in stage 1: 39% and 43.5μV in stage 2; and 42.5% and 50.0 μV in stage REM.

Discussion

A striking suppression of the F wave during sleep was found. In most subjects it almost disappeared in stage REM. Motoneuronal excitability during sleep

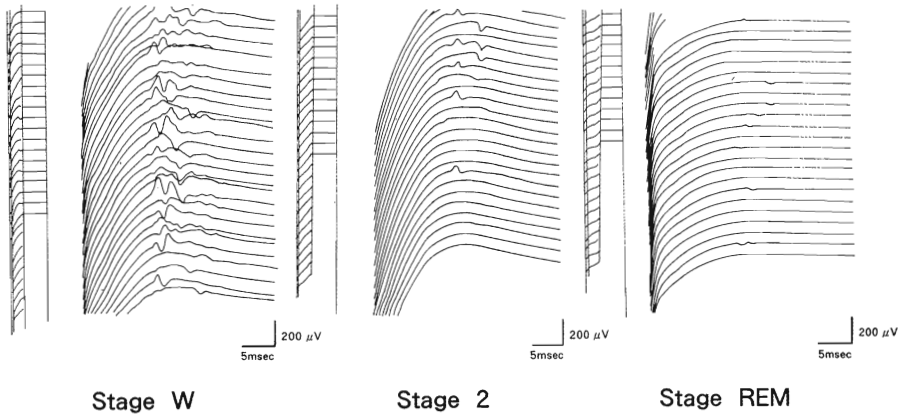

Fig. 1 Waves in Healthy Subject While Awake and Asleep
A 29-year-old subject was tested. In stage 2, the persistence of the F wave is markedly decreased and the mean F-wave size also is reduced during sleep. In stage REM, the F wave has almost disappeared.

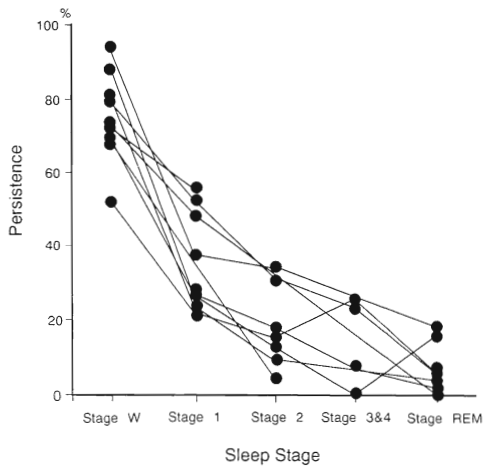

Fig. 2A Persistence of the F Wave in Stages of Sleep and When Awake
The persistence of the F wave decreased during sleep. Persistence was less than 60% in stage 1; less than 40% in stage 2; and less than 20% in stage REM.

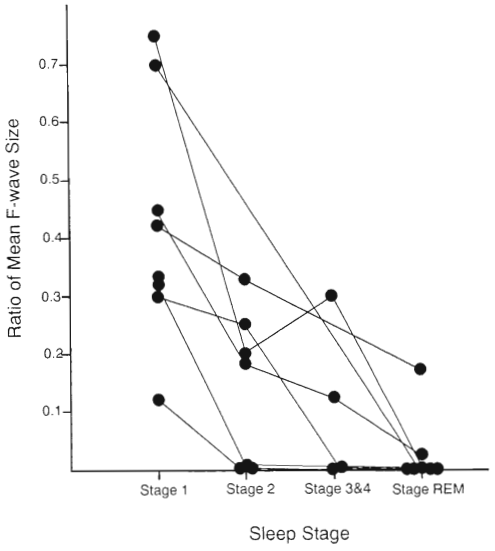

Fig. 2B Mean F-Wave Size in Stages of Sleep
The mean F-wave size decreased during sleep, especially in stage REM, in which stage it was less than 5% in 6 of 7 subjects.

was studied in many animal experiments (Chandler et al. [11]; Chandler et al. [12]; Chase and Morales [13]; Morales and Chase [14]). Intracellular analysis of the hindlimb motoneurons of unanesthetized chronic cat showed that the motoneurons were hyperpolarized during non-REM sleep and that during REM sleep there was marked hyperpolarization of the motoneurons (Glenn and Dement [16]). A similar hyperpolarization of the motoneurons is thought to cause the suppression of the F wave during both non-REM and REM sleep in humans, being especially prominent during REM sleep.

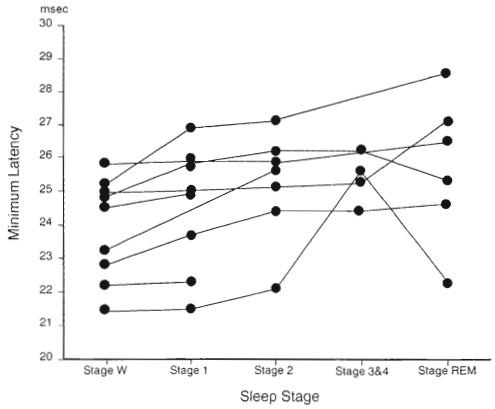

Fig. 3A Minimum F-Wave Latency
The minimum latency of the F wave was prolonged during sleep. Maximum prolongation was 4.2 ms.

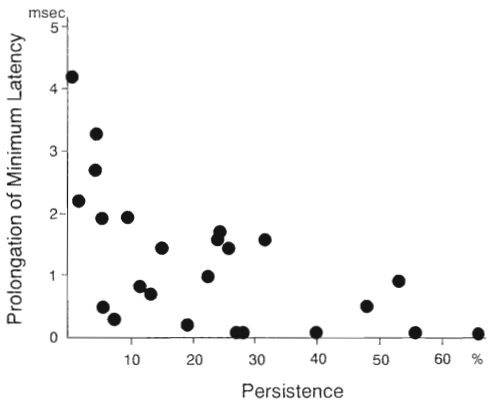

Fig. 3B Prolongation of Minimum Latency and Persistence During Sleep
Prolongation of the minimum latency was 2 ms when the persistence was more than 10%. When the persistence was less than 10%, the prolongation of the minimum latency increased.

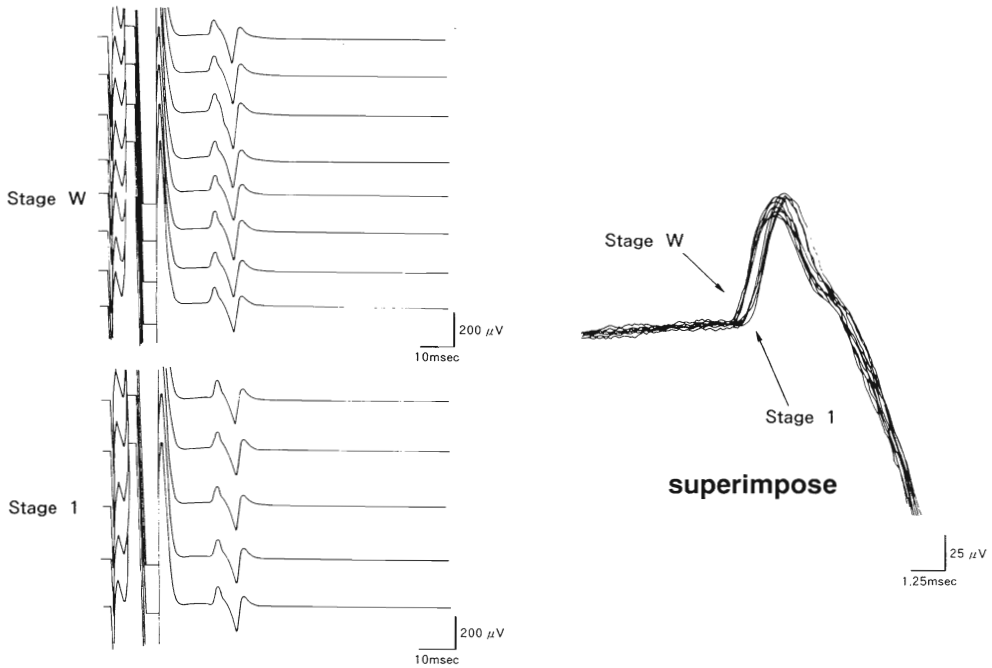

Fig. 4 Single Motor Unit Potentials of F Wave in Stage W and Stage 1
One of the two single motor unit potentials is shown. The mean latency of the single motor unit potentials in stage 1 was prolonged 0.24 ms as compared to stage W.

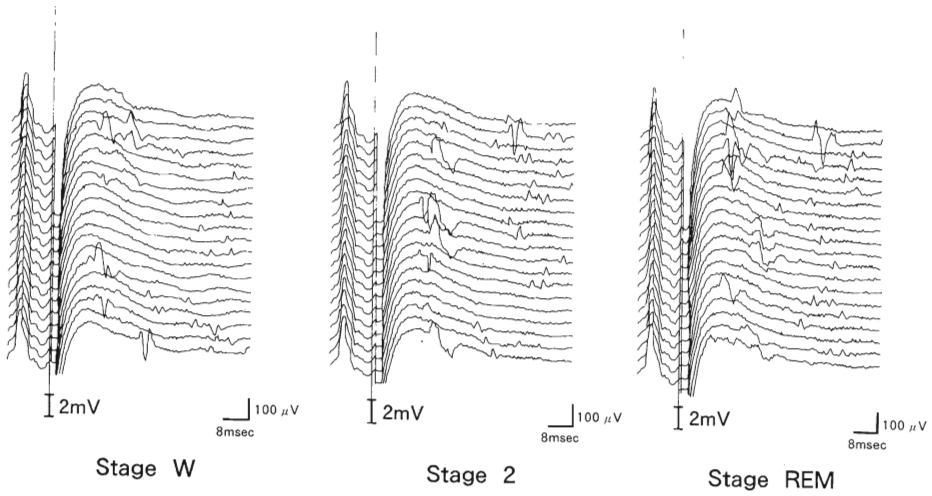

Fig. 5 F Wave While Awake and Asleep in Patient Who Had Complete Transection of Cervical Cord

A 19-year-old patient who had suffered complete cervical cord transection at the C4 level injury was examined. The persistence and amplitude of the F wave show no change during sleep.

Prominent hyperpolarization of the trigeminal motoneurons in the cats during REM sleep was reported (Chandler et al. [11]). Intracellular analysis of the jaw-closure motoneurons of the cats showed that the stimulation of the pont-mesencephalic reticular formation produced excitatory postsynaptic potentials during non-REM sleep, whereas inhibitory postsynaptic potentials (IPSPs) were induced during REM sleep (Chandler et al. [12]). IPSPs during REM sleep produced by the stimulation of other reticular sites also have been reported (Morales and Chase [14]; Chase et al. [17]). One cause of the prominent hyperpolarization during REM sleep was explained by this phenomenon. In addition, the antidromic potentials of the motoneurons were reported to be partially blocked and to decrease in absolute amplitude during REM sleep, but not during non-REM sleep (Chandler et al. [11]). An increase in membrane conductance in conjunction with membrane hyperpolarization is suspected to be the mechanism of the blockade of the antidromic potentials. Hyperpolarization and the increased conductance of the motoneuronal membrane probably were the major cause of the strong suppression of the F wave in stage REM. Supraspinal suppression of the F wave during sleep is supported by the F-wave results during sleep for our patient who had suffered complete transection of the cervical cord.

The F wave is affected by both the physiological and pathological changes in the supraspinal condition. It could be changed by maneuvers which affected the motoneuronal excitability in deafferentated patients (Fox and Hitchcock [18]). Therefore, the F wave in subjects without peripheral neuropathy reflects the motoneuronal excitability. Increases in the mean size and high persistence of the F wave is known in spastic patients (Eisen and Odusote [19]; Komori et al. [20]; Milanov [21, 22]), which facilitation is thought to be caused by the loss of the

central inhibition to the spinal motoneuron (Wilson and Burgess [23]). Suppression of the F wave caused by acute cerebrovascular lesion has been reported (Fisher et al. [24]), as well as suppression after chronic cerebellar stimulation (Fisher and Penn [25]) and dentatotomy in spastic patients (Fox and Hitchcock [26]). During the cataplexy attack disappearance of the F wave also occurs (Yokota et al. [27]). The F-wave size was reported to decrease and the minimum latency to be prolonged after the conditioning of the sensory nerve (Fisher [28]). In none of the reported studies has the relationship of minimum latency to persistence been discussed.

In the nerve conduction studies, the prolonged minimum latency of the F wave is explained as being the result of conduction delay in the motor nerve (Fisher [3]; Fraser and Olney [8]; Kimura [9]; Shahani et al. [10]). But, the minimum latency was prolonged during sleep in our normal subjects. The results of our study suggest that a major cause of prolongation of the minimum latency is the decreased number of the motoneurons that produce the F wave at the fastest conduction velocity, especially when the persistence of the F wave is markedly decreased. Moreover, the increased central delay of the F wave may contribute to the prolongation of the minimum latency because the single motor unit analysis showed that the latency of the F wave increased during sleep. The F wave is considered to be elicited by the electrical synaptic potentials (ESPs) after the invasion of the antidromic spikes to the soma of the motoneuron (Arasaki et al. [7]). Hyperpolarization and the increased conductance of motoneurons need more ESPs to reach the critical level for depolarization, which may be the cause of the prolongation of the single motor unit potentials of the F wave.

Our study has shown the following: 1. The F wave clearly is suppressed during sleep. In the REM stage in particular, the persistence and size of the F wave almost disappeared. Although the suppression of the F wave caused by the inhibitory supraspinal effect is known, the disappearance of the F wave usually is explained as being due to conduction block at the proximal portion in the peripheral nerve disorders (Kimura [29]). Our results provide the first documentation of the disappearance of the F wave in normal subjects due to the supraspinal condition. 2. The F wave is prolonged by the decrease in the motoneuronal excitability in normal subjects. We suggest that the prolongation of the minimum latency of the F wave of more than 2 ms with preserved persistence is a clinical marker of conduction delay in the F wave study.

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