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Mentalis Muscle Responses to Median Nerve Stimulation

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Abstract

Electrical stimulation may produce excitation or inhibition of the motor neurons, as represented the blink reflex and masseter silent period in response to trigeminal nerve stimulation. Clinically, a light touch on the palm may evoke a mentalis muscle response (MMR), i.e. a palmomental reflex. In this study, we attempted to characterize the MMR to median nerve stimulation. Electrical stimulation was applied at the median nerve with recordings at the mentalis muscles. An inhibition study was done with continuous stimuli during muscle contraction (I_1 and I_2 of $MMR_{average}$). Excitation was done with a single shot during muscle relaxation (MMR_{single}) or by continuous stimuli during muscle contraction (E_1 and E_2 of $MMR_{average}$). The characteristic differences between $MMR_{average}$ and MMR_{single} were as follows: earlier onset latencies of $MMR_{average}$ ($MMR_{average}$ < 45 ms; MMR_{single} > 60 ms), and a lower amplitude of $MMR_{average}$ ($MMR_{average}$ < 50 μV; MMR_{single} > 150 μV). The receptive field of MMR_{single} was widespread over the body surface and that of $MMR_{average}$ was limited to the trigeminal, median and index digital nerves. Series of stimuli usually significantly decreased the amplitude of MMR_{single}, as a phenomenon of habituation. On the other hand, it was difficult to evoke the earlier response (i.e. $MMR_{average}$) without continuous stimuli and an average technique. $MMR_{average}$ had the components of both excitation (E) and inhibition (I); for example, E_1-I_1-E_2-I_2 or I_1-E_2-I_2. E_2 was the most consistent component. In patients with dorsal column dysfunction, median nerve stimulation could successfully elicit MMR_{single}, but not $MMR_{average}$. Contrarily, in patients with pain sensory loss, it was more difficult to reproduce MMR_{single} than $MMR_{average}$. It seemed that $MMR_{average}$ and MMR_{single} did not have equivalents across the different modalities of stimulation.

Key Words: brainstem, median nerve, mentalis, long loop reflex

Introduction

The effect of sensory input on the motor neurons of the brainstem is well known from the study of trigeminofacial interaction, e.g. blink reflexes and masseter silent periods to trigeminal nerve stimulation. Extra-trigeminal nerve stimulation is also able to elicit responses in the cranial muscles, such as the masseter, orbicularis oculi, mentalis, and temporalis. It is clear that sensory input may excite or inhibit the motor neurons of the brainstem. Such responses have been suggested to be polysynaptic reflexes and a type of spinobulbospinal

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reflex (14). Polysynaptic reflexes are usually engaged with different levels of the nervous system and change with different behaviors or postures (14).

Clinically, a light touch on the palm may evoke a mentalis muscle response (MMR), i.e. a palmomental reflex. The palmomental reflex is a brief contraction of the mentalis muscles, usually unilateral and ipsilateral to the stimulated thenar eminence, resulting in a unilateral pouting expression. It is not easy to speculate exactly which neural pathways are responsible for the palmomental reflex. It has been suggested to be a polysynaptic reflex that is served by neuronal circuits extending from the lower cervical spinal cord to the facial motor nucleus in the rostral medulla (16). Electrophysiological studies of palmomental reflexes have been conducted in both basic and clinical work (1, 4, 9, 10, 11, 15, 17). In the literature, a study of the mentalis muscle response to median nerve stimulation by electrical single shot (1, 4, 11, 15) and continuous electrical stimuli, with an average, has been carried out (17). Since their methods were different, their results were also different. Therefore, we attempted to quantify the MMR to median nerve stimulation and to explore the mechanism of the afferent pathways using clinical anatomic lesions. In the study, we applied both methods in the same group of subjects to determine the difference in the results.

Materials and Methods

Twenty healthy normal subjects (aged 28-70 years; 10 males, 10 females) were studied after giving informed consent. The subjects were seated in a chair. Using an EMG machine (NeuroPack 8, Nihon Kohden, Tokyo, Japan), we recorded surface EMG activities from the target muscle: the mentalis. The surface EMG was recorded by two disposable surface electrodes (Medtronic, 9013S0241, pre-gelled disposable surface electrode, 0.7 mm TPC, Denmark) with an active one directly on the belly of the mentalis muscles and the reference on the mental protuberance. Electrical stimulation was delivered with a constant current.

For anatomic correlation, we included two patients with dorsal column dysfunction and two patients with congenital insensitivity to pain. The data of these two patients with pain sensory deficits has been published in part (6).

Single Shot with Train Stimuli without Average (MMR_{single})

The median nerve was stimulated mainly at the wrist. The duration of the stimulus was 0.2 ms. Short trains of stimuli were given, typically 8 pulses at 200 Hz. As the perception threshold varied a lot in the subjects, the motor threshold (MT) was taken as the basic reference of stimulating intensity. Using a single stimulus, we measured the MT of the abductor pollicis brevis to median nerve stimulation at the wrist at the beginning of the experiment. All the stimuli were quantified in multiples of threshold. To avoid habituation, the interval between stimuli was at least 2 minutes. We rectified the EMG and measured onset latencies, duration, and peak amplitudes. EMG responses were not included for analysis if their amplitudes were less than 50 μV. The latency of MMR_{single} exhibited considerable variability from trial to trial in an individual subject. MMR_{single}, was considered positive when a burst of EMG activity, with an amplitude > 50 μV and a duration > 10 ms, appeared consistently at a latency compatible with a reflex response (i.e., earlier than a voluntary reaction). A response was considered absent when no positive MMR_{single} was observed. As facilitation occurred in conditions of mild voluntary contraction, all the subjects were asked to relax themselves to the best of their ability with the aid of audio- and visual EMG feedback. Using the same intensity at the wrist, the receptive field of MMR_{single} was studied in three subjects.

Continuous Stimuli with Average ($MMR_{average}$)

The method of $MMR_{average}$ was modified from two studies of long latency response to median nerve stimulation (2, 3, 17). During the assessment of the $MMR_{average}$, subjects maintained a constant contraction of the mentalis muscle and did their best to relax the neighboring muscles with the aid of audio- and visual EMG feedback. In these experiments, the stimulus intensity was 12-28 mA, with a square wave pulse duration of 200 μs. The stimulus rate was 4.7 Hz. The analysis time was 100 ms after the stimulus, and filter bandwidth was 5 Hz-1.5 kHz. Because the recordings were performed with muscle contraction, an automatic artifact rejection was not used. The baseline was taken from the EMG activities before stimulation. The activities above the baseline were defined as excitation (E_1 and E_2), and the activities below the baseline were defined as inhibition (I_1 and I_2). Therefore, the baseline was different from the zero line, which indicated full relaxation of the muscle. Excitatory and inhibitory peaks were identified visually and measured with a cursor. The measurement included peak latency, inter-peak duration, and peak-to-peak amplitude. If the preceding component was not available, the peak amplitude was measured from the baseline. The receptive field of $MMR_{average}$ was studied in three subjects.

The Relationship between MMR_{single} and Voluntary Reaction Time

In three subjects, we studied the following parameters: intensity of stimulation, receptive field, spreading phenomenon, and probability. A reaction time paradigm was also done to exclude the possible role of voluntary muscle contraction. The subjects were instructed to contract their mentalis muscles in response to the median nerve stimulation. A cutaneous silent period was implemented to study the possible relationship between the inhibition of hand muscle activities and the excitation of the cranial muscles. The target muscle was the first interosseous muscle. The index finger was stimulated as the finger clasped an object between the thumb and index finger. Subjects were instructed to keep the proximal muscles relaxed.

Statistical Analysis

Pearson correlation coefficients were used to measure the strength of the linear association between the variables of MMR. The correlation coefficient was between -1 (strong negative association) and +1 (strong positive association). The closer the correlation was to +/-1, the closer to a perfect linear relationship.

The Wilcoxon rank sum test was used to study the variable of sex (male and female), and to determine if the variable was shifted with respect to another. If the *P* value was > 0.05, the data was considered insignificant.

Results

MMR_{single}

The intensity of stimulation was 13.14 ± 2.00 mA for MMR_{single}. For MMR_{single}, the onset latencies were 76.80 ± 7.67 ms, the peak amplitudes were 199.20 ± 47.93 μV, and the durations were 68.85 ± 21.11 ms. The amplitude and the duration of MMR_{single} usually increased along with the train number and the intensity (Fig. 1). The onset latency also varied a lot, but usually decreased when the intensity increased. Though MMR_{single} varied a lot with the subject and the strength of the stimulus, it was definite that appropriate stimulation (e.g., train number 8; intensity 3-5 MT) could consistently elicit MMR_{single} in each subject. At the intensity of 3-5 MT, the majority of subjects perceived the stimulus as uncomfortable but tolerable.

$MMR_{average}$

The intensity of stimulation was 16.20 ± 4.10 mA for $MMR_{average}$. The peak latencies of $MMR_{average}$ were E_1 (33.93 ± 0.57 ms), I_1 (38.94 ± 4.02 ms), E_2 (50.53 ± 3.85 ms), I_2 (71.33 ± 7.50 ms); the peak-to-peak amplitudes were E_1-I_1 (9.19 ± 3.70 μV), I_1-E_2 (26.69 ± 6.64 μV), E_2-I_2 (35.62 ± 6.71 μV); and the durations were E_1-I_1 (8.90 ± 5.01 ms), I_1-E_2 (12.15 ± 1.76 ms), E_2-I_2 (20.81 ± 6.07 ms). The most consistent component was E_2 and the most inconsistent component was E_1 (Fig. 2).

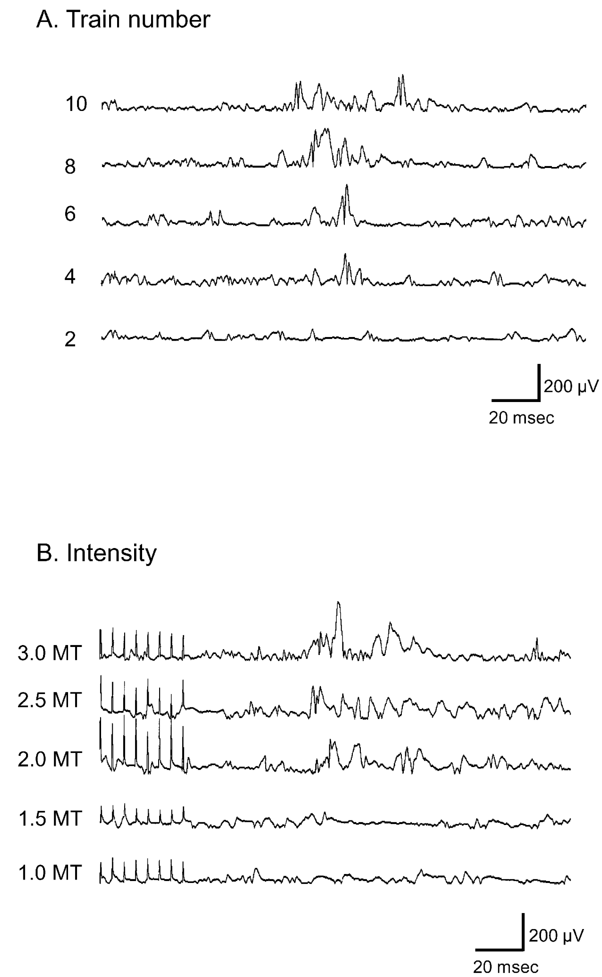

Fig. 1. In a normal subject, the MMR_{single} EMG pattern changed along with the increment of the train number (A) or the intensity (B). The interval between two stimuli was at least 2 minutes.

Probability

Probability, a ratio of the number of successful trials (acceptable responses/number of tests), was calculated in three subjects, and showed that the probability was lower in $MMR_{average}$ (40 - 60%) than MMR_{single} (70 - 90%). With a higher intensity, the consistency would be better.

Receptive Fields of the MMR_{single} and $MMR_{average}$

When the mentalis was at rest, and the intensity was strong and usually painful, MMR_{single} could be elicited by train stimulation from any part of the body surface. The most sensitive areas for eliciting MMR_{single} were the digital fingers, wrist, face, and toes of the

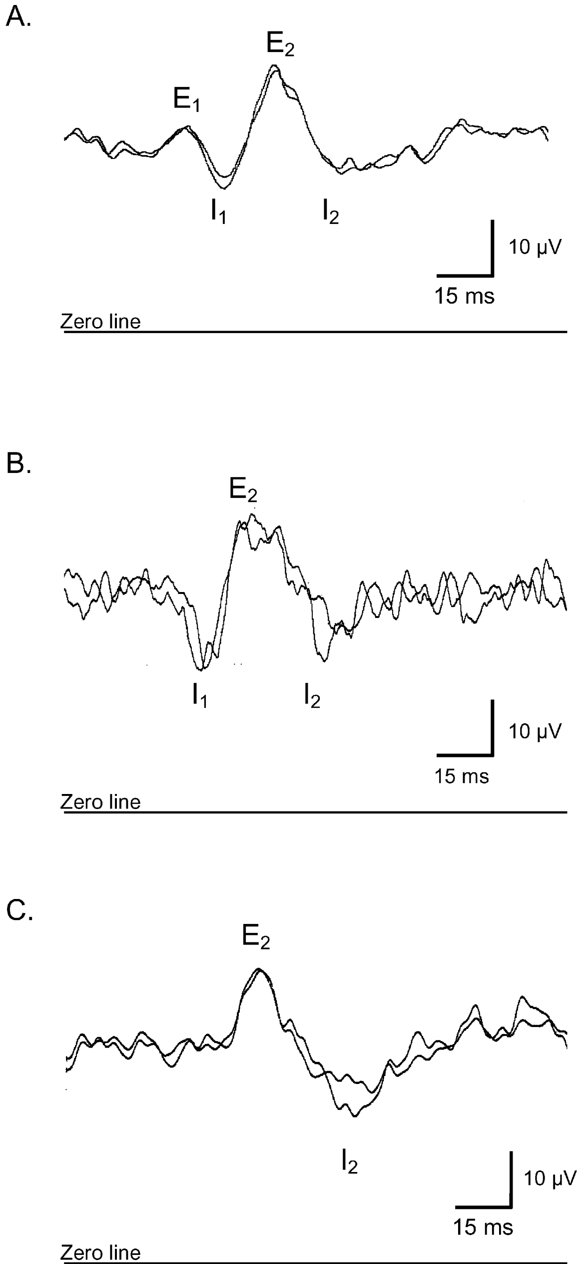

Fig. 2. The $MMR_{average}$ pattern usually had inhibitory and excitatory components and varied in subjects. Figures A, B, and C were from different normal subjects. The E_2 component was the most consistent finding.

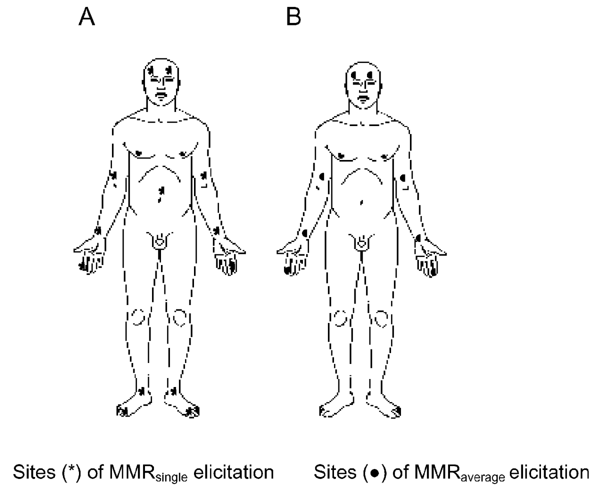

Fig. 3. A: The receptive field of MMR_{single} was widespread over the body surface. B: On the other hand, the receptive field of $MMR_{average}$ was limited to the upper limb and the cranial parts. (*, ● : recording site)

foot (Fig. 3A). When the mentalis was kept at a constant contraction, the EMG patterns of $MMR_{average}$ were elicited only by the stimulation of trigeminal, median, and finger digital nerves (Fig. 3B).

Spread of the Reflex Responses to Single Train Stimulation of the Median Nerve

The stimulation for MMR_{single} usually provoked a more generalized reaction, which included withdrawal of both hands, retraction of the head, extension of the back, and withdrawal flexion (such as the elbow, ankle, knee and hip), occurring in various combinations. Therefore, the train stimulus evoked EMG activities not only in the mentalis muscles but also in other muscles, such as the biceps brachii and flexor carpi radialis, with a latency of less than 100 ms (Fig. 4A). During continuous stimulation with an average, median nerve stimulation could elicit muscle responses not only of the mentalis, but also of the stimulated limb muscles, such as the biceps, flexor carpi radialis, and abductor pollicis brevis (Fig. 4B).

Relationship of MMR_{single} to Blink

Using simultaneous recordings, median nerve stimulation could evoke simultaneous responses at the orbicularis oculi and mentalis, but sometimes only one muscle was available. The latency of the blink reflex to median nerve stimulation was usually between 64.2 ± 6.5 ms, and usually occurred before MMR_{single} was seen. However, on occasion, MMR_{single} could precede the onset of the blink. During repetitive stimulation, MMR_{single} usually habituated earlier than the blink reflex, but the reverse situation might be seen. There was no constant relationship between orbicularis oculi responses and mentalis responses in latencies, sensitization, and habituation.

Spreading Phenomenon of Continuous Stimulation of the Median Nerve at the Wrist

During the paradigm, the target muscle was

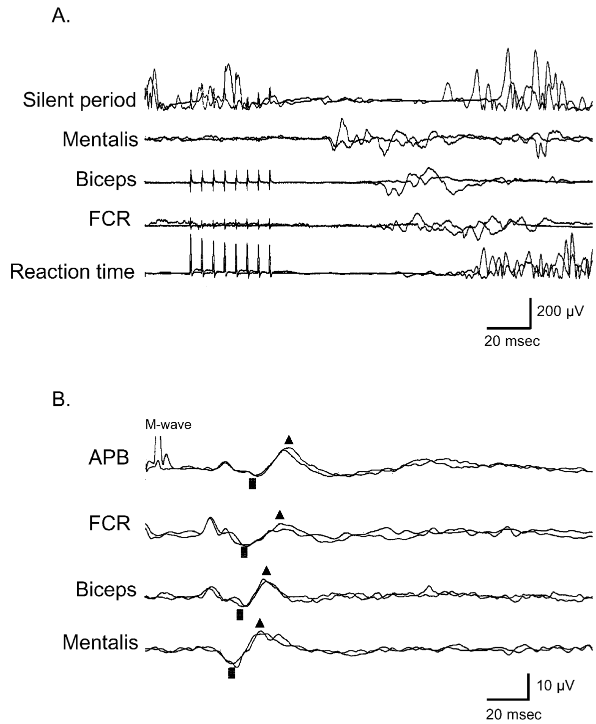

Fig. 4. The index digital nerve stimulation elicited a muscle response not only at the mentalis but also at the flexor carpi radialis and biceps, no matter whether the stimulation was a single shock (A) or continuous (B). In figure A, excitation responses at the mentalis and forearm muscles followed the silent period of the active hand muscles (the first interosseous muscle), but preceded the reaction time of the mentalis contraction. In figure B, the time sequence was noted in the I_1 and E_2 responses of the muscles sampled. (APB: abductor pollicis brevis; FCR: flexor carpi radialis; ▮: the first component of inhibition, I_1 latencies from up to down were 52 ms, 48 ms, 47 ms, 42 ms ; ▲: the second component of excitation, E_2 from up to down 66 ms, 63 ms, 57 ms, 55 ms)

kept at constant contraction. The spreading phenomenon was limited to the muscles of the stimulated limb and the cranial muscles (Fig. 4B). The best consistency was in the hand muscle, and then, in sequence, the biceps, flexor carpi radialis, and the mentalis, which was the least. In the averages of 200 stimuli, several components were identified, as in our previous study, such as E_1-I_1-E_2 or I_1-E_2 (11, 12). For all the target muscles, E_2 was still the most consistent component. The stimulation intensity was higher in the mentalis (3-8 MT), and then, in sequence, the flexor carpi radialis (4-6 MT), biceps (3-5 MT), and the hand muscles (2-3 MT), which were the least.

Comparison between Reaction Time and Reflex Response

The reaction time of the mentalis muscle was always longer than $MMR_{average}$ and MMR_{single} (Fig. 4). It was clear that the latency of MMR to median nerve stimulation was too short to be voluntary. In the finger clips task, median nerve stimulation first blocked the tonic muscle contraction of the hand muscles and immediately excited the muscle responses at the mentalis and limb muscles (such as the flexor carpi radialis and biceps brachii), in sequence. The silent period of the hand muscle usually immediately followed the stimulus, and lasted for 70-100 ms.

Anatomic Correlations

In patients with dorsal column dysfunction, only MMR_{single} was available for elicitation (onset latency: patient A, 64.3 ms and patient B, 74.2 ms ; duration: patient A, 42.9 ms and patient B, 73.8 ms; amplitude: patient A, 166.7 μV and patient B, 120.9 μV) (Fig. 5). In patients with congenital insensitivity to pain and anhidrosis, reproduction of $MMR_{average}$ was available (peak latency: I_1 patient C, 34.3 ms and patient D, 39.4 ms; E_2 patient C, 45.7 ms and patient D, 55.3 ms; I_2 patient C, 65.7 ms and patient D, 73.3 ms; inter-peak latencies: I_1-E_2 patient C, 11.4 ms and patient D, 15.9 ms; E_2-I_2 patient C, 10.0 ms and patient D, 18.0 ms; peak-to-peak amplitude: I_1-E_2 patient C, 15.8 μV and patient D, 16.7 μV; E_2-I_2 patient C, 18.3 μV and patient D, 19.4 μV). But, it was difficult for median nerve stimulation to evoke consistent MMR_{single} (Fig. 5), even when the intensity was up to 50 mA.

For MMR_{single}, Pearson correlation coefficients did not reveal any significant findings in the variables of MMR_{single} (age and latencies, r = 0.15; age and amplitude, r = - 0.21; height and latencies, r = 0.03; height and amplitude, r = - 0.13; intensity and latencies, r = 0.13; intensity and amplitude, r = 0.17).

As E_1 of $MMR_{average}$ was observed in only three subjects, E_1 latencies and E_1-I_1 durations were not included for analysis. For $MMR_{average}$, Pearson correlation coefficients showed significance between height and latency (E_2, r = 0.83 ; I_1, r =0.90; I_2, r = 0.53) but not between age and latency (E_2, r = -0.41; I_1, r = -0.49; I_2, r = -0.06), age and amplitude (E_1- I_1, r = 0.32; I_1- E2, r = -0.34; E_2- I_2, r = 0.05), height and amplitude (E_1- I_1, r = 0.28; I_1- E_2, r = 0.13; E_2- I_2, r = -0.10), intensity and latency (I_1, r = -0.36; E_2, r = -0.35; I_2, r = -0.10), or intensity and amplitude (E_1- I_1, r = 0.03; I_1- E_2, r = 0.07; E_2- I_2, r = 0.26).

In this study, there was no significant difference between male and female groups (P > 0.05).

Discussion

The Mechanism of MMR_{single}

Our studies showed that muscle responses to

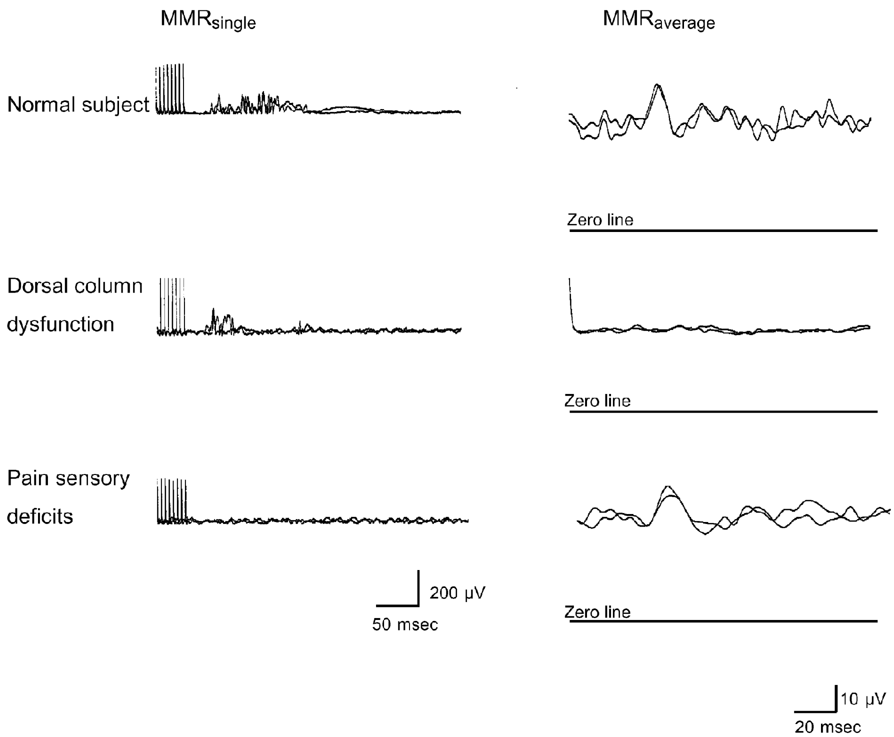

Fig. 5. Anatomic correlation

median nerve stimulation spread widely over the body. In the facial muscles, this included not only the mentalis muscle, but also the orbicularis oculi muscle. The comparison between mentalis and orbicularis oculi showed that cranial muscles could simultaneously respond to external stimuli. However, the orbicularis oculi muscles did not always respond to median nerve stimulation exactly as the mentalis. Neither had a constant relationship, in terms of latencies, sensitization, and habituation. Therefore, MMR_{single} was not exactly a spreading phenomenon of the blink. The dissociation between the mentalis and the orbicularis oculi responses indicates that limb afferents project onto specific facial motor neurons following different paths (15). This is further confirmed by clinical observation of palmomental reflexes that scratch over the palm usually evokes responses at the mentalis muscles, but not at the orbicularis oculi.

In our study, both MMR responses were faster than reaction time. The afferent limb of the MMR was served by a wide range of fibers of varying conduction rates and diameters. The role of small fibers on MMR_{single} was shown in our case study. Our study also showed that MMR_{single} was not elicited in patients with pain sensory deficits, but available in patients with dorsal column dysfunction. It is clear that MMR_{single} can be evoked by pain afferents even without the large fibers of proprioception. Otherwise, MMR_{single} was still available when a forearm ischemic test produced distal paresthesia with impairment of the larger fibers before the small fibers (11). The conduction velocities calculated for MMR_{single} of the orbicularis oculi muscle ranged from 24.4 to 34.4 m/s (10). This also inferred the role of the small fiber in the mechanism of MMR_{single}.

Single stimulation without train usually did not evoke a cranial muscle response, especially when the intensity was low and not painful. Using train stimulation, the duration of stimulation would increase. When the intensity was kept constant, train stimulation would produce a summation effect (accumulation of neuronal responses) and increase the excitability of motor neurons at the spinal cord and the brainstem (13). As the stimulus continued in the train model, the wind-up phenomenon was usually observed (Fig. 1). At that point, most subjects felt uncomfortable, and C fibers should have been activated in such intensities. Therefore, MMR_{single} was inferred to be a reflex through the transmission of C fibers and/or Aδ fibers in part.

Based on the wind-up mechanism, train stimulation is able to elicit nociceptive or flexor reflexes, i.e., the excitatory response of the flexor muscles (7). This is taken as protective withdrawal behavior in response to electrical stimulation (7). We suggest that such afferents, described in leg withdrawal

Table 1. Comparison between MMR_{single} and $MMR_{average}$

	MMR_{single}	$MMR_{average}$
Stimulation at the wrist	Single train stimulation	Continuous stimulation
Average	No	Yes
Series of stimuli	habituation	preserved responses
Intensity (mA)	13.14 (± 2.00)	16.20 (± 4.10)
Onset latency (ms)	> 60	< 45
Amplitudes (μV)	> 150	< 50
Sensory pathway	small fibers	large fibers
Receptive fields	widespread over the body surface	the distribution of median/trigeminal n

MMR: mentalis muscle reflex.

reflexes (13), are similar for the MMR_{single}. In our study, the onset of MMR_{single} not only coincided with, but also followed the silent period in active hand muscles, and had an associated elbow movement (i.e., a muscle response at the biceps). We concluded that electrical stimuli to the median nerve activated a complex motor pattern that tended to withdraw the hand at the same time the hand muscle contraction was released. This also confirmed the hypothesis that MMR_{single} (e.g. orbicularis oculi response) to median nerve stimulation was a defensive behavior to protect the subject from various invasive stimuli (9, 10). With a higher intensity, the duration of MMR_{single} increased (Fig. 1), due to the recruitment of new motor units and repetitive discharges of those previously active.

The Mechanism of $MMR_{average}$

Using an average technique, peripheral electrical stimulation may produce not only excitation but also inhibition on the motor activities of muscle contraction, such as the long latency reflex of the hand muscles to median nerve stimulation (7). $MMR_{average}$ was provoked by median nerve stimulation during tonic contraction of the mentalis, as a hand muscle reflex to median nerve stimulation. It seems that $MMR_{average}$ shares the similar mechanisms of the long loop reflex of the hand muscle with the dorsal column, as afferent paths. The long latency reflex of the hand muscle to digital nerve stimulation is mediated through fast conducting cutaneous and Ia afferents, and is subsequently transmitted within the dorsal column to the nucleus cuneatus and along the lemniscal pathway to the cortex (5). The role of large fibers on $MMR_{average}$ was also evidenced by our patients with dorsal column dysfunction. In these patients, $MMR_{average}$ decreased in amplitude significantly. Our observation confirmed the postulation that long loop reflex with an afferent arc via a cortical connection could be one of the mechanisms of $MMR_{average}$ (17). We further inferred that the excitation from median nerve stimulation passes from the sensory to the motor cortex, and from there along the corticospinal tract back to the motoneurons of the mentalis, biceps brachii, and flexor carpi radialis. As the EMG pattern of $MMR_{average}$ has both phases of excitation and inhibition, the $MMR_{average}$ may appear as a result of the integration of facilitatory and inhibitory mechanisms within the brainstem.

The receptive field of $MMR_{average}$ appears to be specific to median nerve stimulation and far less than that of MMR_{single} (17). In normal subjects, the $MMR_{average}$ was not evoked by motor point stimulation of the thenar muscle (17). These researchers argued that the afferent inputs of $MMR_{average}$ were nociceptive and tactile sensory fibers, with little or no participation of proprioceptive Ia fibers or muscle spindle afferents. However, in our study, it was difficult to evoke $MMR_{average}$ in patients with dorsal column dysfunction, as evidenced by the somatosensory evoked potentials of the median nerve. The anatomic observation strongly supported the role of the dorsal column in the mechanism of $MMR_{average}$.

The Difference between MMR_{single} and $MMR_{average}$

The differences between $MMR_{average}$ and MMR_{single} were very clear, as seen in Table 1, and were as follows: 1. MMR_{single} had longer onset latencies than $MMR_{average}$; 2. MMR_{single} decreased in amplitudes after repetitive stimulation, but $MMR_{average}$ was evoked after repetitive stimulation; 3. MMR_{single} had wider receptive fields than $MMR_{average}$; 4. the intensity to provoke $MMR_{average}$ was higher than that for MMR_{single}. This further indicated that MMR_{single} and $MMR_{average}$ did not exactly share the same mechanism. Our study showed that different methods can provoke different MMR responses. Both responses are likely to reflect the convergence of cutaneous inputs and descending inputs onto the brainstem level. It is said that sensory inputs enter the brainstem and modulate the excitability of the facial nerve nucleus or adjacent structures (12). Further investigation, exploring why the intensity of $MMR_{average}$ (a reflex through large fibers) is higher than MMR_{single} (a reflex through small fibers), is needed.

The stimulating intensity was so high as not to be a pattern of light touch, group II (Aβ) afferents. Therefore, we had to be very careful in the interpretation before we concluded that it was an experimental method of palmomental reflexes. However, our study proved that brainstem excitability to remote stimulation can be assessed by electrophysiological methods. Median nerve stimulation can provoke cranial muscle responses and is a method to assess brainstem excitability to extra-trigeminal nerve stimulation. Continuous stimulation could provoke a response with an earlier latency, and single nociceptive stimulation could provoke a response with a longer latency and a characteristic of habituation. $MMR_{average}$ was related to the large fibers and MMR_{single}, was chiefly related to the small fibers. Based upon the results of habituation character and latency, it was clear that $MMR_{average}$ and MMR_{single} did not have equivalents across the different modalities of stimulation.

Acknowledgments

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