Frequency resonance investigation of the H reflex

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SUMMARY Results of a previous study demonstrated transformation of the sustained activity of a muscle into rhythmic, tremor-like activity by stimulation of different motor centres. The optimum for this transformation was in the 4–7 Hz frequency band (resonance band). Sustained rhythmic stimulation with stimuli at 0.1–20 per second caused a normal frequency curve of the H reflex in subjects with intact motor systems. The resonance phenomenon of the frequency curve of the H reflex was in agreement with that found in previous studies stimulating the different motor centres. As this requires connections between spinal and higher motor centres, it is suggested that this investigation is appropriate for a detailed functional study of spinal cord lesions.

In previous studies we have investigated the motor modification effect of stimulating the ventrolateral nucleus of thalamus, pallidum, dentate nucleus, and motor cortex in patients with chronic implanted electrodes (Tóth, 1972; Tóth *et al.*, 1974, 1975, 1977, 1979a, b). The modification effect of the stimulated site was studied in the electrical activity of the voluntarily contracted muscle along with the evoked potentials within the motor system at the non-stimulated sites. The stimulus was followed by periods of facilitation and inhibition of the electrical activity of the voluntarily contracted muscle. These different periods could be detected clearly using double stimuli (conditioning and test stimuli) when those were not expressed in the electrical activity (Tóth *et al.*, 1977). The investigation proved that stimulation of the motor system elicits a motor control process resulting in periods of excitation and inhibition of the electrical activity of the contracted muscle. When the frequency of stimulation was raised in steps from 1 to 15 Hz, the electrical activity of the contracted muscle became transformed in a specific manner. Instead of different periods of excitation and inhibition after stimulation at 1.0 Hz, on raising the frequency of stimulation there remained only one period of inhibition and one period of excitation. The electrical activity of the contracted muscle became rhythmic, resembling tremor (Fig. 1). During this transformation the electrical activity was usually enhanced, like a resonance effect, and

this was the most pronounced at 5–7 per second stimulation (Tóth *et al.*, 1974). The time relation of the periods of facilitation and inhibition after stimulation of ventrolateral nucleus, pallidum, and motor cortex resembled the time relation during H reflex recovery described by Magladery *et al.* (1952) and Paillard (1955). This suggests that evocation of the H reflex or the stimulation of the different sites of the motor system releases a similar motor control process at least in its main features. This stimulus elicited control process has been studied extensively from the central side of the motor system. The present study is an attempt to follow the motor control process evoked by H reflexes with different stimulus frequencies. The results on subjects with healthy motor systems were compared with the results from patients with spinal cord lesions.

Subjects and methods

The investigation was carried out on 57 healthy subjects and on 64 patients with spinal cord lesion (Table) classified according to localisation and nature of the lesion, the rate of progression and the grade of paresis and spasticity.

The H reflex was elicited by sustained rhythmic stimulation of the posterior tibial nerve. The stimulating electrodes were fixed at the site of stimulation with constant pressure by means of a rubber band. The recording electrodes were subdermal needle electrodes over the calf muscle with an interelectrode distance of 50 mm. The electrical stimulus was delivered by a DISA

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Fig. 1 Voluntary contraction of the left opponens pollicis muscle. Stimulation of the ventrolateral nucleus of the right thalamus (20 V, 0.7 ms, 6 per second). After the first stimulus the motor response consists of a synchronised potential, a silent period followed by a rebound electrical activity group, and another silent period. As the stimulation continues the synchronised potential decreases and disappears, and the grouped, tremor-like activity remains. Calibration: 100 μ V, 63 ms.

Table Classification of patients studied according to type, severity, and progression of lesion

Spinal lesion	Tumour	Trauma	Vascular myelopathy	Degenerative diseases	Multiple sclerosis
Acute flaccid paraplegia	1	2			
Subacute or quickly progressing lesion with moderate spasticity					
Severe paresis	2				
Moderate paresis	3				
Mild paresis	1				
Chronic or slowly progressing lesion with spasticity					
Plegia	4				
Severe paresis	9	3	7		1
Moderate paresis	10		7	4	1
Mild paresis	2		4	2	1
Healthy subjects	57				
Patients with spinal cord lesion	64				

Multistim with frequencies of 0.1, 0.25, 0.5, 1, 3, 3.5, 5, 6, 7, 8, 10, 15, 20, 25 per second. The pulse duration was 0.5–1.0 ms in control subjects and 0.2–0.7 ms in patients with spinal cord disease. The other stimulus parameters were selected at 0.5 per second to produce the greatest H and the lowest M response. At each frequency 40 responses were averaged (ICA-70, KFKI), and the frequency curve was drawn from the averaged responses. Every investigation was carried out with the subject at rest and during voluntary contraction of the calf muscle. To study the changes of the amplitudes of the H reflex in time, continuous registration was also made.

Results

CONTROL SUBJECTS

In the resting state it was possible to separate two different parts of the frequency curve: (1) from 0.1 to 1.0 per second, and (2) from 1.0 to 20, 25

per second. In the first part the amplitude of the H reflex gradually decreased (Fig. 2a, e). In the second part the amplitudes of the H reflexes had a minimum at 3 to 3.5 per second and one or two maxima in the 5 to 8 per second frequency band (Fig. 2a, b, c, d, e). In this frequency band the enhancement of the H reflex resembled a resonance effect. The resonant frequency itself was characteristic for each person, being constant at repeated investigations. Sometimes at the resonant frequencies the amplitude of the H reflex waxed and waned, so that the averaged amplitude became lower. In these cases the resonance phenomenon could be established by continuous registration. When the M response was studied along with the H response at different stimulation frequencies, increase of the H response and decrease of the M response at the resonant frequencies could be seen (Fig. 2c).

In a few patients the resonance was not well expressed in the resting state but it became more

Fig. 2 H reflex frequency curves of healthy control subjects. DVC=during voluntary contraction, Rest=in resting state.

significant during voluntary contraction (Fig. 2f, g). Generally, voluntary contraction enhanced the amplitudes of the H reflex along the frequency scale. The amplitudes became higher than in the resting state, the decrease of the amplitudes in the first part of the frequency curve was less obvious, but the resonance was more marked in the second part (Fig. 2d, f).

PATIENTS WITH SPINAL CORD LESIONS

In the case of acute spinal cord transection there was no H reflex at all. When the spinal cord lesion was subacute or rapidly progressive, the frequency curve showed monotonous decrease, and this did not depend on the grade of the paresis (Fig. 3b, left).

A chronic, stationary, or slowly progressing spinal cord lesion enhanced the H reflex itself; the frequency curve and the resonance phenomenon altered. In chronic severe spastic paraparesis or paraplegia the amplitudes of the H reflex became uniform in the first and second parts of the frequency curve, without any sign of resonance (Fig. 4C, D). When the patient had moderate paresis with spasticity, the first part of the frequency curve was uniform and slight resonance was noted at the beginning of the second part (Fig. 3a). With mild chronic paresis and spasticity the frequency curve showed a uniform first part and a resonance or enhanced resonance in the second part within the normal frequency band (Fig. 4E). In these states the voluntary contraction

could have a greater enhancing effect than in the control group (Fig. 4F).

Discussion

From published reports (Magladery *et al.*, 1952; Paillard, 1955) we know that the H reflex uses a motor control process which influences the subsequent H reflex at least for one second. This control process involves not only a spinal system, but also the ascending and descending bulbospinal

pathways and centres (Shimamura and Livingston, 1963; Shimamura and Akert, 1965). According to our results the effect of the H reflex on the subsequent H reflex is much longer if rhythmic stimulation is used. This was clear from the first part of the frequency curve because in this the amplitudes of the H reflex decreased when the stimulation frequency was raised from 0.1 Hz to 1.0 pulses per second. The second part of the frequency curve showed that the rhythmic stimulation had different effects on the direct motor response and on the reflex response. Rhythmic stimulation in the resonant frequency band depressed the direct motor response (M wave) and enhanced the H reflex response which is triggered by the intrafusal system.

Ioku *et al.* (1969) studied the changes of the H reflex amplitudes on high frequency stimulation, but only with respect to the first reaction of the motor control process elicited by the H reflexes. Many authors have suggested that stimulation of the ventrolateral muscles of the thalamus influences the intrafusal motor system (Stern and Ward, 1960; Yanagishawa *et al.*, 1963; Ohye *et al.*, 1964; Stern *et al.*, 1968; Laitinen and Ohno, 1970). However, there are different opinions about the nature of the effect. According to our previous investigations (Tóth, 1972; Tóth *et al.*, 1974, 1975, 1977) the thalamic stimulation elicits a series of events which result in periods of facilitation and inhibition of the contraction of the contralateral muscles. These periods facilitate or inhibit the H reflex, evoked in the appropriate period. The effect of the ventrolateral stimulation on reflex activity depends on the time interval between the thalamic and reflex stimulation (Tóth, Sólyom, and Vajda, in preparation). In the electrical activity of the contracted muscle the thalamic stimulation could be followed by a synchronised potential (direct motor response) with a short latency, followed by a silent period and then a rebound in the electrical activity (reflex response). Thalamic stimulation in the resonant frequency

Fig. 3 H reflex frequency curves on patients with spinal cord lesions.

Fig. 4 H reflex resonance curves on patients with spinal cord lesions.

band clearly depresses the direct motor response and enhances rebound (reflex) activity (Fig. 1).

The resonance phenomenon implies that during sustained voluntary contraction a tremor-like transformation appears on thalamic stimulation. The same is true, during sustained voluntary contraction, for the H reflex which is enhanced, as is the resonance in the same resonance frequency band observed in the resting state. Involvement of common motor control processes could be suggested. These processes have similar time relations (facilitation and inhibition periods) and similar behaviour in a special frequency band (resonance band) of stimulation. The differently evoked motor control processes need not require the function of the same neuronal circuit, but of common pathways and centres. Therefore, it was not unexpected to find that the resonance phenomenon of the H reflex disappeared in the chronic state after total spinal cord transection. This is supported by the findings of earlier investigators who suggested that the motor control process evoked by the H reflex uses both spinal and bulbar mechanisms (Shimamura and Livingston, 1963; Shimamura and Akert, 1965).

In the case of subacute or rapidly progressing lesions, and sometimes immediately after a spinal cord operation (with moderate or mild spasticity), the motor control process is disturbed. In these circumstances there is no time for reorganisation of the motor control circuit so the frequency curve is monotonous and the resonance phenomenon does not occur. This kind of frequency curve does not depend on the grade of paresis.

In the chronic spinal state with moderate or severe spasticity and moderate or severe paresis, the reflex activity is enhanced but as the motor control circuit could not reorganise the frequency curve is monotonous or there is a mild resonance effect earlier than the normal.

In patients with chronic mild paraparesis and with moderate or mild spasticity the reflex activity is enhanced. The first part of the frequency curve is monotonous but the resonance appears in the normal resonance frequency band and can be enhanced as well.

This suggests that the motor control circuit is reorganised in this case, at least in connection with the resonance phenomenon. This enhanced resonance phenomenon at rest is similar to the enhancement in the control group during voluntary contraction. It is interesting that in this way a mild spasticity has the same effect on resting muscle as does voluntary contraction on muscle of healthy subjects.

In cases of spinal cord disease with bilateral

signs, the frequency curve could be different on each side depending on the functional state. The frequency curve could change after surgical operation on benign spinal tumours, and the resonance phenomenon appears (in 10–20 days) when the functional recovery of the patient is favourable (Fig. 5).

The H reflex resonance investigation along with the results of our previous study, indicates that the resonance phenomenon is a general rule within the motor system for motor control processes used by the H reflex or by stimulation of different sites in the motor system. Further investigation is required to study whether this is so for all rhythmic (alternating) movements. The resonance phenomenon of the H reflex could appear only if the spinal cord is connected with the higher motor centres. Investigation of the frequency curve and the resonance phenomenon of the H reflex seems to be appropriate for following the different functional states in patients with a spinal cord lesion.

Fig. 5 Spinal tumour (meningioma) at T7 cord segment. At the time of investigation the paresis progressed rapidly and the preoperative frequency curve showed monotonous decrease. Two weeks after the removal of the tumour the resonance phenomenon appears (dotted line).

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