A Comparison of Methods to Assess the Excitability of Lower Motoneurones

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ABSTRACT: The purpose of this investigation was to compare three methods of assessing the excitability of lower motoneurones — TA-reflex, H-reflex and F-wave — in 120 patients with spastic hemiparesis following a stroke. The H-reflex was recorded from the soleus muscle after submaximal electrostimulation of the tibial nerve. The T-Achilles (TA) reflex was recorded from the soleus muscle after percussion of the Achilles tendon. The F-wave was recorded in the distal limb muscles after supramaximal electrostimulation of the median, ulnar, fibular and tibial nerves. The patient's healthy side was used as a control. The TA-reflex, H-reflex and F-wave showed increased amplitudes on the spastic side. All amplitude ratios: TA/M, H/M, Fmax/M and Fmean/M were increased. The H-reflex thresholds were decreased. The F-wave duration, persistence and number of phases were also increased on the spastic side. Despite clinically decreased muscle tone, there were no changes in TA or H-reflex parameters after treatment. On the other hand, F-wave parameters tended to normalize after treatment in all groups. In conclusion, the F-wave is a more sensitive method than the TA and H-reflexes in assessing the excitability of the lower motoneurone.

RÉSUMÉ: Comparaison des méthodes d'évaluation de l'excitabilité des neurones moteurs périphériques. Le but de cette étude est de comparer trois méthodes d'évaluation de l'excitabilité des motoneurones périphériques - réflexe tendineux achilléen (TA), réflexe H et onde F - chez 120 patients avec hémiparésie spastique suite à un accident cérébro-vasculaire. Le réflexe H a été enregistré à partir du muscle soléaire après électrostimulation submaximale du nerf sciatique poplité interne. Le réflexe TA a été enregistré à partir du muscle soléaire après percussion du tendon d'Achilles. L'onte F a été enregistrée dans les muscles distaux des membres après électrostimulation supramaximale des nerfs médian, cubital, sciatique poplité externe et sciatique poplité interne. Le côté sain du patient a été utilisé comme contrôle. L'amplitude du réflexe TA, du réflexe H et de l'onde F étaient augmentées du côté spastique. Tous les rapports d'amplitude, TA/M, H/M, Fmax/M et Fmoyenne/M étaient augmentés. Le seuil des réflexes H était diminué. La durée de l'onde F, la persistance et le nombre de phases étaient aussi augmentés du côté spastique. Malgré un tonus musculaire diminué, il n'y avait pas de changement dans les paramètres de réflexes TA ou H après traitement. D'autre part, les paramètres de l'onde F avaient tendance à se normaliser après traitement dans tous les groupes. En conclusion, l'onde F est une méthode d'évaluation plus sensible de l'excitabilité du motoneurone périphérique que les réflexes TA et H.

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The T- and H-reflexes described by Hoffmann in 1918, are widely used in assessing lower motoneurone excitability. As they are monosynaptic reflexes, their amplitudes depend on the excitability of the motoneurone.[1] A more precise index of motoneurone excitability is the ratio of their amplitudes to the amplitude of the M-response: the T/M and H/M ratios.[1,2] The H-reflex thresholds with minimal and maximal amplitude also depend on the excitability of the lower motoneurone.[3,4]

In 1950, Magladery and McDougal described the F-wave[5] as a recurrent discharge of antidromically activated motoneurones.[6-8] F-wave parameters also depend on the excitability of the lower motoneurone.[9]

The sensitivity of these methods can be assessed after some change in motoneurone excitability. Motoneurone excitability is decreased in "spinal shock". In such cases, the T and H reflex amplitudes, as well as the T/M and H/M ratios are decreased[1] and the persistence and mean F-wave amplitude are also decreased.[10,11] In spasticity, when motoneurone excitability is increased, there is an increase in the T-reflex amplitude, T/M ratio,[1,12-14] H-reflex amplitude and H/M ratio[2,14,15] and the persistence[8,16,17] and mean amplitude of the F-wave.[17-19] The H-reflex thresholds were decreased in spasticity.[3,4] After treatment of spasticity when the motoneurone excitability is reduced, the physiological findings are controversial. Decreases of the T and H reflex amplitudes and T/M and H/M amplitude ratios have been reported after treatment of spasticity with benzodiazepines,[20,21] Baclofen,[14,15] tizanidine,[22,23] chronic cerebellar[13,24,25] and spinal[26,27] electrostimulation. However, other papers have reported no change in these parameters after treatment with the same myorelaxants.[2,12,21,28-31] There are no F-wave

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data after treatment with myorelaxants, although a decrease in the F-wave persistence and mean amplitude was found after chronic cerebellar electrostimulation.[13]

The excitability of the lower motoneurone is important. The purpose of this study was to compare these three methods for assessing the excitability of the lower motoneurone excitability in a large group of patients with spastic hemiparesis.

Patients

One hundred and twenty patients (87 women and 33 men) with spastic hemiparesis after stroke were evaluated. The mean age was 57 ± 8.6 years (from 34 to 76 years). The mean duration of the disease was 36 months. Only patients with no clinical or electromyographical evidence of peripheral nerve injury took part in this investigation. The patients were divided into four groups of 30. Patients in each group received a different treatment of spasticity for a mean of 24.9 ± 7.2 days. There were no significant differences ($p > 0.1$) between the groups for age, duration of the disease, duration of treatment, sex, degree of spasticity or weakness. Since results of the electromyographic methods are bilaterally identical in healthy persons and since no changes on the healthy side in spastic hemiplegia have ever been reported,[16,32,33] the patients' unaffected side was used as a control. All patients signed an informed consent.

Patients in three of the groups were treated with myorelaxants as follows: Baclofen (Polfa-Polland) — mean daily dose 54 ± 12 mg. Myolastan (Sanofi-France) — mean daily dose 102 ± 36 mg. Sirdalud (Sandoz-Switzerland) — mean daily dose 16 ± 6 mg. The individual daily doses varied according to the patients' tolerance, and was divided into three oral doses.

The fourth group was treated with electroacupuncture. The acupuncture points for treatment of spasticity were as follows:[34,35] Hegu (LI-4), Quchi (LI-11), Leique (Lu-7), Zusanli (St-36), Neiting (St-44), Weizhong (UB-40), Chengshan (UB-57), Kunlun (UB-60), Taichong (Liv-3), Yanglingquan (GB-34), Huantiao (GB-30), Tongli (H-5), Yashu (Gov-2), Jizhong (Gov-6), Yamen (Gov-15). The points were needled and electrostimulation with a biphasic current of 100 Hz was applied for half an hour at an intensity comfortable to the patient. A mean of 16 daily treatment sessions were given. The electroacupuncture used in this investigation resembles spinal and muscle electrostimulation.

Methods

Clinical Methods

Neurological examination was performed before and after treatment. The well known five point scales for muscle tone (Ashworth scale), muscle force (Medical Research Council Scale) and tendon reflexes were used in the neurological examination.[36,37] Babinski's sign and ankle clonus were registered when present.

Electromyographical Methods

"Medicor" (Hungary) electromyographic equipment with a memory scope was used. Since all electromyographic measurements were obtained both before and after treatment, special care was taken to standardize the examination. Identical recording locations were used and the maximal amplitude of the M-response was the same in both sessions.[38] Since the parameters being measured are stable in normal individuals over time,[32,33,38] any change in these parameters after treatment should be caused by the treatment. During the examination the patients were as relaxed as possible and only recordings without visible background EMG activity were used for analysis. The following methods were used:

(i) The H-reflex was recorded by a monopolar surface electrode over the soleus muscle[4] with a reference electrode on the opposite Achilles tendon. A 1 ms duration square wave electrical pulse was applied to the tibial nerve in the popliteal fossa.[4] The stimuli were given every 10 seconds. The stimulus strength and site of stimulation was adjusted so as to obtain an H-reflex with the lowest threshold and then with the maximal amplitude.[4] The maximal (peak to peak) reflex amplitude was evaluated by cursors. The stimulus thresholds to elicit an H-reflex with minimal amplitude and an H-reflex with maximal amplitude were measured.

(ii) T-Achilles (TA) reflex was recorded from the same electrodes as used for the H-reflex studies.[38] The reflex was produced by percussion on the Achilles tendon with a neurological hammer.[39] The maximal (peak to peak) reflex amplitude was evaluated by cursors.

(iii) F-waves were recorded by bipolar surface electrode from abductor pollicis brevis, abductor digiti quinti, extensor digitorum brevis and abductor hallucis muscles. The median, ulnar, fibular and tibial nerves were respectively stimulated (cathode proximal) at wrist or ankle with supramaximal 0.5 ms duration square-wave voltage pulses.[18] Twenty stimulations for each nerve were performed. The F-wave maximal amplitude (peak-to-peak), duration and number of phases were evaluated by cursors. The F-wave persistence was evaluated as a percentage of the F-waves obtained to the number of stimulations. The mean amplitude and the ratios of F-wave maximal amplitude to M-response amplitude (Fmax/M) and of F-wave mean amplitude to M-response amplitude (Fmean/M) were calculated.

Statistical Methods

Paired student's t-tests and ANOVA with Neuman-Keuls method were used to compare the parameters of electromyographic methods. The Wilcoxon t-test was used to compare the parameters of neurological examination. Regression and correlation analyses were also used.[40]

Results

Before Treatment

Significant increases ($p < 0.001$) of TA-reflex amplitude and TA/M amplitude ratio was found on the spastic side (Table 1). On the spastic side there was also an increase ($p < 0.001$) of H-reflex amplitude and H/M ratio (Table 2). The thresholds for the H-reflex with minimal and with maximal amplitude were decreased ($p < 0.001$).

On the spastic side maximal and mean F-wave amplitudes, as well as Fmax/M and Fmean/M amplitude ratios were significantly ($p < 0.001$) increased (Table 3). The F-wave duration was prolonged ($p < 0.001$) and the persistence and number of phases were significantly ($p < 0.001$) increased.

Moderate ($r > 0.3$) to considerable ($r > 0.5$) correlations were found between the amplitude parameters of all three electromyographic methods (Table 4). There were no correlations

($r < 0.3$) between the other electromyographic parameters or between disease duration and electromyographic parameters. The correlations between electromyographic measurements and the clinical measurements of muscle tone, force and reflexes were poor ($r < 0.3$).

After Treatment

The results from the neurological examination revealed decreased muscle tone ($p < 0.01$) on the spastic side with a mean of 50 percent (Table 5). There were no differences between the different modes of treatment except that the effect of Baclofen on reducing muscle tone was less than the other treatments ($p < 0.01$). Muscle force, tendon hyperreflexia, Babinski and ankle clonus were not generally influenced by the treatments ($p < 0.1$). However, a reduction in the patients with Babinski sign ($p < 0.01$) was observed after Baclofen treatment.

The results from the electromyographic examination revealed no influence ($0.1 > p > 0.05$) from any treatment on TA-reflex parameters (Table 1). There was also no effect ($0.1 > p > 0.05$) by any treatment on H-reflex parameters (Table 2).

All parameters of the F-wave in all four groups tended to normalize (Table 3). The mean and maximal F-wave amplitudes, amplitude ratios, persistence and number of phases decreased and the duration was shortened with treatment ($p < 0.001$). There were no differences ($p > 0.1$) between the four treatments.

There were no changes in any of the electromyographic measurements on the healthy side after treatment ($p > 0.1$).

Table 1: Mean Values of T-Achilles Reflex Parameters

Parameters	Healthy Side		Spastic Side		Spastic Side After Treatment	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Maximal amplitude mV	2.14	2.01	4.28	3.41	3.88	3.07
TA/M Ratio — %	17.48	11.3	38.64	21.41	35.55	20.44

The mean values are calculated across all four patient groups, as there are no significant ($p < 0.1$) differences between them.
$\bar{X}$ — mean value
SD — standard deviation

Table 2: Mean Values of H-Reflex Parameters

Parameters	Healthy Side		Spastic Side		Spastic Side After Treatment	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Maximal amplitude mV	3.4	2.4	6.3	3.6	5.9	3.8
H/M ratio — %	29.2	13.7	52.1	20.9	49.9	19.6
Threshold of H-reflex with minimal amplitude — V	181.5	71.3	138.3	69.0	142.6	48.9
Threshold of H-reflex with maximal amplitude — V	220.9	72.4	176.7	74.3	192.9	69.8

The mean values are calculated across all four patient groups, as there are no significant ($p < 0.1$) differences between groups.
$\bar{X}$ — mean value
SD — standard deviation

Discussion

The results of this study reveal that all three electromyographic methods for assessing the excitability of the lower motoneurone are significantly altered by spasticity. The maximal amplitudes of the TA- and H-reflex and their amplitude

Table 3: Mean Values of F-Wave Parameters

Parameters	Healthy Side		Spastic Side		Spastic Side After Treatment	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Maximal amplitude mV	0.4	0.2	1.0	0.4	0.6	0.2
Mean amplitude — mV	0.2	0.1	0.6	0.3	0.3	0.15
Fmax/M ratio — %	5.3	3.3	12.4	5.3	7.1	3.3
Fmean/M ratio — %	2.2	1.5	7.8	3.5	3.6	2.0
Duration — ms	5.6	1.3	12.5	3.1	7.6	1.9
Persistence — %	55.7	15.3	92.0	13.1	62.0	12.1
Number of Phases	2.1	0.3	4.0	1.0	2.4	0.6

The mean values are calculated across all four patient groups and four peripheral nerves ($n = 480$), as there are no significant ($p < 0.1$) differences between them.
$\bar{X}$ — mean value
SD — standard deviation

Table 4: Values of the Correlation Coefficient (r) Between Parameters of TA, H-Reflexes and F-Wave

Parameters	TA-reflex amplitude	TA/M	H-reflex amplitude	H/M
H-reflex amplitude	0.7	0.4	—	—
H/M ratio	0.5	0.6	—	—
F-wave maximal amplitude	0.2	—	0.3	0.1
F-wave mean amplitude	0.1	—	0.3	0.2

Table 5: Mean Values of Neurological Examination Parameters

Parameters	Spastic Side Before Treatment	Spastic Side After Treatment
Tendon reflexes-points	3.2	3.0
Muscle tone-points	2.5	1.2
Muscle tone-Baclofen	2.3	1.4
Muscle strength-points	2.2	2.2
Ankle clonus-% patients	18.3	12.7
Babinski sign-% patients	48.9	40.0
Babinski sign-Baclofen	53.3	33.3

The mean values are calculated across all four patient groups, as there are no significant ($p < 0.1$) differences between groups, except for muscle tone and Babinski sign after Baclofen.

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ratios are increased. The thresholds for the H-reflex with minimal and with maximal amplitude are decreased. The mean and maximal F-wave amplitudes, as well as the amplitude ratios are increased. The persistence and number of F-wave phases are increased and the F-wave duration is prolonged. However, these electromyographic measurements do not correlate with the degree of spasticity. The reason for this lack of correlation may be that electromyographical methods assess only one of many pathophysiological mechanisms of spasticity. These alterations of TA and H-reflex parameters are well known. However, the literature has not paid much attention to H-reflex thresholds, and these results show that they can also be used to assess the excitability of the lower motoneurone.

As regards F-wave, there are reports in the literature of an increase in its persistence and mean amplitude[16,18,19] and a few reports of an increased F-wave maximal amplitude[17,41] in spasticity. Our results reveal other alterations in F-wave parameters in spasticity: an increase in the number of phases and the duration. All F-wave parameters depend on one common factor — the lower motoneurone excitability. [8,17,18,33]

Treatment did not affect the TA- and H-reflex measurements in spite of a clinically observable reduction in spasticity. Other studies have reported that TA- and H-reflexes are not reliable methods for assessing spasticity, since they did not change after decreases in muscle tone.[2]

It is therefore impressive that all treatments influenced F-wave parameters equally well. The alpha-motoneurones are the final common pathway, integrating all segmental and suprasegmental excitatory and inhibitory influences. Consequently, any change in segmental gamma-motoneurones or interneurons would alter the alpha motoneurone excitability. This is probably the reason why myorelaxants like Baclofen and Sirdalud, which are known not to exert their effects directly upon alpha motoneurones could have influenced the F-wave parameters. However, these methods give no information about the pathophysiology since it is not possible to distinguish between primary and secondary changes in alpha-motoneurone excitability. For more detailed analysis of spasticity and myorelaxant action it will be necessary to examine other pathophysiological mechanisms. Increased excitability of the alpha-motoneurone is only one of many mechanisms of spasticity.

The literature about changes in motoneurone excitability after treatment of spasticity is controversial. In all these investigations only TA- and H-reflexes were studied except for a single report of F-wave changes after chronic cerebellar electrostimulation.[13] The present study has shown a great difference between the TA- and H-reflexes and the F-wave in regard to the effects of treatment. This could be explained by the differences between the methods. The H-reflex and TA-reflex depend not only on the excitability of alpha-motoneurone, but also on the activity of gamma-motoneurones and presynaptic inhibition.[9,42] F-wave parameters depend solely on the excitability of the alpha-motoneurone. This is probably the reason why the F-wave method is so much better at detecting an effect of treatment.

In conclusion, TA- and H-reflexes are not sensitive enough to assess changes in the excitability of the lower motoneurone. Aside from the fact that their parameters do not depend solely on the excitability of the lower motoneurone, they have some other disadvantages: special conditions are needed to examine both reflexes[4] and their investigation is restricted to the lower limbs. On the other hand, the F-wave is easy to observe in both upper and lower limbs and no special recording conditions are needed. It depends only on motoneurone excitability and is sensitive enough to monitor the effects of treatment for spasticity.

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