

CLINICAL ELEMENTS FOR THE NMS AND FES PROTOCOLS IN THE PRACTICE OF NEUROREHABILITATION

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INTRODUCTION

We are witnessing a very fruitful period in the development of progress of biomedical engineering of devices, new methods for external control of paralyzed extremities due to neurological disorders. If we give just a look to the program of the 7th Vienna International Workshop on Functional Electrical Stimulation, it is easy to support this statement. During this meeting there are presentations and discussions on

1. electrical stimulation of denervated muscles,
2. NMS and FES in the paraplegia due to upper motor neuron lesion,
3. FES cycling,
4. implant technology,
5. command and feedback signals, stimulation parameters, up to
6. stimulation and closed loop control,
7. functional restoration of the drop foot,
8. stimulators for upper extremity and their functional restoration.

Therefore, it is opportunity to advance further practice of the NMS and FES within clinical programs of neurorehabilitation.

In the past, it can be that we didn't promote enough presentation and demonstration of clinical protocols of NMS and FES for treatment of neurological conditions and applications of electrophysiological bracing, orthosis. Therefore, to bring to your attention of necessity to discuss clinical protocols and their elements, in order to facilitate interest of clinician for NMS and FES in the clinical practice of the neurorehabilitation, we shall present in this lecture, some of the elements of such protocols for percutaneous stimulation.

First steps before we initiate programs of NMS and FES

After a patient with paralysis meet recruitment criteria for treatment with NMS or FES procedure or for fitting with electrophysiological brace, orthosis and thus become potential candidate for clinical program and defined functional goal, following steps we should perform:

1. Practicing professional must be fully informed by patient attending physician about patient condition. After this we shall describe to the patient what he will experience while we are applying electrodes for application of stimulation of peripheral nerves structures. Furthermore, we shall explain operation of stimulation unit and then whenever possible apply at first at the site of the skin where we expect normal sensation (preferably over the skin with underlying muscle and skin intact innervation) as well as under visual control of the subject while we perform initial testing.

We should provide opportunity to the subject to experience tingling sensation evoked by train of stimuli and progressively and carefully by controlling stimulus parameters to inform subject about

different threshold of stimulation. Thresholds for

- a) sensation and just below the sensation
- b) definite and comfortable sensation
- c) evoked movement
- d) maximal tolerance of discomfort.

Moreover all this threshold can be changed by repetition of stimulation and patient accommodation to externally induced sensation and thresholds above evoked motor responses can be decreased by stimulus features and duration of stimulation. We shall avoid application of NMS or FES within areas with altered, decreased threshold for electrical stimulation, hyperesthesia, hyperalgesia.

After such training session we shall be ready to proceed with examination and evaluation of functional responses to neuromuscular stimulation in order to learn of neuromuscular physiological conditions and effect of electrical stimulation on initiation, external control and modification of movement performances.

2. The second step consist of evaluation procedure of muscle capability to respond to percutaneous stimulation to repetitive single stimuli with visible or by palpation recorded muscle twitches. If we measure time for how long muscle respond with muscle twitch we shall learn about endurance and fatigability of muscle contraction and force production capabilities. Afterwards depending from patient condition and our tentative goals, we should examine response of stimulation of cutaneous nerves for modulation of muscle tone, modification of volitional movements as well when necessary what will be effect of stimulation of mixed nerve trunk, or motor point for eliciting functional movements.

In short we should not start treatment program of NMS and FES unless we examine and prove that we have available expected properties of the electrical stimulation of the nerve structures and there are responding to our electrical parameters within comfort to the stimulated person. We should carry examination of physiological properties of neuromuscular system and responses of altered motor control to stimulation parameters to the different sites and by use of different size of electrodes.

Such clinical evaluation sessions should be performed in several sessions.

After evaluation is completed, we shall be ready to start to develop clinical goals of NMS and FES protocols by being aware that they can be:

- a) Conditioning protocol,
- b) Neuroaugmentive and
- c) Learning one.

None of these protocols exclude each other and their sequence or application will depend from our findings.

Neuromuscular stimulation (trophic state of the muscle)

During upper motor neuron dysfunction, either partial or complete, muscles with impaired innervation (after weeks and months) will suffer from progressive muscle disuse atrophy and alter capacity for muscle force and fatigue resistance. Muscle bulk decreases, and when muscle contraction are induced electrically there can be sometime in the decondition muscle only a few contractions and their amplitude will progressively diminish. Thus it is essential to develop a rigorous daily NMS program before use of the muscles with impaired upper motor neuron innervation by means of externally controlled electrical stimulation for the generation of the muscle force.

After the muscle force has become stronger, we then add a program of physical therapy with subject active movements, so that we can increase the endurance of the whole body and not only of the stimulated muscles.

Nerve electrical and neuromuscular stimulation and modification of muscle hypertonia

Muscle hypertonia usually results from chronic upper motor neuron dysfunction. When it is not to severe and its distribution is not generalized, but moderate and restricted to several muscle groups, stimulation of cutaneous nerves or spastic muscle groups can be effectively applied to diminish increased muscle tone (Lit. 1, Lit. 2).

The train of stimuli (20-50 Hz) adjusted to strength below threshold for sensation is the appropriate electrical stimulation strength for the control of spasticity. (In case patient has absent sensation we can use threshold for minimal motor response and then to adjust amplitude to be reasonable below threshold for motor response and within the range we shall expect to be if subject has preserved sensation). Stimulation should be applied for 30 minutes, twice a day. It is important to take care of the skin and to build skin tolerance for long-lasting electrical stimulation. Once skin tolerance is developed, and if muscle hypertonia is persistent, it is possible to stimulate one or several cutaneous nerves or the skin above the spastic muscle groups for several hours and several times per day.

Overall, electrical nerve and neuromuscular stimulation for the modification of muscle hypertonia has the advantage of being simple, whereas some difficulties lies in the proper placement of the electrodes over cutaneous nerves of sural, saphenus, lateral cutaneous femoral nerve, and cutaneous branches of radialis, musculocutaneous, ulnaris, radialis, axillaris nerves Another requirement is careful tuning of the strength of train of stimuli. This procedure is useful in those cases when spontaneous recovery will diminish spasticity.

Neuromuscular stimulation for the modification of patterns of movement

Another feature of upper motor neuron dysfunction is the presence of multi-joint patterned flexion-extension movements instead of the fine coordination control of different joints during the same motor sequence. A predominant extensor trust pattern with weakened flexor pattern is usually well recognized as the circumduction movement of the ambulatory hemiparetic patient after stroke, or the ambulatory SCI patient who can develop functional or non-functional slow gait when using crutches or other devices. In these patients, it is first necessary to use the electrical muscle conditioning (described above) and when muscle resistance improves, then proceed simultaneously with electrical stimulation and volitional movement. This is always a need for multi-site stimulation since motor deficits are present in several muscle groups.

There is not general recipe indicating how and when to stimulate different muscle groups: for example, in ambulatory spinal cord subjects, there are rarely identical motor patterns for both limbs or similarity between patients even when they have similar spinal cord lesions. Therefore, we have found that it is beneficial to use multi-site stimulation in the laboratory environment to assess the responsiveness of motor pattern, and one- to two- channels unit at home for daily training.

Functional electrical stimulation for impaired functional movement of the single muscle group

Isolated drop-foot and drop wrist are rare motor deficits in chronic neurological patients after stroke, brain or spinal cord injury, usually there are part of impaired pattern movements. However, these conditions are more likely to respond positively to the use of FES, since it is a very simple technological task to substitute the loss of control of single muscle group in the presence of volitional activity of all other muscle groups. This external approach is also very effective for the correction of more deficits and the improvement of motor activity.

However, while working with upper motor neuron drop-foot or drop-wrist, we have found that on eliciting functional movement of single muscle groups, the presence of subclinical impairment of other leg and thigh muscle group become more noticeable. Therefore, even when applying FES to one muscle

group, it is imperative to incorporate in the program exercise and gait correction of motor activity of the other muscles groups not obviously affected at the beginning.

Externally electrically induced modification of altered neurocontrol

The application of external electrical control in patients with paralyzed extremities has given rise to two basic questions:

1. how effective is this approach to overcoming motor neuron dysfunction and
2. is it possible to accomplish the long term modification of motor control even in the absence of electrical stimulation.

The answer these question depend from the degree and the pattern of upper motor neuron dysfunction and also on the level of the lesion (spinal cord, brain stem, or brain).

In ambulatory SCI patients there have been reported observations that after longer period of NMS or FES the patient can achieve new features of motor activity which persist without any further stimulation

(Lit. 3). Similar finding were reported by Kralj and Bajd (Lit. 4) and Boucher and Pepin (Lit. 5).

The electrically and externally induced modification of altered neurocontrol in this population of patients requires that stimulation should be tailored according to the patient's residual motor control. Therefore, it is essential to have a multi-site stimulation system with a variety of controls for the amplitude and duration of the train of stimuli from different channels. The patient's understanding of this approach and his commitment to the relatively modest functional outcome is also factor to be considered.

The topic of improvement of locomotor recovery after sensorimotor stimulation in the spinal cord injury has been revived from the neuroscience's point of view by Muir and Steeves, (Lit. 6) and from Clinical point of view recently by P.H. Gorman (Lit.7).

SUMMARY AND CONCLUSIONS

Significant contemporary progress in the designs, production of devices and methods for external control of impaired motor control in humans is asking for promotion of the NMS and FES practice of neurorehabilitation. Our recommendation is to make an effort to report together with description of clinically applicable devices also detailed protocols how application supposed to be conducted when a clinical device is introduced to NMS and FES therapy as well as when FES orthotic device is applicable.

In this lecture, we have illustrate some of the elements of such clinical protocols in order to promote discussion of how to facilitate wider application of NMS and FES neurophysiological procedures to the clinical programs of neurorehabilitation.

Neurophysiological features of NMS as an external substitution and control of peripheral inflow from paralyzed parts of the body can bypass alter connections by the injury of the CNS between processing nuclei of the brains and spinal cord.

This additional input to the CNS can prevent secondary neurogenic lesions by prevention of the effects of disuse in the early stages of CNS injuries. In addition, during recovery of function after acute phase by

NMS we can facilitate and maintain nonspecific and generalized "central state of excitability of the CNS" which is critical to be operational on the appropriate higher functional level during recovery of impaired specific sensory-motor functions.

All this above listed effects of application of NMS and FES as a procedure for prevention of effects of disuse and to provide externally controlled substitution for activity-dependent processes of recovery are at present known neurobiological bases for repair processes. However, we should not neglect active role of NMS and FES procedures for maintaining optimal biological conditions in patients with chronic lesion and established incomplete recovery. We should use those mentioned procedures for clinical protocols to support maintenance of the optimal patient brain and neuromuscular functional condition even when neurological deficits can't be ameliorate.

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