FUNCTIONAL ELECTRICAL STIMULATION (F.E.S.) IN STROKE

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Abstract

Electrical stimulation is a physical therapist technic used on many different pathologies; stroke is a recent application field that involves specific adjustment parameters, wich are different from other pathologies, based on last neurosciences advances, specially related with the work way to obtain cognitive activation.

Key words

Stroke, electrical stimulation, paretic muscle, spastic muscle, cognitive activation, synaptogenesis, training, application parameters

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INTRODUCTION

When performing bibliographic searches, several key words may be used for "electrical stimulation":

- E.S. electrical stimulation.
- N.M.E.S. neuromuscular electrical stimulation.
- E.M.S. electrical muscular stimulation.
- F.E.S. functional electrical stimulation.

The main objectives for the use of electrical stimulation in stroke are:

1. Increase force and decrease atrophy of paretic muscles.
2. Stretch spastic muscles that are subject to fatigue.
3. Improve proprioception through stimuli produced in tendon and muscle receptors (fig. 2).
4. Maintain muscle and connective tissue trophism, avoiding accumulation of waste products, deficiency of water, oxygen and nutrients, and minimizing adhesions that restrict gliding planes of tissues, which can lead to shortening of the tissues.

Thanks to this double action, contraction of paretic muscles and elongation of spastic antagonistic muscles, spasticity is inhibited (fig. 1).

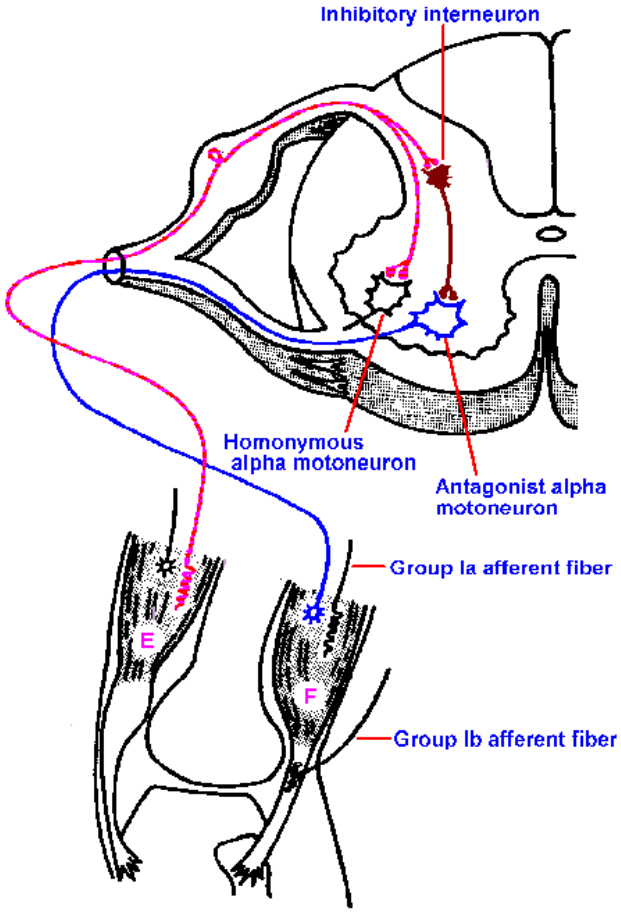

Fig. 1. The reciprocal inhibition mechanism.

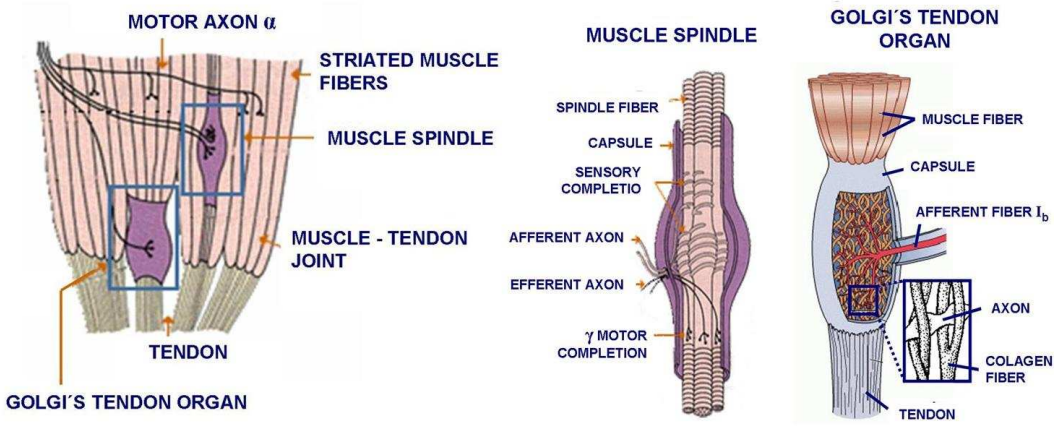

Fig. 2. The tendon and muscle receptors.

Kotz theory (Russian stimulation)

Based on 2500 Hz being the best frequency to stimulate the muscle, according to the following mathematical formula (fig. 3).

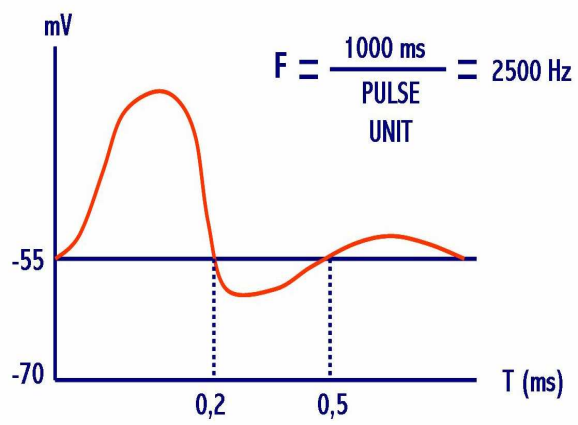

Fig. 3. The pulse unit.

However, no system in the body functions at such a high frequency; only spinal cord glia contain fibers sensitive to vibration at 750 Hz, although the average is 128 Hz., In general, muscle fibers respond to frequencies at 20 Hz (slow-twitch fibers) to 80-150 Hz (fast-twitch fibers). Therefore, there is a conflict between the 2500 Hz proposed by Kotz and the frequencies of physiological systems; muscle metabolism is not prepared to adapt such a high frequency.

On the other hand, on average a muscle fiber has energy reserves, in the absence of water and oxygen, to produce 100,000 action potentials; therefore, after 40 s at 2500 Hz, the cell has no energy remaining. During an intense contraction, the muscle utilizes its own reserves since blood transport of food and oxygen is almost completely interrupted; so at a maximal contraction of 25-40 s the muscle will stop responding to the stimulus.

Also, nerves have a physiological stimulus frequency; if a very high stimulus is applied (2500 Hz o 1000-4000-8000 Hz, whatever), the motoneurons will try to sustain this frequency for a few seconds; but, since this is impossible, end up functioning at their own physiological frequency (fig. 4).

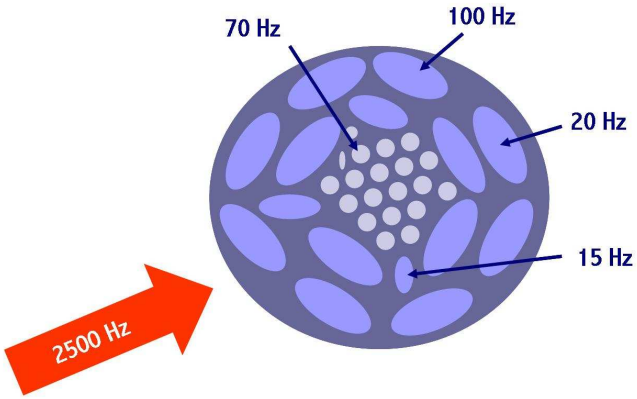

Fig. 4. Nerve fibers work frequency.

Another problem is that if there are no pauses in the applied current, time is not allowed for the nerve to repolarize; so if a current of 2500 Hz is used, the frequency must be modulated to generate these pauses (fig. 5).

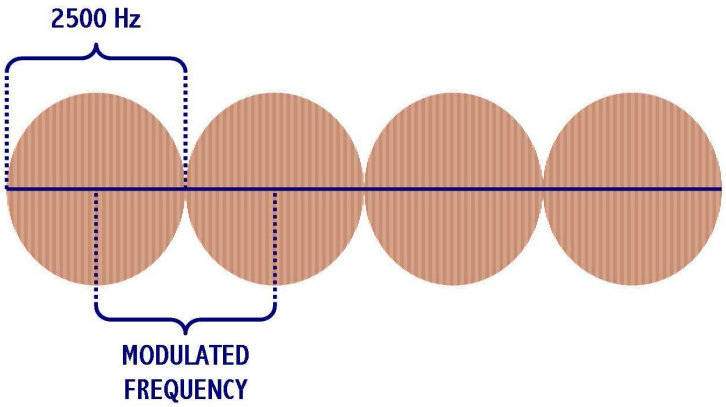

Fig. 5. The modulated frequency.

The predominance of slow or fast-twitch fibers gives its name to a muscle when one of the two contains a percentage above 70% (Jonson). With training, it's possible to convert super fast fibers to others which are slightly faster or slower; but it is impossible to directly change type I fibers to type IIb and vice versa.

It's the proportion between type IIc and IIa fibers that determines more focus on force or endurance (fig. 6).

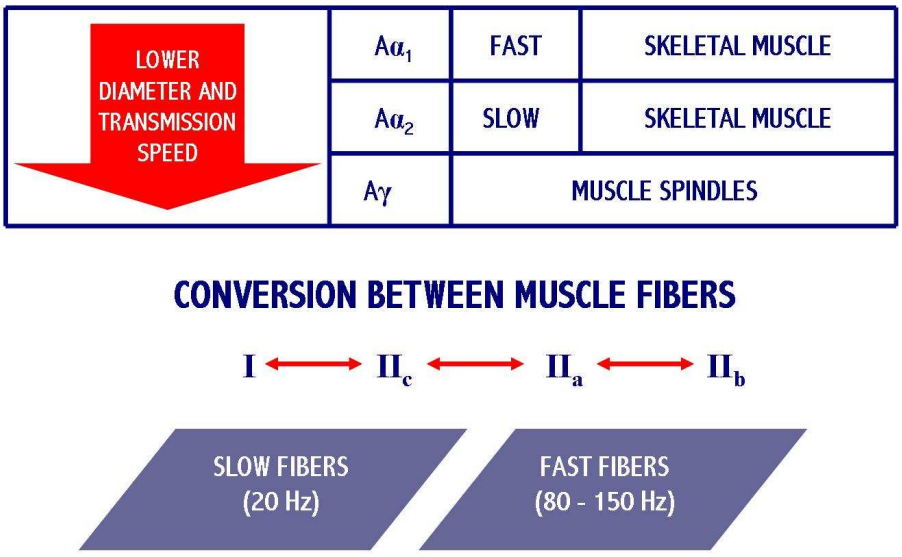

Fig. 6. Different types of afferent fibers.

APPLICATION PRINCIPLES

Several factors must be taken into account when applying electrical stimulation:

1. The voluntary contraction depends on the size principle; that is, first the slow-twitch fibers are recruited, then the fast-twitch fibers are recruited according to the force production needed. (fig. 7).

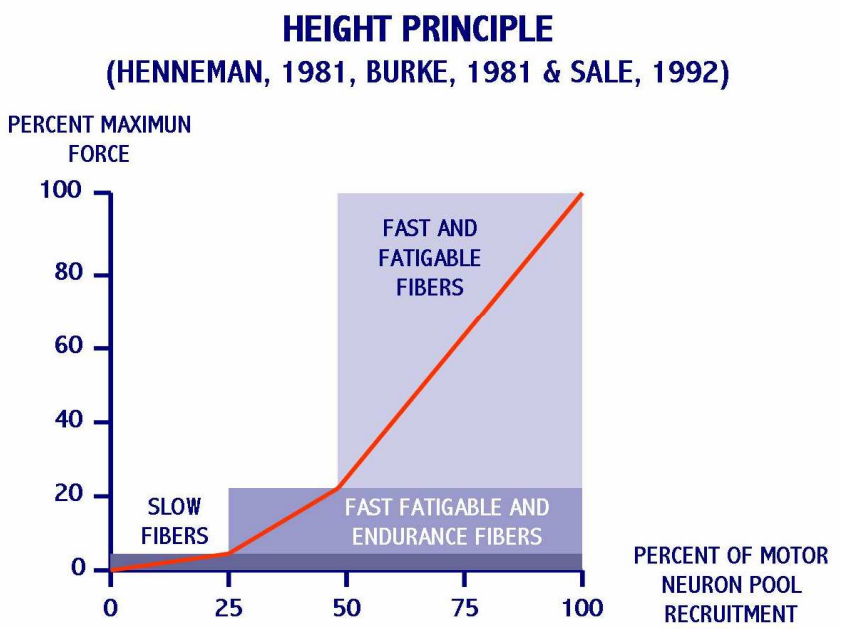

Fig. 7. Henneman´s principle.

2. Nearly all of the movement generators are in the spinal cord, but cortical activity is fundamental in motor control; for this reason it is fundamental to observe the movement produced (fig 8).

Fig. 8. The cortical generators.

3. Cortical activity, through concentration, is also fundamental to optimize muscle performance; hence it is very important to pay attention to the stimulus and try to execute voluntary movement that electrical stimulation induces. Only by paying attention to the stimulus, changes are produced at the cortical level through synaptogenesis (fig. 9).

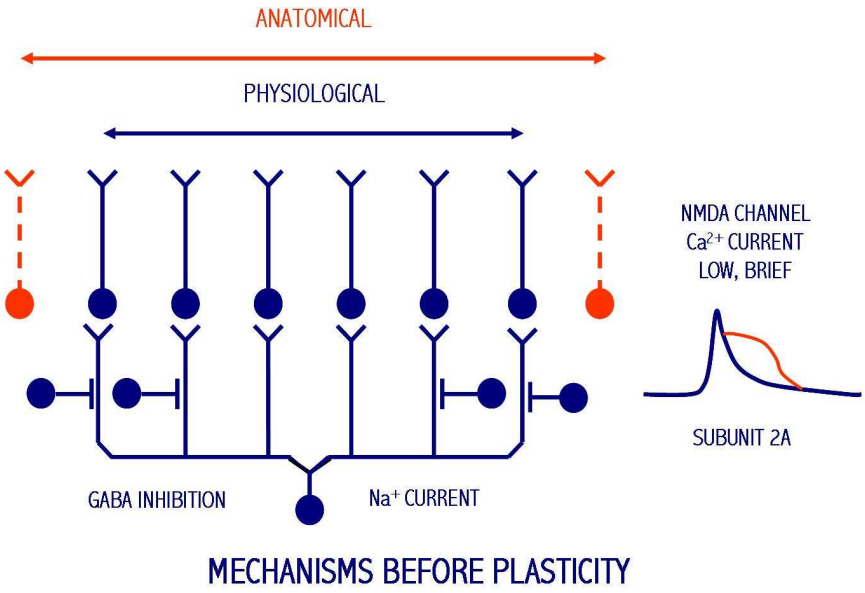

Fig. 9. The brain tissue in normal situation.

In the damaged area, brain neuroplasticity can provoke very fast changes, with ~~a~~ neuronal growth between 1 and 400 mm daily (fig. 10).

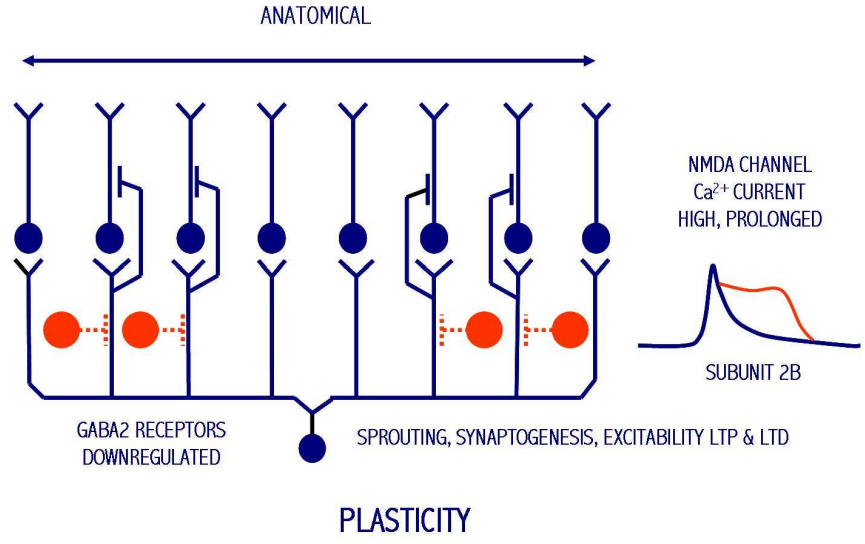

Fig.10. Synaptogenic growth.

Thanks to this learning capacity, the cortex can experience extensive changes within its own structure (fig. 11 and fig. 12).

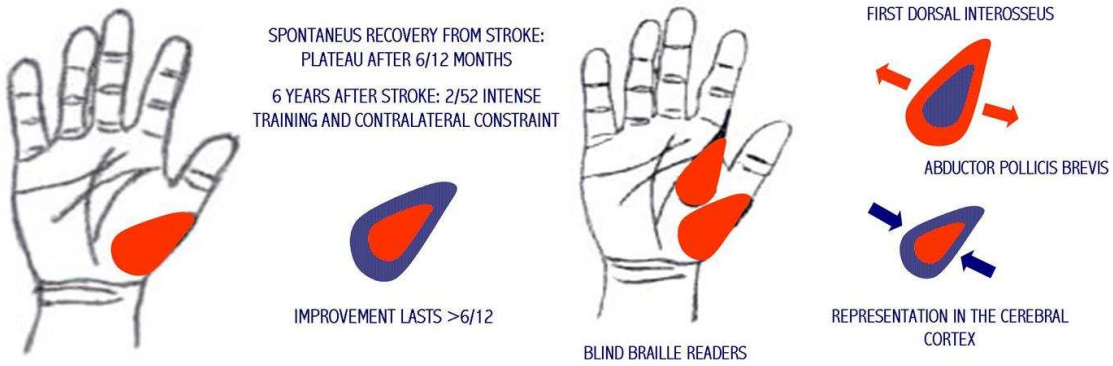

Fig.11. Growth of brain hand muscle representation after a stroke trhought cognitive training.

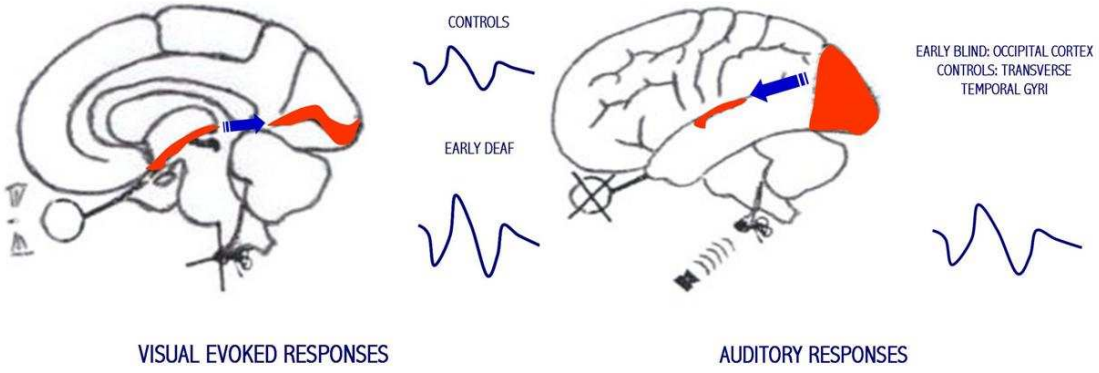

Fig. 12. The cognitive training can modify the cortex structure and interconnections.

To some extent, mental representation is as important as movement execution (fig.13) and, without it, the movement will be pathological; for this reason it is very important during the electrical stimulation session to request that the patient sense the movement caused by the current and try to execute it. Even if the patient does not achieve it, this mental visualization process provokes motoneuron recruitment at the cortical and spinal cord levels (fig. 14).

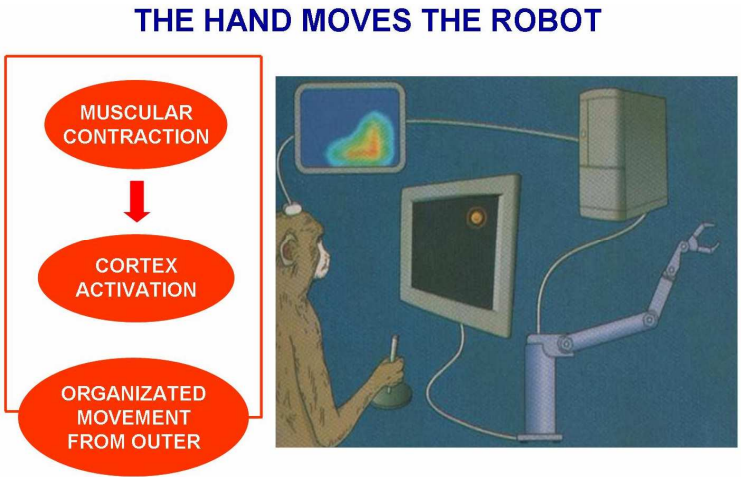

Fig. 13. Traditional motor control representation.

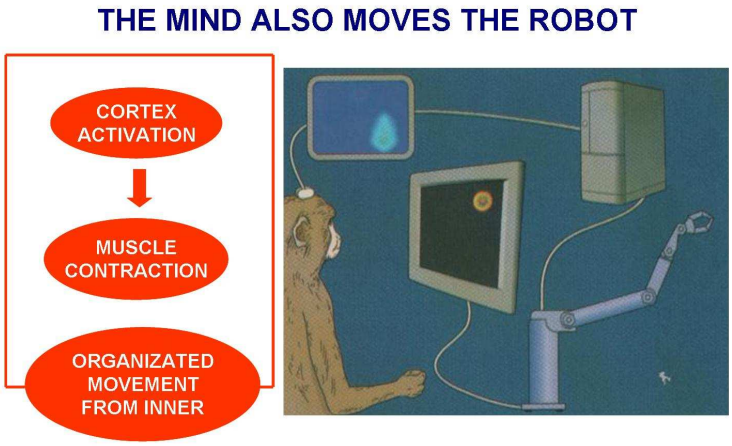

Fig. 14. Present motor control representation.

4. Voluntary contraction is asynchronous (concept of space summation). In other words, the number of fibers recruited is determined by the size principle, according to the desired force. Electrostimulation is synchronous, meaning one pulse provokes a simultaneous contraction of all the muscle fibers (100% recruitment). Electrical stimulation is not physiological, so voluntary contraction must always be combined with electrostimulation.

5. Voluntary contraction is more fatiguing than electrical stimulation at both the cardiovascular and nervous levels (neurotransmitter fatigue); this can be useful since stroke patients tend to suffer from associated cardiovascular problems. Electrostimulation is only more fatiguing than voluntary contraction at the energy consumption level (ATP use).

6. Voluntary contraction produces a stronger contraction than electrical stimulation (it generates only 20-30% of voluntary maximum force). This is due to the fact that voluntary contraction provokes not only the contraction of a single muscle, but of an entire muscular chain, in addition to generating ~~a~~ complex nervous activity. Meanwhile, electrical stimulation only causes hypertrophy at the level of the sarcomeres (structural training) (fig. 15), but it doesn't influence coordination processes (functional training).

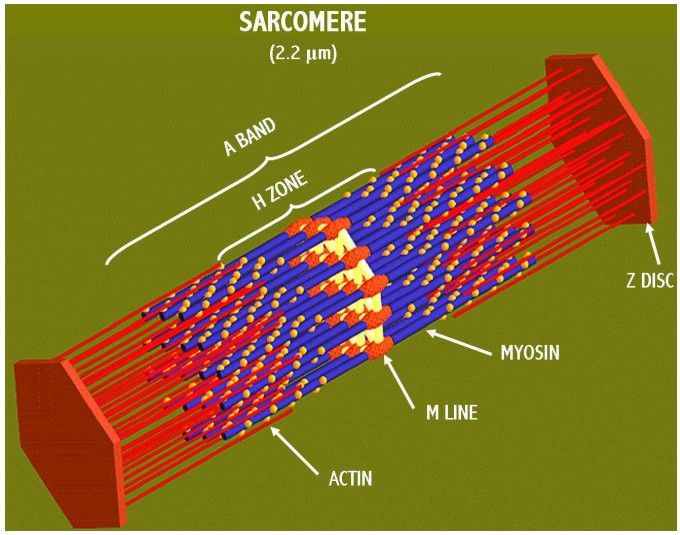

Fig. 15. Sarcomere structure.

Therefore, it is very important to have the patient try to contract the muscle at the same time it is stimulated;, moreover, after the session it is important to perform activities of daily living (ADLs) that involve the stimulated muscles within 10 minutes after ending the session (cognitive training).

7. The frequency of 33 Hz (or a range between 30 Hz and 35 Hz) provokes muscle tetanization. As the frequency increases, the force of contraction also increases as faster, but more fatigable, muscle fibers are recruited. As a result, the muscle fatigues and claudicates (fig. 16).

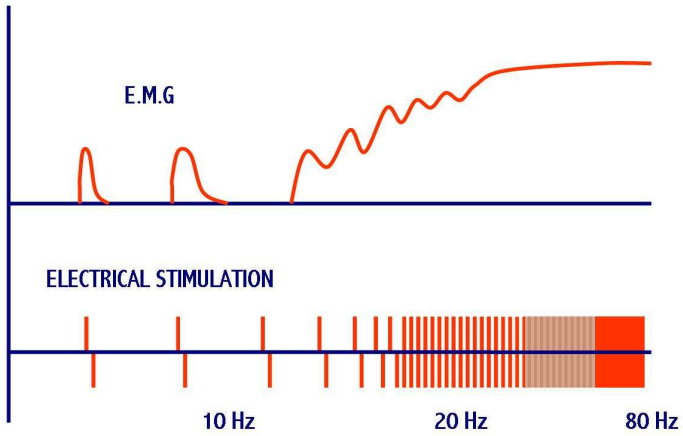

Fig. 16. Electrical stimulation muscle response.

8. When the electrical stimulus reaches the nerve, it first penetrates the most peripheral and superficial fast-twitch fibers and, as the intensity is increased, deeper and slower fibers are activated. So electrical stimulation provokes first the activation of fast-twitch fibers, and later the slow fibers. This is the reverse of the physiological process: first slow-twitch fibers are activated, and then the fast-twitch fibers are progressively recruited. In other words, voluntary contraction provokes activation of muscle fibers (motor units) in order from smallest to largest (Henneman's Size Principle). During a contraction, first the slow the small α_2 units are recruited, then the fast α_1 fibers for very intense contractions. Under normal circumstances, we primarily use slow-twitch fibers, and only use fast-twitch fibers for intense contractions. Electrical stimulation allows, precisely, recruitment of fast-twitch fibers that we normally don't use (fig. 17).

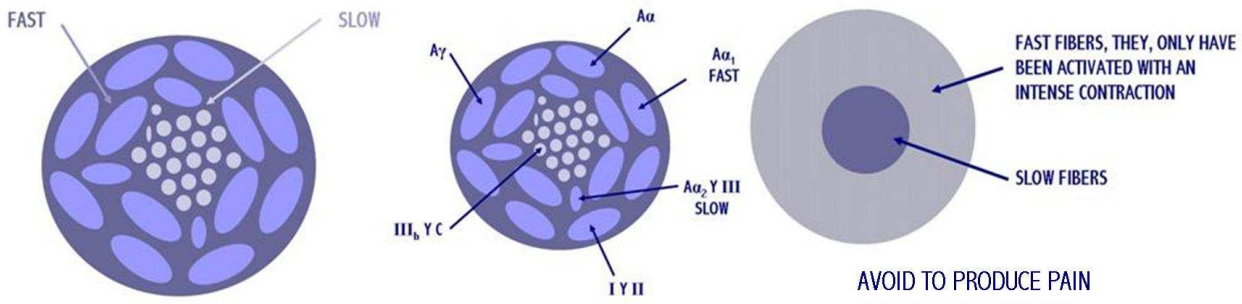

Fig. 17. Electric stimulus action on nervous fibers.

This characteristic of electrical stimulation subjects the muscle connective tissue to a great deal of tension, restoring gliding planes and improving metabolism.

9. Electrodes are generally placed on the motor points. A motor point is a macroscopic point, and there is one in each muscle belly. It is the point where the nerve crosses the muscle fascia to divide into millions of axons that terminate at their own end plate; this point is usually located in the middle of the muscle belly and coincides with the most prominent part of muscle; in the stroke patient, this point is identified by moving the electrode over the zone where we believe the motor point is located, until we achieve an optimal contraction (fig. 18).

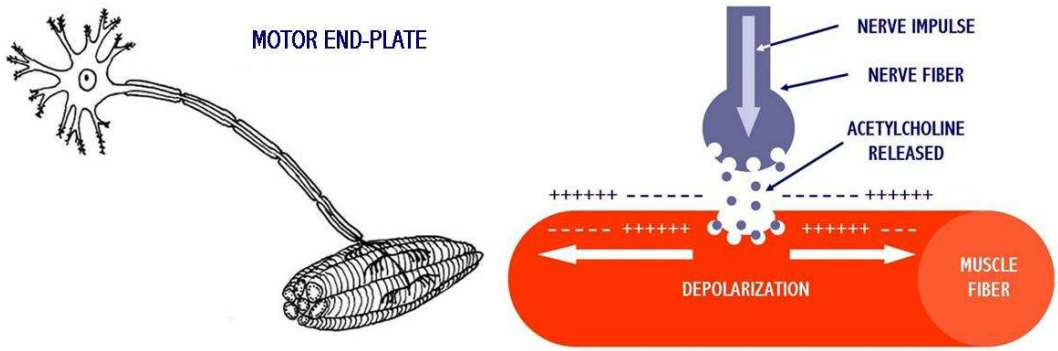

Fig. 18. The motor end-plate.

10. Associate the electrical and the voluntary contractions through a greater sensation of muscle tension but a lesser sensation of current; this permits greater intensity and more comfort (or "less discomfort").

11. Avoid electrically stimulating a shortened muscle because it is more painful and it does not allow the fascia to increase in volume while producing the contraction; so it is generally preferable to place the joint in a position in which the involved muscle is slightly stretched.

APPLICATION PARAMETERS

1. The work frequency used is 33 Hz (or a range between 30 Hz and 35Hz) to activate type I slow-twitch fibers (red and small), that work during aerobic and slow training. 33 Hz reduces atrophy because the slow-twitch fibers are the first to atrophy due to their need to be always active (fig. 19).

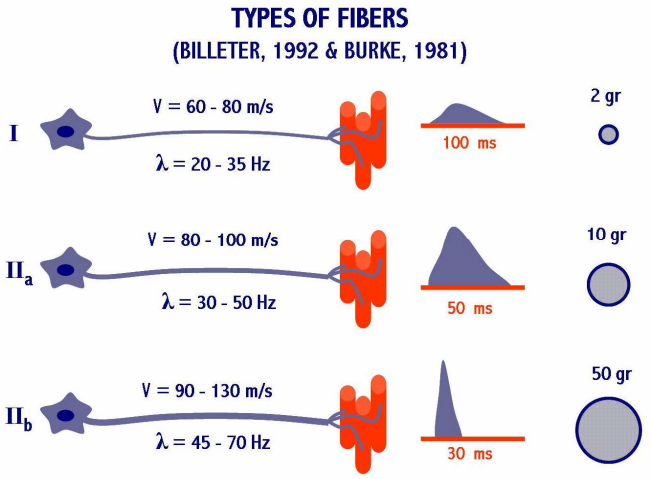

Fig. 19. Work frequencies in differents types of fibers.

2. The stimulus must never be painful (comfort concept), so we use symmetrical or asymmetrical biphasic rectangular impulse. Biphasic, as opposed to monophasic, impulses are used to decrease the risk of chemical burns at the electrodes, allowing greater intensities and longer application times (fig. 20).

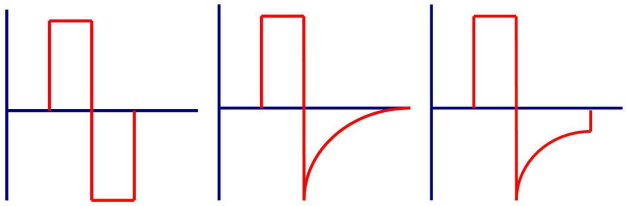

Fig. 20. Different types of pulses used.

3. The longest pulse time possible is selected (between 350 and 450 μs, depending on the machine) so that only the paretic fibers contract, and so that they don't adapt to the stimulus.

4. The intensity must be high but not painful; it has been observed that there is a limit to the intensity of contraction; the impulses that exceed this maximum only generate pain (fig. 21).

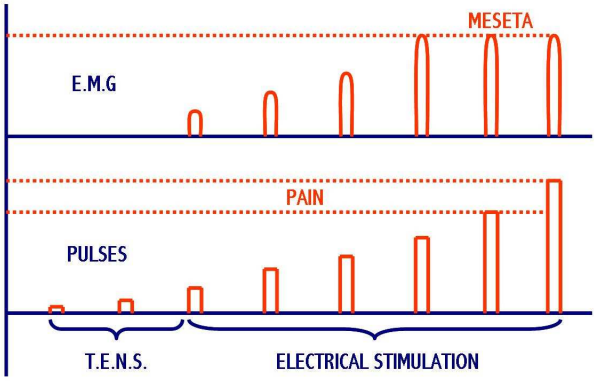

Fig. 21. Intensity used in electrical stimulation.

5. In the stroke patient, impulse trains are constructed with long work (on) times, and, moreover, progressive ramping of the impulse as long as possible spasticity (in my own practice, 5 to 10 seconds is enough); also, the "off time", between each train, must be double the "on time", because the paretic muscles need greater time for recovery (fig. 22).

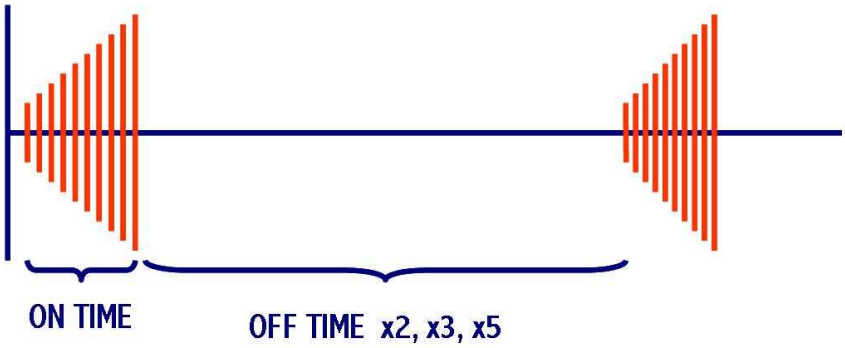

Fig. 22. Making the impulse trains.

6. The electrodes are placed to our preference, with the objective being that we generate a good contraction that is as comfortable as possible. The most appropriate muscles are:

- On the one hand, on supraspinatus (fig. 23) or infraspinatus muscles (fig. 24), and on the other hand on the posterior deltoid muscle; the objective is to involve the glenohumeral joint, that tends to be subluxed inferiorly; it is important to look for the placement that generates the best contraction, without provoking shoulder elevation by the upper trapezius.

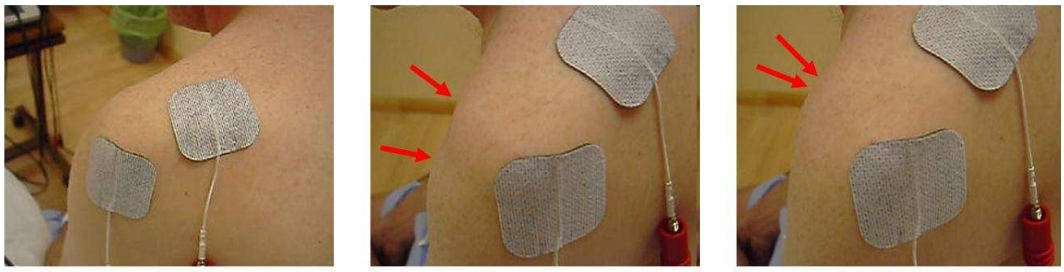

Fig. 23. Placing on supraspinosus and posterior deltoid.

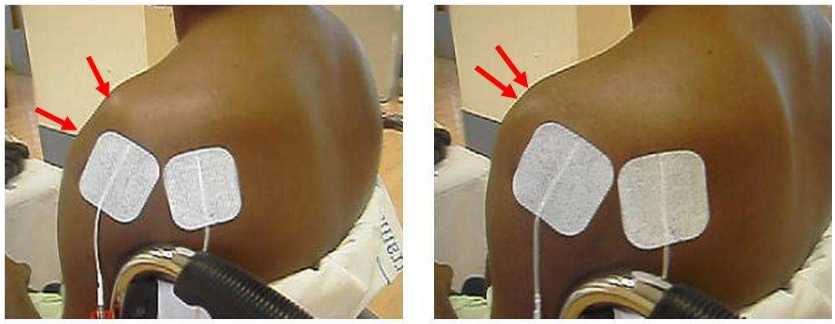

Fig. 24. Placing on infraspinosus and posterior deltoid.

- On the extensor muscles of the wrist,one electrode on the lateral epicondyle and the other on the lateral aspect of the forearm (fig. 25), or on the radial nerve point, about 10 cm above the lateral epicondyle (fig. 26); the objective is to activate extension of the wrist and to avoid edema formation; again we try to obtain the best contraction with extension and radial (not ulnar) deviation of the wrist.

Fig. 25. Placing on forearm.

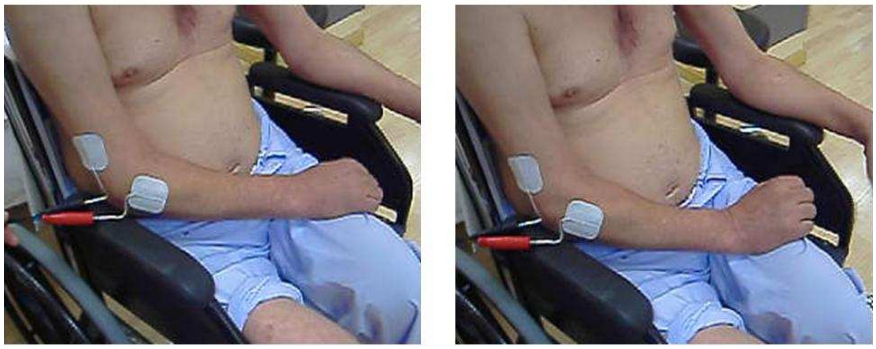

Fig. 26. Placing on radial nerve point.

- On the opponens pollicis muscle, one electrode over the thenar eminence, and the other over the middle of the carpal tunnel to stimulate and activate the median nerve (fig. 27); the objective is avoid atrophy and fibrosis of the first interdigital commissure. Avoid wrist and finger flexion since it reproduces the patient's pathology.

Fig. 27. Placing on opponens pollicis muscle.

- On the peroneus longus and peroneus brevis muscles (fig. 28); the objective is to activate them and to avoid dragging the foot during gate. Try to provoke ankle dorsiflexion and eversion, never foot inversion since it activates the tibialis anterior muscle, reproducing the pathology.

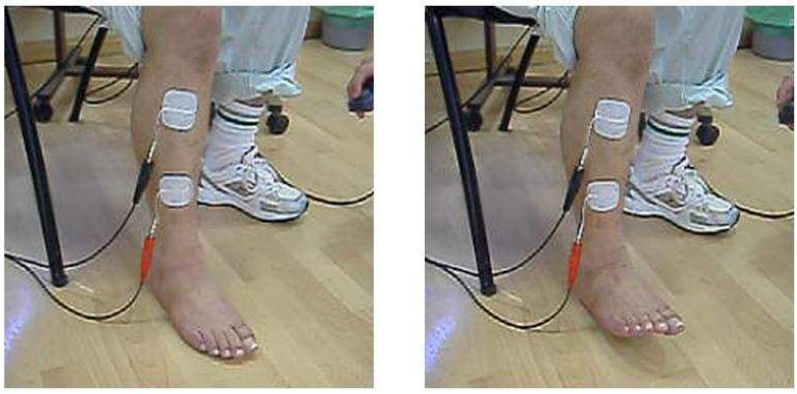

Fig. 28. Placing on peroneus longus and brevis muscles.

6. The typical session lasts 30 minutes daily; it is preferable to apply electrical stimulation immediately after the manual training of paretic and spastic muscles to take advantage of the learning that took place in the nervous system.

CONCLUSION

Electrical stimulation in the stroke patient is an efficient tool for the maintenance of muscle trophism, helping to reduce the appearance of edema and fibrosis in paretic muscles, and allowing the patient voluntary access to these muscles when combined with cognitive activation.

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