Functional electrical stimulation of denervated muscle: Clinical improvements

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Abstract

Spinal-cord injury (SCI) causes a rapid loss in both muscle mass and contractile force, and the process is especially severe when the injury involves spinal motoneurons. By using an adapted stimulation protocol with increased number of stimuli per day, thus increasing the amount of the muscle activity, we were able to improve the condition of the patient's thigh muscles. The perfusion was increased by 100% - 480% and muscle fiber size increased by +53%. This is also confirmed by measuring the muscle cross sectional area with computed tomography (CT) of the thigh showing an increase in m. quadriceps area of 34.6%. The electrically induced contraction force was improved by 828% in patients which were paralyzed up to 2 years. An additional effect of this therapy was the better cosmetic appearance of the thigh, that is highly appreciated by the patients. Overall the above mentioned factors are an important contribution for preventing secondary diseases like decubitus ulcers in patients with permanent denervation of lower extremity.

Key Words: human muscle, permanent denervation of the lower extremity, FES, muscle recovery, prevention of secondary diseases.

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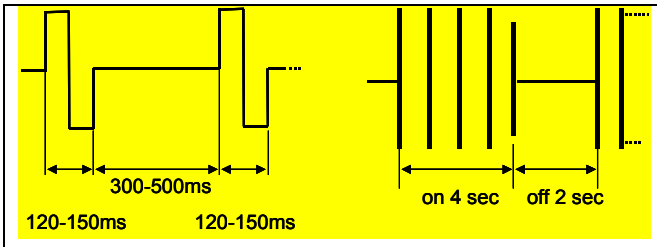
Spinal-cord injury (SCI) causes a rapid loss in both muscle mass and contractile force. The process is especially severe when the injury involves spinal motoneurons since atrophy is followed by fibrosis and fat substitution. By using an adapted stimulation protocol (Figure 1 and 2), with higher currents and much more per day stimuli than those elicited during standard electrotherapy, it is possible to induce an extent of muscle activity, that improve the condition thigh muscles of the patients (1-6).



AT THE BEGINNING: TWITCH TRAINING
40 msec impulse and 10 msec rest (20 Hz)
2 sec. on /2 sec. off for 3 - 5 minutes, 1-2 minutes pause,
3 - 5 times a session, twice a day

FORCE TRAINING: BURST TRAINING
15 repetitions per set - 2 min rest between each set,
6 - 8 sets a day - first sessions without ankle weights,
later on 1 to 5 kg on the ankle

Figure 1. *Patterns of currents for long-term denervated human muscle stimulation. Twitch contractions are elicited by biphasic rectangular current pulses of duration 120 ms and amplitude 200 mA, representing delivering an impulse energy of 1.92 Joules, to recruit fibers throughout the quadriceps femoris muscles. The long duration of the impulses precluded the use of frequencies that would elicit tetanic contractions; training is therefore initiated at 2 Hz and delivered for 15 min/day, 5 days/week.*

Figure 2. *Burst Stimulation induces tetanic contractions of the thigh muscles. After several months of twitch stimulation the muscle becames more excitable and pulses of shorter duration could be used. The protocol is changed to a tetanic burst stimulation consisting of pulses of 40 ms delivered at 20 Hz for 2 s ON, 2 s OFF for 15 min/day, 5 days/week. later on 1 to 5 kg on the ankle Finally, 1 to 5 kg is charged on the ankle.*

As the consequence of the training, the thigh muscle perfusion increases by 100% - 480% and muscle fiber size in muscle biopsies are increased by +53% (Figure 3). The electrically induced tetanic contraction force was improved by 828% in patients, which were paralyzed up to 2 years.
This is confirmed by measuring the muscle cross sectional area with computed tomography (CT) of the thigh, that shows an increase in m. quadriceps area of 35% (Figure 4). After long term FES training, there is better cosmetic appearance of the thighs, that is highly appreciated by young patients and their relatives.
We conclude that FES-training of paraplegics is safe and effective. Overall its effects are important in preventing secondary diseases, like decubitus ulcers, in patients with chronic denervation of the lower extremities.

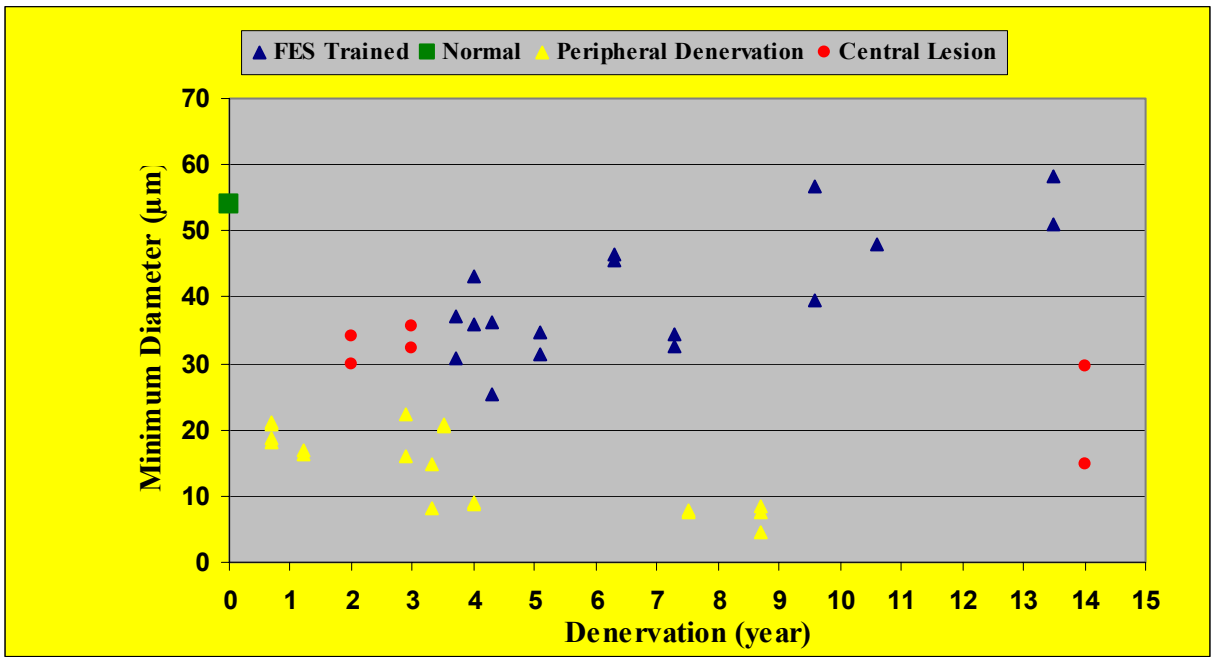


Figure 3. *Morphometry of muscle biopsies show a significant increase in muscle fiber size after FES Training.*

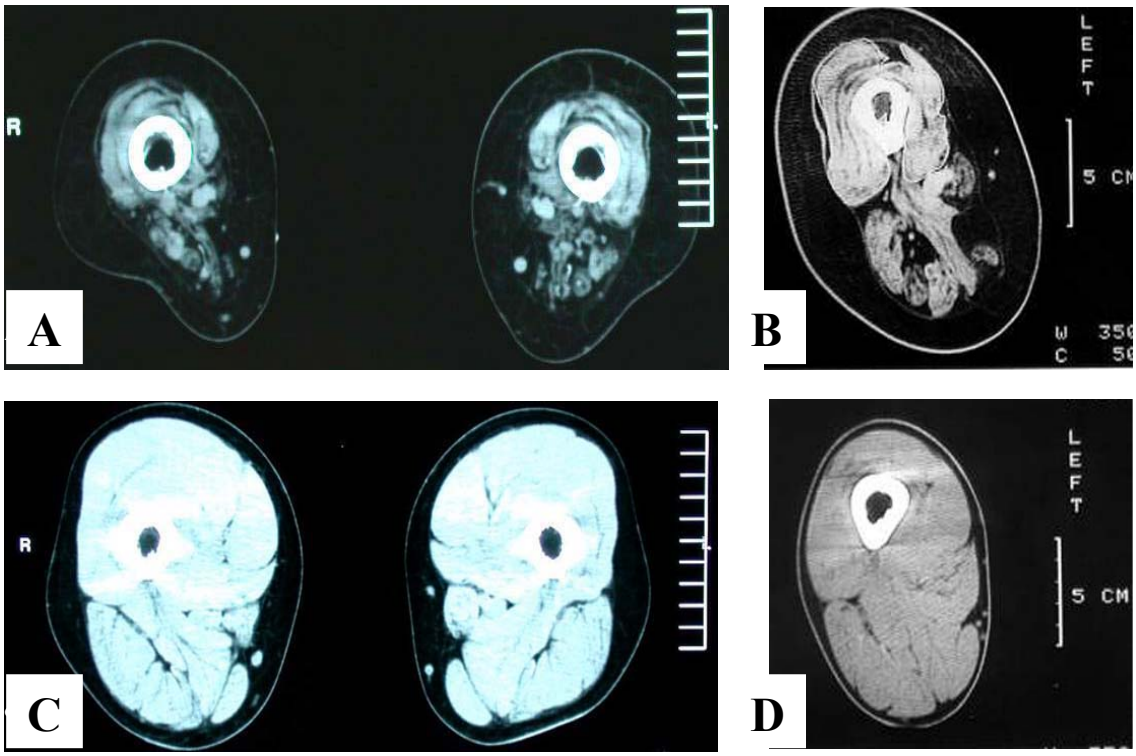


Figure 4. *CT-Scans cross-section of the thighs of two long term denervated patients without stimulation (A, B), of a long term denervated patient with stimulation (C) and of a patient with a spastic lesion and stimulation (D).*

Acknowledgements

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