PLANTAR FLEXION STIMULATION IN FOOT DROP FES TREATMENT

FESIA TECHNOLOGY

WHITE PAPER

May 2020

PLANTAR FLEXION STIMULATION IN FOOT DROP FES TREATMENT

Functional electrical stimulation (FES) is one of the most commonly used technologies for the treatment of foot drop. Usually, the devices stimulate dorsal flexion (DF), but not plantar flexion (PF). This document provides a scientific and academic justification of the importance of stimulating the plantar flexion of the **Fesia** Walk system, reviewing the available scientific evidence in this regard.

INTRODUCTION

Hemiplegic patients often demonstrate 2 common gait impairments: "foot drop", caused by inadequate DF; and PF spasticity or stiffness, causing decreased propulsion. Most research about foot drop FES overlook the role of the PF as primary controllers of the leg-ankle-foot complex during stance phase[1] and the important contribution of the PF to the transfer of mechanical energy to push the body forward[i]. The reduction of the propulsive force generation by the PF is related to deficits during both swing and stance phases as well as to slow walking speeds[ii,iii].

Most of the propulsion during walking comes from the PF, that's why if we help the foot to lift with just DF and not propel the body forward, we do not create natural steps. If we can propel our body forward with the PF and lift during the DF phases, then we can create a more physiological walking pattern[iii].

The PF muscles generate the push-off force needed for propulsion (concentric contraction) during the terminal-stance phase[i]. But the most important role of the PF muscles is to generate the propulsive force at the pre- swing phase, which is essential for walking speed[iii,iv]. The timing of the onset plays an important role during this phase to control the forward progression of the tibia (eccentric contraction).

It is true that the classic DF FES can correct swing phase foot drop in many cases, but stimulating these muscles alone fails to address other gait deficits. Neurological patients tend to have multiple gait problems, including important stance and swing phase poststroke gait deficits at the hip and knee[iii], and that's why solutions involving different muscles are needed[iii,v].

WHY PLANTAR FLEXION?

Based on the evidence published at the date of writing this document, the benefits of stimulating plantar flexion in addition to dorsiflexion are:

Neurological Restoration

Neurological repair, and not only compensation of motor dysfunctions, is one of the main objectives of the actual neurorehabilitation. That is why the science is searching solutions to retrain the brain for

[1] The terms used by J. Perry will be used throughout this white paper. [*Perry J, Burnfield J. Gait Analysis: Normal and Pathological Function.2nd ed. New Jersey: SLACK Incorporated; 2010*

efficient walking or doing other functional movements.

Different authors describe that, in addition to be a neuroprosthetic device, FES works as a motor learning or gait training tool that patients can use to take advantage of the brain's plasticity to relearn correct walking patterns[i].

The neuroplasticity is based in a correct afferent feedback nerve activation. Therefore, to restore gait function, the feedback should be both active in PF and DF, as it simulates a more physiological movement. These stimuli have an effect not only on the areas corresponding to the stimulated muscles in the brain motor cortex but also on the central pattern generators.

Gait Function

As explained before, it has been shown that foot drop patients do not push effectively with their PF during gait, and there are several publications that suggest better gait function when PF is active[i,iii ,iv].

Neurological patients usually demonstrate knee flexion deficits in the paretic leg during the swing phase, and it has been suggested that DF FES exacerbates this type of gait impairment and in turn may adversely affect foot clearance. This could happen because the decreased PF angles lead to reduced push-off forces at the ankle during the transition from swing to stance. Based in this hypothesis, delivering stimulation to the PF could potentially increase force generation during push-off and attenuate this issue[vi].

Compared with walking without FES, doing it with FES to both the DF and PF, increases the peak anterior ground reaction forces and the peak swing phase ankle DF for the paretic limb[ii]. In addition, peak knee flexion angles are also significantly greater than the ones obtained with only DF or without FES (Figure 1), which is especially interesting in chronic stroke survivors, who usually show decreased knee flexion angles in the paretic leg during walking[iii].

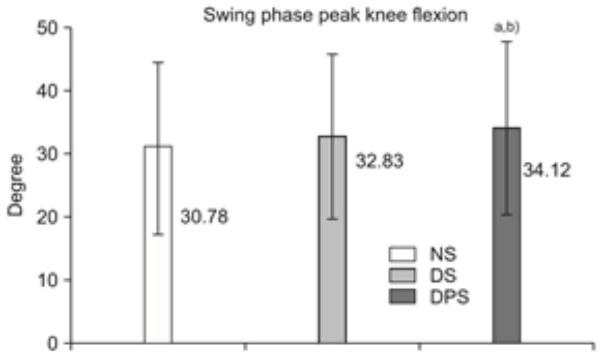


Figure 1 – Comparison between swing phase peak knee flexion: DF and PF stimulation (DPS, 34.12 ± 13.77º), DF stimulation only (DS, 32.83 ± 13.07º), and no stimulation (NS, 30.78 ± 13.64º). [a]p<0.05, significant difference from NS. [b]p<0.05, significant difference from DS. Ob. Taken and adapted from: Lee YH, et al. *Ann Rehabil Med* 2014;*38*(3):310–316[iii].

Other biomechanical parameters have been studied and have also demonstrate to be improved with PF FES. The hip joint transfers 2 cm in the horizontal forward direction when electrical stimulation is not applied, and 14 cm when it is. This is particularly interesting because it contributes to the main task of human gait, the transfer of the body forward to a new location. The hip joint horizontal displacement assessed during the FES-assisted terminal-stance phase is displayed in Figure 2[v]. Furthermore, in incomplete spinal cord injury patients, a 40% increase from the resting stance level was observed during the push-off, being the duration of this push-off shortened from 2s to 0.5s (Figure 3). Figure 3a represents the trial where the ankle PF were not activated electrically, and the vertical line shows the start of FES delivered to the peroneal nerve. Figure 3b represents the same, but when FES-assisted PF is active. In this case, the first line indicates the activation of the ankle PF, while the second one shows when the subject triggered the flexion reflex[v]. In general, immediate effects of combined FES have shown to be greater than those with DF-alone FES, but long-term effects must be studied[iv].

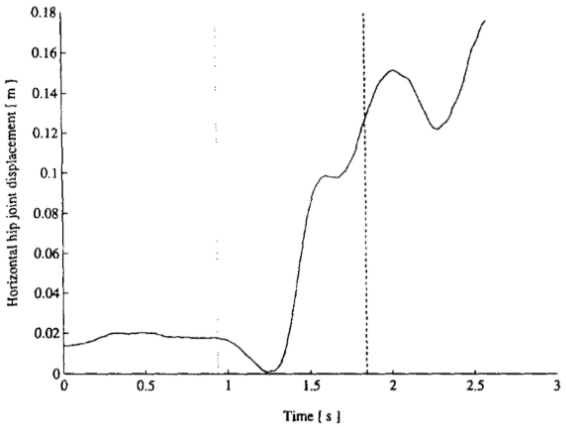
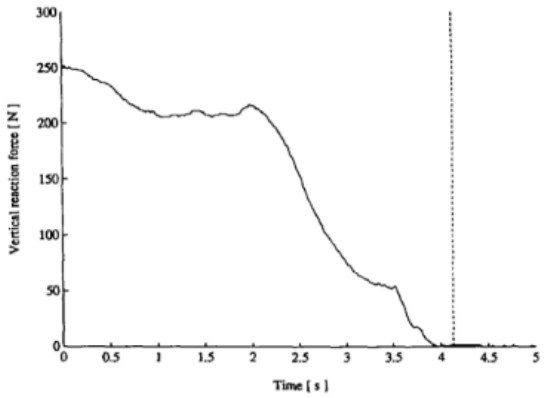


Figure 2 - Horizontal displacement of the hip joint during the terminal-stance phase. Taken and adapted from: Bajd T, et al. Gait and Posture 1994;2(1):5–10[v].

a



b

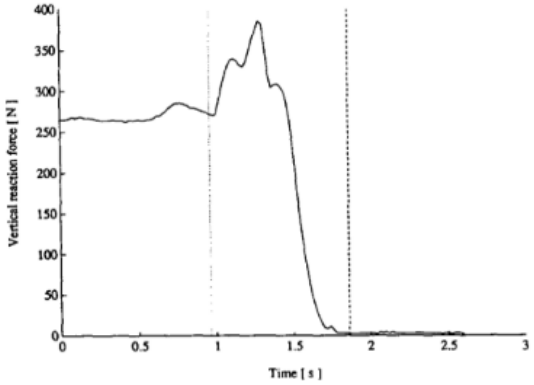


Figure 3 – Vertical ground reaction force assessed: a without PF stimulation; and b with active FES-assisted push-off. Taken and adapted from: Bajd T, et al. Gait and Posture 1994;2(1):5–10[v].

Furthermore, FES applied to the PF and DF combined with fast treadmill walking in post-stroke patients has showed to increase anterior ground reaction force, trailing limb angle and swing phase knee flexion to either fast walking or FES alone[iv].

Others

The combination of the stimulation of DF and PF muscles may carry other benefits as:

- **Spasticity reduction**: Spasticity of the PF seems to be decreased with the application of electrical stimulation to the DF. The reason may be the mechanism of reciprocal inhibition[vii,viii,ix].
- **Stretch reflex reduction**: The stretch reflex of PF in adults with stroke may be reduced by stimulating the DF muscles[x,xi].

REFERENCES

[i] Embrey DG, Holtz SL, Alon G, et al. Functional electrical stimulation to dorsiflexors and plantar flexors during gait to improve walking in adults with chronic hemiplegia. *Arch Phys Med Rehabil.* 2010;91(5):687-696.

[ii] Kesar TM, Perumal R, Reisman DS, et al. Functional electrical stimulation of ankle plantarflexor and dorsiflexor muscles: effects on poststroke gait. *Stroke.* 2009;40(12):3821-3827.

[iii] Lee YH, Yong SY, Kim SH, et al. Functional electrical stimulation to ankle dorsiflexor and plantarflexor using single foot switch in patients with hemiplegia from hemorrhagic stroke. *Ann Rehabil Med.* 2014;*38*(3):310–316.

[iv] Knarr BA, Kesar TM, Reisman DS, et al. Changes in the activation and function of the ankle plantar flexor muscles due to gait retraining in chronic stroke survivors. *J Neuroeng Rehabil. 2013*;*10*:12.

[v] Bajd T, Kralj A, Karčnik T, et al. Significance of FES-assisted plantarflexion during walking of incomplete SCI subjects. *Gait Posture.* 1994;*2*(1):5–10.

[vi] Kesar TM, Perumal R, Jancosko A, et al. Novel patterns of functional electrical stimulation have an immediate effect on dorsiflexor muscle function during gait for people poststroke. *Phys Ther.* 2010; 90(1):55-66.

[vii] Apkarian KA, Naumann S. Strech reflex inhibition using electrical stimulation in normal subjects and subjects with spasticity. *J Biomed Eng.* 1999;13:67-73.

[viii] Crone C, Nielsen J, Petersen N, et al. Disynaptic reciprocal inhibition of ankle extensors in spastic patients. *Brain.* 1994;117:1161-8.

[ix] Morita H, Crone C, Christenhuis D, et al. Modulation on presynaptic inhibition and disynaptic reciprocal Ia inhibition during voluntary movement in spasticity. *Brain.* 2001;134:826-37

[x] Veltink PH, Ladouceur M, Sinkjaer T. Inhibition of the triceps surae stretch reflex by stimulation of the deep peroneal nerve in persons with spastic stroke. *Arch Phys med Rehabil.* 2000; 81:1016-24.

[xi] Thomson AK, Estabrooks KL, Chong S, et al. Spinal reflexes in ankle flexor and extensor muscles after chronic central nervous system lesions and functional electrical stimulation. *Neurorehabil Neural Repair.* 2009;23;133-42.