CLINICAL NOTE

Near-Normal Gait Pattern With Peroneal Electrical Stimulation as a Neuroprosthesis in the Chronic Phase of Stroke: A Case Report

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In recent years, the use of functional electrical stimulation (FES) of the peroneal nerve has increased as an alternative for an ankle-foot orthosis (AFO) to treat stroke-related drop foot. We present a chronic stroke patient demonstrating an almost normal gait pattern with peroneal FES as a neuroprosthesis. A 60-year-old survivor of a right hemisphere infarction 21 months ago, who regularly used a polypropylene AFO, was provided with a surface-based peroneal FES device for severe drop foot. In a second instance, he received an implanted FES system because of skin problems with the surface stimulator. With both FES devices, the patient achieved an adequate foot elevation. Moreover, his hip and knee flexion angles during walking increased to normal values and his ankle push-off power increased. His gait pattern became almost symmetrical and less variable than with the AFO. Furthermore, his ability to avoid a sudden obstacle improved to normal values with FES. Our patient showed benefits from peroneal FES beyond what can be attributed to improved foot lift alone. With regard to the potential working mechanisms underlying this response to FES, biomechanical benefits related to improved ankle push-off are suggested as the main mechanism.

Key Words: Electric stimulation; Peroneal nerve; Rehabilitation; Stroke; Walking.

IN STROKE PATIENTS who suffer from a drop foot, an AFO is usually provided to lift the foot during the swing phase and early stance phase of gait in order to prevent the toes from touching the ground and to facilitate heel loading. As an alternative treatment, FES of the peroneal nerve as a form of neuroprosthesis is gradually becoming more feasible due to advanced and commercially available systems. Peroneal FES activates the muscles that dorsiflex and evert the ankle joint as well as the toe extensors and may lead to significant improvement in the gait pattern[1] and gait speed[2,3] compared to walking without aids. Although FES has several theoretical advantages over an AFO and patients' preferences often support the use of FES, there is as yet no conclusive evidence for the superiority of peroneal FES over an AFO with respect to walking abilities.[4,5] The aim of the present report is to demonstrate the potential superiority of peroneal FES over an AFO. To this end, we present a stroke patient who was used to walking with a polypropylene AFO and who showed functional benefits from FES that went beyond what can be attributed to improved foot elevation alone (open access videos on http://www.neurorehab.nl/APMR_english.htm). Secondly, we aim to discuss the potential mechanisms underlying the observed functional improvements.

CASE DESCRIPTION

Patient and Methods

A 60-year-old farmer presented himself at the outpatient clinic of our university hospital 21 months after a right hemispheric infarction. Characteristics of the participant are provided in table 1. The Motricity Index[6] of his left lower limb was 27% with a 0 score for the ankle dorsiflexors. The strength of his calf muscles was scored Medical Research Council[7] grade 4. Because of his ankle dorsiflexor paralysis, the patient used an AFO, which was a custom made polypropylene (2.5-mm thickness) posterior splint, trimmed behind the malleoli of the ankle. The AFO was rigid into plantar flexion, but allowed about 15° of ankle dorsiflexion. The patient was hardly able to walk without this AFO due to foot drag during the swing phase of gait, which he was not able to compensate by active hip and knee flexion. At baseline (t0), his gait ability with AFO was assessed, after which he received a surface-based peroneal FES device, the NESS L300.[a] The L300 stimulated the peroneal nerve and the anterior tibial muscle using 2 electrodes embedded into a lightweight orthosis placed just

List of Abbreviations

AFO	ankle-foot orthosis
COV	coefficient of variation
FES	functional electrical stimulation
V_{plfl}	maximal ankle plantar flexion velocity (at push-off)
$T_{swing}asym$	asymmetry in swing time duration between left and right limb
M_{plfl}	maximal ankle plantar flexion torque (at push-off)

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Table 1: Characteristics of the Participant at Baseline

Variable	Patient's outcome
Age (y)	59
Time poststroke (mo)	21
Sex (male/female)	Male
Body weight (kg)	101
Body height (m)	1.78
Hemisphere of stroke	Right
Type of stroke	Infarction
Modified Ashworth Score (0–5)*	
Knee flexors/extensors*	0/0
Ankle plantar flexors/dorsiflexors*	0/0
Lower extremity Motricity Index (0–100) *	27
Ankle score (0–33)*	0
Lower extremity Fugl-Meyer Assessment (0–34)*	6
Calf muscle strength (Medical Research Council 0–5)*	4
Quantitative Vibration Threshold (0=no sensation; 8=normal)*	
First metatarsophalangeal joint*	<2
Lateral malleolus*	2
Berg Balance Scale (0–56)	41
Passive range of motion at ankle (degrees)*	
Dorsiflexion (knee extended/flexed)/ Plantar flexion*	(0/10)/35
Varus/Valgus*	30/15

*Scores at the paretic body side.

below the knee (symmetrical bipolar 42mA current; pulse rate 30Hz; phase duration 200μsec) during the swing phase and the subsequent loading response. Stimulation onset and offset were based on detection of heel-off and heel-on by an insole foot switch that communicated wirelessly with the stimulator that was attached to the orthosis. In the following 2 weeks, the patient increased the use of FES up to 6 hours a day. Subsequently, the gait assessment was repeated with both the AFO and FES (t1 [measurements after 2 wk]). In the third week, the patient developed an allergic skin reaction to the electrodes, which was dermatologically confirmed. Because no alternative electrodes were available at that time, the patient had to terminate the use of the surface stimulator shortly after he had started. One year later, this patient was the first person to be implanted with the ActiGait[b] peroneal stimulator in The Netherlands. With this system, the common peroneal nerve was directly stimulated through 4 distinct electrode arrays embedded in a cuff, which was surgically placed around the nerve about 4cm above the knee joint (asymmetrical bipolar 1.2mA current; pulse rate 20Hz; phase duration 247, 236, 210, and 0μsec for channel 1 to 4). The stimulation settings of the 4 channels were individually adjusted such that a balanced eversion and dorsiflexion were evoked during the swing phase and early stance phase of gait. Stimulation onset was timed simultaneously with heel-off, and the offset of stimulation was timed using a ramp-down period of 0.5 seconds following heel strike. Heel contacts were detected by an insole foot switch that communicated wirelessly with the control unit that was worn on a waist belt. The control unit was hard-wired externally to a transmitter coil (antenna), positioned on the skin over a receiver and stimulator, which was implanted subcutaneously on the lateral side of the proximal thigh. The stimulator was hard-wired subcutaneously to the cuff electrode. After he had used this system all day long for 6 months, a third gait assessment was conducted with his AFO and with the implanted stimulator (t2 [measurement after 1.5 y]. In addition, in spite of the difficulties the patient experienced when he walked without an orthosis, the assessment of comfortable walking was also performed without any device at this occasion.

During each gait assessment, 70 gait cycles of treadmill walking at a comfortable speed of 0.56m/s were analyzed. Flexion-extension movements of the hip, knee, and ankle joints were measured with goniometers[c] at a sample rate of 1000Hz, and maximal flexion and extension joint angles during the step cycle

Table 2: Results of the Gait Assessments

	t0	t1		t2			
Variable	AFO	AFO	Surface FES	AFO	Implanted FES	NO	Referent
Hip flexion (deg)	23.2±1.5	17.9±1.5	24.2±1.5	20.5±3.2	24.5±1.3	21.8±2.1	18.6±5.4[12]
Hip extension (deg)	0.5±1.6	−7.7±3.6	−8.1±1.5	8.9±5.2	−9.3±1.5	6.3±5.0	−11.3±7.8[12]
Knee flexion (deg)	45.6±5.9	45.9±5.5	66.3±1.6	27.6±2.4	56.8±1.2	25.9±9.5	61.8±7.0[12]
Knee extension (deg)	1.8±0.9	4.2±0.6	2.7±0.7	6.3±4.6	4.4±0.6	5.9±1.4	1.7±3.2[12]
Ankle dorsiflexion (deg)	9.2±1.3	6.8±1.8	9.5±0.8	3.2±2.1	10.8±1.0	1.0±4.1	8.6±3.6[12]
Ankle plantar flexion (deg)	−7.9±0.9	−8.0±1.4	−17.1±2.7	−13.2±2.7	−16.6±0.8	−26.9±4.0	−17.6±4.7[12]
M_{plfl} (Nm/kg)	ND	ND	ND	0.93±0.06	1.50±0.02	1.15±0.21	1.54±0.23[12]
V_{plfl} (°/s)	76.5±15.0	88.7±14.1	135.0±28.0	31.1±10.1	181.0±34.2	117.4±46.0	136±53*[12]
COV_{hip} (%)	16.0	26.8	15.4	22.5	14.6	27.1	8[8]
COV_{knee} (%)	37.1	37.6	23.2	65.0	18.5	71.7	8[8]
COV_{ankle} (%)	33.6	34.3	29.4	48.1	26.3	37.6	21[8]
T_{swing} *asym* (%)	42.0	38.6	14.8	35.9	18.1	60.1	−0.1±11.3[9]
OA success (%)	17.0	0.0	68.0	7.0	90.0	ND	89.7±5.8[10]
Gait speed (m/s)	0.99±0.13	1.06±0.06	1.07±0.04	1.01±0.09	1.00±0.17	0.41±0.02	1.36±0.21[13]

NOTE. Results are displayed as mean ± (within subject) SD at the paretic body side or as otherwise noted. Referent data are retrieved from literature[8-10,12,13] and displayed as mean ± (between subjects) SD.
Abbreviations: COV_{ankle}, coefficient of variation for the ankle; COV_{hip}, coefficient of variation for the hip; COV_{knee}, coefficient of variation for the knee; deg, degrees; gait speed, 10-m comfortable walking speed; M_{plfl}, maximal ankle plantar flexion torque (at push-off); ND, no data; NO, no orthosis; OA success, obstacle avoidance success score; T_{swing} *asym*, asymmetry in swing time between left and right leg; V_{plfl}, maximal ankle plantar flexion velocity within 200ms before toe-off.
*Referent SD of V_{plfl} was estimated from the figure of Winter.[12]