Functional Electrical Stimulation for Treatment of Chronic Foot Drop Due to an Incomplete Sacral Nerve Root Lesion: A Case Study

by Katharine Ambrose, MSPT CBIS[1], Mary Ann Wilmarth, PT, DPT, OCS, Cert MDT, MTC [2]

The Foot and Ankle Online Journal 3 (8): 1

A prevalent cause of foot drop is peripheral nerve injury (PNI). The current treatment options for foot drop after PNI include surgery for nerve repair, physical therapy (PT) for strengthening and bracing for support. The purpose of this case study is to describe the outcomes of treating a patient with foot drop caused by PNI with functional electrical stimulation (FES). The patient discussed has foot drop due to a sacral nerve root lesion resulting from a pelvic fracture. After 1 year of PT intervention including gait progression, neuromuscular re-education, balance training and therapeutic exercise the patient was unable to progress from a single-tip cane due to continued local weakness of the anterior tibialis. A trial of FES using the Bioness L300 was initiated as a trial treatment to progress the patient from ambulation with a single tip cane to ambulation without an assistive device. Outcomes included improved 6 minute walk test distance, decreased falls risk on Dynamic Gait Index and decreased reported fear of falling on the Modified Falls Efficacy Scale, and ability to walk and run on uneven terrain with the L300.

Key words: Ankle foot orthosis, Dynamic Gait Index, Foot drop, Functional electrical stimulation, Modified Falls Efficacy Scale, Peripheral nerve injury.

Accepted: July, 2010 **Published:** August, 2010

Foot drop is the inability to dorsiflex the foot and /or control dorsiflexion during the full gait cycle and is often an indicator of neurological dysfunction.[1,2] There are many causes of foot drop.

Address correspondence to: Katharine Ambrose, DPT
3906 Lawrence Ave, Kensington, MD 20895

[1] Physical Therapist National Naval Medical Center 2006-2009, Northeastern University, College of Professional Studies 2007-2010
[2] Harvard University, Chief of Physical Therapy. Assistant Dean for the College of Professional Studies with Northeastern University, Director of the post-professional DPT program.

Clearance for Publication was approved by the National Naval Medical Center IRB Review Board.

The two main causes are central nervous system (CNS) disease or injuries including: multiple sclerosis, spinal cord injury, cerebrovascular accident, and traumatic brain injury; or peripheral nervous system (PNS) disease or dysfunction[1] including post-polio syndrome, Charcot Marie Tooth, lumbar disc herniation, and peripheral nerve injury (PNI).

Dependent on the cause of foot drop, treatment varies, and can include surgical treatment, electrical stimulation (ES), rehabilitation, and bracing.[1]

ISSN 1941-6806 doi: 10.3827/faoj.2010.0308.0001

The knowledge base, imaging abilities and understanding of CNS disorders are well understood and documented.[1,2] The CNS consists of the cerebral cortex, cerebellum and spinal cord.[2] Traditionally, treatment for foot drop using functional electrical stimulation (FES) is reserved for patients with CNS disorders such as multiple sclerosis, spinal cord injury, cerebrovascular accident, and traumatic brain injury.[3-7]

The rationale for using FES for patients with CNS disorders is the FES modality uses the local spinal loop reflexes of the peripheral nervous system (PNS) to compensate for a disorder in the CNS.[8,9] There is a vast body of knowledge supporting the use of FES to treat foot drop in the acute and chronic stages of CNS injury/disease.[3-7]

Currently there is limited evidence to support the use of ES after damage or injury to the PNS including PN due to the lack of an innervated local spinal reflex loop. Limited applications of ES have proven to be successful including the use of ES intra-operatively after PNI allows improved nerve recovery.[10,11] Electrical stimulation has been proven to be a successful neuroprosthetic in the long term treatment and management of bowel and bladder dysfunction due to cauda equina syndrome.[12] Transcutaneous electrical nerve stimulation (TENS) is used as an alternative to pharmacological treatment of PNI-related pain.[13,14] Pain due to PNI is very common with neuropraxia.[15] Aside from treating pain, or bowel and bladder dysfunction due to PNI with ES, motor dysfunction of the upper extremity and lower extremity is not currently treated using ES. Upper and lower extremity motor dysfunction after PNI is treated with a combination of rehabilitation for range of motion, strength and bracing for functional positioning.

Clinical rehabilitation of patients with foot drop due to PNI does not include ES for motor recovery due to the lack of evidence to support its use and the compromise of the local loop reflex utilized with FES. Patients with foot drop due to PNI are fitted with an ankle foot orthosis (AFO) to minimize the foot drop during gait.

Brugin, et al., found that despite patients with PNI being fitted for an AFO, patients displayed poor compliance associated with continued strength and gait deficits, which interfered with activities of daily living.[16] The use of FES has not been researched for the treatment of motor dysfunction with PNI.[1,2,3-7,15-19] The purpose of this case study is to examine a case of successful treatment of foot drop due to PNI with FES as an intervention.

Case Description

History

The patient is a 21 year-old male, active duty United States Marine Corps, and was injured in Iraq. He suffered the following injuries: left scapular fracture, right tibial fracture, pelvic diastasis, and sacral fracture with documented sacral nerve root injuries. The patient had no significant past medical history, although he does report occasional tobacco and alcohol use. He was hospitalized for 15 days at a major medical center. His initial inpatient physical therapy (PT) evaluation revealed fair gross motor strength of bilateral lower extremities and he was non-weight bearing bilateral lower extremities. The focus of his PT during his acute care episode of care was safe independent transfers and mobility to allow for safe discharge home for convalescent leave. At the time of his discharge from the hospital his weight bearing status was as follows: left lower extremity was weight bearing as tolerated, and his right lower extremity was partial weight bearing. When he was discharged home from acute care he was walking short distances with a walker and able to ascend /descend stairs with crutches. Shortly after his discharge home he experienced a significant increase in bilateral lower extremity pain during gait and weight bearing activities. His orthopedic physician advised him to return to bilateral lower extremity non-weight bearing until full sacral healing had occurred. He received a home PT evaluation and treatment. Documentation from his home PT episode of care was not accessible to the authors of this case.

The patient returned to the medical center 3 months after his initial injuries for further follow-up care including outpatient PT. In addition, six months after his initial injury the patient had electromyography testing which revealed sacral nerve root injury at levels L5/S1/S2 with specific dysfunction of his right anterior tibialis.

Examination

The patient was referred to the Outpatient PT Department by his orthopedic physician for evaluation. At the time of the initial outpatient PT evaluation, he remained non-weight bearing bilateral lower extremities and used a motorized scooter for mobility. He reported minimal physical therapy intervention during his 3 months at home on convalescent leave due to his restrictions in place and conservative treatment of his sacral and pelvic injuries. His initial outpatient PT evaluation reveal: left lower extremity manual muscle testing was 3/5 in all major groups (hip flexor, hip abductor, hip adductor, hip extensor, knee flexor, knee extensor, ankle dorsiflexion and ankle plantar flexion); his right lower extremity was painful with manual muscle testing 2-/5 in all major groups (hip flexor, hip abductor, hip adductor, hip extensor, knee flexor, knee extensor, ankle dorsiflexion and ankle plantar flexion.)

One month after his initial evaluation he was cleared by his orthopedic physician to begin weight bearing as tolerated for bilateral lower extremities and was re-evaluated at that time for bilateral lower extremity strength, mobility and gait. Since the initial evaluation there was improved strength: left lower extremity to 5/5 in all major muscle groups hip flexor, hip abductor, hip adductor, hip extensor, knee flexor, knee extensor, ankle dorsiflexion and ankle plantar flexion) and right lower extremity to 3-/5 in all major muscle groups hip flexor, hip abductor, hip adductor, hip extensor, knee flexor, knee extensor, ankle dorsiflexion and ankle plantar flexion) and remained painful.

Sensory testing of the right lower extremity revealed decreased sensation to light touch and proprioception as well as decreased deep tendon reflexes. Sensory testing of the left lower extremity was normal, deep tendon reflexes were decreased. He was able to perform sit to stand transfer with minimal to moderate assistance in the parallel bars. Ambulation evaluation was attempted; however, gait assessment was unable to be completed. This was due to the patient's fear of pain with ambulation, associated with the pain he experienced during ambulation after his discharge home from his acute care hospital stay.

Interventions

The patient received PT for 1 year with a total of 68 visits. Physical therapy treatment for his left upper extremity deficits was directed using practice pattern 4G, from the Guide to Physical Therapy Practice, 2nd edition.[20] Treatment progression for his gait and bilateral lower extremity deficits was facilitated using practice pattern 5F from the aforementioned text.[20] Interventions for his left upper extremity deficits included: range of motion, strength training, neuromuscular re-education and progression to a home exercise program. Interventions for his lower extremity deficits included: neuromuscular re-education, standing balance, bilateral lower extremity strengthening exercises progressing from gravity minimized to against gravity and finally to include resistance; and gait training progression from walking in the parallel bars to a rolling walker, to a single-tip cane. The patient has a home exercise program he completed on days he did not have PT. His home exercise program consisted of left shoulder strengthening, bilateral lower extremity strengthening and standing balance activity. See Table 1, progression of home exercise program (HEP) in 6 month increments.

In June of 2009, 14 months after the initial injury and 12 months after beginning gait training, the patient still required a single-tip cane for gait.

July 2008	January 2009	June 2009
Shoulder HEP	**Shoulder HEP**	**Shoulder HEP**
Scapular Retraction	Shoulder Flexion w/ 1.5lbs	Patient reports independence with HEP and is self progressing his upper extremity strength at the gym. The patient denied any pain or difficulty with his left shoulder.
Shoulder Int. rotation	Shoulder Abduction w/ 1.5lbs	
Shoulder Ext. rotation	Bicep Curls w/ 1.5lbs	
Right Lower Extremity HEP	**Bilateral Lower Extremities**	**Bilateral Lower Extremities**
Quad sets	SLR	Bridging
Heel Slides	Prone Hamstring curls	Prone Hamstring curls w/ 1-2 lbs
Ankle pumps	Wall Squats	Ankle 4-ways w/ medium resistance tubing
Left Lower Extremity HEP	Ankle 4-ways	Side-lying Hip Abduction w/ medium resistance tubing
Straight leg raise (SLR)	Side-lying Hip Abduction	Single leg stance practice on each leg
Hamstring Curls		

Table 1 Progression of home exercise program (HEP) in 6 month increments.

He was unable to walk on uneven terrain and had experienced multiple falls due to continued right ankle dorsiflexion weakness and associated foot drop during gait which increased with fatigue despite PT intervention. The patient was very frustrated at his continued need for single-tip cane during ambulation and his personal goal was to walk without assistance and return to running. Due to the patient's plateau and maximal attempt to treat this patient's gait dysfunction with therapeutic exercise, and neuromuscular re-education, a clinical trial of FES was conducted in attempt to normalize his gait without a single-tip cane. Physician approval and IRD guidelines were followed for the FES trial. The patient was informed of the risks and benefits of a FES trial. The risk of using FES are minimal and include mild skin irritation from the cuff and electrodes, and muscle soreness from increased muscle contraction[18,19] He was informed of the lack of research to support the use of FES with PNI.[1,2-7,15-19] He verbalized understanding of the risk, benefits and the possibility of the FES being unsuccessful in the treatment of his foot drop and consented to a trial of FES for his right foot drop.

The specific device utilized in this case is the L300, a product by Bioness. The L300 is a foot drop stimulation device using wireless communication between an electrode cuff and intell-sense gait sensor in the patient's shoe. The total weight of the functional stimulation cuff, intell-sense gait sensor, and control unit total 7.4 ounces. It is indicated to treat foot drop associated only with upper motor neuron injury or disease.[18] The L300 has been proven to improve gait, decrease/retard muscle atrophy, maintain/increase joint range of motion and increase local blood flow.[18] The L300 provides biphasic pulsatile current, 22 to 40 pulses per second, and 0-60 milliamps creating a non-fatigue tetanic muscle contraction.[19] The Bioness clinician is able to change the waveform, phase duration, pulse rate milliamperage, and ramp time dependent on the needs and impairments of each patient

A total of 14 visits were needed to train and progress the patient using the L300. Visits 1-4 were used to adjust settings for optimal gait with improved step symmetry and equal stance time. Visits 5-14 were used to progress the patient from walking on the treadmill, to running on the treadmill and progressing towards uneven surfaces (foam, ramps, and steps) in the clinic and eventually to uneven surface in the community including grass, gravel and curbs.

	Initial Visit for L300 trial	1 month of L300	2 months of L300
6MWT w/ cane	150 feet	897 feet	Not tested
6MWT w/ L300	690 feet	2,376 feet	2,957 feet
DGI w/ cane	Not tested	Not tested	15/25
DGI w/ L300	Not tested	Not tested	24/24
MFES rated w/ cane	Not tested	Not tested	2/10 = not confident
MFES rated w/ L300	Not tested	Not tested	10/10 = completely confident

Table 2 Objective outcomes following clinical trial of L300.

Outcomes

During the first nine months of conventional PT intervention this patient showed continued progress towards his goals of independent gait, full strength and ROM. He has had almost full recovery of his left shoulder ROM and strength. His left lower extremity has full recovery of strength. His right lower extremity manual muscle test at 9 months revealed: quadriceps 4/5, hamstring 4/5, anterior tibialis 3-/5, gasctrocmenius 3/5 with poor ankle neuromuscular coordination during gait and diminished deep tendon reflexes. There is visible decreased muscle tone when compared to the left lower extremity.

At nine months the patient had plateaued with PT. Once the L300 was trialed he was able to overcome his plateau and made significant gains towards his goals of independent gait and progression back to running using the L300 as a long term neuroprosthetic device. Outcome measures initially used to measure progress with the L300 included the 6 minute walk test (6MWT). The 6MWT is an objective measure of functional gait capacity and due his limitations was the only dynamic tool he was able to participate in initially. Dynamic Gait Index (DGI) and Modified Falls Efficacy Scale (MFES) were added after two months of training with the L300 to compare the patient's functional balance with and without the L300. The 6MWT was chosen to measure a change in gait distance over a period of 2 months training with the L300. At his re-evaluation two months after using the L300, additional tests and measures including the DGI and MFES the were used to gather more information on the functional gains he experienced when using the L300 as a gait aid versus his single-tip cane.

During the 14 visits for training with the L300 he demonstrated improved gait distance, improved balance and decreased subjective fear of falling. Average gait speed for 20-60 year old, healthy men is 82 meters per minute.[24] The average gait speed for this patient prior to the L300 trial was 7.6 meters per minute well below the age related normative values for his age group; his gait speed with the L300 after 2 months of training improved to 150 meters per minute. See Table 2 for specific outcomes.

Discussion

The specific gains of this patient demonstrate the efficacy of using the L300 to treat his foot drop due to PNI. Prior to using the L300 he was walking with a dysfunctional gait pattern, using a cane and unable to keep up with his peers. Using the L300 he improved gait speed to match and surpass the mean gait speed for his peers. Without the L300 the patient's DGI score places him at risk for falls, with the L300 he scored 100% and is no longer a falls risk. In addition, his gait confidence is 20% without the L300, and 100% with the L300 using the MFES. His success with the L300 clinical trial has led to pursuit of ordering a personal L300 for long term home use and continued gait training for return to running. The patient's prior high level of physical fitness in the United States Marine Corps and his desire to return to a very active lifestyle sparked the idea for a clinical trial using FES for improved functional gait pattern and speed.

Lack of research looking at the use of FES in patients with motor dysfunction due to PNI leaves a large patient population to examine for potential increased motor function and quality of life. In future studies looking at the success of using FES for foot drop, patient records of falls outside of the clinic, falls / balance scale, patient-reported activities limitation scale and muscle girth of the calf will provide additional information for outcomes measurement.

The tests and measures used for the case were determined based on the physical condition of the patient and his goals of therapy. The 6MWT is a reliable measure of functional mobility in patients with different levels of physical ability.[22-24] The 6MWT was used due to patient's intolerance to lengthier testing involved with other tools such as the DGI, and the Berg Balance or Tinneti. The DGI was added at the two month re-assessment due to clinical improvements of the patient and his history of falls The DGI is a reliable tool to examine gait, balance and risk of falls.[2] Dynamic Gait Index scoring incorporates the use of an assistive device in dynamic gait with turns and head movement, unlike other balance scales such as the Berg Balance.

The MEFS was added at the 2 month re-assessment to look at the patient's confidence level in his own abilities and his history of falls. The MEFS is a reliable tool to measure patient's fear of falls in multiple settings.[25,26] The patient's history of falls and fear of falling greatly limited his confidence in his gait. Patients with high fear of falling self-limit their activity, which leads to decreased quality of life.[26] The patient often reported subjective fear of falling and therefore the MEFS was added to monitor his fear of falling when using his single-tip cane versus the L300. Since using the L300 the patient reported a decrease in the amount of fall incidents at home. The cause for this is not known. Prior to using the L300 the patient estimates fall and near fall incidents at least 3-4 times a week; since using the L300 the patient reports 0-1 fall and near fall incidents per week. The patient was not actively tracking the number of falls at home; therefore objective data is not available.

The MEFS was used over other fear avoidance scales due to its specific implications to gait in different environments. Earlier implication of the MEFS or another tool such as the activities-based confidence score might have revealed additional outcome measures to support the benefit of using the L300 over a single-tip cane.

Based on the success shown with this patient a large patient sampling with PNI is indicated to develop rehabilitation treatment guidelines for the future use of FES in patients with PNI. A large patient sampling needs to include a variety of levels of dysfunction to determine patients who are good candidates for successful trial of FES.[27] It is considered that FES provides patients with foot drop increased functional gait pattern, prevention of muscle atrophy, increase local blood flow for tissue health and assist with increased cortical activation for further recovery.[28,29] The more conventional method for correcting foot drop is bracing with an AFO. The use of AFO's in patients with foot drop and associated decreased foot sensation leads to increased risk for skin breakdown.[30,31] The AFO also limits active muscle contraction leading to decreased functional use and associated disuse atrophy of the anterior tibialis.[30,31] The benefits of FES make this a better option for the treatment of PNI motor dysfunction to maintain local tissue health and prevent side effects of bracing including: skin breakdown, disuse muscle atrophy, decreased functional use of the involved limb, and limited or no chance for further recovery.

References

1. Foot drop. The Mayo clinic. http://www.mayoclinic.com/health/foot-drop/DS01031/DSECTION=treatments-and-drugs. Accessed August 17, 2009.
2. Umphred DA. *Neurological Rehabilitation.* 5th edition. St Louis, MO, Mosby Elsevier, 2007: 32-36.
3. Sheffler R, Hennessey M, Naples G, Chae J. Peroneal nerve stimulation versus an ankle foot orthosis for correction of foot drop in stroke: Impact on functional ambulation. Neurorehabil Neural Repair 2006 20 (3): 355-360.
4. Ring H, Treger I, Gruendlinger L, Hausdoff J. Neuroprosthesis for footdrop compared with an ankle foot orthosis: Effects on postural control during walking. J Stroke Cerebrovasc Dis 2009 18 (1): 41-47.

5. Liu L, Nicholson G, Knight S, Ramesh C, et al. Pressure changes under the ischial tuberosities of seated individuals during sacral nerve root stimulation. J Rehabil Research Dev 2006 43 (2): 209-218.
6.Dunning K, Black K, Harrison A, McBride K, Israel S. Neuroprosthesis peroneal functional electrical stimulation in the acute rehabilitation setting: A case series. Phys Ther 2009 89 (5): 499-506.
7. Karmel-Ross K, Cooperman D, Van Doren C. The effect of electrical stimulation on quadriceps femoris muscle torque in children with spina bifida. Phys Ther 1992 72 (10): 723-730.
8. Prentice WE. *Therapeutic Modalities for Physical Therapist.* New York, McGraw-Hill, 2002: 107-109.
9. Schmidt RA, Lee TD. *Motor Control and Learning. 3rd Edition, A Behavioral Emphasis*. Champaign, IL, Human Kinetics, 1999: 119-123.
10. Franz C, Rutishauser U, Rafuse V. Intrinsic neuronal properties control selective targeting of regenerating motorneurons. Brain 2008 31: 1492-1505.
11. Bohannon RW, Gajdosik RL. Spinal nerve root compression - some clinical implications: A review of the literature. Phys Ther 1987, 67(3): 376-382.
12. Gstaltner K, Rosen H, Hufgard J, Mark R, Schrel K. Sacral nerve stimulation as an option for the treatment of faecal incontinence in patients suffering from cauda equina syndrome. Spinal Cord 2008 46 (9): 644-647.
13. Gersh MR, Wolf S, Rao V. Evaluation of trancutaneous electrical nerve stimulation for pain relief in peripheral neuropathy. Phys Ther 1980; 60 (1): 48-52.
14. Fontaine D, Bruneto JL, Hasna EF, Paquis P, Lanteri-Minet M. Short-term restoration of facial sensory loss by motor cortex stimulation in peripheral post-traumatic neuropathic pain. Headache Pain 2009 10 (3): 203-207.
15. Kim DH, Midha R, Murovic JA, Spinner Teil J. *Nerve Injuries: Operative Results for Major Nerve Injuries, Entrapments, and Tumors.* 2nd edition. Philadelphia, PA, Saunders Elsevier, 2008: 23-43.
16. Bruijn I, Geertzen J, Dijkstra P. Functional outcomes after peroneal nerve injury. Int J Rehabil Res 2007 30: 333-337
17. Garozzo D, Ferraresi A, Buffatti P. Surgical treatment of common peroneal nerve injuries: Indications and results. J Neurol Sci 2004 48 (3): 105-112.
18. Ness L300 *Clinical Training Materials*. Valencia, CA: Bioness Inc; 2008: 1-4
19. Ness L300 *Clinicians Guide*. Valencia, CA: Bioness Inc; 2009: 85-89
20. *Guide to Physical Therapy Practice*. 2nd edition. American Physical Therapy Association, Alexandria, VA, 2001.
21. Perry J. *Gait Analysis: Normal and Pathological Function*. SLACK Inc. Thorofare, NJ. 1992 452-455.
22. Pohl P, Duncan P, Perera S, et al. Influence of Stroke-Related Impairments in 6 Minute Walk Test. J Rehabil Res Dev 2002 39(4): 439-444.
23. Ohtake P. Impact of obesity on walking: Implications for fitness assessment and exercise prescription. Cardiopulm Phys Ther 2008 19(2): 52-53.
24. Kennedy D, Stratford P, Riddle D, Hanna S, Gollish J. Assessing recovery and establishing prognosis after total knee arthorplasty. Phys Ther 2008 88(1): 22-32.
25. Hill K, Schwarz J, Kalogeropoulos A, Gibson S. Fear of falling revisited. Arch Phys Med Rehabil 1996 77(10): 1024-1029.
26. Yardley L, Beyer N, Hauer K, Kempen G, Poit-Ziegler C, Todd C. Development and initial validation of the falls efficacy scale-international. Age Ageing 2005 34: 614-619.
27. Weiner R. Peripheral mononeuropathy; peripheral nerve neurostimulation techniques have renewed interest. Med Devices Surgical Tech Week September (21) 2003: 132.
28. Giaquinto S. Neurorehabilitation: Old and new concepts. Cerebreovasc Dis 2000 10 (suppl. 4): 49-51.
29. Thompson AK, Stein RB. Short-term Effects of functional electrical stimulation on motor-evoked potentials in ankle flexor and extensor muscles. Exp Brain Res 2004 159: 491-500.
30. Diffenbaugh N. Stepping up. Advance Physical Therapists & PT Assis 2008 19 (19): 31.
31. Hesse S, Werner C, Matthias K, Stephen K, Berteanu M. Non-velocity-related effects of a rigid double-stopped ankle-foot orthosis on gait and lower limb muscle activity of meniparetic subjects with an equinovarus deformity. Stroke 1999 30: 1855-1861.