History of Motor FES: who were the pioneers?

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Abstract

Who were the first pioneers of FES locomotor neural prostheses? A preliminary investigation reveals that a number of early devices were independently invented by some very interesting and high-profile individuals - some of whom have received scant recognition for their contributions. ***Keywords****: history of FES, neural prostheses.*

Introduction

Many reviews of locomotor FES neural prostheses begin with the peroneal nerve stimulator for drop foot described by Liberson [1]. See for example: http://en.wikipedia.org/wiki/Functional_electrical_stimulation However, using the search engine Google and Google Patents has revealed other high-profile contributors.

Material and Methods

Guillaume-Benjamin-Amand Duchenne

Behr, in his obituary to Duchenne says "Who does not remember the astonishment caused by the clinical experiments of Duchenne pulling people from their beds who look absolutely paraplegics and loading them to bending with the weight of a man of ordinary stature? It was one of his merits to always have at his disposal a means of demonstration to attract attention and establish the facts in memory." [2] Duchenne, a neurologist, used electrical stimulation for therapy as well as to demonstrate functional anatomy. Could he have also made the first demonstrations of FES? http://en.wikipedia.org/wiki/Duchenne_de_Boulogne

Norbert Weiner

He proposed a system he called the "Nervous Prosthesis" around 1948 [3]. This shows that signals from the brain after electronic processing could be used to control electrical stimulation of the peripheral nerve below the level of the spinal lesion – something we are just now developing more than 60 years later! Norbert Weiner was a famous MIT mathematician and founder of the field of Cybernetics. http://en.wikipedia.org/wiki/Norbert_Wiener

Weiner also presented at the early meetings of the External Control of Human Extremities (ECHE) held in Dubrovnik.

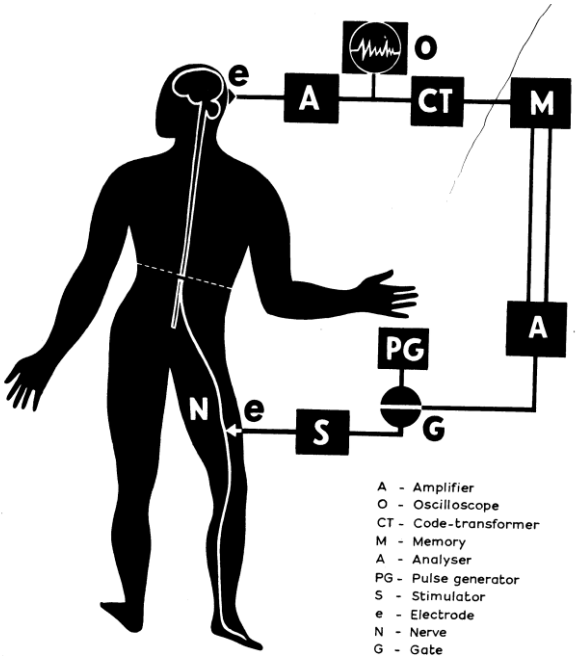


Fig. 27. Design for a nervous prosthesis to bring impulses from the brain to the sciatic nerve.

Charles Giaimo

Giaimo was the chief engineer for the large US Lionel Corporation famous for its innovation in Toy Trains. In 1935, Giaimo invented Lionel's first whistle in a model train based on the sounds of real railroad whistles that had been recorded for study. It was a marvel of design simplicity and became an instant success. Giaimo had MS and developed two assistive systems, (Life magazine Feb 21st 1955). The first was a FES system filed in 1951 US#2,737,183. The second was a electric powered cable driven hand orthosis to restore grip function in neurological disorders, detailed in his US patent filed in 1954 and described in an article in Life Magazine Jan 31st 1955 shows a quadriplegic patient using this device in the Institute of Physical Medicine and Rehabilitation at New York University.
http://books.google.com/books?id=5VMEAAAAMBAJ&pg=PA50&as_pt=MAGAZINES&source=gbs_toc_r&

cad=2#v=onepage&q&f=false It would appear to be a useful orthosis that is relatively unknown in prosthetics and orthotics.

James E Keegan Jr.

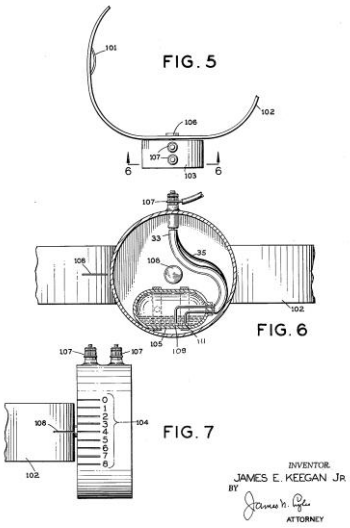
Keegan filed his patent US#3,083,712 on Nov 29th 1961and assigned to the Heinicke Instruments Corp now called HEICO www.answers.com/topic/heico-corporation He describes a drop foot brace in which stimulation can be applied to either peroneal nerve or motor points for peroneus longus or brevis. The control system could be triggered by a shoe inserted footswitch or a mercury tilt switch. The latter could be mounted onto the leg as shown in or attached to the subjects arm and mechanically adjusted for limb segment inclination. Using a sensor on an intact upper limb that is naturally involved in the movement of the paralysed lower limb seems an interesting idea and worth exploring further. The control system is sophisticated and featured programmable delays from heel rise to stim ON, the ON time for the stim and the delayed turn OFF from heel contact. The latter was used to control heel contact to foot flat without foot slap.

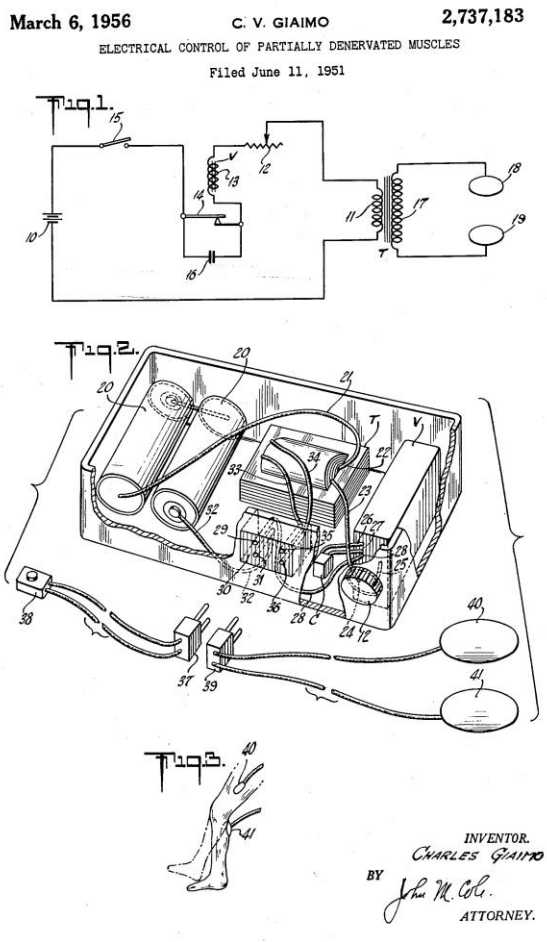
Wladimir Theodore Liberson

Liberson is well known for his version the peroneal nerve drop foot brace in 1961 [1]. Interestingly, Liberson is less well known for describing the use of the flexion withdrawal reflex to control stepping in mid thoracic paraplegics [4] "In such patients low intensity 40c/sec, 50 - 100μs electrical pulses applied to the sural or tibial nerves (in the popliteal fossa) results in reflex hip and knee flexion with simultaneous reflex ankle dorsiflexion, simulating the swing phase of gait. A switch ((pacemaker) is placed in the shoe on the contralateral side. "Reflex Walking" in such patients wearing a portable stimulator is much less fatiguing than the natural locomotion. It also permits the patient to negotiate stairs."

Adrian Kantrowitz

Katrowitz is regarded as the pioneer of heart transplant surgery and the development of neural prostheses, in collaboration with General Electric, for cardiac pacing and bladder control, see http://en.wikipedia.org/wiki/Adrian_Kantrowitz He also developed a FES control system for leg extension in dogs and standing in paraplegics in1960.
http://profiles.nlm.nih.gov/ps/retrieve/ResourceMetadata/GNBBBM In these early reports Kantrowitz describes closed-loop control of the knee based on a potentiometric knee angle sensor, in one scheme the quadriceps are used to extent the knee against gravity, in another the quadriceps were opposed by the adductor magnus, the semitendinosis, and the biceps femoris [5,6,7].

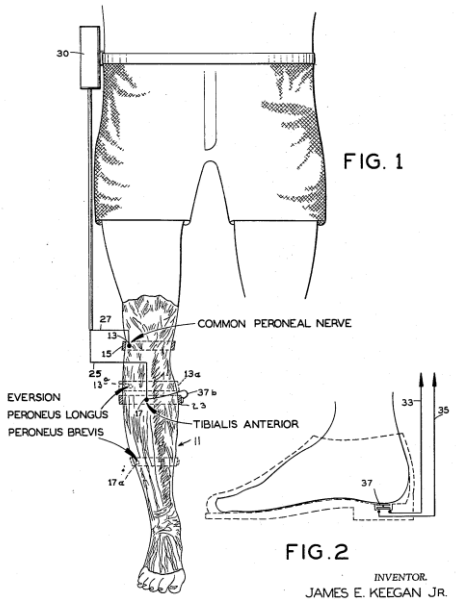




John Moe and Herbert Post

These authors describe in The Journal-Lancet (not to be confused with the Lancet) the application of a

commercially available small (less than 7oz) battery powered belt mounted stimulator produced by the Theratron Inc and detailed in their US patent #193,964.

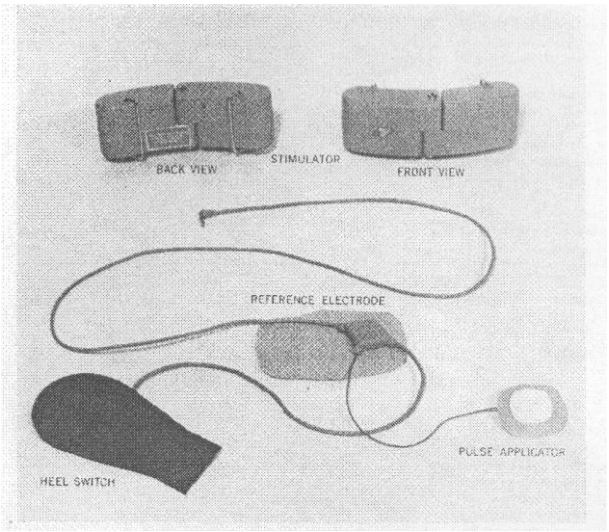


A shoe inserting switch was used to automatically switch ON stimulation when the foot was raised from the floor. The surface electrodes were located using an elasticised cuff. The active electrode being placed over the chosen dorsiflexor. They describe the application in three case histories of stroke in which FES was initiated in May 1961. In patient case#3 the insertion of tibialis anticus surgically transferred into the middle cuniform of the foot to correct an overly strong varus contraction. These authors also noted the carry-over effect where the patients become less dependent on the stimulator with time. They also noted in case#3 and improvement in blood circulation to the affected foot [8]. John Moe, an eminent orthopaedic surgeon, is now regarded as the father of modern scoliosis spine surgery, founded the Scoliosis Research Society and author of the definitive textbook on the subject.

Discussion & Conclusion

Surprisingly, three US investigators/groups were all working independently on the similar idea at the same time - a FES device controlled by shoe insole heel switches to assist drop-foot after stroke. In addition, Keegan introduced an alternative control system using delays to optimise control through the swing to foot contact to foot-flat. His idea regarding positioning the control tilt switch on an upper limb still merits further investigation.

A deeper search may discover the extent of Duchenne's experiments in the field of FES. The visionary contribution of Norbert Weiner is inspiring - even more so given that the technology of the day was the relay and thermionic valves!



There is much more to discover about these pioneers and others who have made contributions to FES, for example Krieg, an eminent neuro-anatomist at Northwestern, suggested in 1949 that "It ought to be possible to place electrodes over denervated muscles and, by activating them in proper sequence and intensity, to produce useful movements" [9].

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