Hybrid Functional Electrical Stimulation (FES)/Articulated Ankle Foot Orthosis (AFO) Device to Treat Drop Foot Gait

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What is Drop Foot Gait?

- **What is it?**
  - Lack or loss of dorsiflexion in ankle due to neural lesions and/or disruption of peroneal nerve

- **How many people are affected?**
  - 6.7 million American civilians (approx. 1 in 50)

- **What diseases are affected?**
  - Caused by strokes (20% of all cases), cerebral palsy, or other neuromuscular deficiencies (e.g. multiple sclerosis, ALS)

- **Also referred to as “foot drop” or “slap foot”**
  - Named because the front of the foot tends to “slap” the ground due to lack of resistance from ankle dorsiflexors
Gait Pattern: Drop Foot

https://wiki.ucl.ac.uk/display/BECS/Engineering+solutions+to+foot+drop

https://www.youtube.com/watch?v=O5MJpVH-2Bs
Lower Leg Anatomy

- Muscles involved in ankle dorsiflexion (distal to knee)
  - Gastroc
  - Soleus
  - Extensor digitorum longus (EDL)
  - Tibialis anterior
  - Extensor hallucis longus (EHL)
- Ankle dorsiflexion is also dependent on the Achilles tendon and the peroneal nerve

Dorsiflexion vs. Plantar flexion

- **Dorsiflexion** is the upward movement/flexion of the ankle

- **Plantar flexion** is the downward movement/flexion of the ankle

  - While dorsiflexion is the primary problem for people with drop foot, plantar flexion is also dependent on the peroneal nerve and can also be affected if the nerve is damaged

https://www.youtube.com/watch?v=o6U2ulKxje0
Ankle Foot Orthoses (AFO)

- Most traditional treatment of drop foot gait
- Orthotic brace that controls stiffness and neutral point of ankle
- Two main functions:
  - Resist plantar flexion movement in swing phase and loading response
  - Allow free dorsiflexion movement in stance phase
- Advantages:
  - Very effective in supporting forefoot clearance with ground
  - Inexpensive
  - Functional in daily use
- Disadvantages:
  - Most provide little to no upward force in dorsiflexion direction
  - Limited ankle mobility based on stiffness of device

Types of AFOs

- **Passive**
  - Non-Articulated AFO (B)
    - Single piece, rigid plastic brace that holds ankle in fixed position
    - No plantar flexion movement at all
  - Articulated AFO (A and C)
    - Jointed, multiple piece plastic or carbon-fiber braces
    - Incorporates mechanical elements like springs or dampers

- **Active**
  - Devices that actively control the flexibility of the ankle
  - Contain a power source, control system, sensors, and actuators
  - Only used in rehabilitation environments due to its cost, complexity, and accessibility
Neuro Swing Articulated AFO (Fior & Gentz)

- Novel Articulated AFO with adjustable spring loaded ankle joint that allows for three areas of adjustability:
  - Alignment of the neutral point based on locking hinge
  - Range of motion in dorsiflexion and plantar flexion direction based on motion limiting screw
  - Multiple thicknesses of springs to control resistivity of motion


https://www.fior-gentz.us/neuro-swing-orthosis/neuro-swing-afo.html

Functional Electrical Stimulation (FES)

- Devices that stimulates lower motor neurons to initiate damaged muscle contraction
- Drop foot stimulators:
  - Electrodes are placed transcutaneously on the peroneal nerve
  - Footswitch is attached under the heel to only apply current during swing phase
  - Initiates dorsiflexion movement past neutral point to maintain toe-clearance
- Advantages
  - Creates movement in dorsiflexion direction
  - Reduced device weight and muscle spasticity
  - Improved motor learning effect
- Disadvantages:
  - Slap foot still an issue
  - Time and skill consuming to apply

https://www.youtube.com/watch?v=gnMHxxnn8ro
Odstock Drop Foot Stimulator (ODFS)

- One of the most common FES devices prescribed for 20 years
- Components:
  - Single channel stimulator the size of a small box that can be worn in pocket or on belt
  - Biphasic waveform
    - Maximum output of 80 mA
    - Pulse duration of 300 µsec
    - Frequency of 40 Hz
  - Skin-surface electrodes on peroneal nerve under fibula and over motor point of tibialis anterior
  - Footswitch that turns stimulation on at heel lift and ends at heel strike
  - Able to add “extension time” to stimulation to help combat slap foot but is hard to perfect

https://www.youtube.com/watch?v=1NrPUcuILH4
Proposed Research

- Create a novel treatment for drop foot gait that’s more functional and encompassing
- Hybrid FES and articulated AFO device
- FES Component
  - Odstock Dropped-Foot Stimulator
  - Stimulator connected to surface electrodes and a footswitch aligned with swing phase
  - Produce biphasic waveforms to peroneal nerve calibrated to create 20° dorsiflexion movement without “extension time”
- Articulated AFO Component
  - Neuro Swing Articulated AFO
  - Heavy resistivity spring on plantar flexion side and smallest resistivity spring on dorsiflexion side
  - Set range of motion to 10° plantar flexion and 20° dorsiflexion
Function Cycle

- Spring resists foot drop in loading phase to prevent slap foot
- Stimulation turns on, foot lifts up
- Footswitch on
- Heel strike
- Footswitch off
- Stimulation turns off, foot drops
- Leg and foot swing
Specific Aims

1. Determine the effect of the combination of an articulated AFO and a FES system on the walking speed of individuals with drop foot gait.

2. Evaluate the resulting vertical ground force on the bottom of the forefoot during loading phase to ensure that the addition of a FES system to an articulated AFO will adequately prevent slap foot in drop foot gait patients.
Subjects and Groups

- 40 people aged 50-65 with drop foot gait that experience >10° unwanted plantar flexion movement
- No previous AFO or FES treatment experience
- Broken into four groups of 10 people
  - Control Group (No Treatment)
  - AFO Group (Only Neuro Swing AFO)
  - FES Group (Only ODFS Treatment)
  - Hybrid Group (Proposed Hybrid Device)
- Short term study
Walking Speed Trial

● Participants walk on level surface for six minutes and average the walking speed of each group

● Previous studies:
  ○ Use of ODFS increased walking speed of stroke patients with drop foot gait by 27%
  ○ Neuro Swing didn’t increase speed patients can walk and sometimes even decreased speed

● Expected results:
  ○ AFO group will have comparable speeds to the control
  ○ FES group will have faster speeds than control and AFO
  ○ Hybrid group will have speeds greater than the other three groups
    ■ Since there will be more dorsiflexion movement in the hybrid group than AFO group, the springs will produce lift off force

● Analysis:
  ○ In the hybrid device, the AFO will not decrease the effect of the FES on patient motion but will actually increase it
Vertical Ground Reaction Force Trial

● Procedure
  ○ Attach a force sensor to the bottom of the forefoot of each subject’s shoe
  ○ Have each subject walk for 20 yards on a hard, level surface
  ○ Average peak force values and compare averages between groups

● Expected results
  ○ FES group will have comparable GRF values to control
  ○ AFO group will have significantly less GRF values than FES and control
  ○ Hybrid group will display slightly larger GRF values than AFO group but much less than FES and control

● Analysis
  ○ Although higher downward forces will be applied to the AFO springs in the hybrid group than the AFO group, we predict vertical GRFs will still be small enough to prevent slap foot
Conclusion

● Drop Foot Gait
  ○ Loss of dorsiflexion in ankle due to neural damage
  ○ Affects approximately 2% of the US population

● Previous Treatments
  ○ AFO
  ○ FES

● Proposed Research
  ○ Hybrid articulated AFO/FES device to more effectively treat both drop foot and slap foot gait

● Conclusions
  ○ Hybrid AFO/FES device will create faster walking speeds and enough plantar flexion resistance in loading phase to prevent slap foot
  ○ The hybrid device provides a more encompassing and effective treatment for all the aspects of drop foot gait than the individual treatments
Questions?
References


