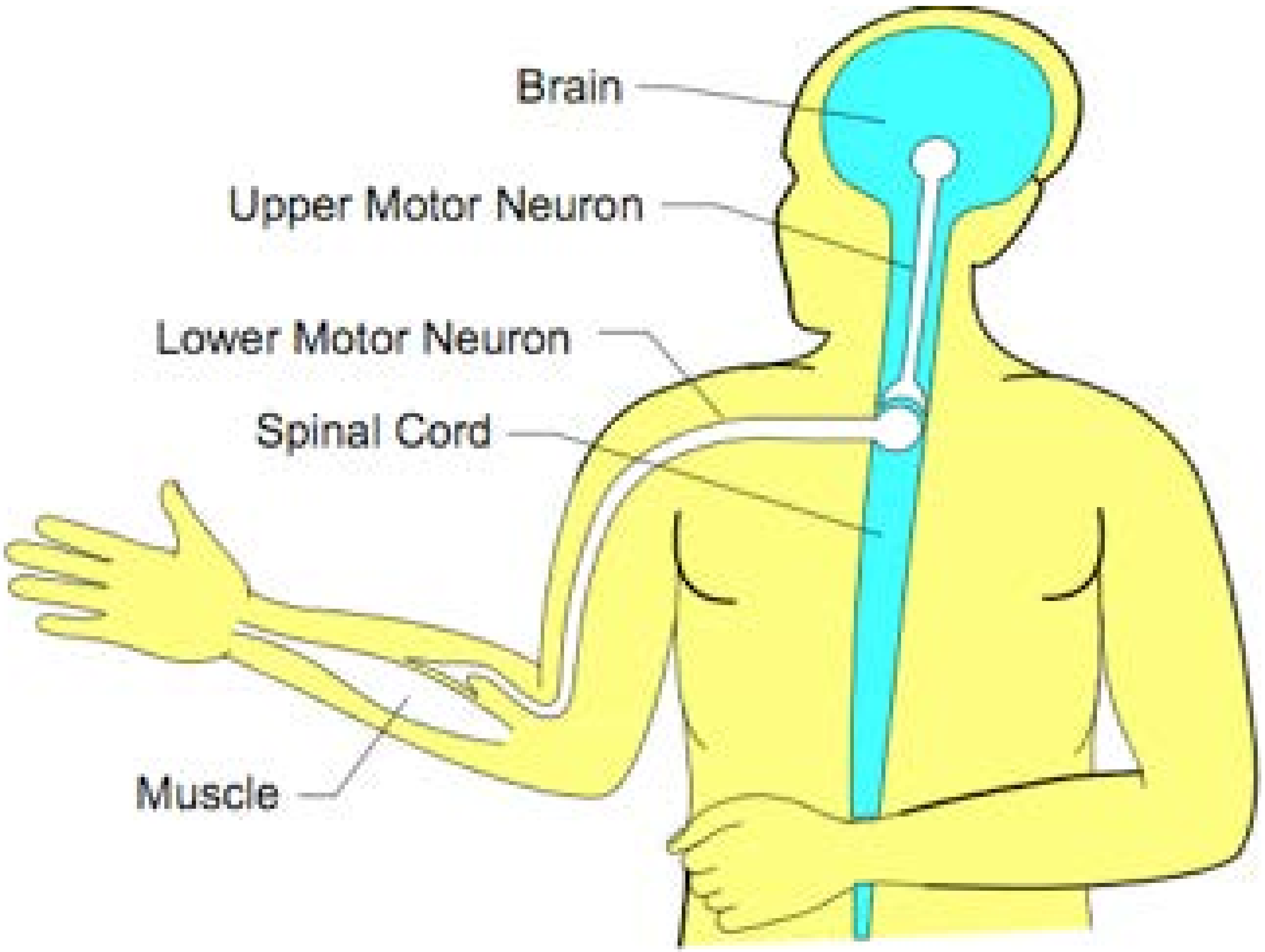
EE 791 Lecture 10

FES

March 23, 2015

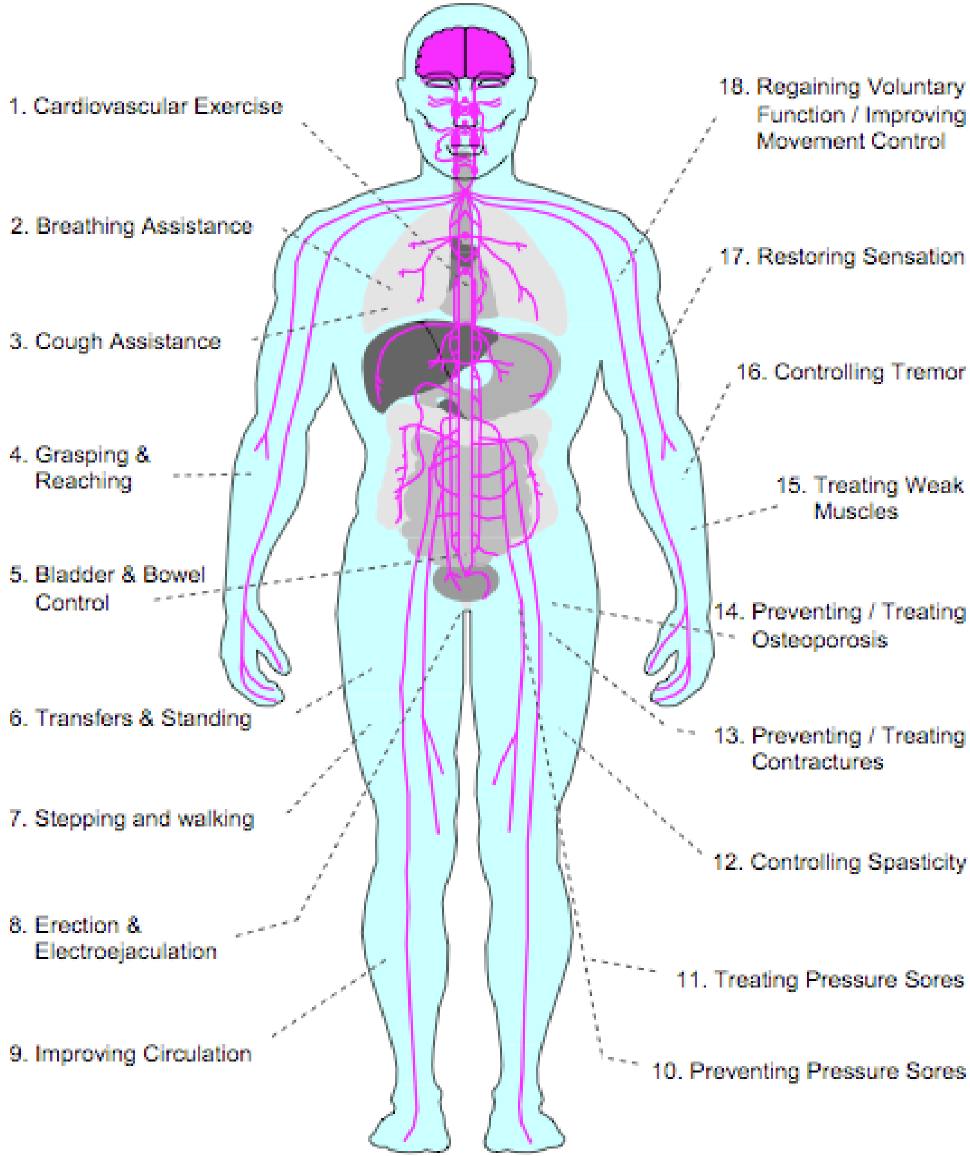
Normal Functional Control



Current uses of FES

- Cardiovascular Exercise
- Breathing assist
- Grasping and Reaching
- Transfer and Standing
- Stepping and Walking
- Bladder and Bowel function

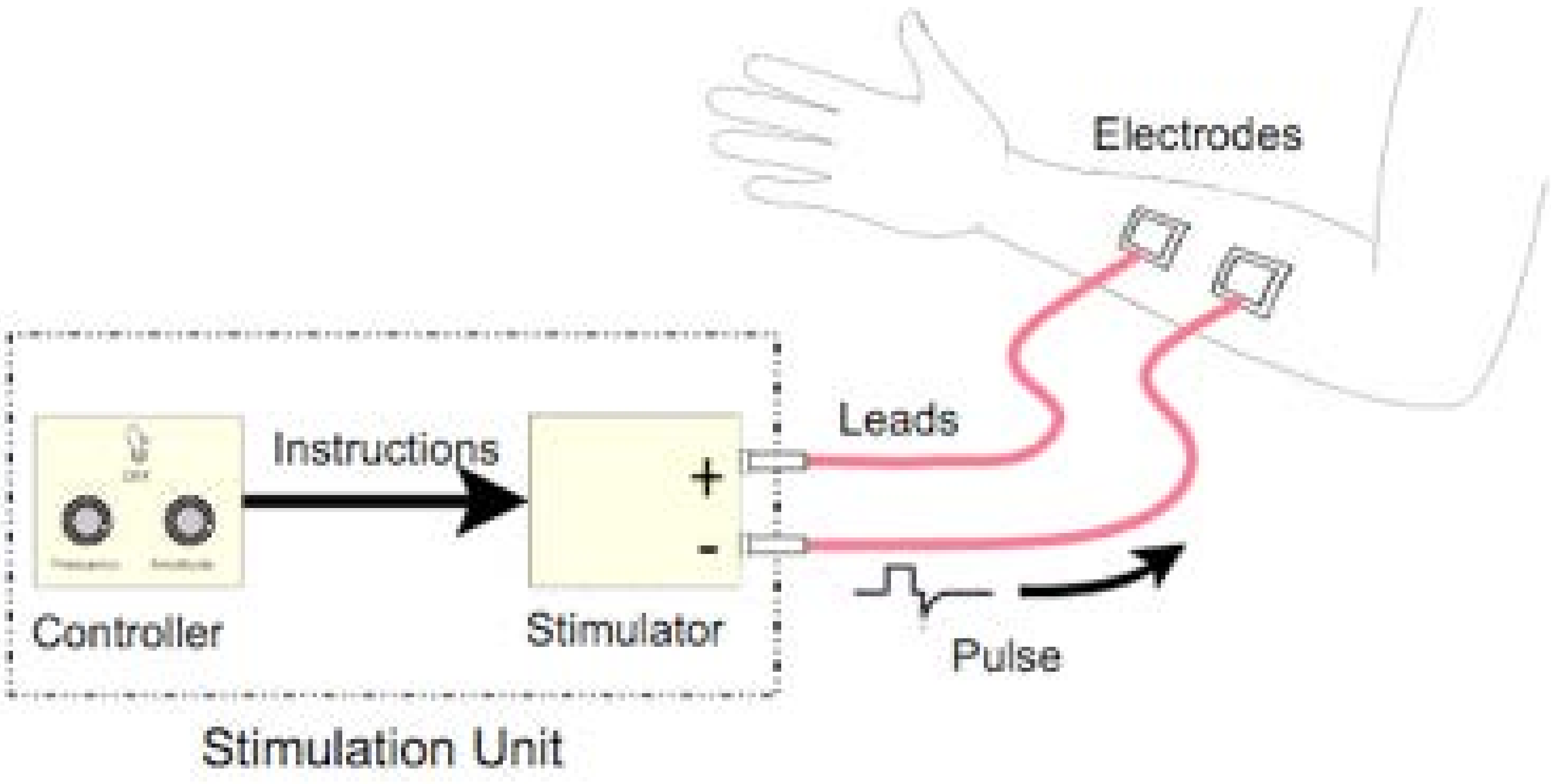
Areas of Intervention



FES System

- Controller
- Pulse Train Generator
- Electrode leads
- Electrodes
- Feedback?

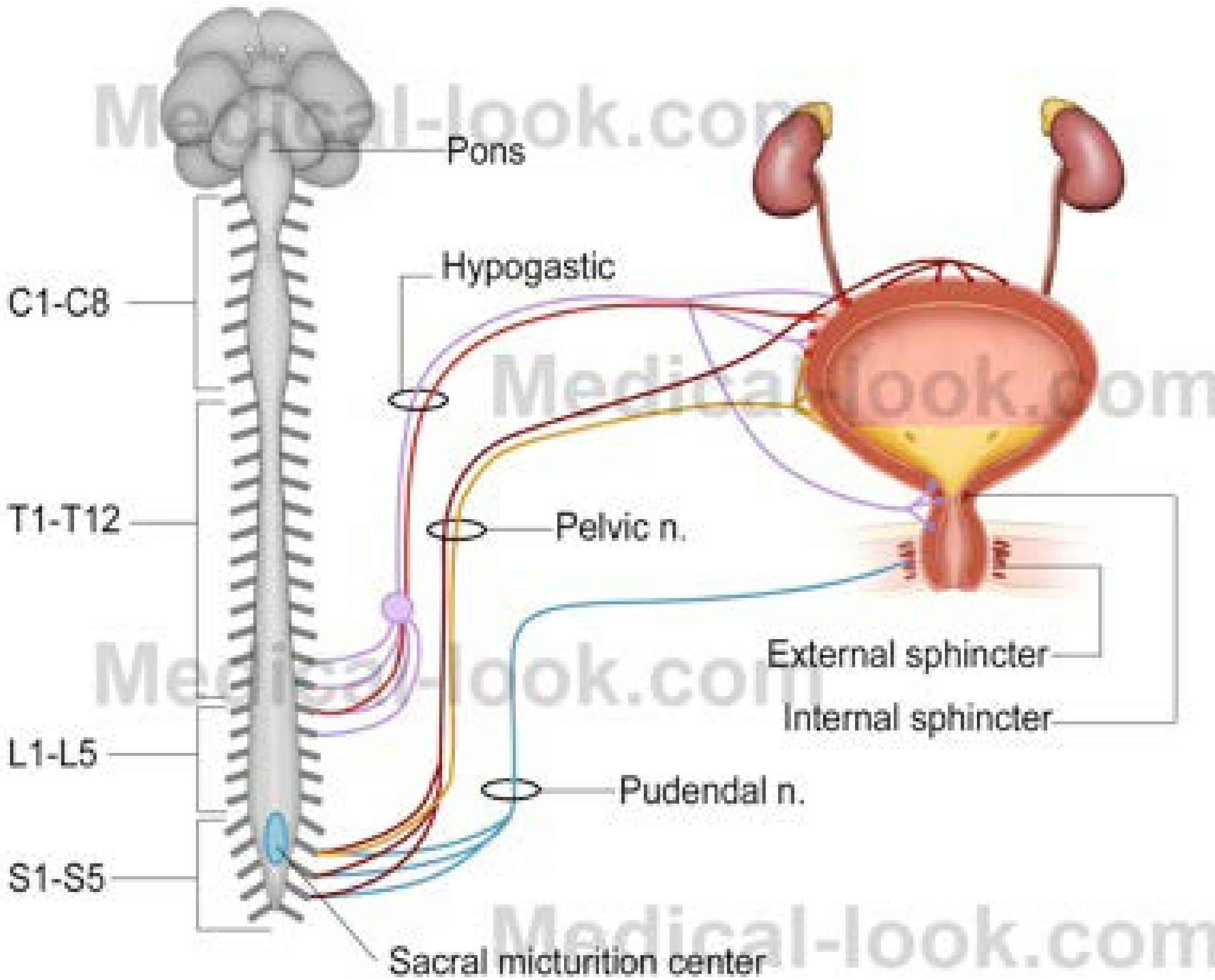
FES System (cont'd)



Bladder function

- Urine flows from kidney to bladder via ureters
- Bladder is a sac covered by the detrusor muscle
- Normally detrusor is relaxed allowing bladder to fill
- Emptying accomplished by urine flowing out of bladder via urethra
- At bladder neck urethra enclosed by smooth muscle internal sphincter and striated muscle external sphincter
- Emptying prevented by voluntary contraction of external sphincter
- When full sensors send signal to brain.
- Voiding is a combination of voluntary and involuntary muscle contractions and relaxations
- Detrusor contracts while both sphincters relax

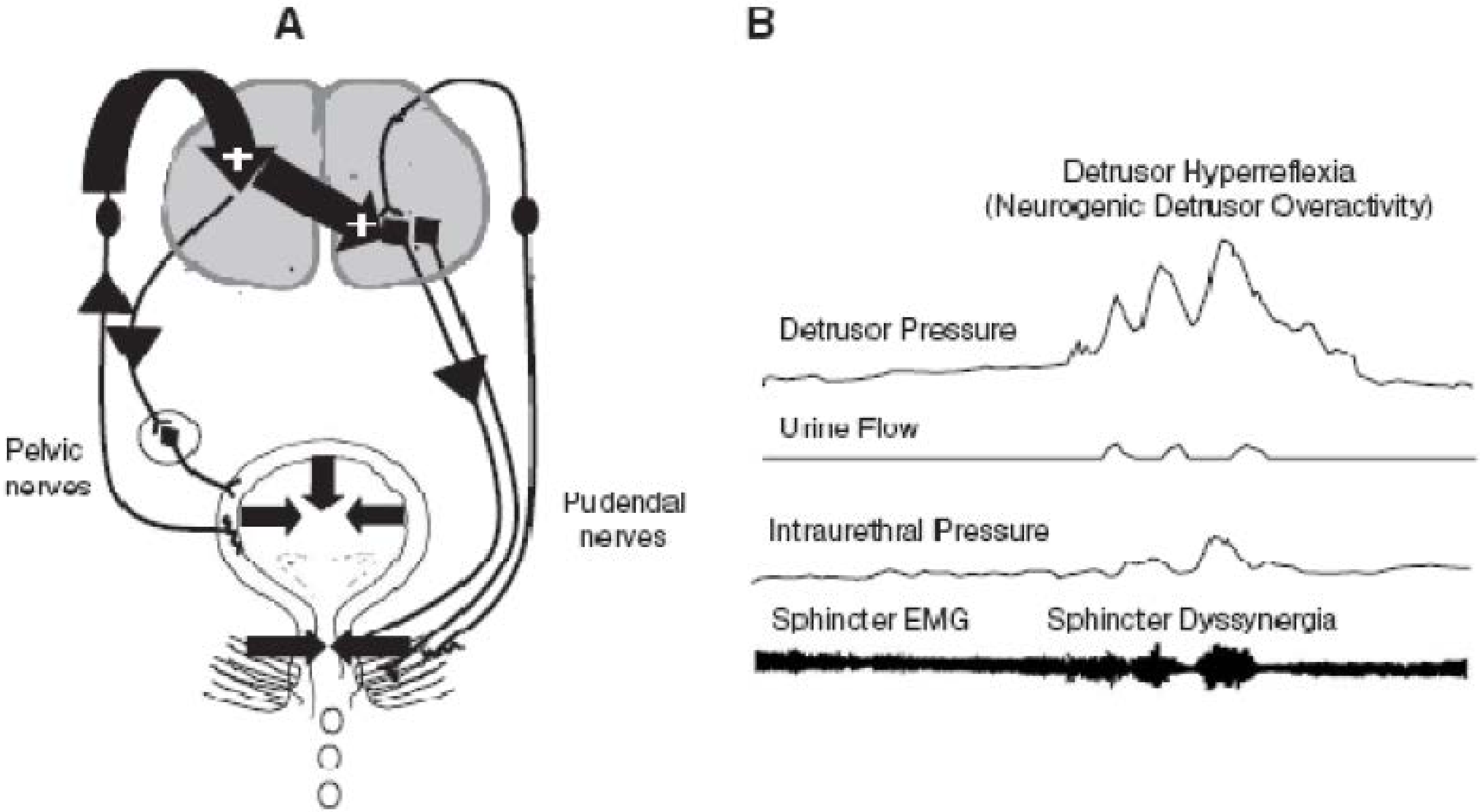
Normal System



Bowel and/or Bladder Assist

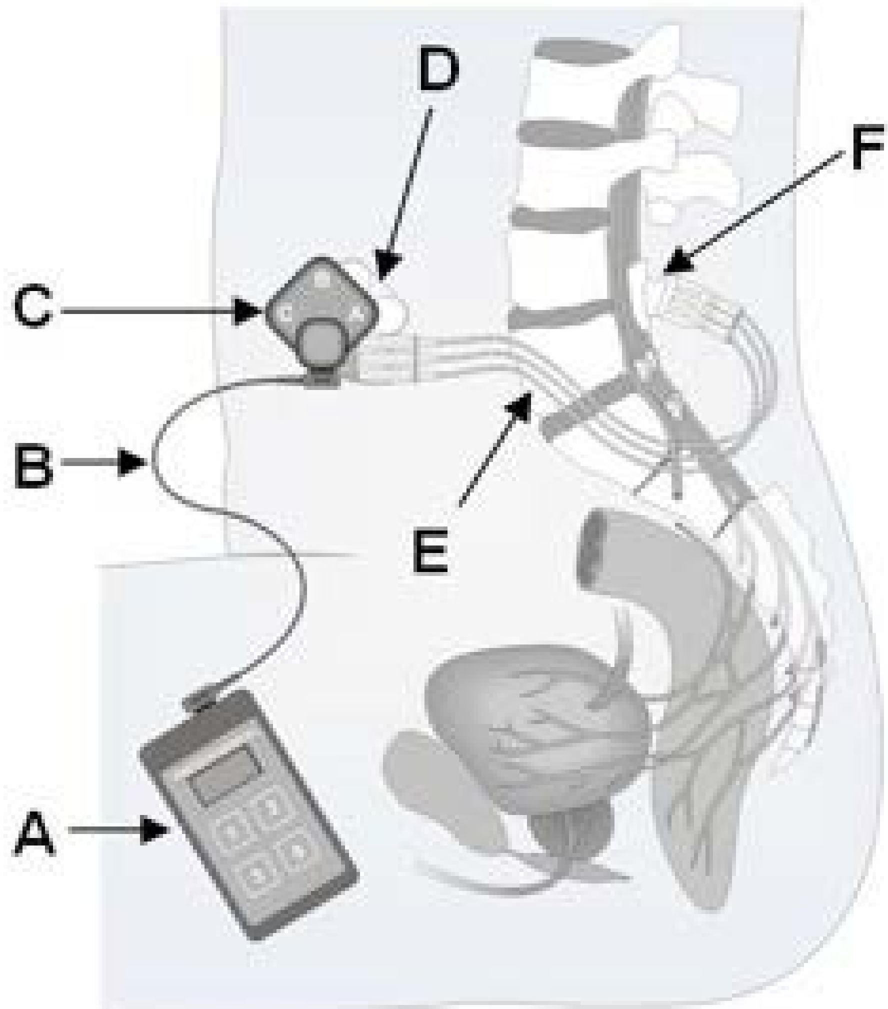
- Required after spinal cord injury
- Bladder can be flaccid leading to hyperextension or hyper-reflexive leading to incontinence
- Catherization the usual method of bladder voiding but can lead to damage of urethra
- Partial emptying of bladder can also lead to infection
- Functioning bladder required for independence

Hyper-reflexia



Finetech-Brindley System

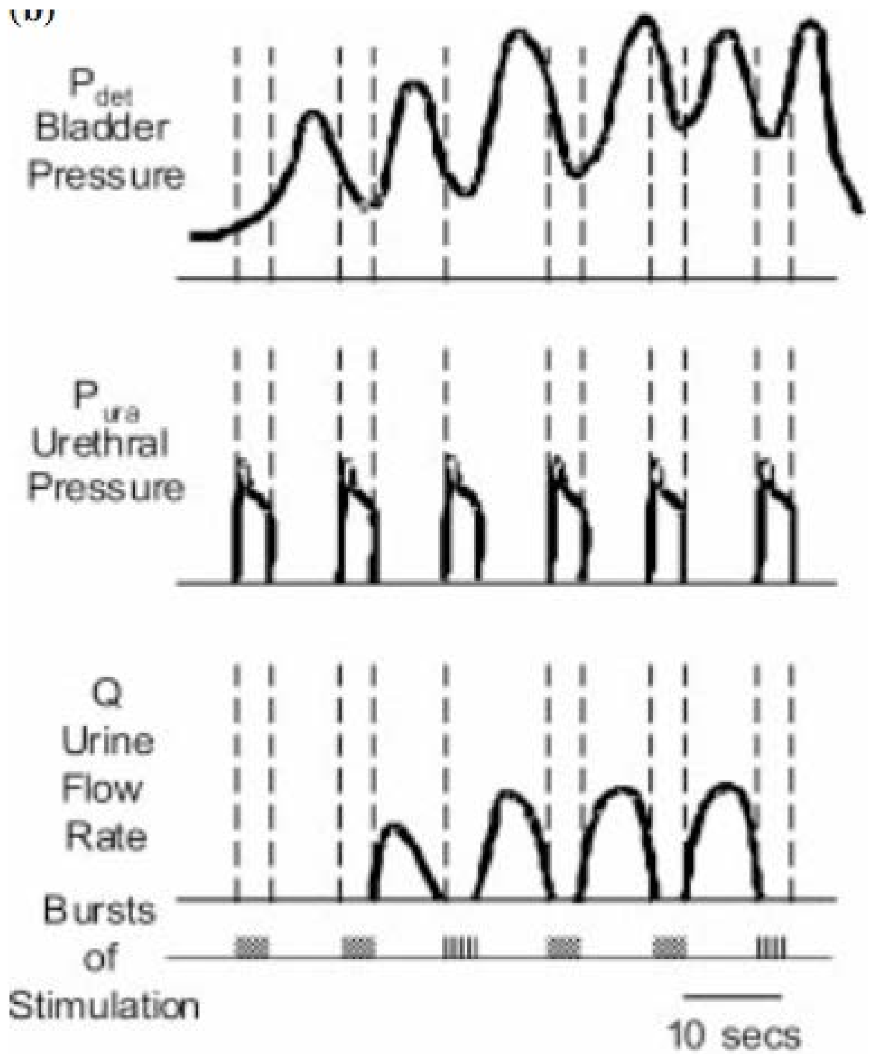
Application of F-B System



Operational Characteristics

- Control box A generates a pulse train encoded at 7 to 9 MhZ
- C and D are transmitter (external) and receiver (internal) pairs
- Electrodes directly stimulate nerves from S2 to S4
- Pulse width is generally 300 μsec. In majority of the patients, the stimulation is of 3 sec duration at interval of about 6.5 sec at frequency 26 Hz.

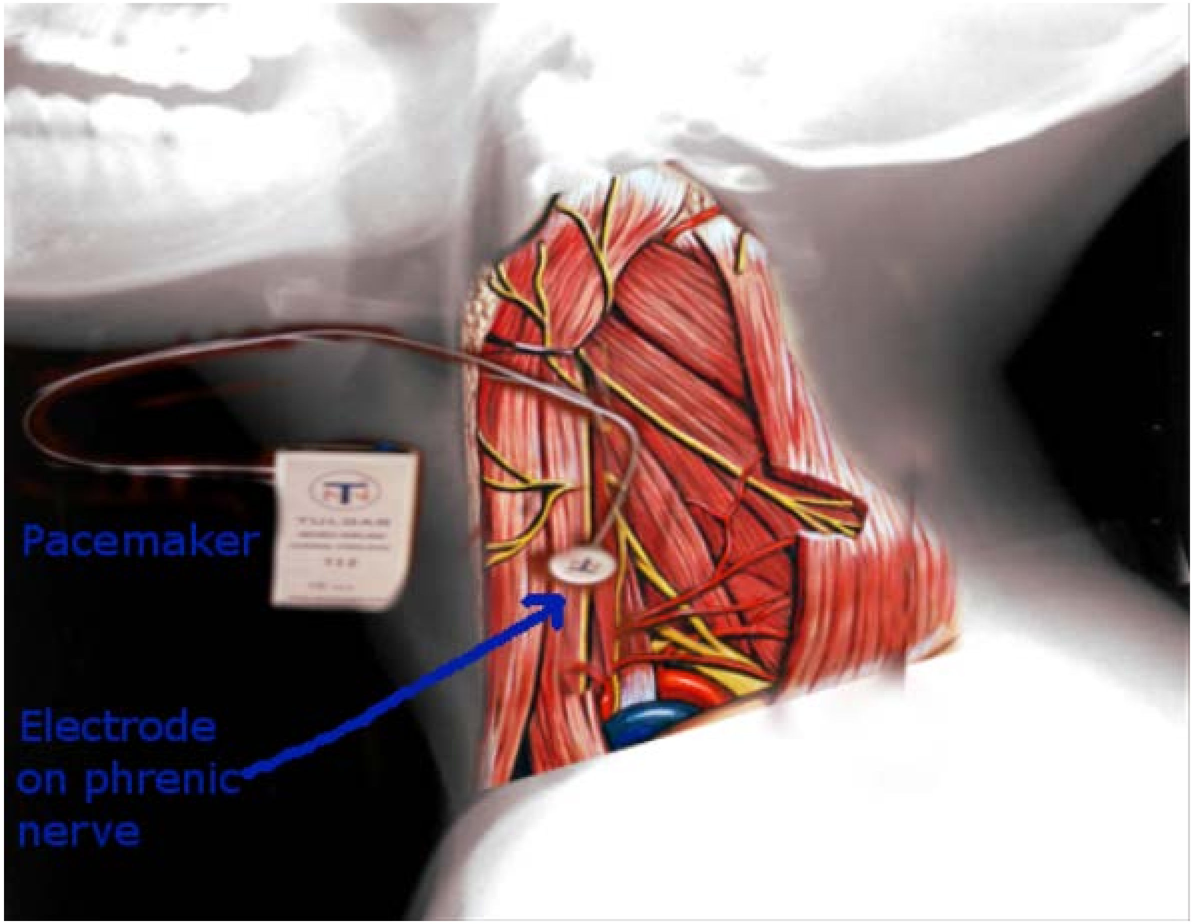
Typical Results



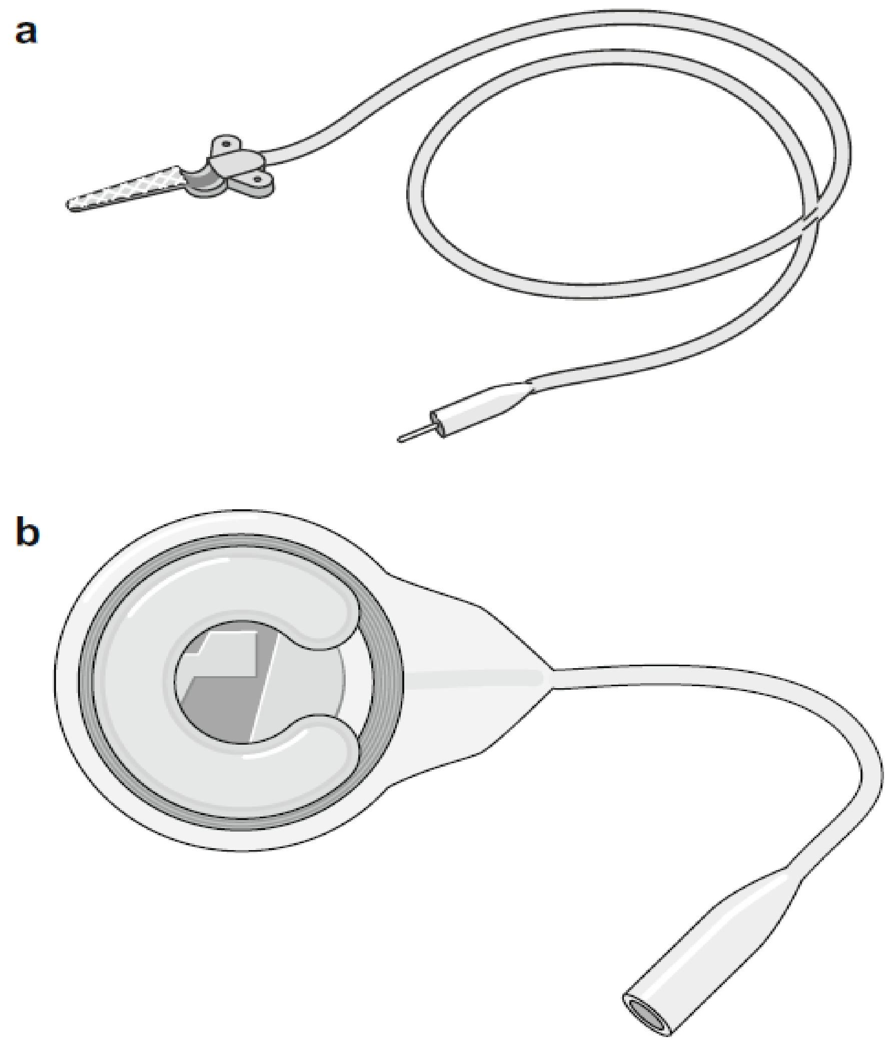
Respiratory Assist -Phrenic Nerve Stimulation

- For high quadriplegia and central hypoventilation syndrome
- External power pack and controller/pulse generator system
- Transmitter/receiver pair
- Phrenic electrode
- Stimulation of phrenic nerve initiates respiration

Phrenic Nerve Concept



Receiver and Monopolar Electrode



System (poor figure)

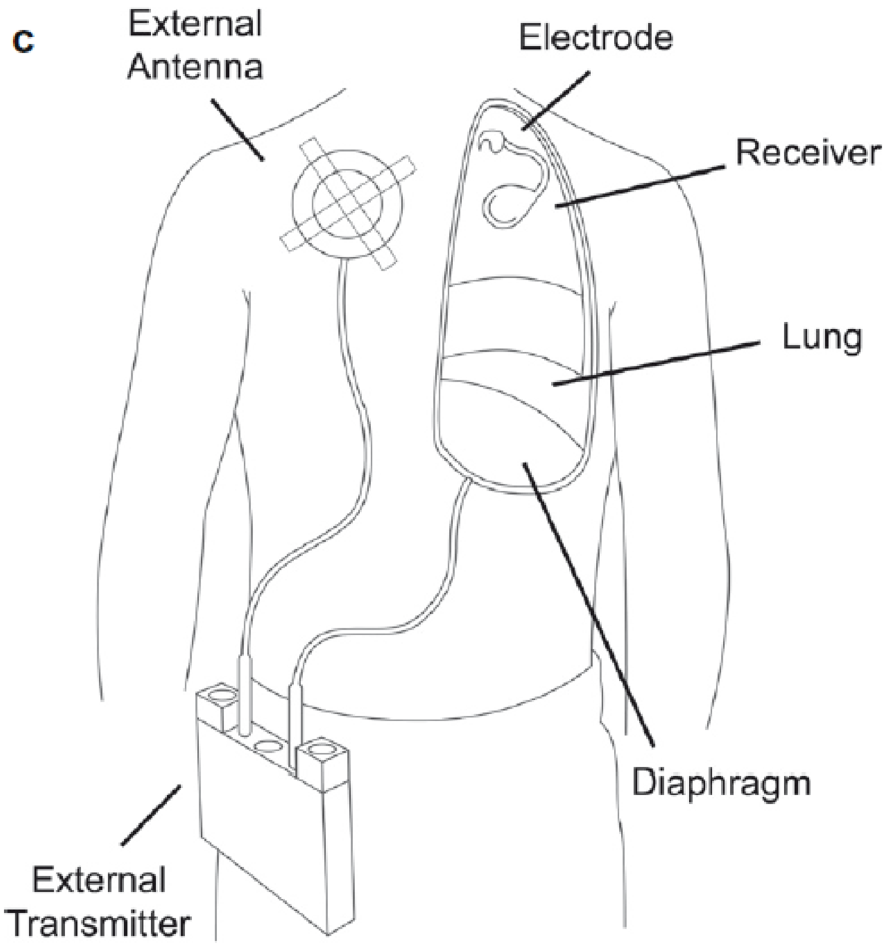
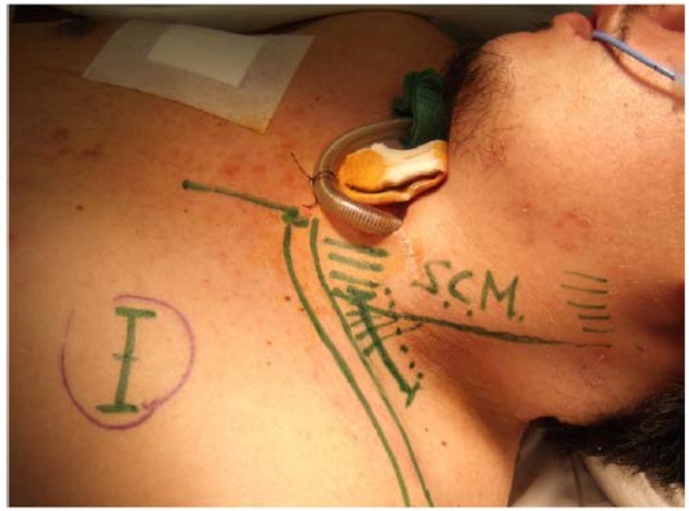


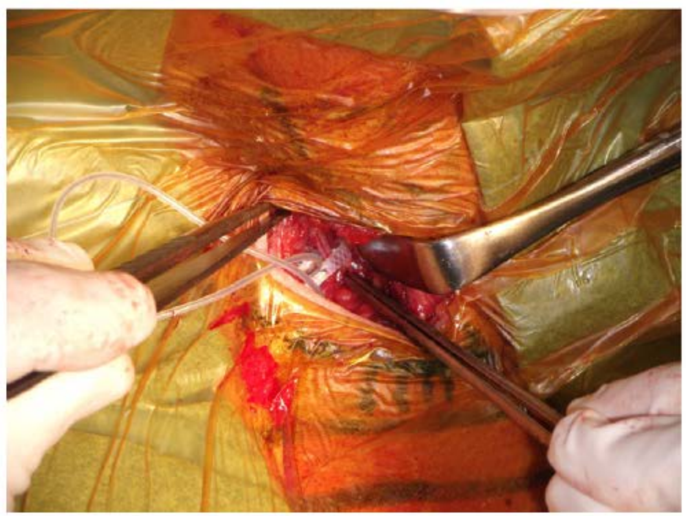
Fig. 1. The phrenic nerve stimulator system showing (a) a monopolar electrode, (b) a I-110 receiver (Avery Biomedical Devices; Commack, NY, USA) and (c) location of the system components.

Surgical Attachment

a



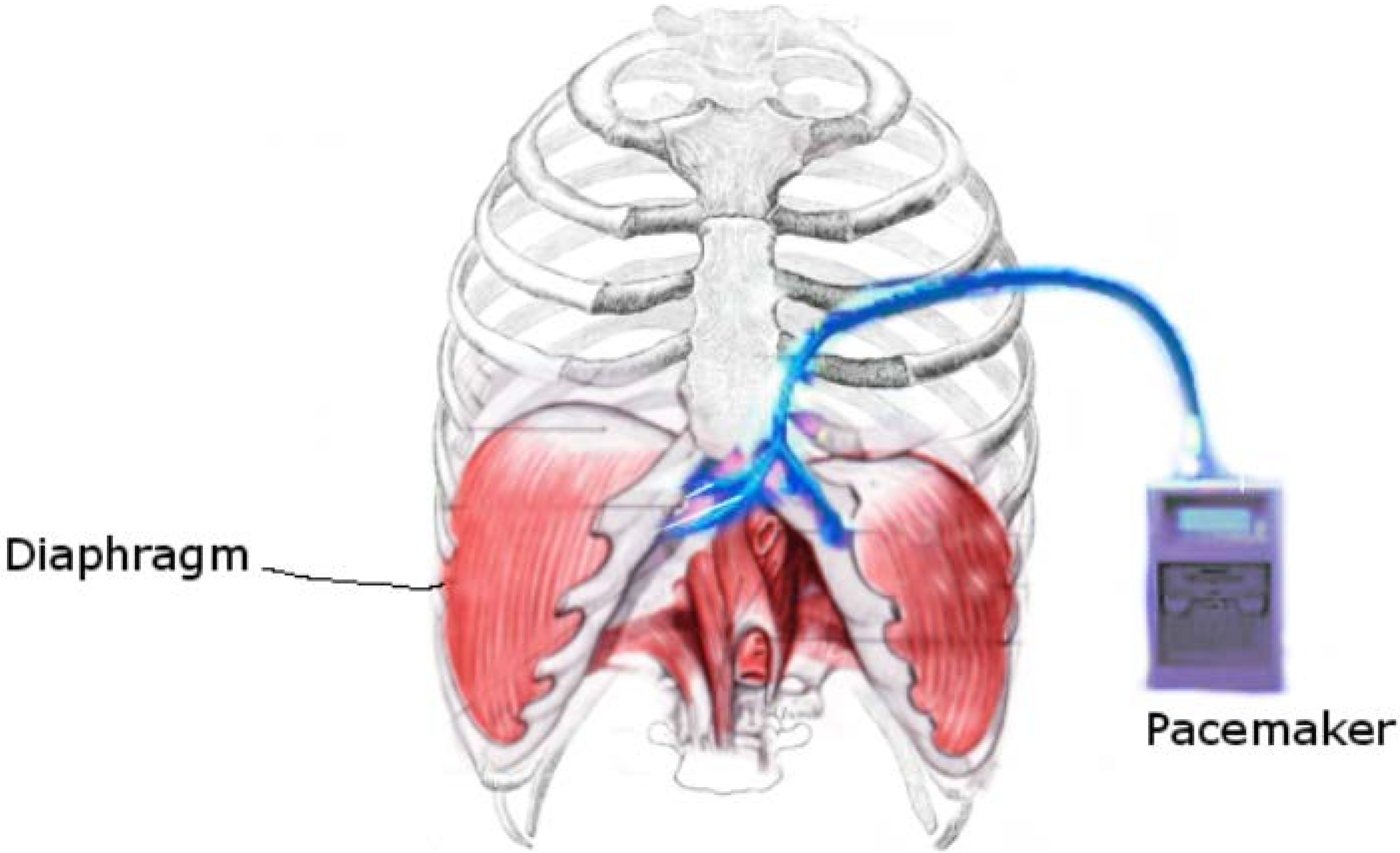
b



Respiratory Assist – Diaphragm Pacing

- More than 12,000 spinal cord injuries in U.S. annually
- >500 need mechanical ventilation (high quadriplegics)
- Does pacing diaphragm interfere with cardiac pacing? No
- Overall system same as phrenic

Diaphragm Concept



Electrode Position (Motor Point)

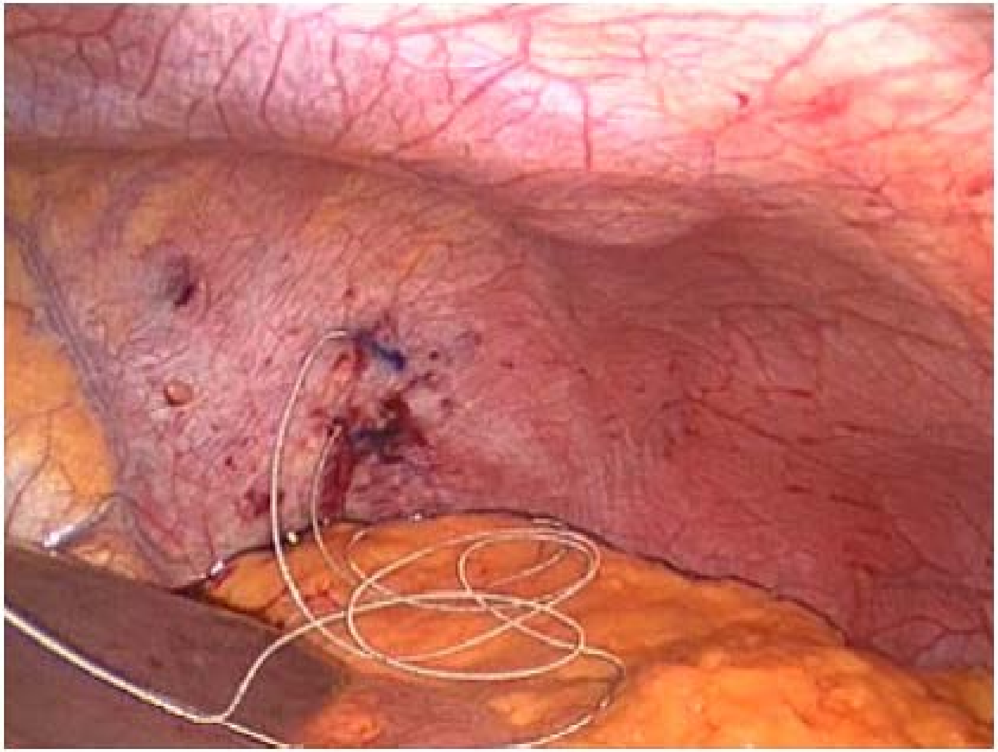


Fig 1. Two electrodes have been placed in the left diaphragm at the motor point, which is lateral to the pericardium. Mapping identified the motor point, which is marked on the diaphragm.

Right Diaphragm

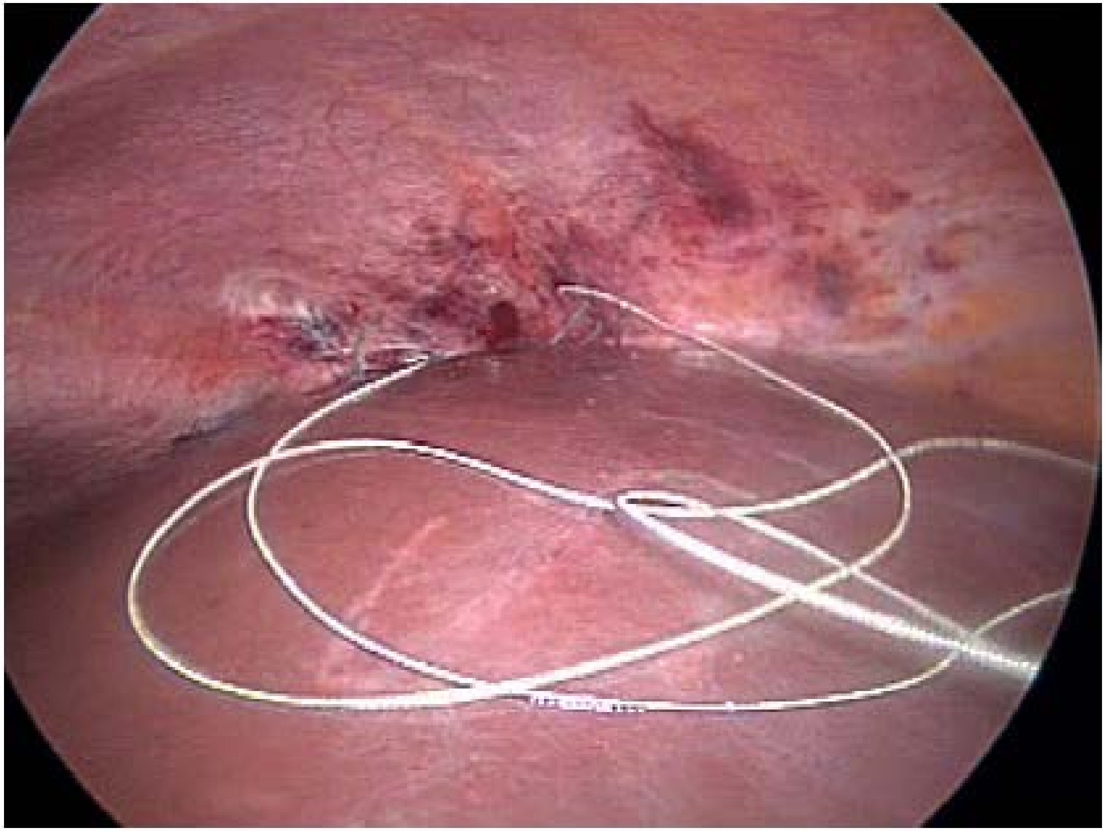


Fig 3. Repaired right diaphragm with implanted electrodes.

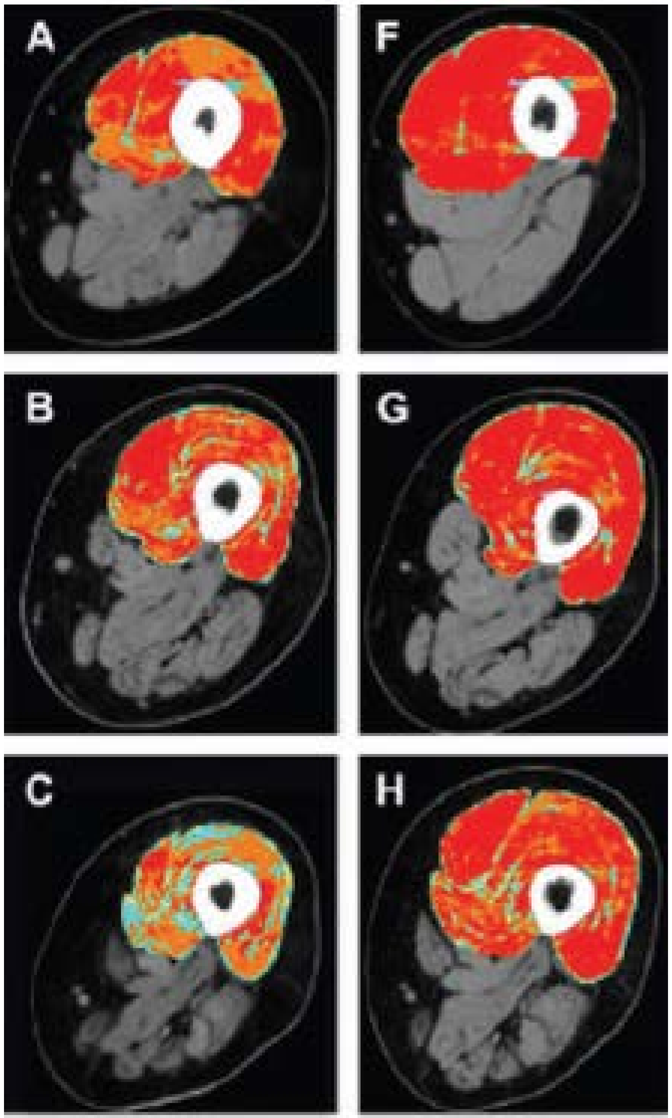
Skeletal Muscle Stimulation

- To provide function to muscles innervated by lower motor neurons but no motor cortex connection because of spinal cord (SC) injury
- To maintain muscle health following lower motor neuron trauma
- To strengthen muscles that are deconditioned due to other medical conditions (renal, cardiac)

Current state of FES for muscle with LMN injury

- RISE study in Europe to restore standing to paraplegics
- Kern et al, 2010, studied patients with SC and LMN injury
- Stimulation pattern using at first 120-150 ms biphasic pulses with very high amplitude (80 – 250 V) despite large (180 cm^2 electrodes

Results of Stimulation



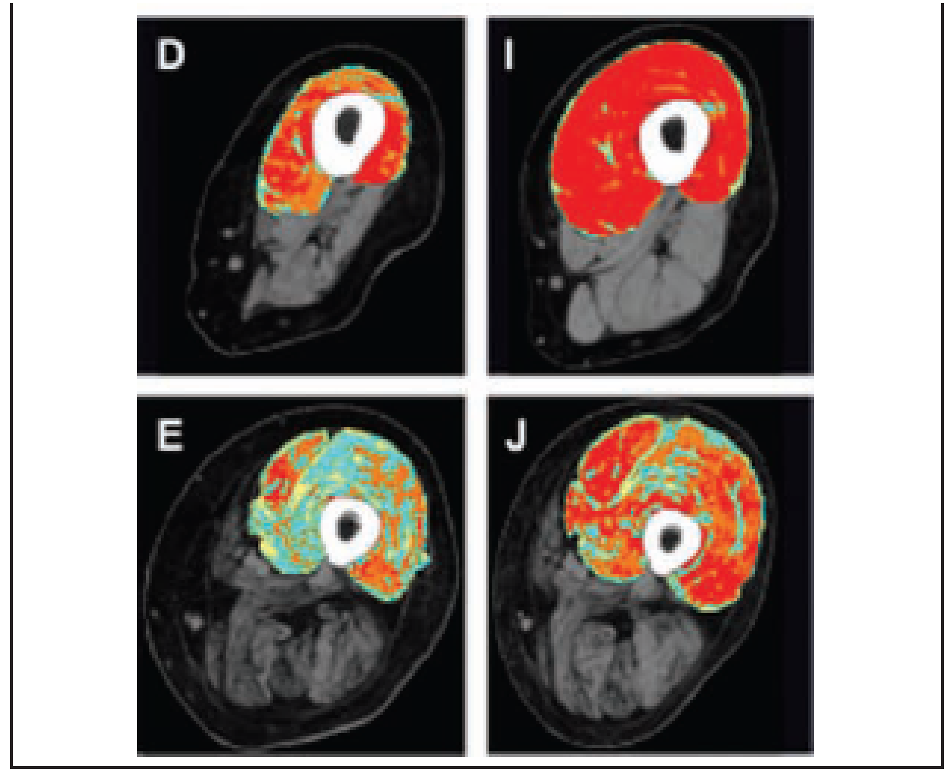


Figure 1. Color CT scans of thigh muscles before and after 2 years of home-based functional electrical stimulation (h-bFES). The cross-sectional area of quadriceps muscles in patients starting h-bFES at different time points after denervation (A, 0.8; B, 1.2; C, 1.7; D, 3.2; and E, 5.4 years) increased after 2 years of home training (F, G, H, and I, J, respectively). Moreover, the interstitial tissues that increase with the denervation time (compare yellow, green, and blue areas in panels A, B, C, D, and E) decreased in the respective patient after 2 years of h-bFES (F, G, H, and I, J, respectively)

Functional Outcomes

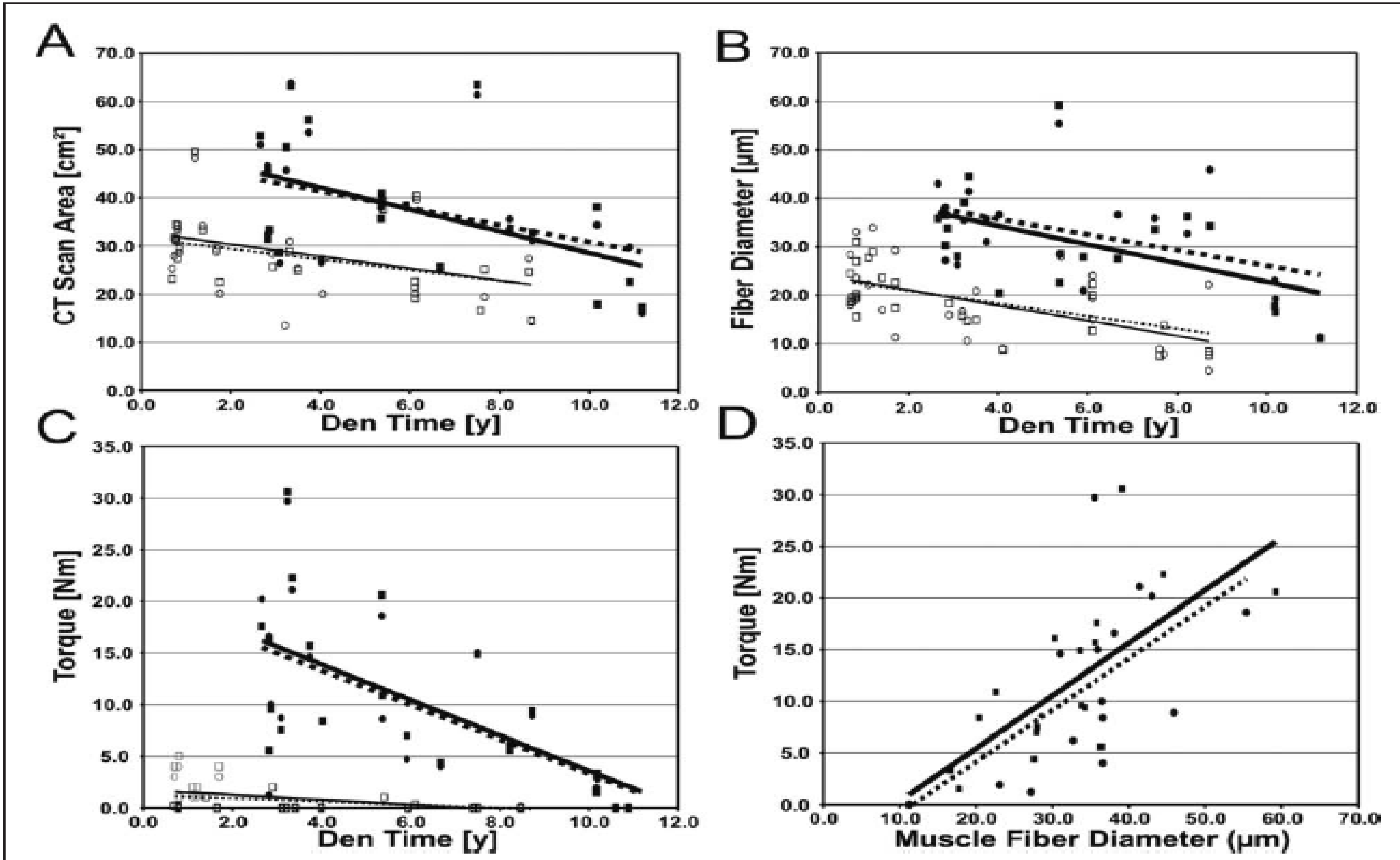
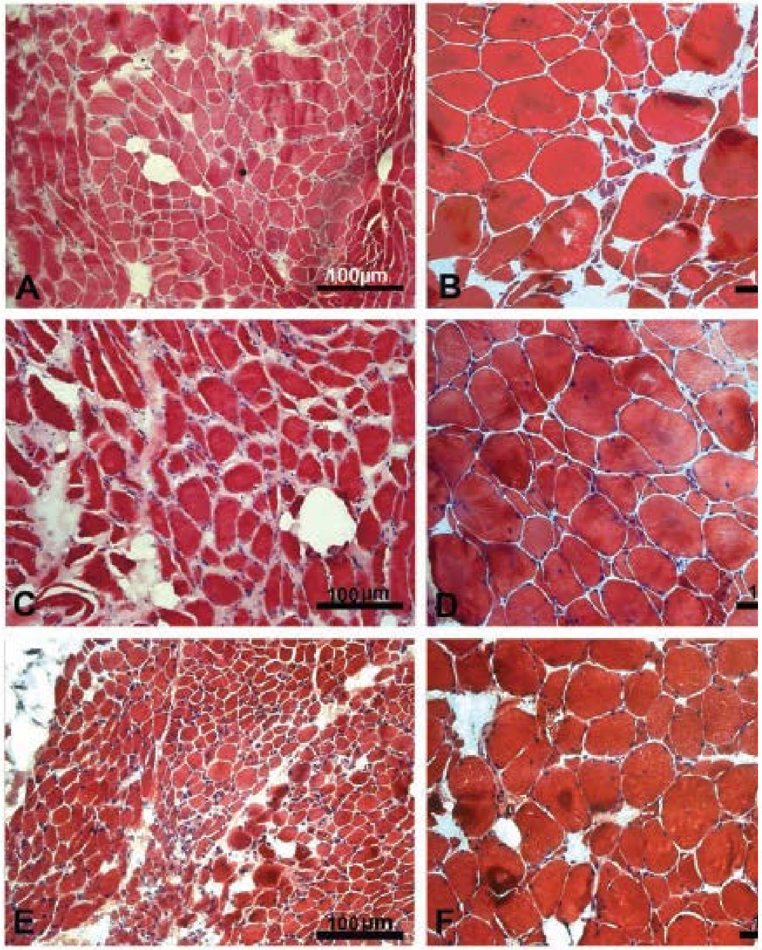


Figure 2. Morphological and functional outcomes after 2 years of home-based functional electrical stimulation (h-bFES) of lower motor neuron denervated human muscle. Thin and thick lines and empty and filled squares/circles show results before and after h-bFES, respectively. Continuous and dotted lines and squares and circles refer to right and left legs, respectively. (A) Muscle cross-sectional area as determined by computed tomography scan. (B) Size of vastus lateralis muscle fibers before and after FES. (C) Effects of h-bFES on maximum tetanic force in correlation to the denervation time. (D) Correlation between mean fiber size and stimulated tetanic force

Histology Results



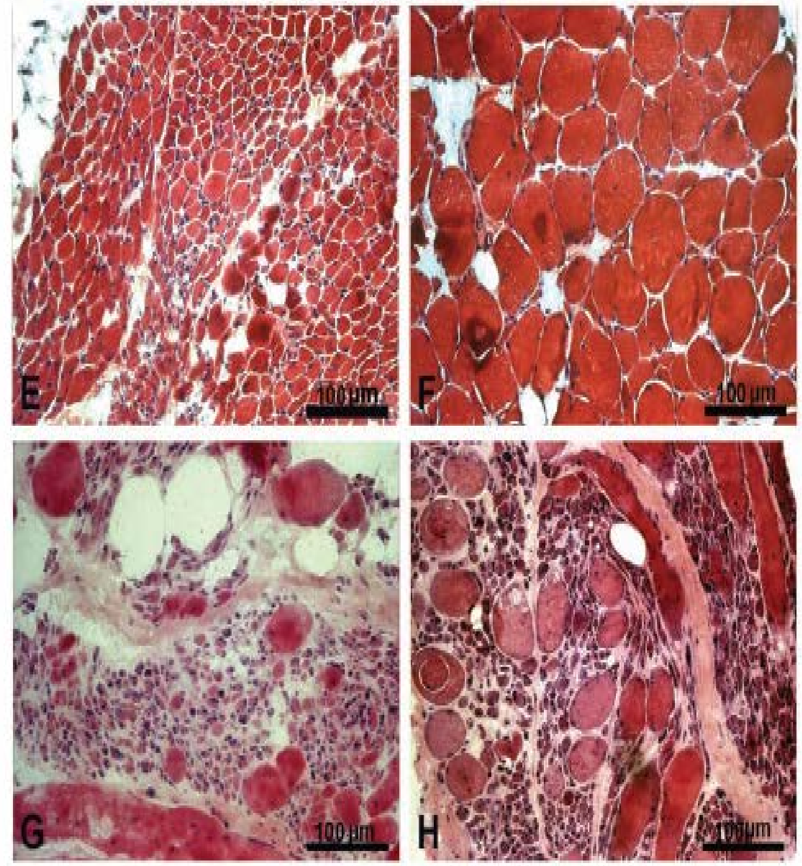
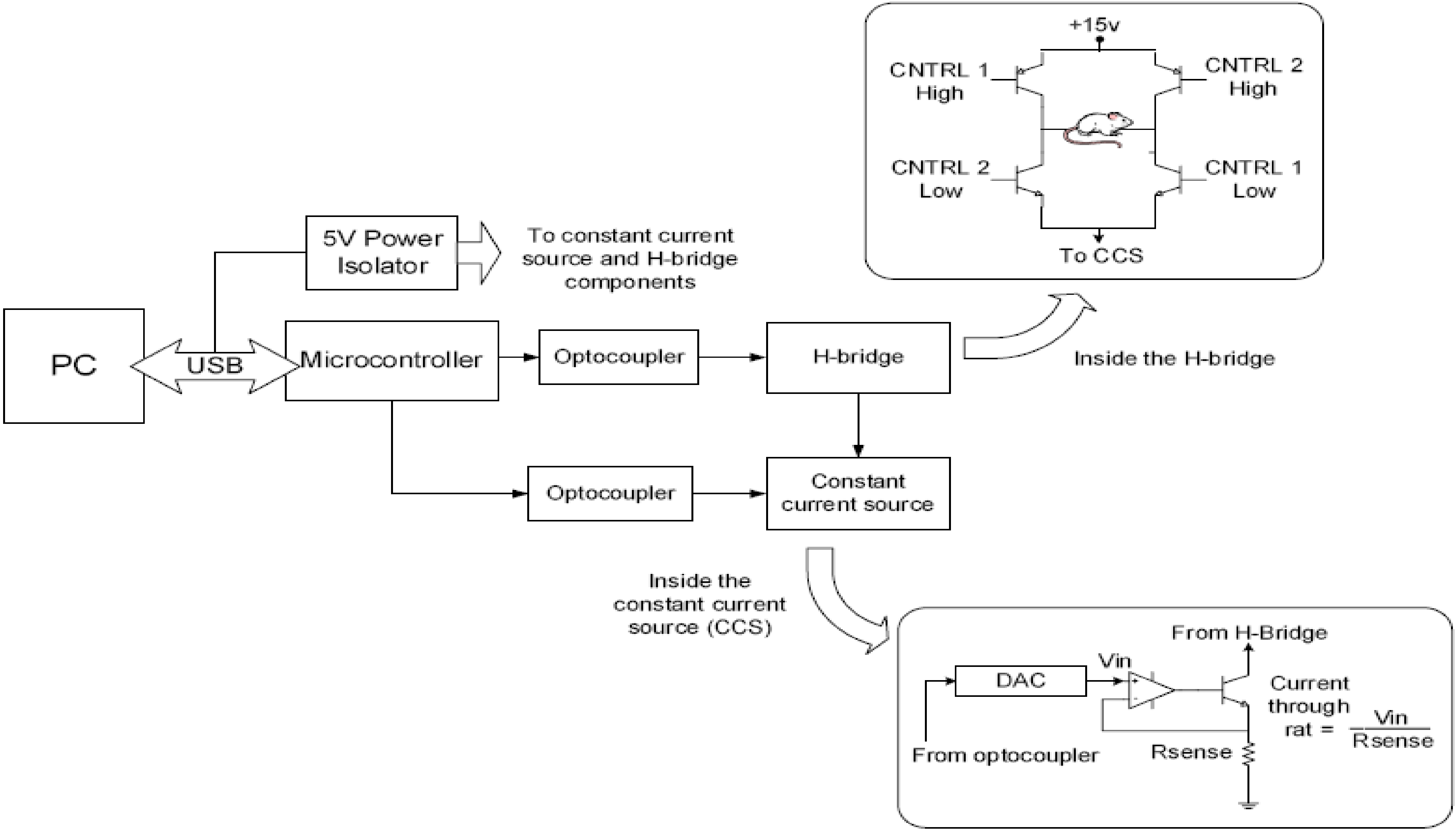


Figure 4. Lower motor neuron (LMN) denervated human muscles recover from atrophy after 2 years of home-based functional electrical stimulation (h-bFES). Hematoxylin and eosin staining of muscle biopsies harvested from vastus lateralis of LMN paraplegic patients before (A, C, E, G) and after (B, D, F, H) 2 years of h-bFES. When started earlier than 2 years after LMN lesion, the h-bFES treatment increases muscle fibers to healthy innervated values; however, with a later start of h-bFES, muscle biopsies show only some large muscle fibers and adipose and fibrous connective tissue do not fully regress

Basic Study to Determine Effects

- Stimulate rat gastrocnemius with 200 μsec biphasic pulses at 100 Hz for 400 ms bursts separated by 6 sec rest for 1 hour/day for 5 days over 1 month after denervation
- Measure histology and functional outcomes at end

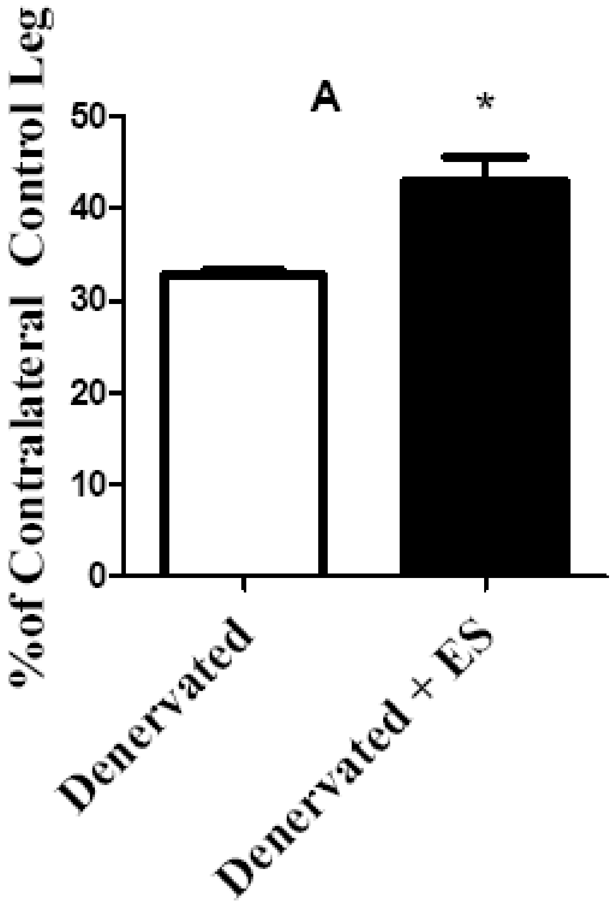
Instrumentation



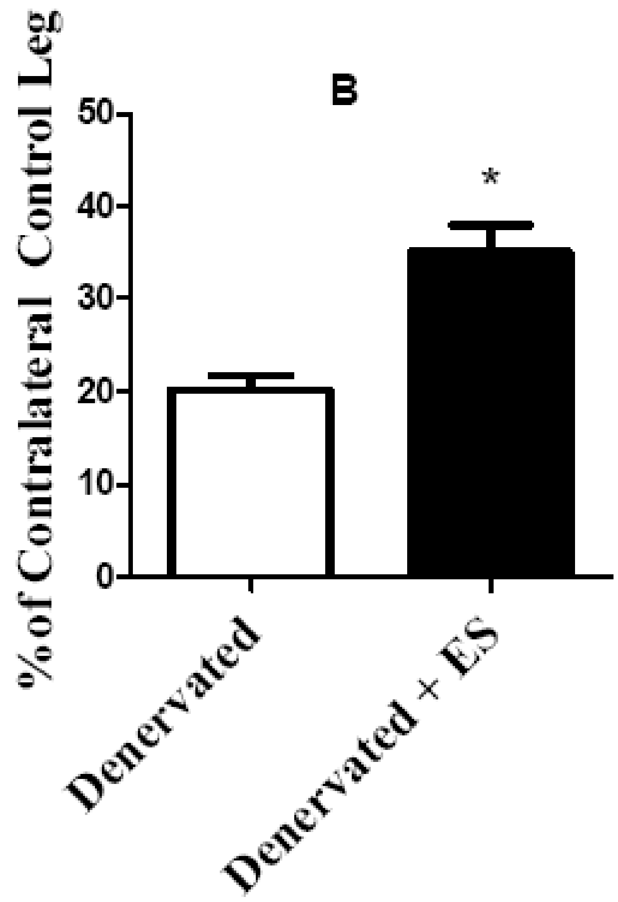
Rat in Holder

Functional Results

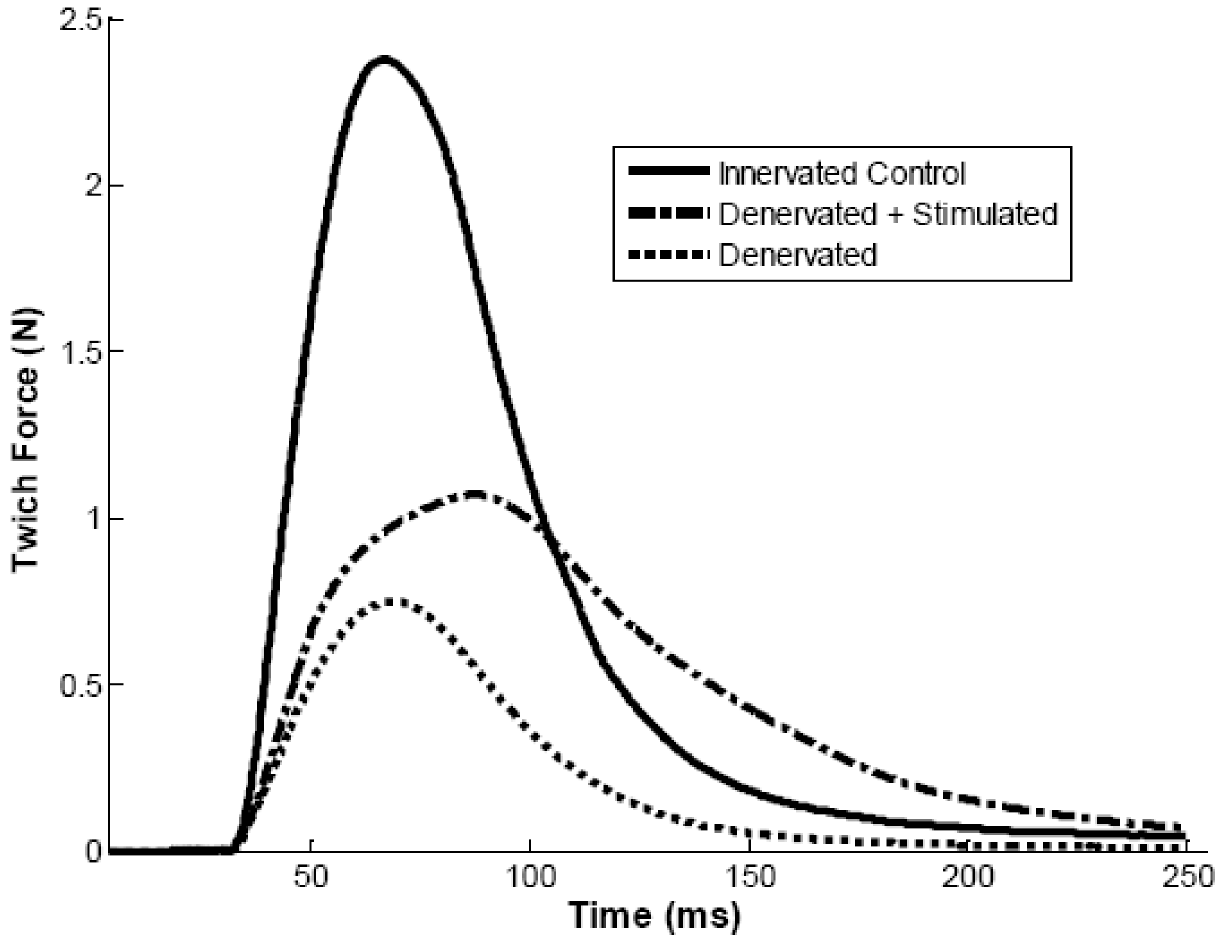
Weight



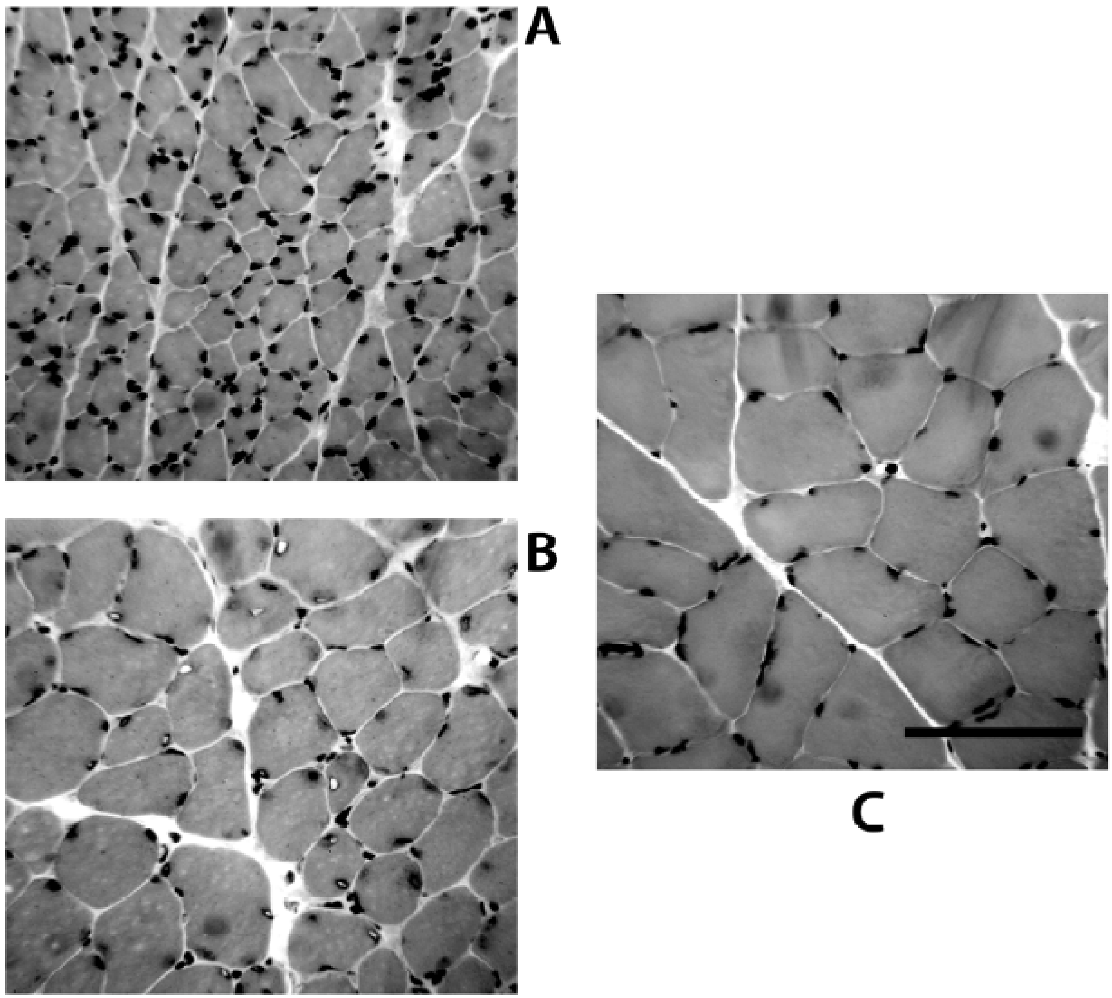
Twitch Force



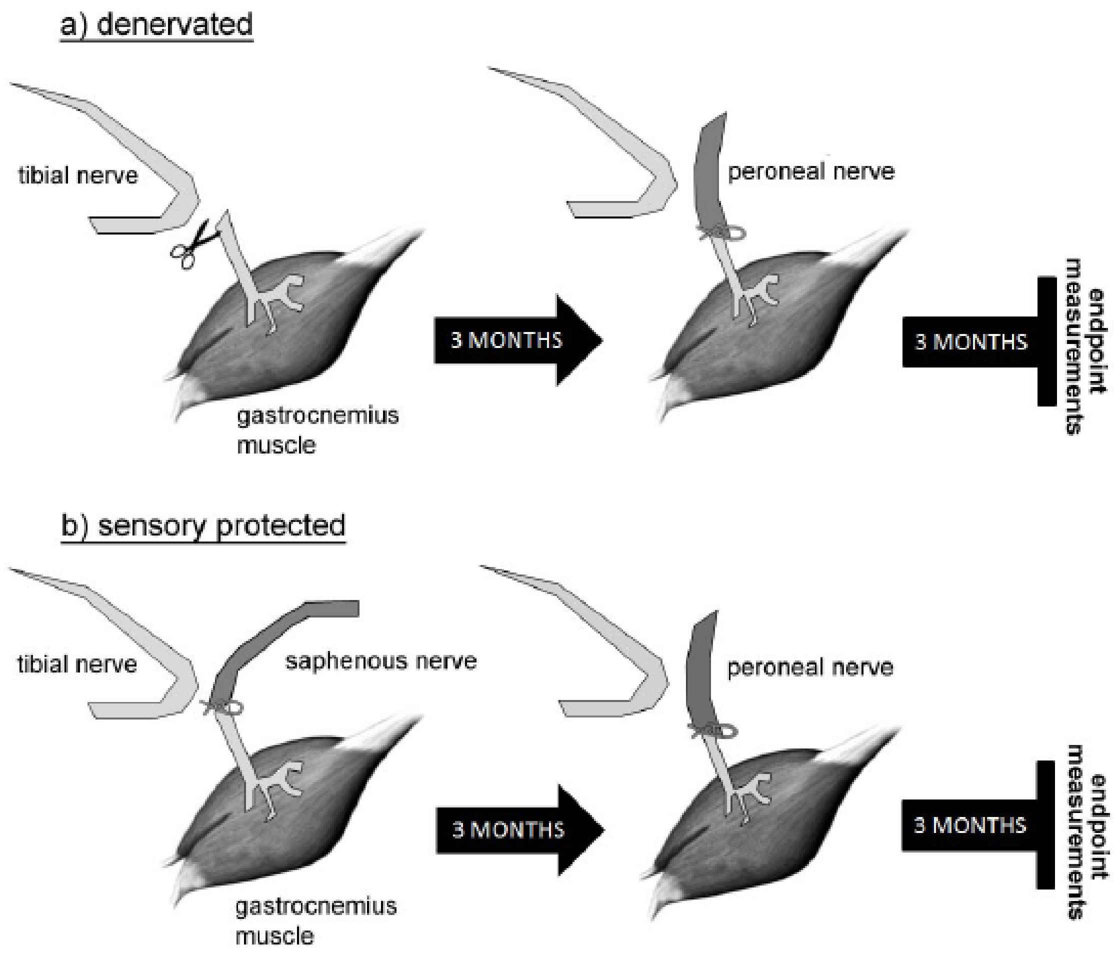
Muscle Twitches



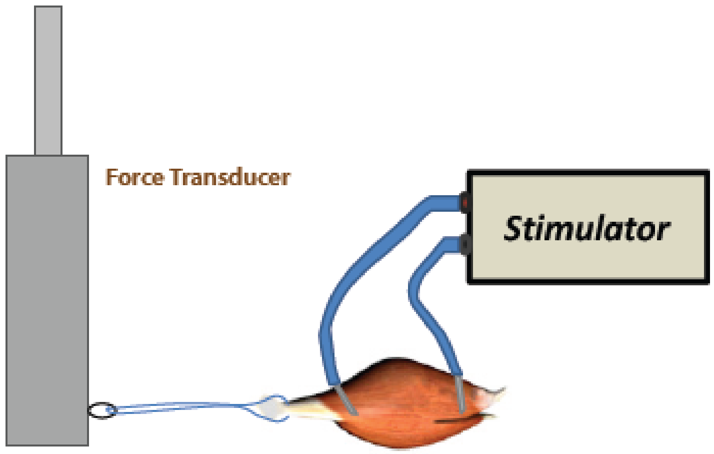
Histological Results
A-Denervated, B-Denervated plus Stim, C-Control

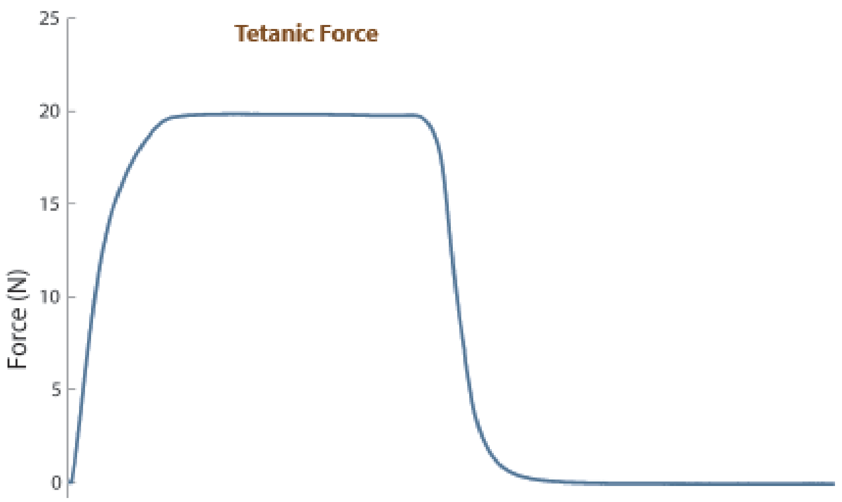


Does FES Improve Recovery?

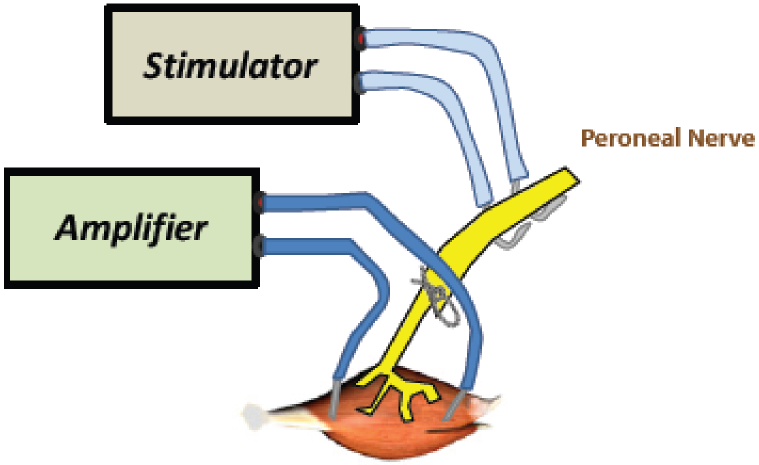


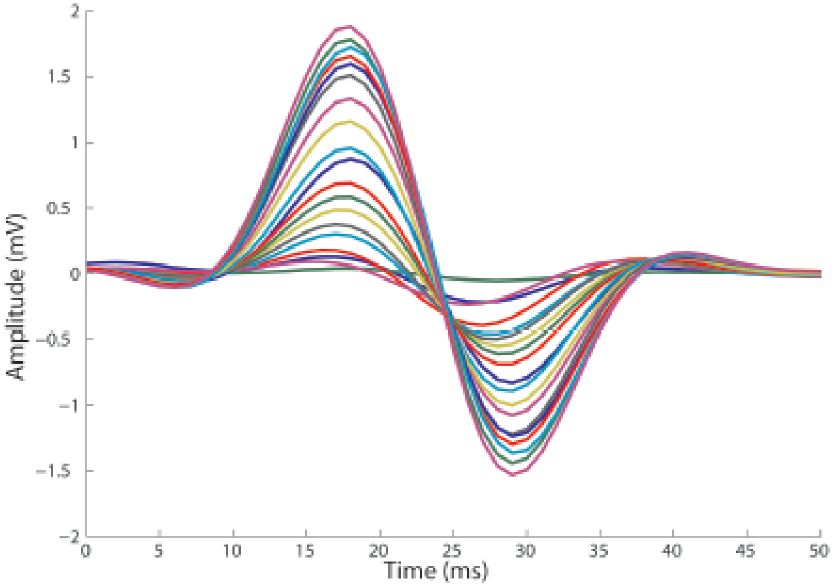
Endpoint Measures
(Twitch and Tetanic Force)





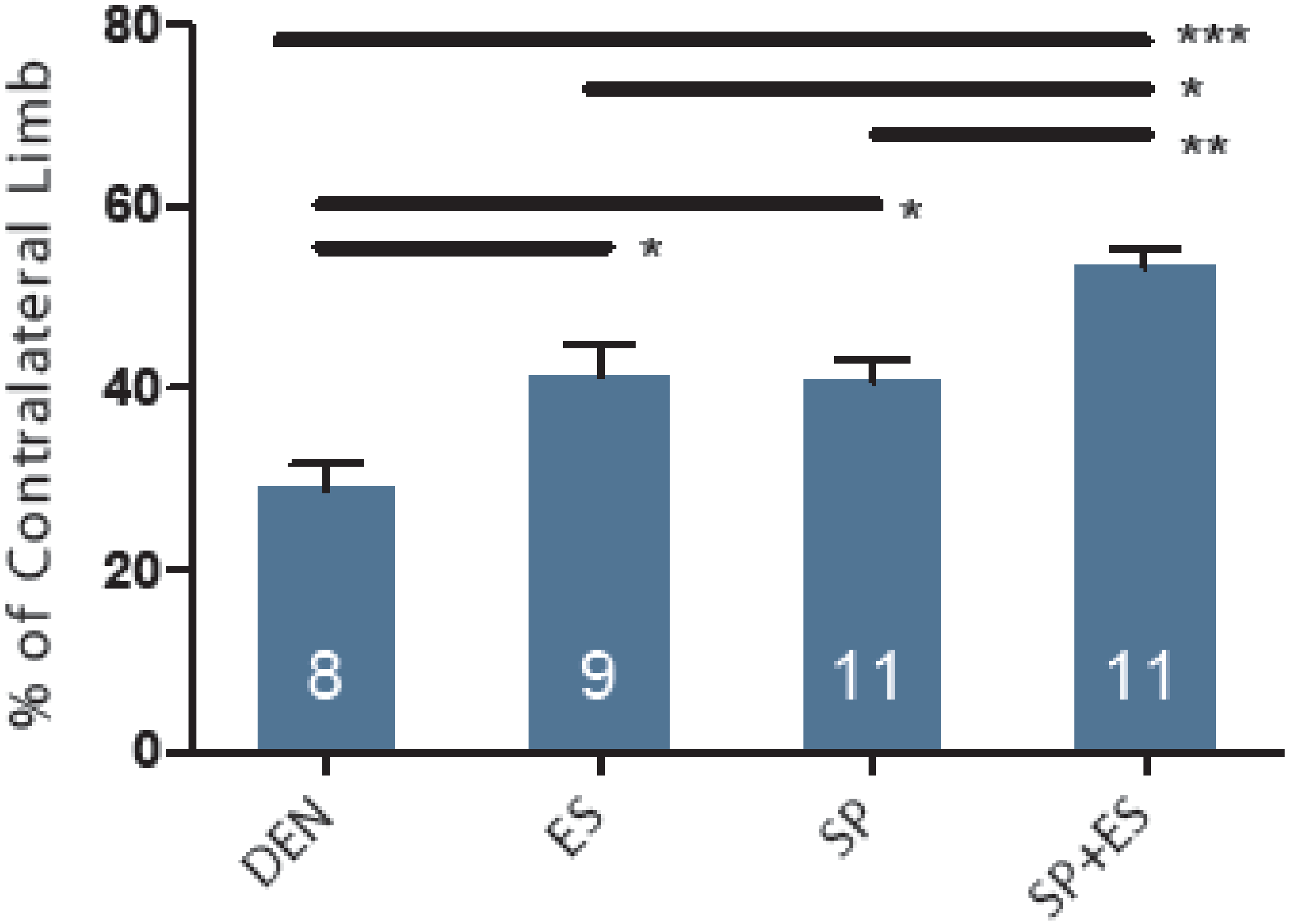
Endpoint Measures (Motor Unit Counts)



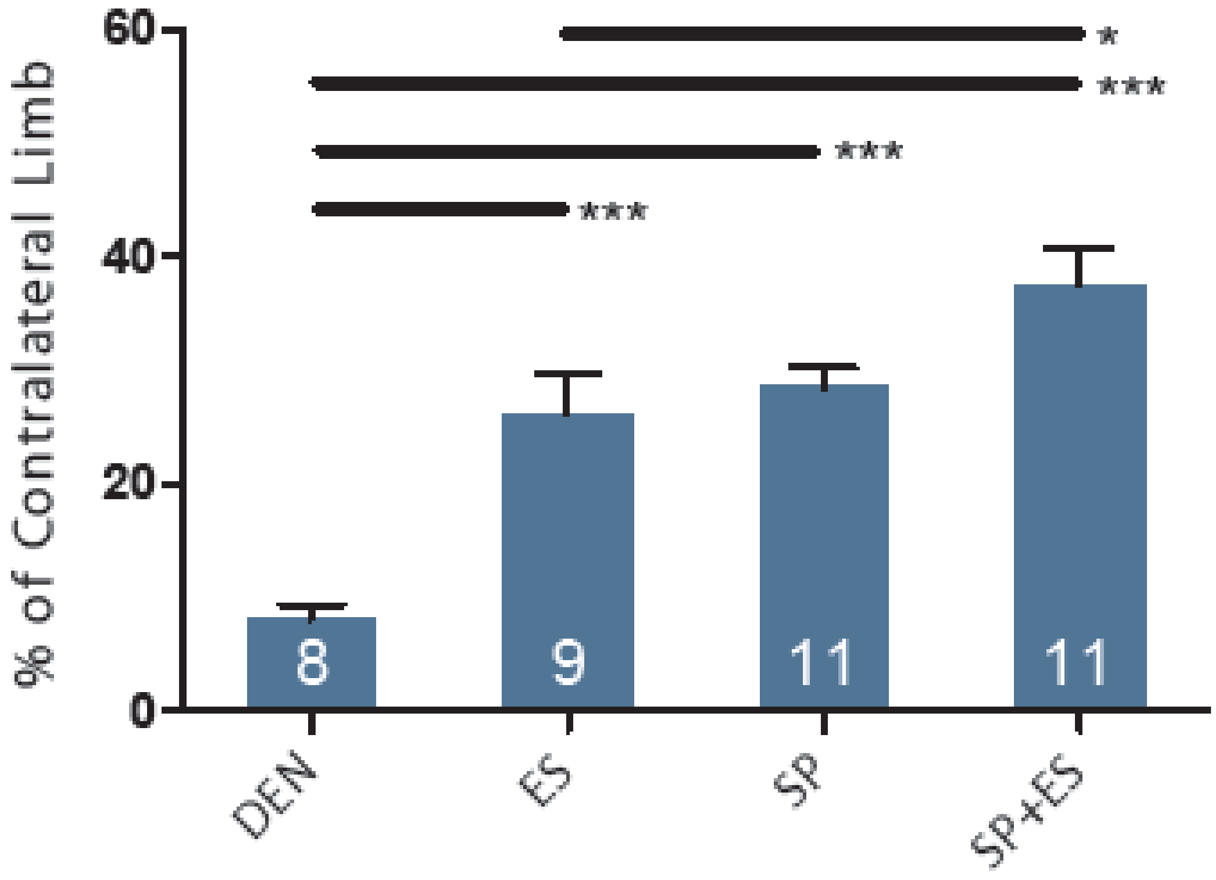


Endpoint Measures (Fiber Size and Type)

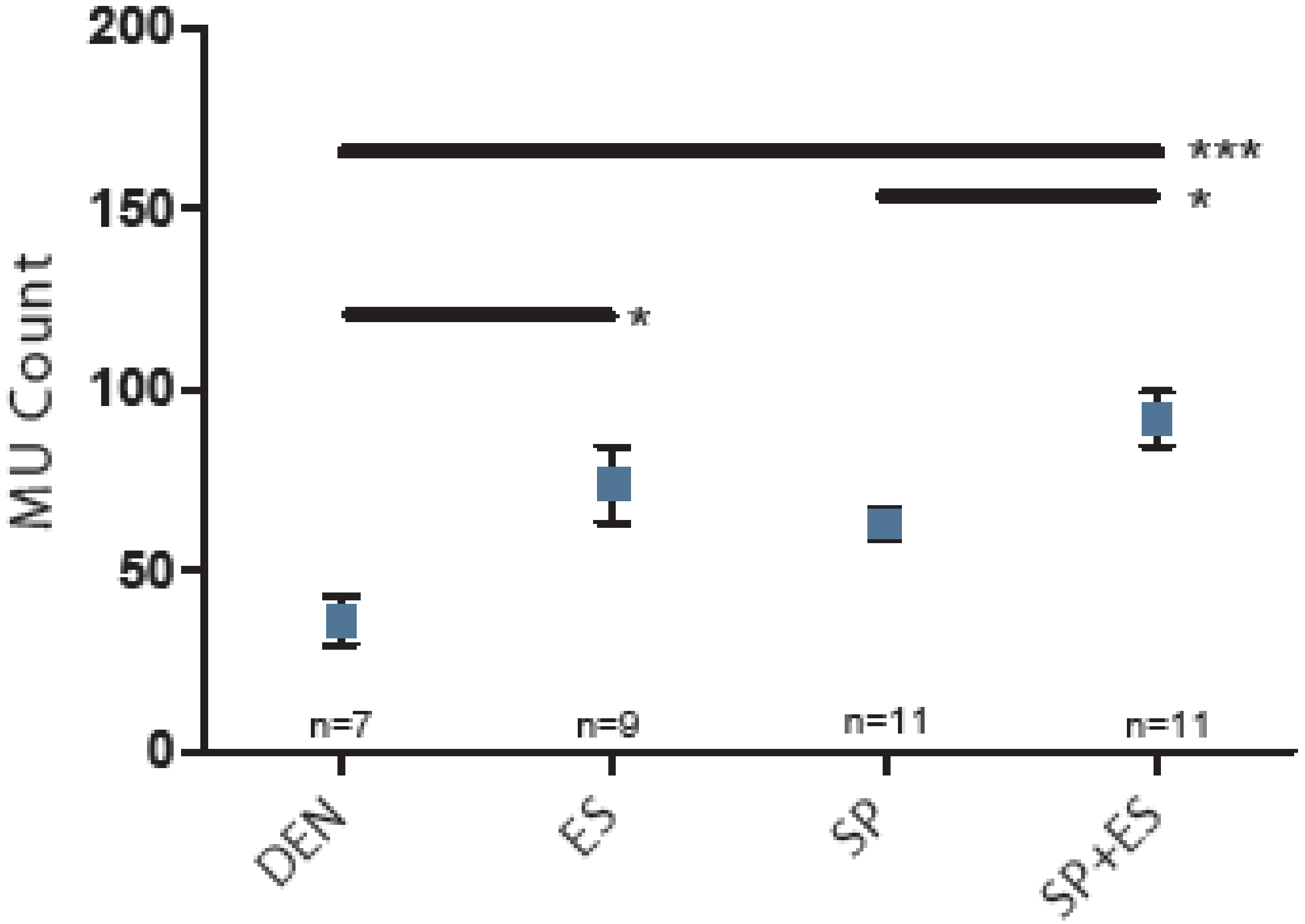
Results
(Muscle Weight)



Results
(Twitch Force)



Results
(Motor Unit Numbers)



Results (Histology)