EE 4BD4 Lecture 20

Therapeutic Stimulation

Stimulation of excitable tissues

- Design And Development Of Medical Electronic Instrumentation - D. Prutchi, M. Norris (Wiley, 2005)

Single axon stimulation

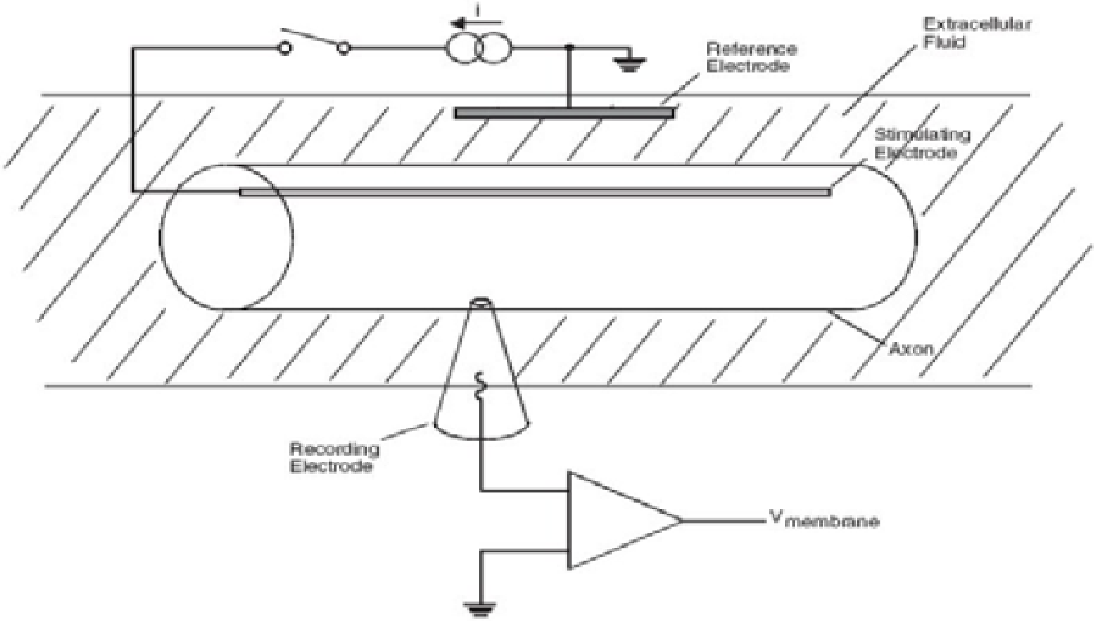


Figure 7.1 The classical space-clamped current-pulse stimulation of the giant squid axon is simulated by the Matlab program HODKIN-HUXLEY.M using Hodgkin and Huxley's membrane model.

Extracellular Stimulation

(at cathode)

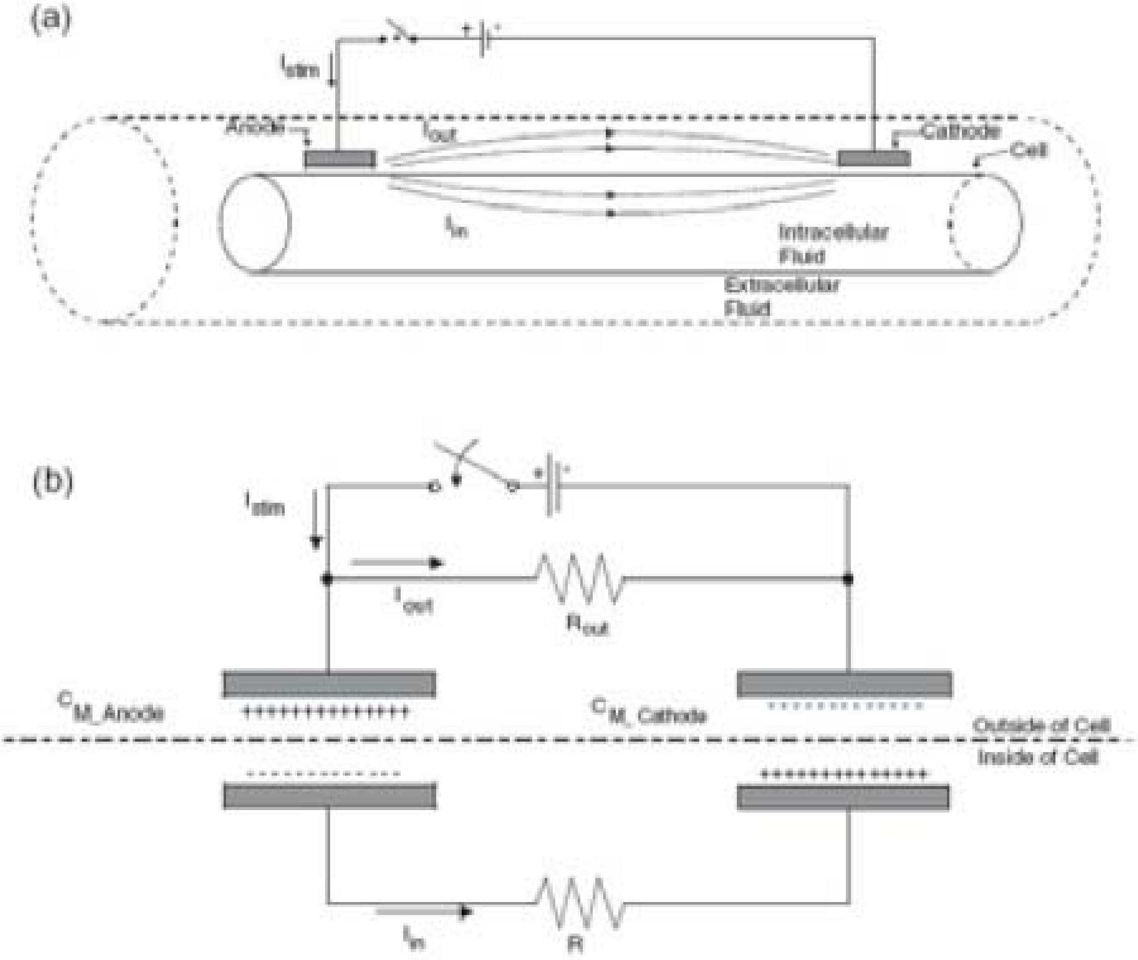


Figure 7.3 Simplified model of electrical stimulation of a cell by a current applied through extracellular electrodes. *(a)* A transmembrane current is assumed to flow only at the anode and cathode. The vector current flux is indicated by arrows. *(b)* The current through the membrane hyperpolarizes the intracellular membrane region under the anode and depolarizes the intracellular region under the cathode. Stimulation occurs when the transmembrane potential at the cathode crosses the membrane's threshold voltage.

Extracellular Stimulation stimulation modes

- Bipolar
  - Both electrodes close to the target tissue
- Monopolar
  - One electrode close to the target tissue
  - The second one is remote
- Field stimulation
  - Both electrodes are remote
  - Inefficient
  - However – it will be less invasive

Design of FES (cont.):

Example stimulus waveform shapes:

- monophasic,
- biphasic,
- chopped,
- triphasic, and
- asymmetric,

and parameters:

- pulse amplitude,
- pulse width,
- interphase gap, and
- pulse rate.

(From Shepherd & Javel, *Hear. Res.* 1999)

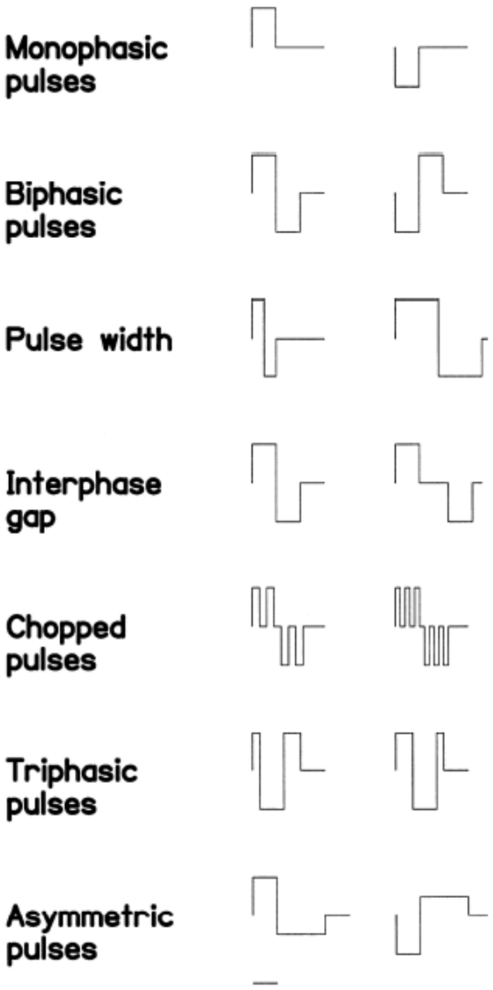


Fig. 1. Diagram illustrating the range of stimulus waveforms used in the present study. Note that all stimuli in the first column deliver an initially anodic current pulse to the most apical electrode.

Extracellular Stimulation

- Stimulation threshold – minimum strength of stimulus required to excite the membrane
- Defined by current pulse amplitude and duration
- For unmyelinated nerve fibers and muscle fibers can be anywhere along fiber
- For myelinated depolarization only at the Node of Ranvier

Non-Experimental Curve

Extracellular Stimulation

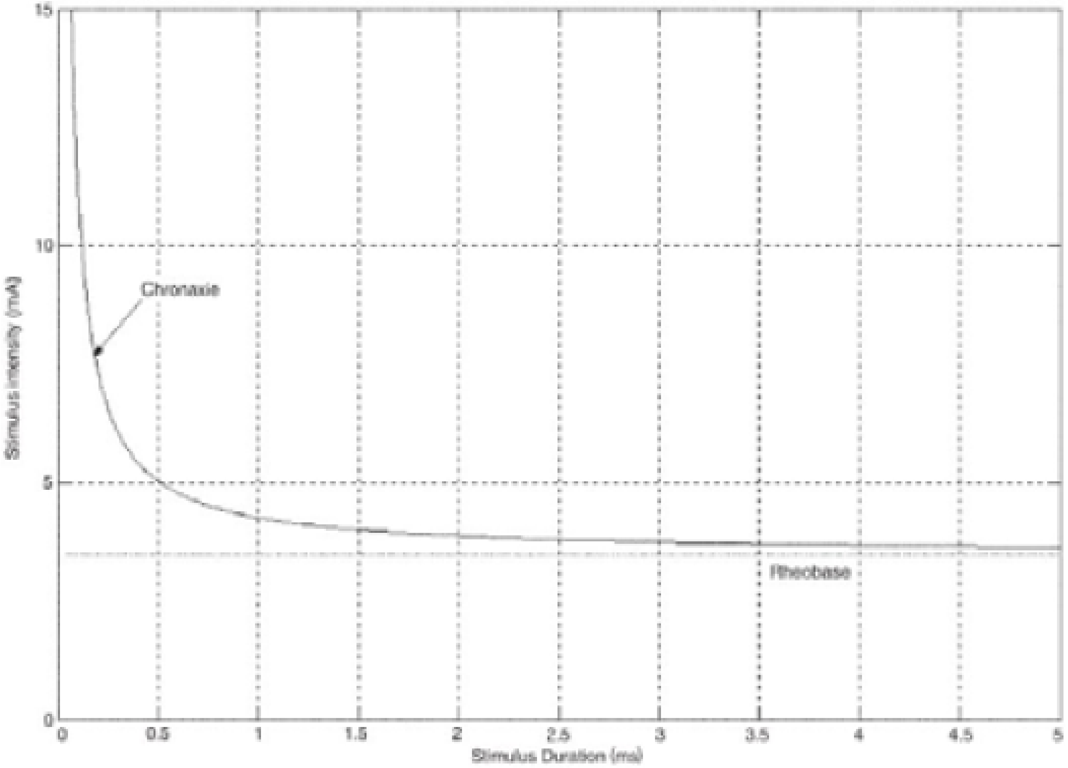
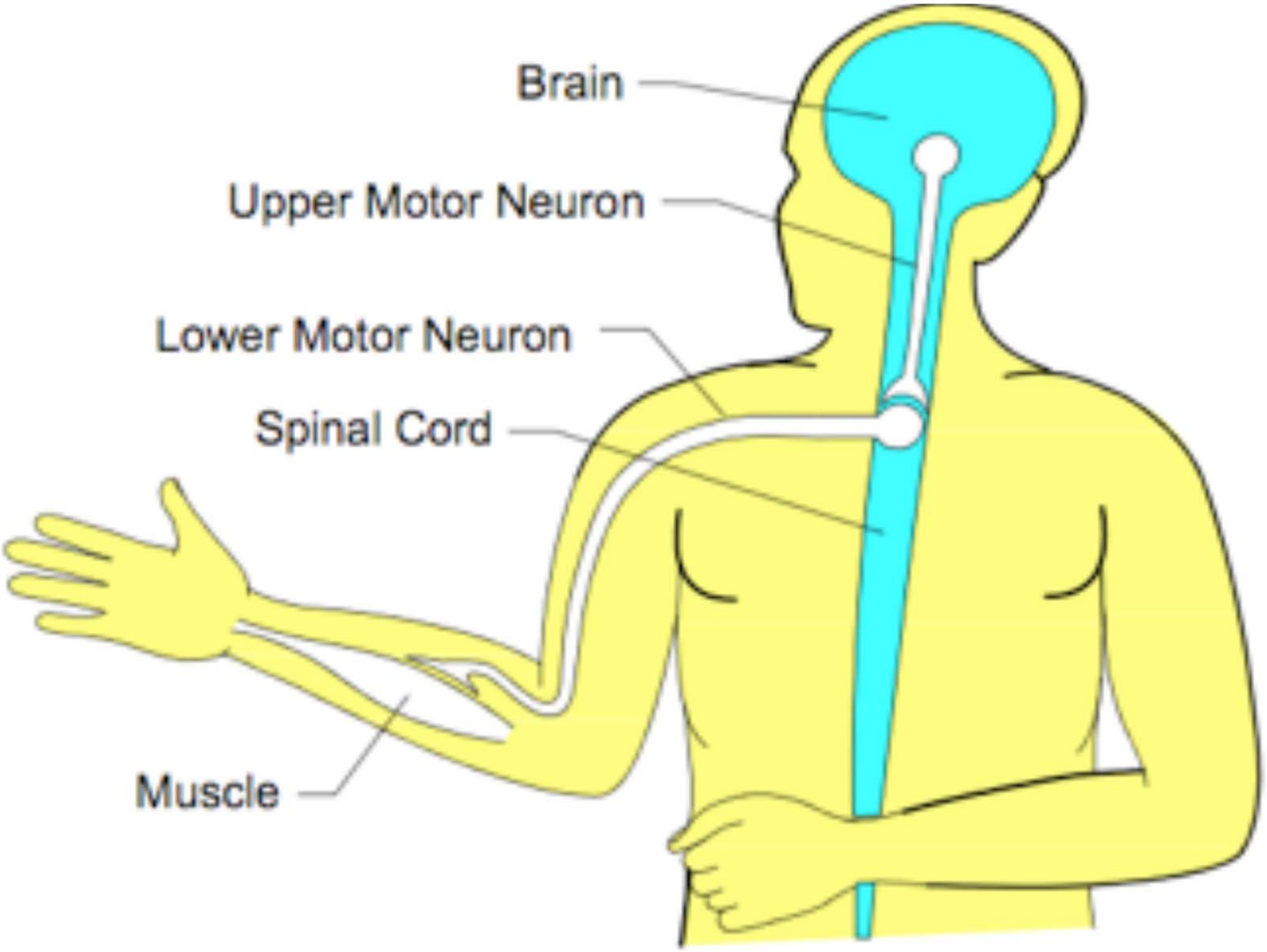


Figure 7.4 It is possible to see from this stylized strength–duration curve that stimulus current and duration can be mutually traded off over a certain range. The strength–duration curve was characterized by Lapicque by the value of the rheobase (in volts or milliamperes) and the chronaxie, which is measured along the time axis and defined as the stimulus duration (in milliseconds) that yields excitation of the tissue when stimulated at twice the rheobase strength. In this example, rheobase = 3.5 mA and chronaxie = 0.22 ms.

Extracellular Stimulation Clinical Applications

- Cardiac Pacing
- Cardiac defibrillation
- Functional electrical stimulation (next slide)
- Diagnostic stimulation for nerve conduction velocities
- Innervated or denervated muscle maintenance
- Therapeutic brain stimulation (ECT, vagal or direct brain stimulation for Parkinsonism or epilepsy, rTMS – repetitive transcranial magnetic stimulation, tDCS – transcranial direct current stimulation, etc.)
- Artificial cochlea and vision prosthesis

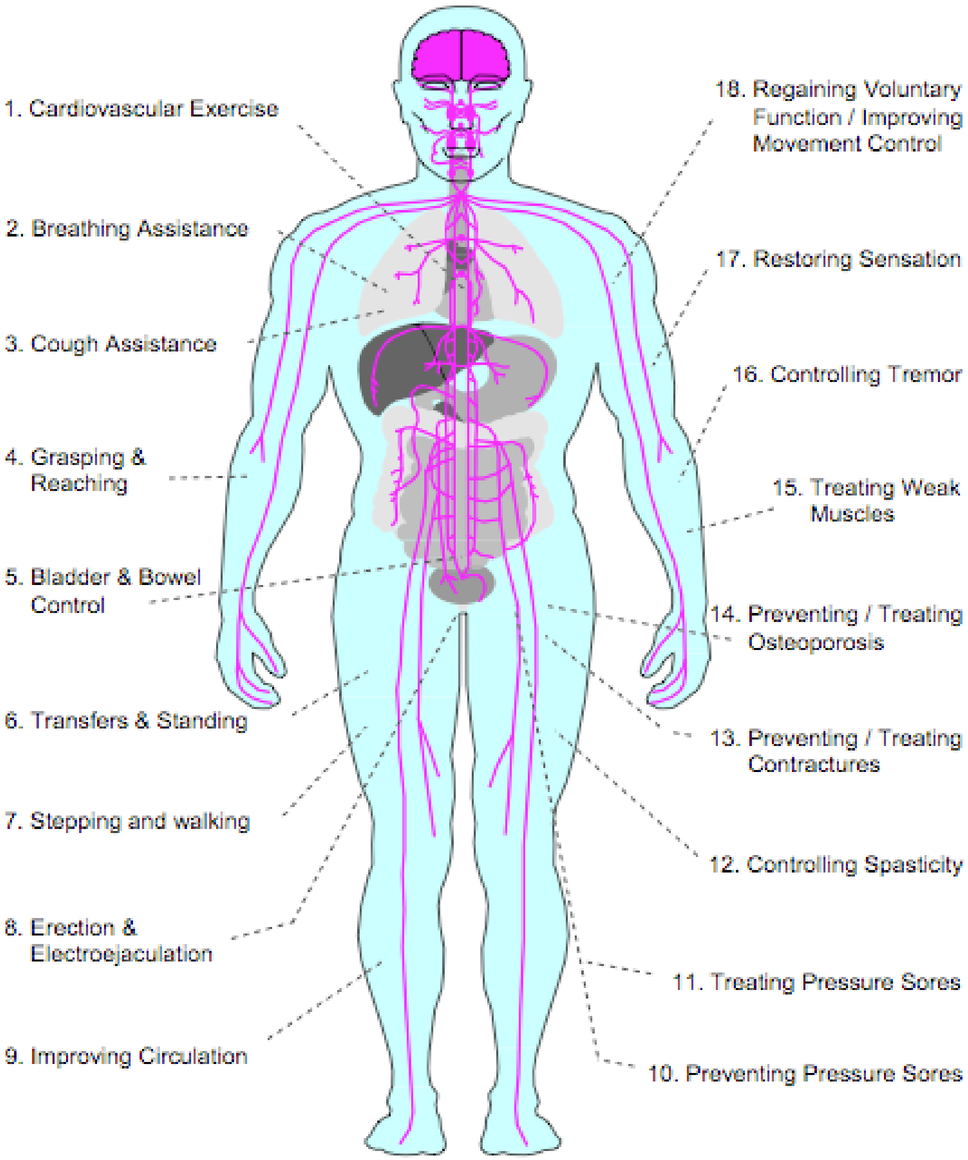
Normal Functional Control



Current uses of FES

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

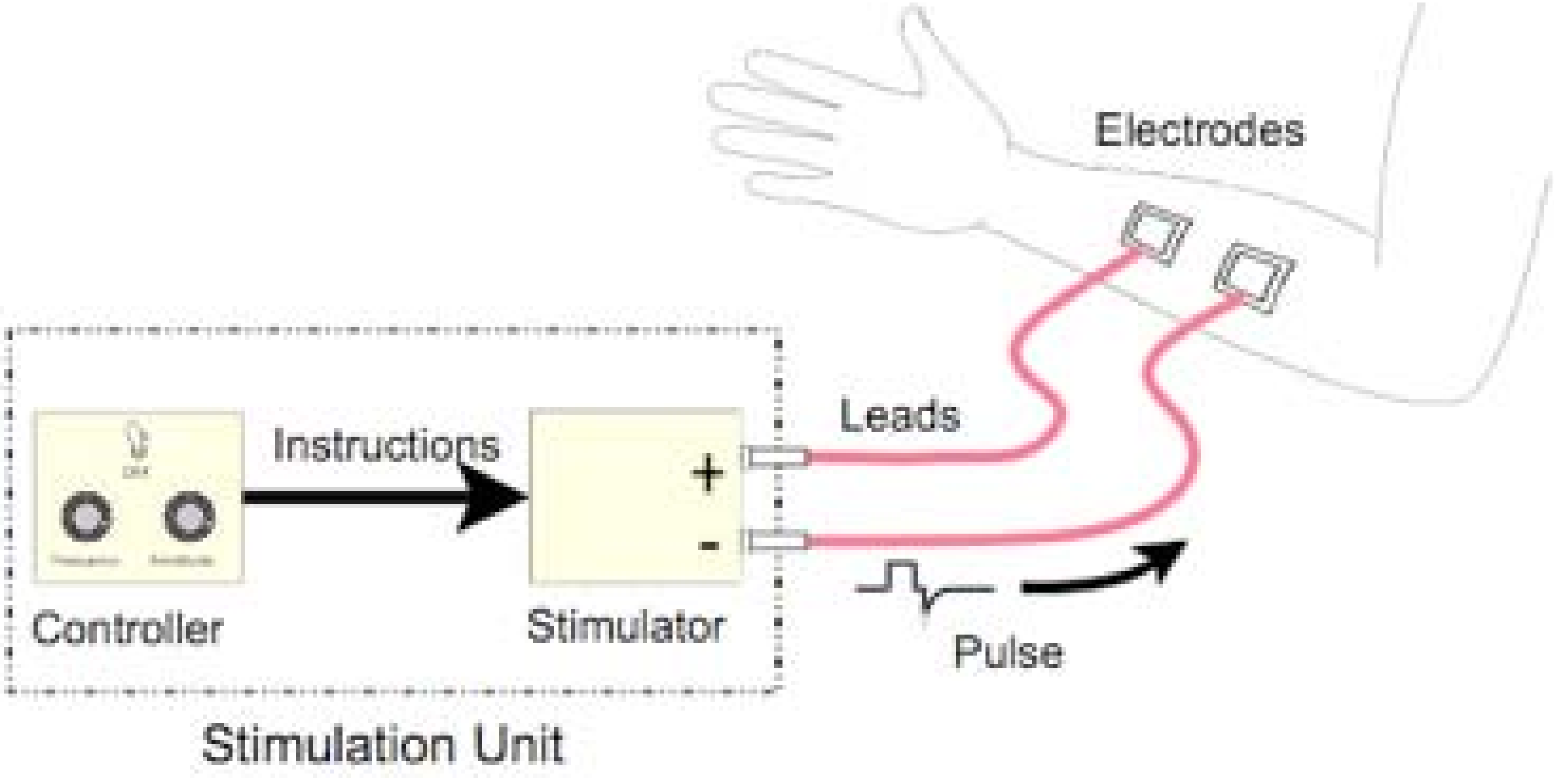
Areas of Intervention



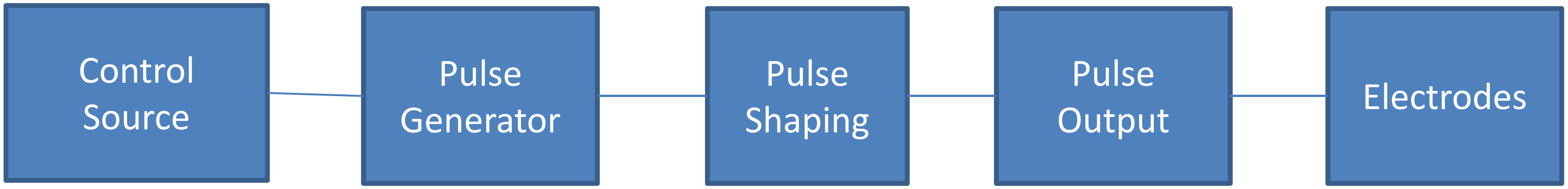
FES System

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

FES System (cont'd)



General Instrumentation Layout



Control Source

Pulse Generator

Pulse Shaping

Pulse Output

Electrodes

Stimulator Design

- Constant voltage (current determined by electrode and tissue impedance)
- Constant current (more modern)
- Typical pulse durations are 50 µs to 200 µs (some applications use 1 ms and longer
- Cardiac or smooth muscle require these longer durations because membrane gates take longer to depolarize
- Implantable constant current stimulators can deliver mA’s with voltages < 10V but should have bipolar shapes to minimize charge buildup and tissue damage.
- External stimulators can be monopolar but require higher current amplitude (>10 ma) and voltage output

Electrical Muscle Stimulation

Purpose

- Provide muscle control where path from brain is interrupted
- Provide feedback control during muscle retraining
- Keep muscle healthier when it has been dennervated (no alpha motor unit connection)
- Strengthen or maintain muscle when joints have been immobilized

What Pulse Shapes Have Been Used?

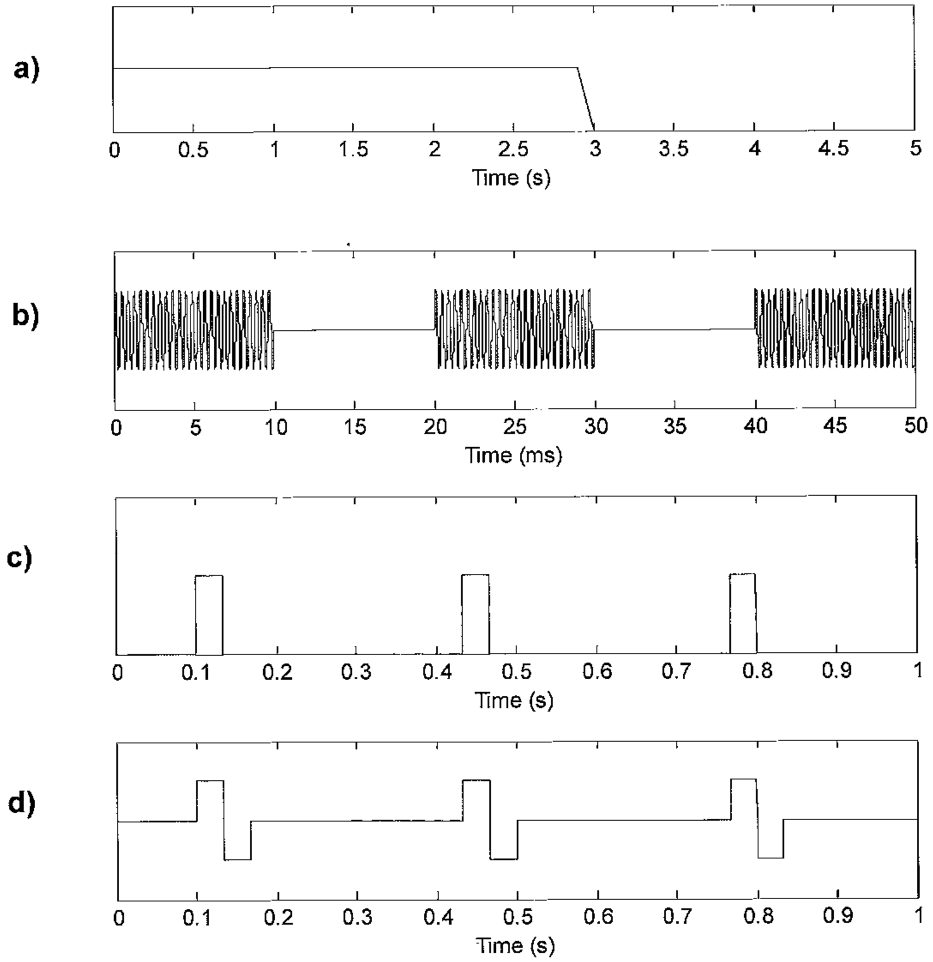


Figure 2-6 – A variety of stimulus waveforms. DC current shown in a), Russian current (2500 Hz bursts) shown in b), monophasic pulsed DC current shown in c), and biphasic pulsed DC current shown in d).

What Pulse Train Frequency?

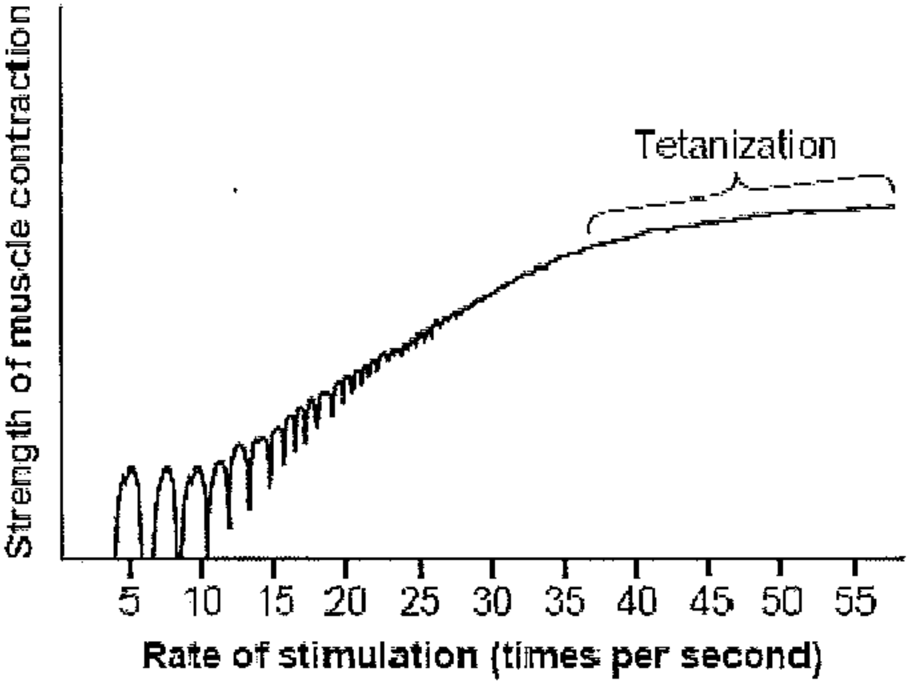


Figure 2-5 – Frequency summation and tetanization (Guyton & Hall, 2006)

Pulse Generator

- Can use constant voltage (i.e. current determined by patient electrode/skin impedances) or constant current (voltage across electrodes determined by patient skin/electrode impedances)
- Stimulation is determined by current flow so constant current is more modern design
- For surface stimulation and motor nerve close to skin with 50 µsec pulses get sensation around 10 ma and nerve stimulation around 15 ma for 6 mm^2 electrodes

Constant Current Designs

- Patient not grounded and $R_{sense} \gg R_{load}$

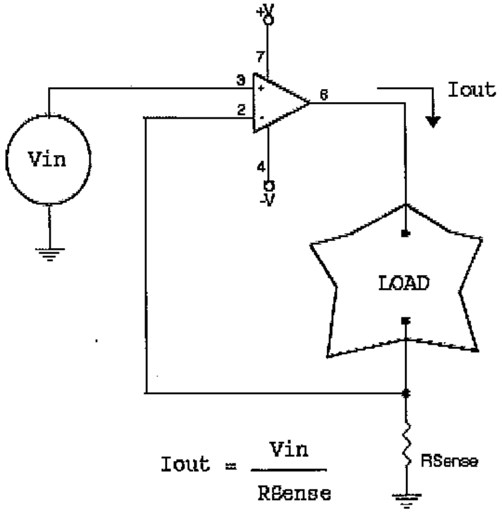


Figure 3-2 – Simple op-amp based voltage to current converter (Prutchi & Norris, 2005)

Howland Current Pump

- Patient grounded

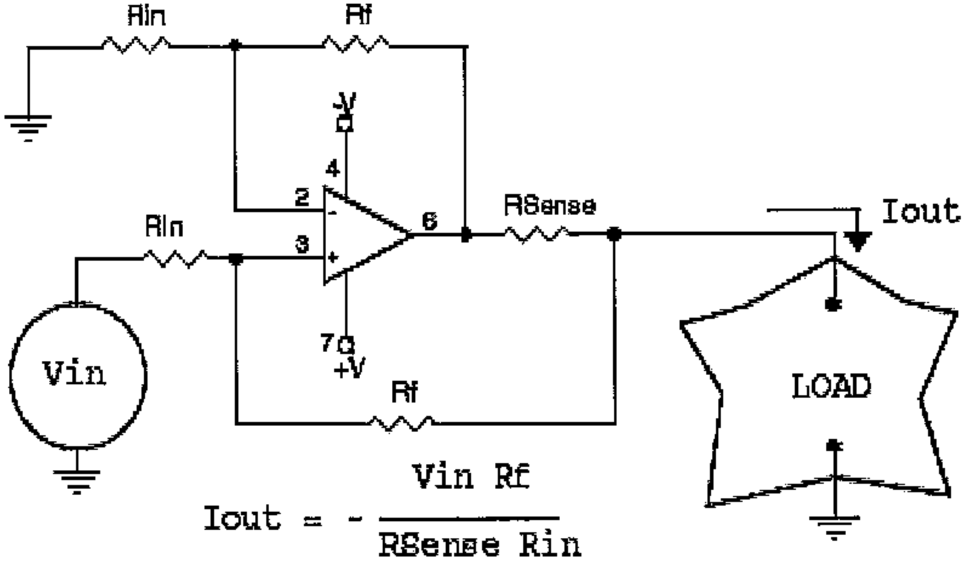


Figure 3-3 – Howland current pump implementation (Prutchi & Norris, 2005)

Limitations of These Designs

- Voltage compliance (maximum voltage resulting from impedance) is limited to power supply voltages)
- With typical load impedances of 1 kΩ and 30 ma stimulating current you already require 30 V, requiring high voltage op amps (and power supplies)

Simpler Designs

Transistor Based

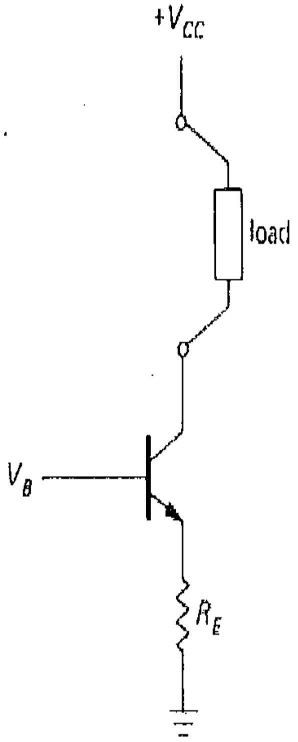


Figure 3-5 – Transistor based current source (Horowitz & Hill, 1989)

Op amp Added

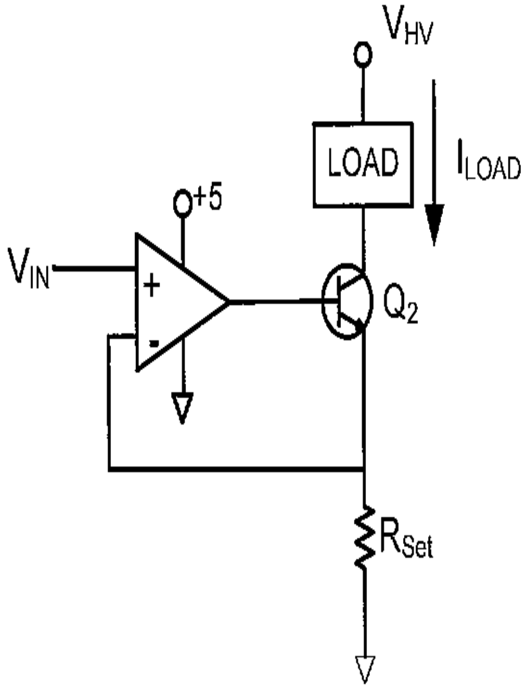


Figure 3-6 – Constant current source used in stimulator design

Safety Lockout

- Transistor switch added to stop inadvertent stimulations

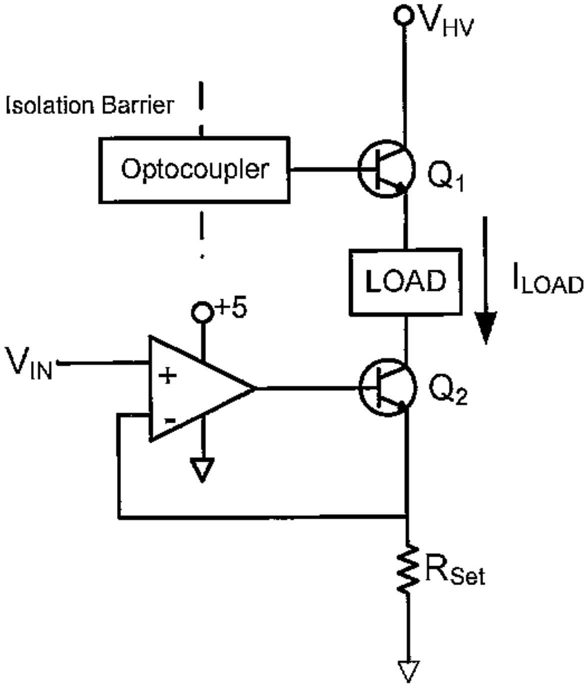


Figure 3-8 – Voltage to current converter with high end gating

Specs for Last Circuit

- Transistor is TIP50
- Op amp is LM358M
- Setting resistor determined by current required at that input voltage
- V_{HV} Can be high voltage source

Overall System

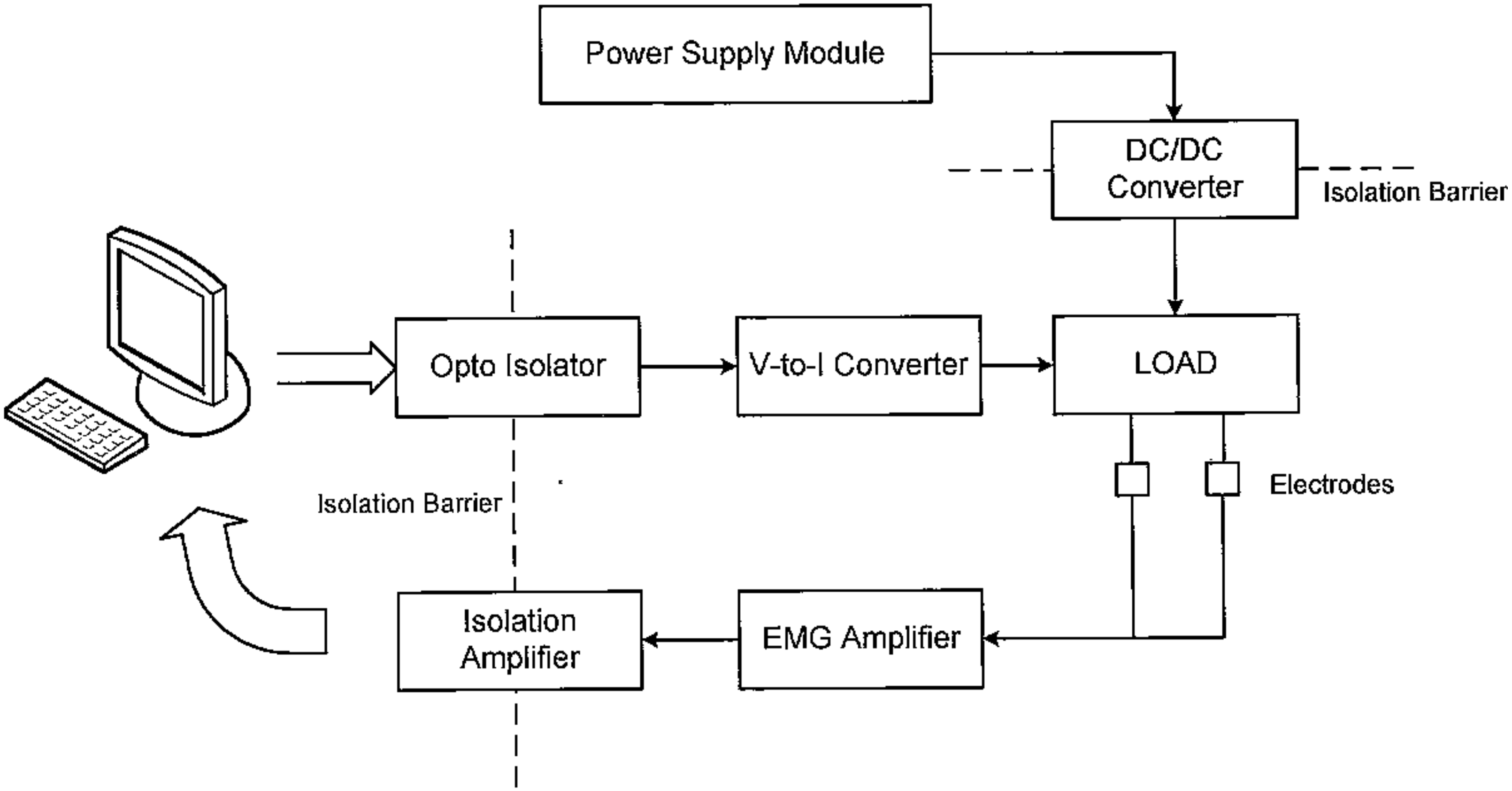
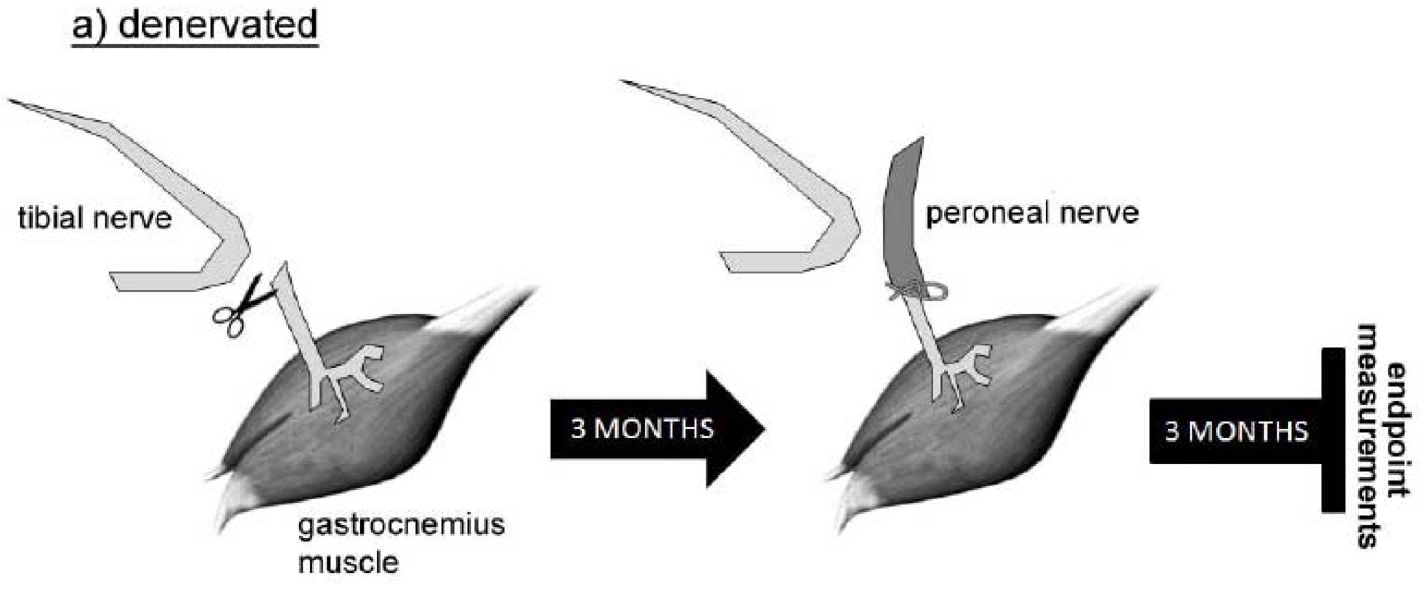


Figure 3-7 – Overall system design block diagram

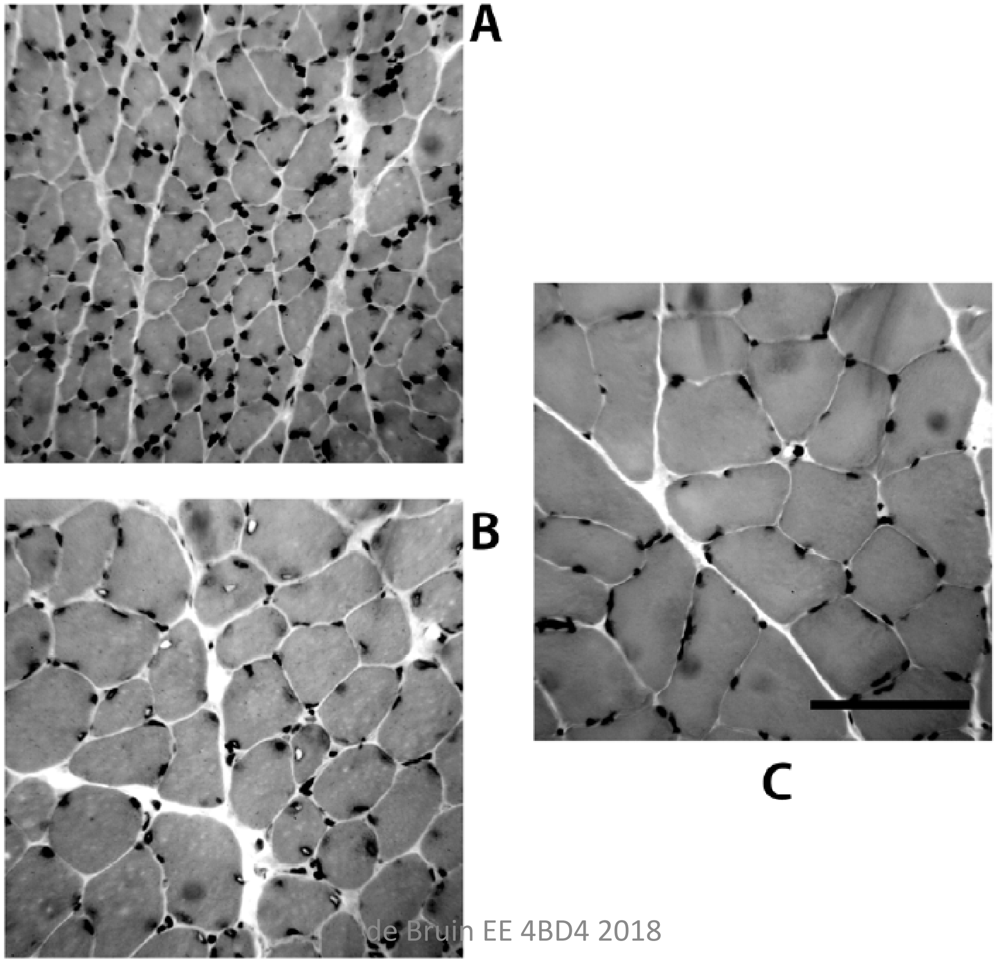
Muscle Stimulation to Maintain Health

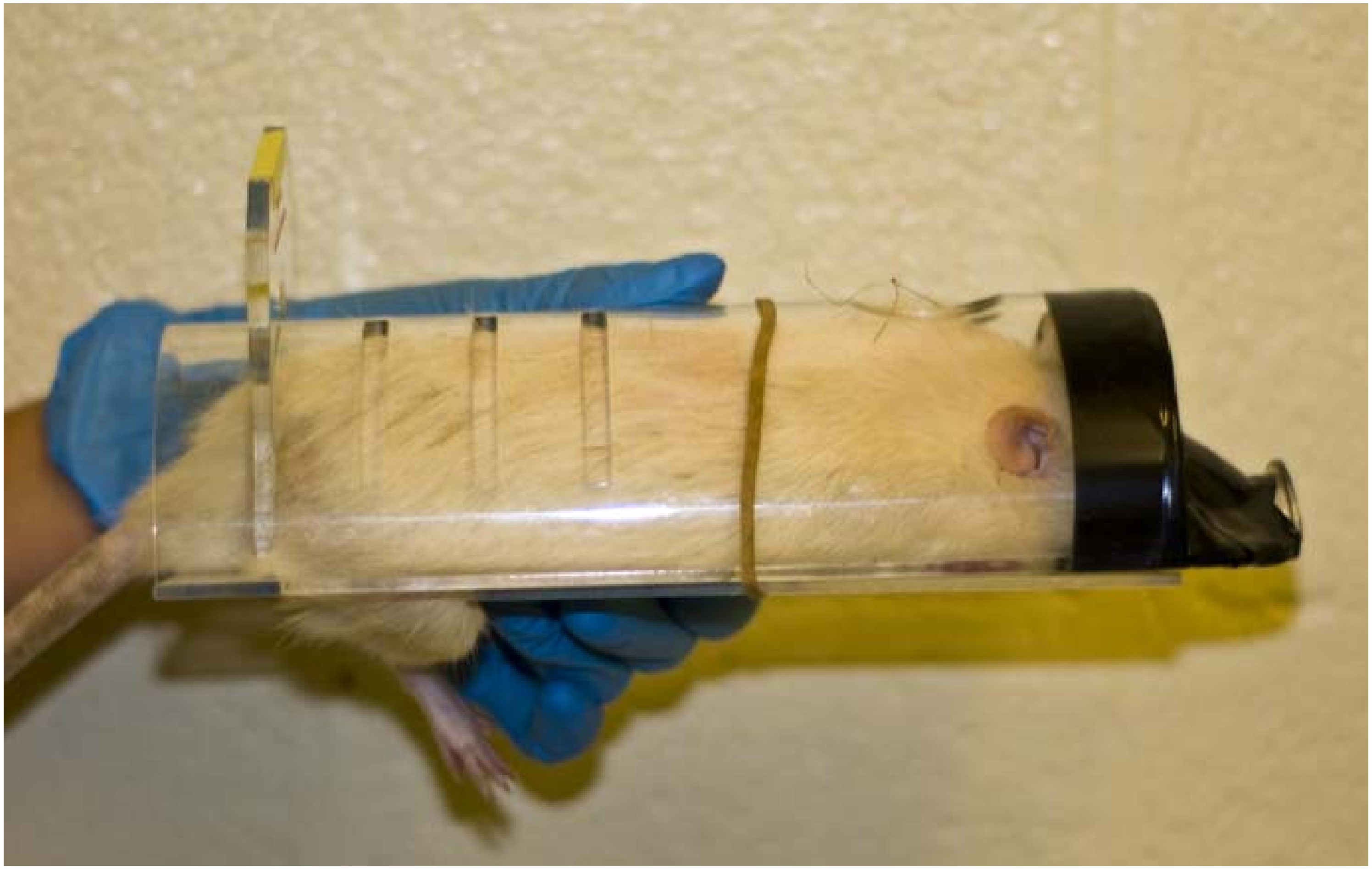
- What happens to muscle after the nerve supply is lost due to an accident



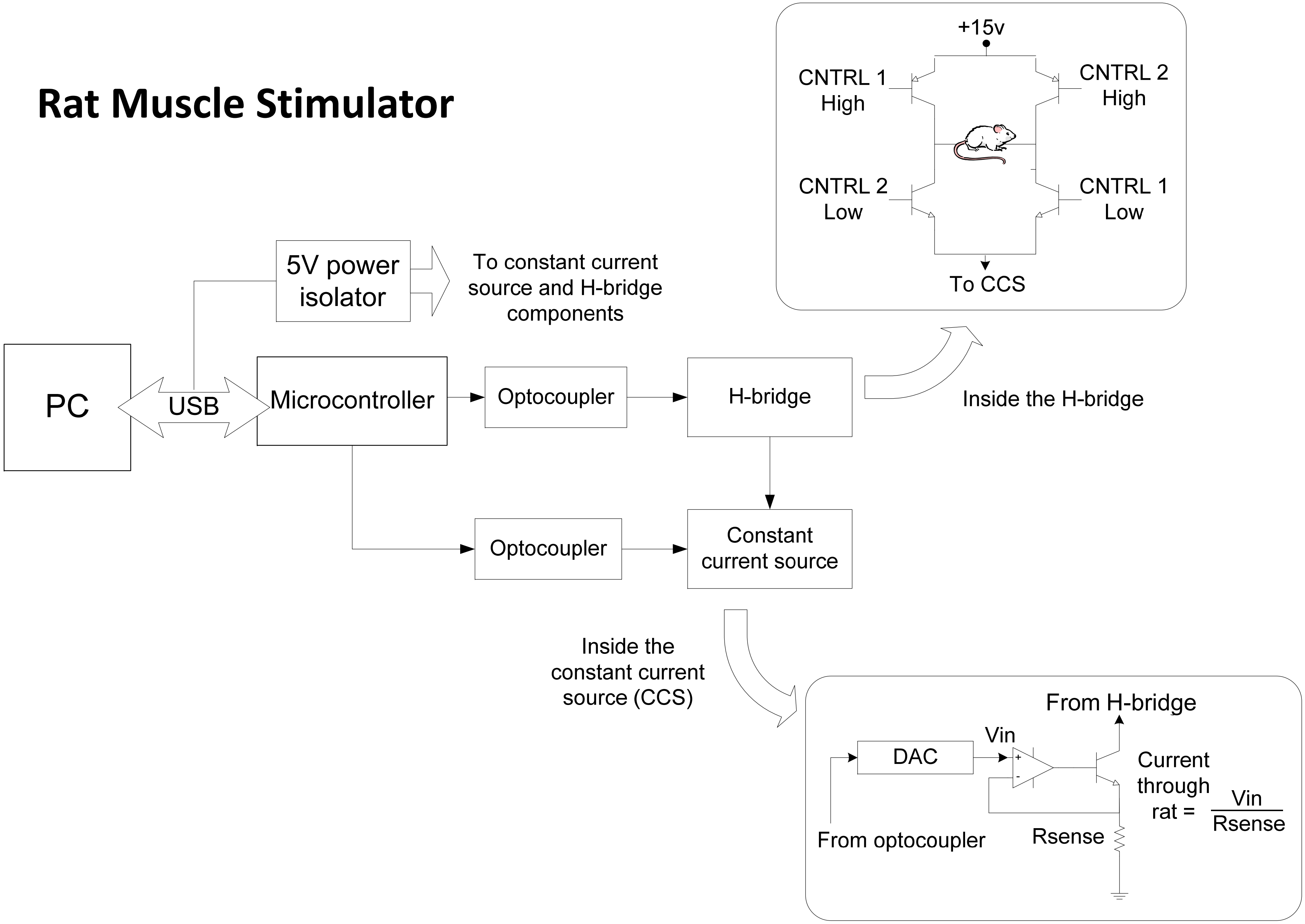
Muscle Structure after 1 Month

- Muscle Cross-sections A – denervated, B – denervated and stimulated, C – innervated; bar = 100 µm





Rat Muscle Stimulator



PC

USB

5V power isolator

To constant current source and H-bridge components

Microcontroller

Optocoupler

H-bridge

Inside the H-bridge

Optocoupler

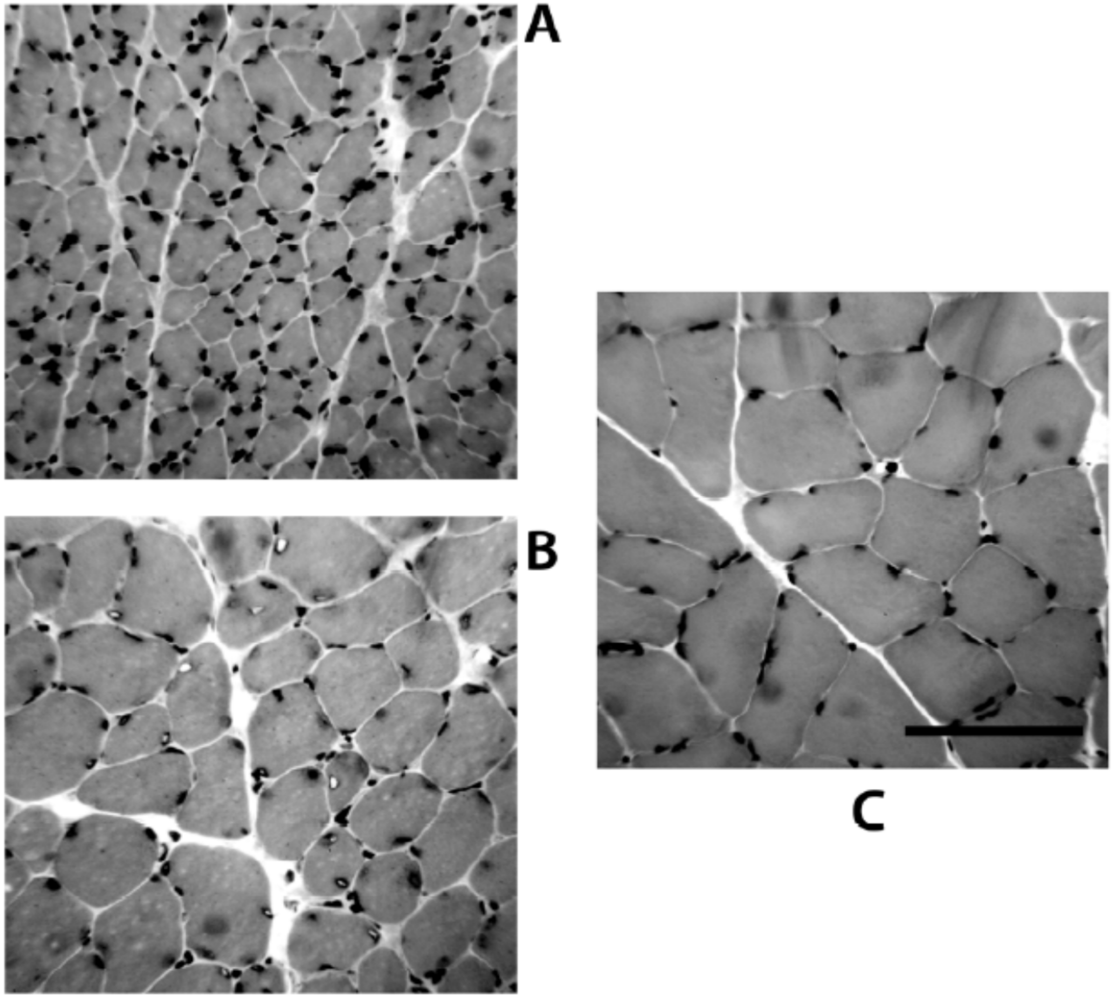
Constant current source

Inside the constant current source (CCS)

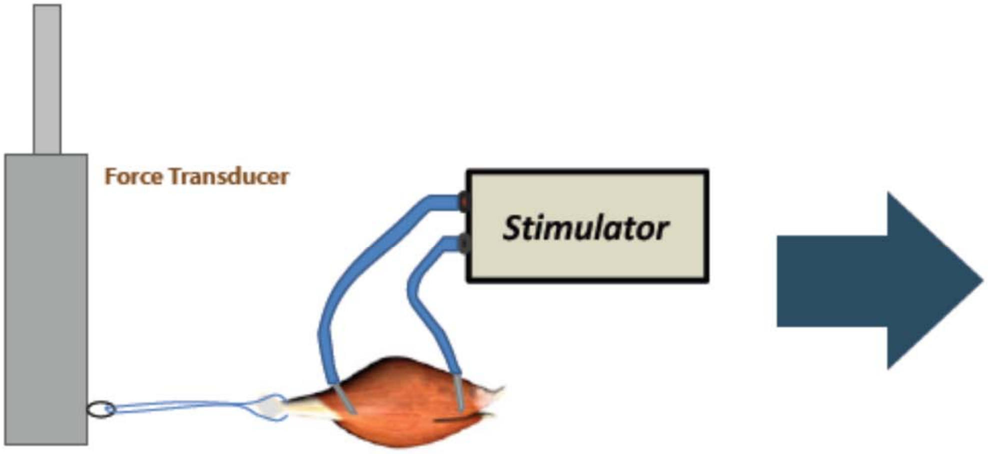
Current through rat = $\frac{Vin}{Rsense}$

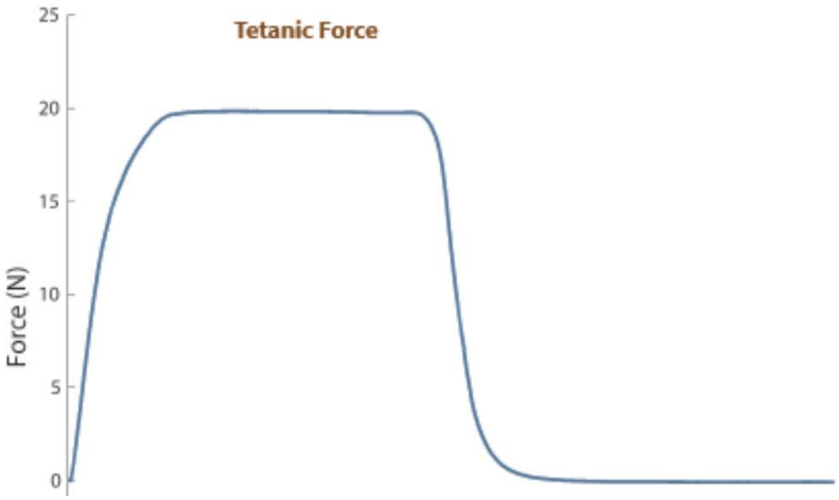
Histological Results

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

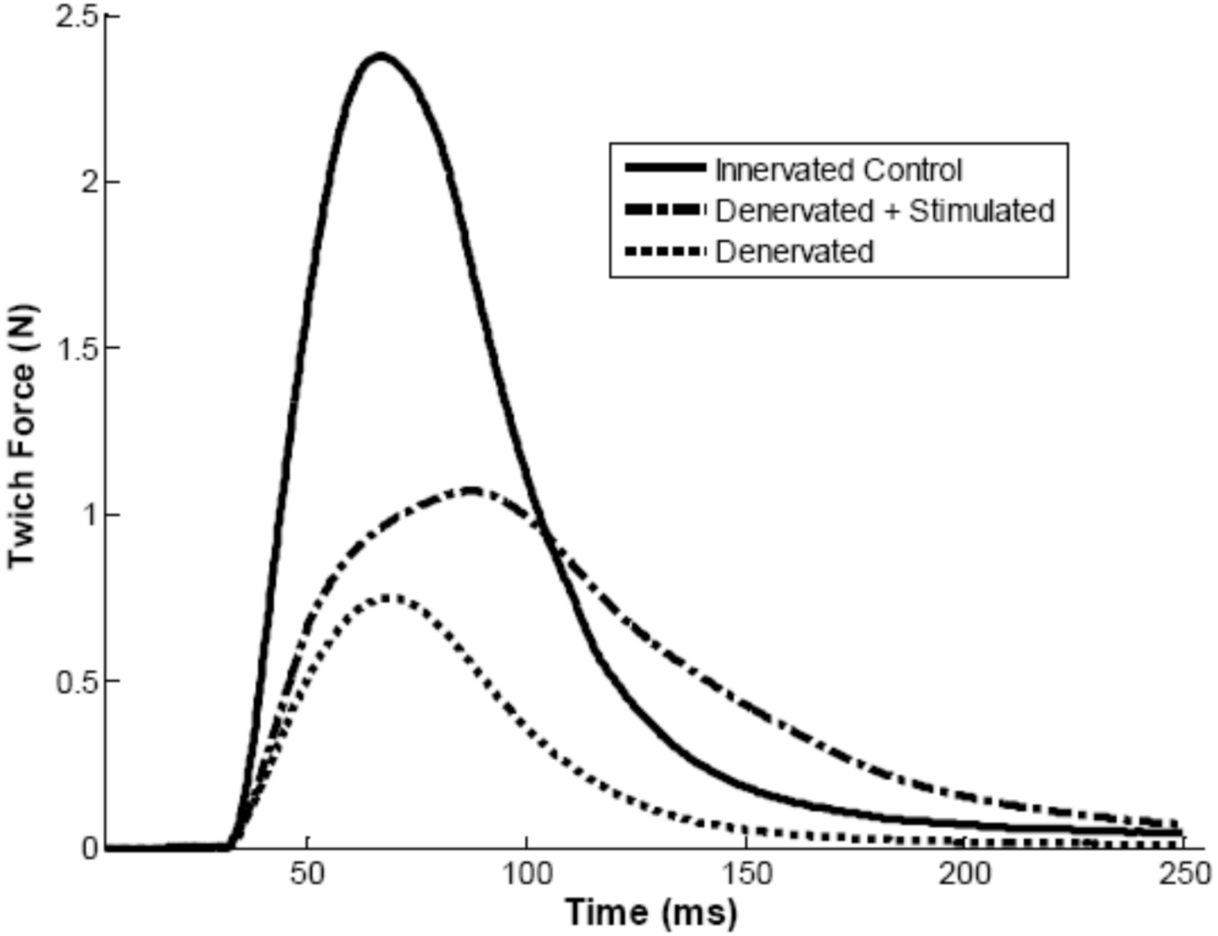


Endpoint Measures (Twitch and Tetanic Force)



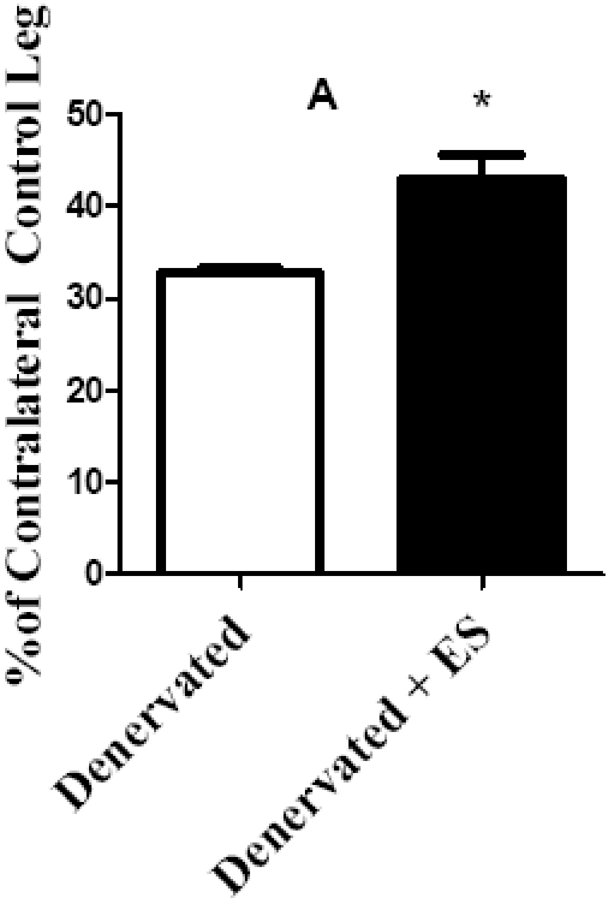


Muscle Twitches

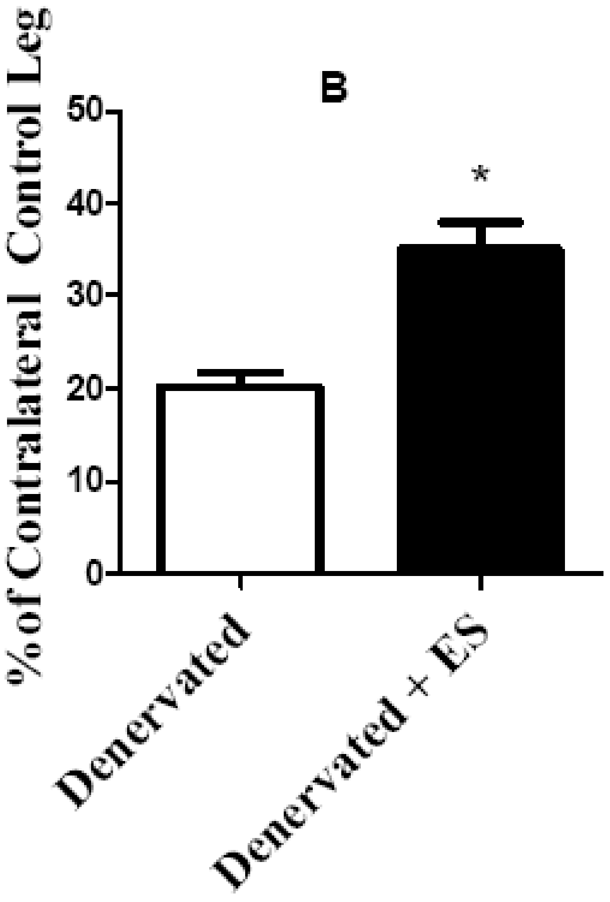


Functional Results

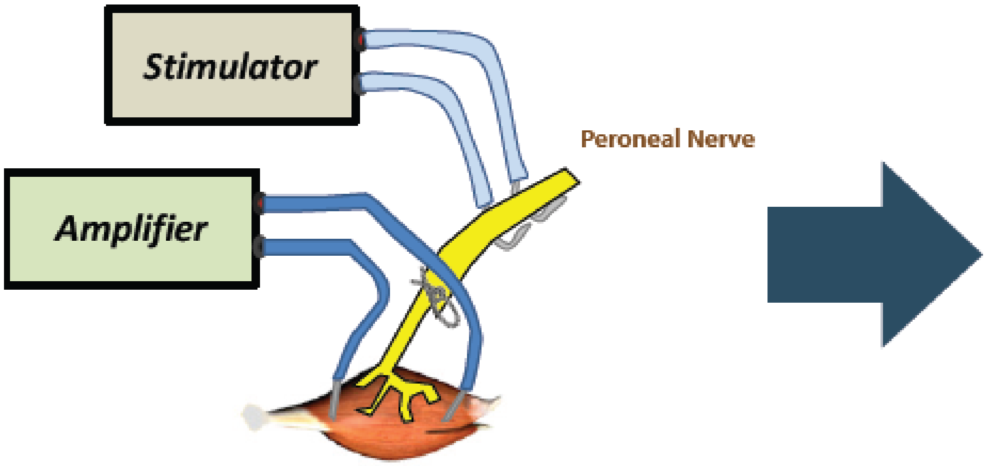
Weight

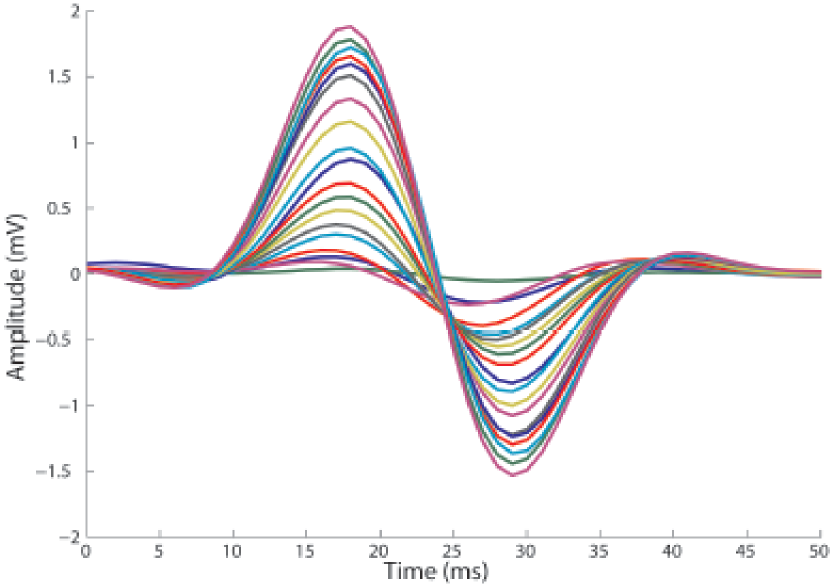


Twitch Force

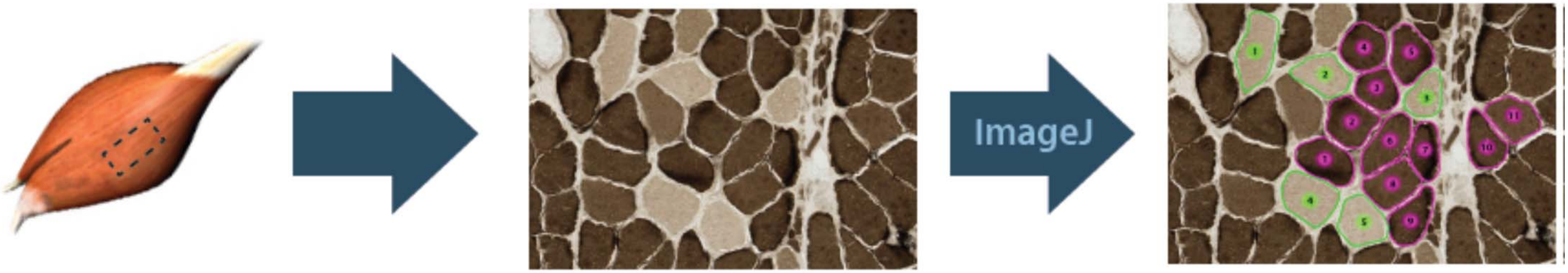


Endpoint Measures (Motor Unit Counts)

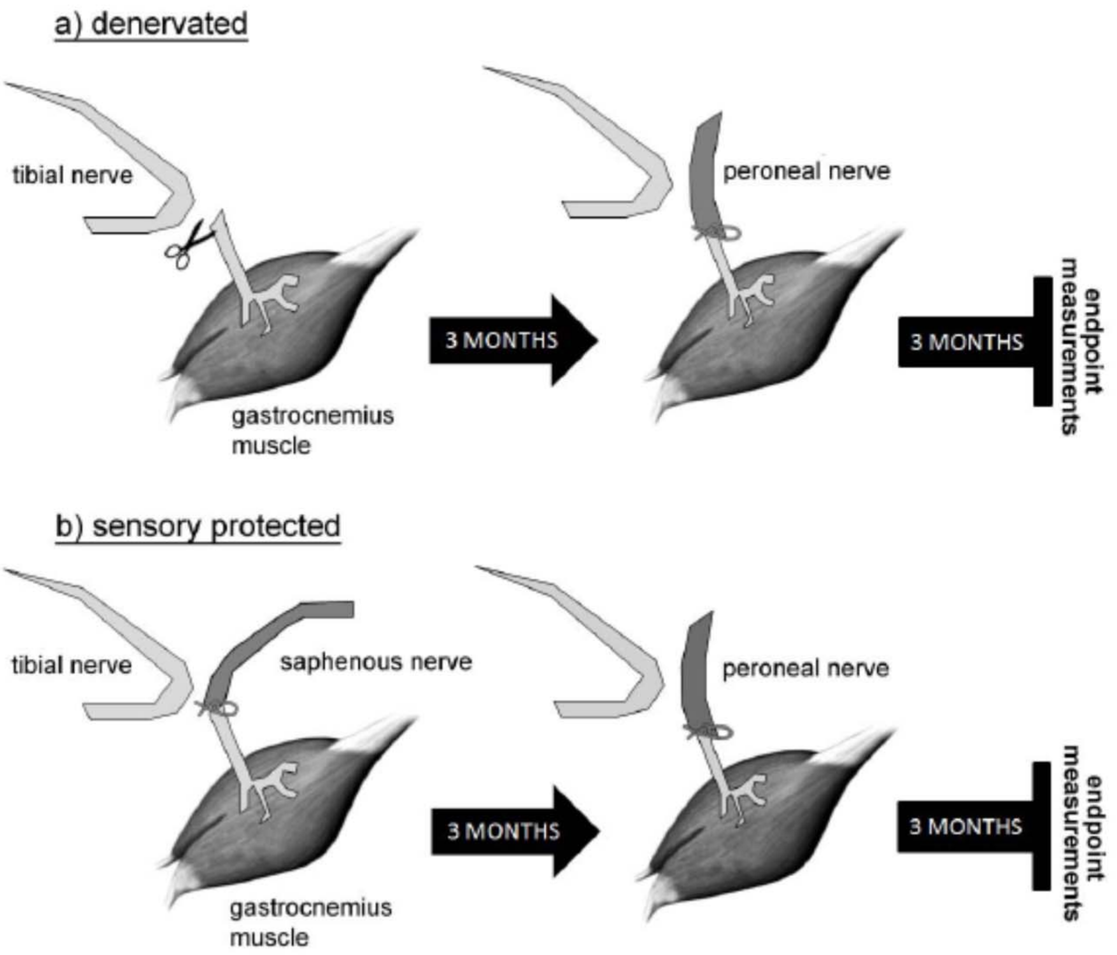




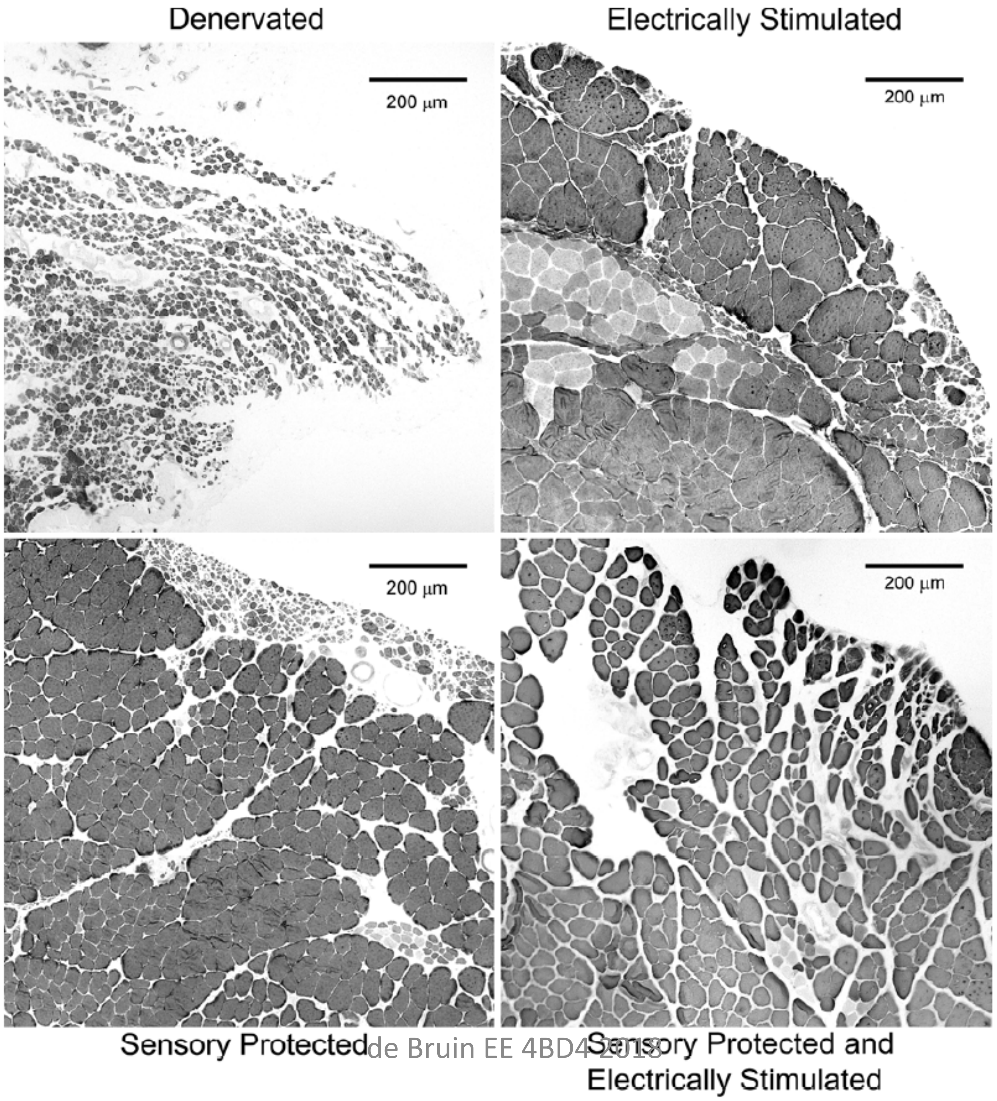
Endpoint Measures (Fiber Size and Type)



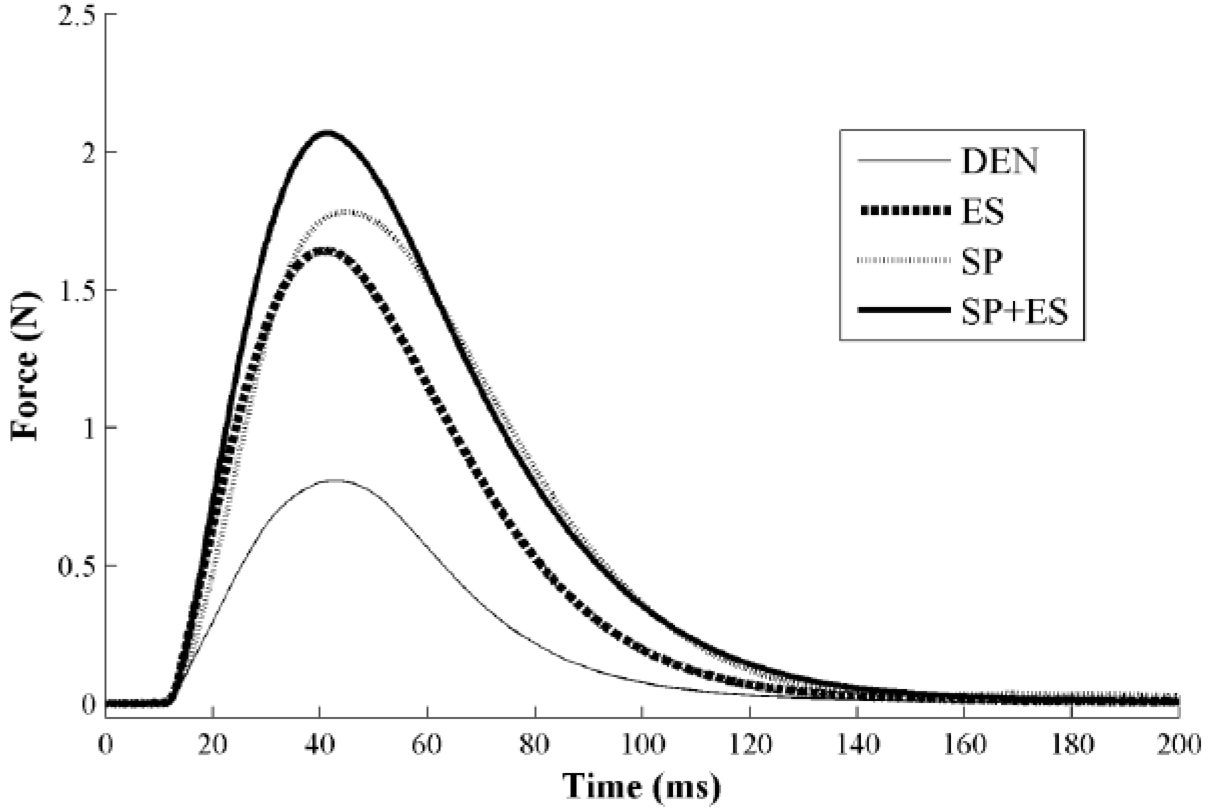
Does FES Improve Recovery?



After 3 months + 3 months Nerve Attached



Final Forces Produced by Muscle



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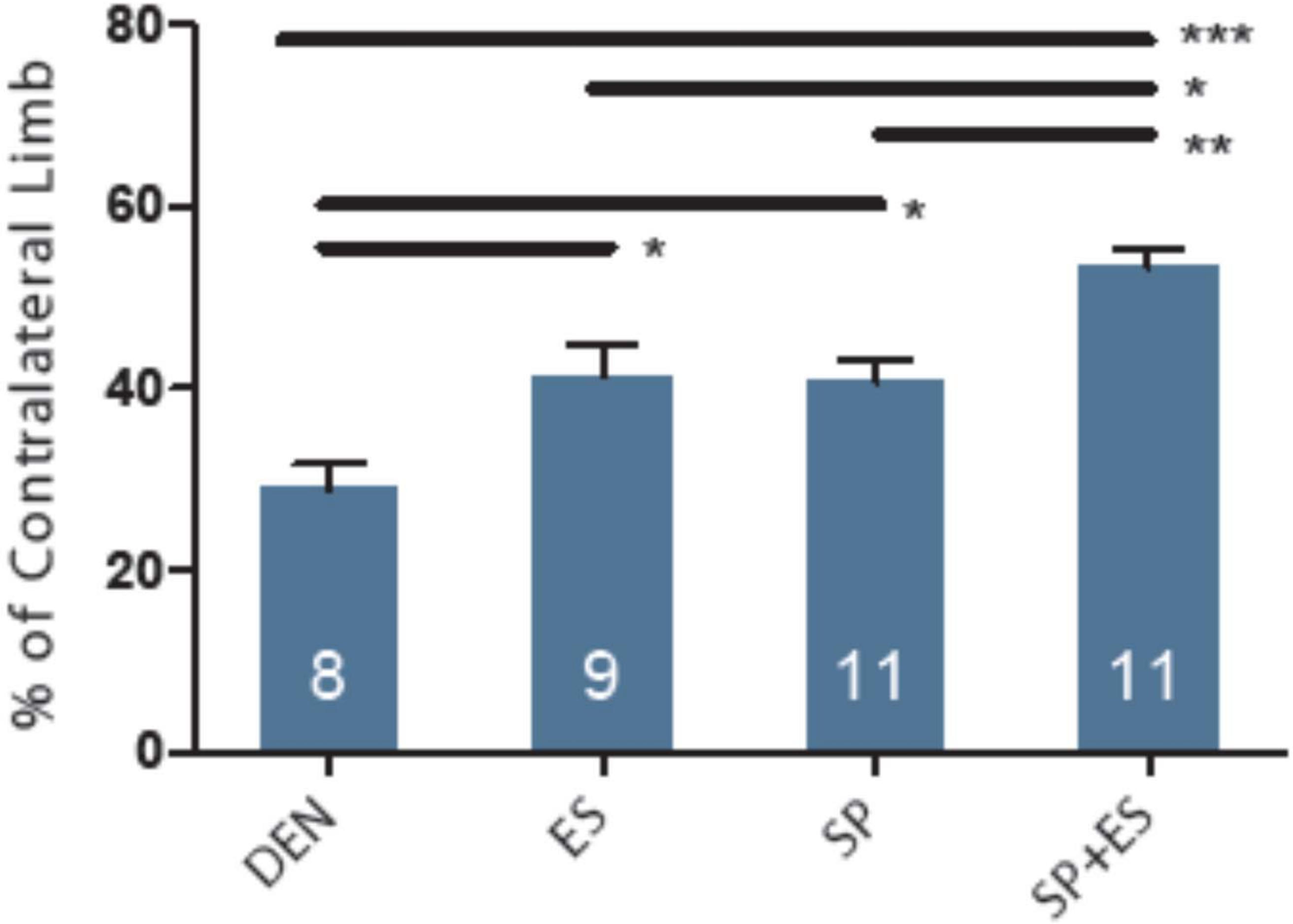
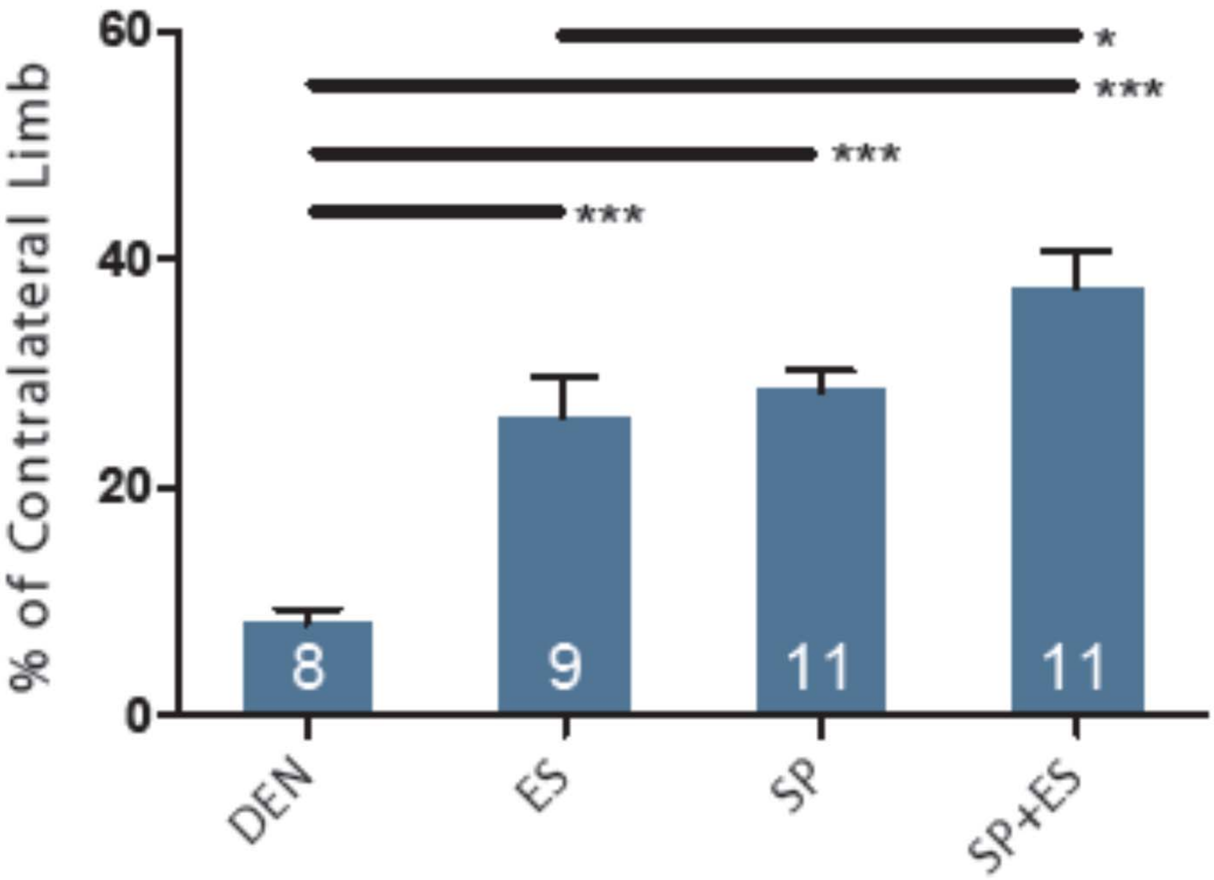
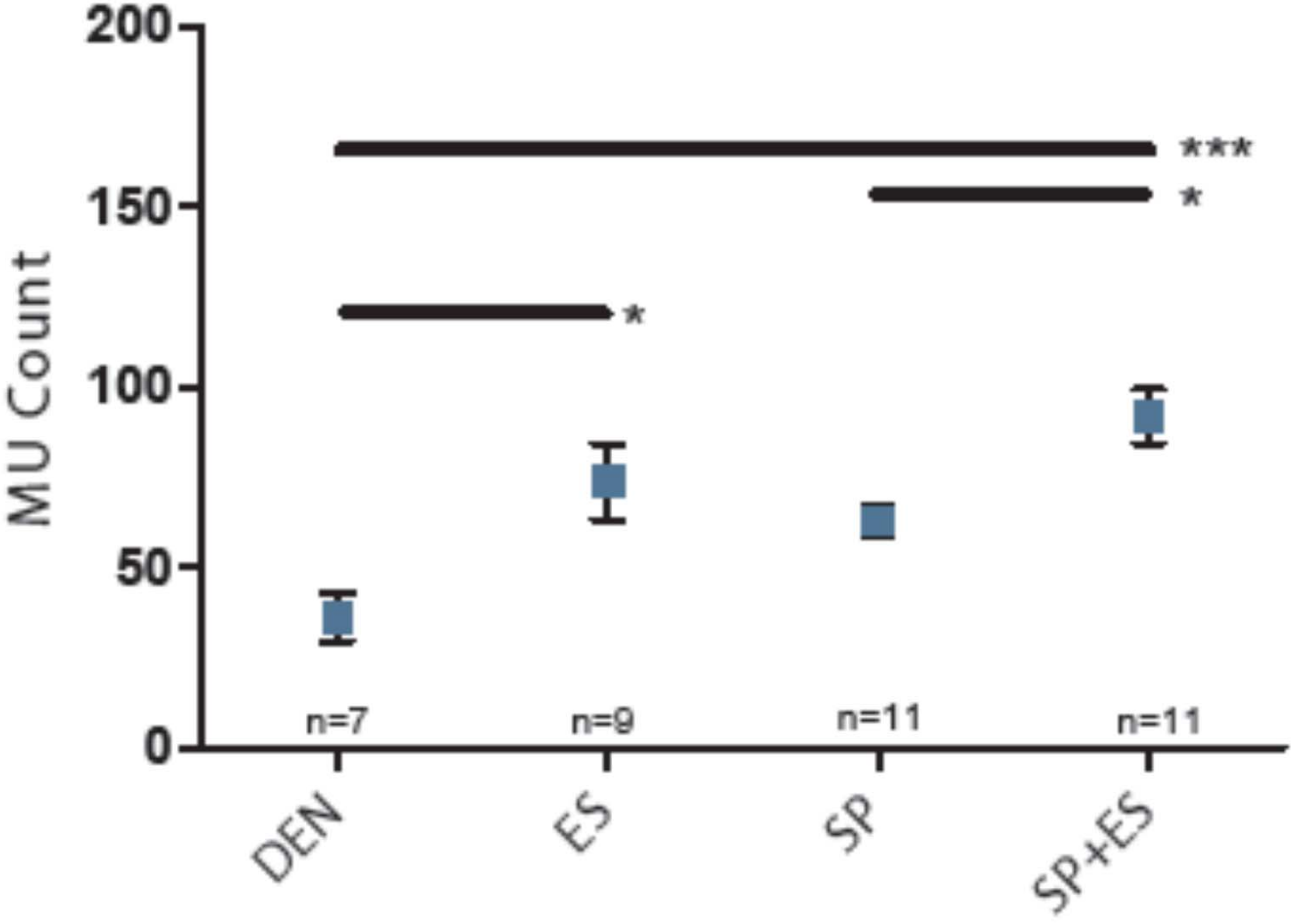
Results (Muscle Weight)



Results
(Twitch Force)



Results
(Motor Unit Numbers)



Results (Histology)