The electric eel - *Electrophorus electricus*

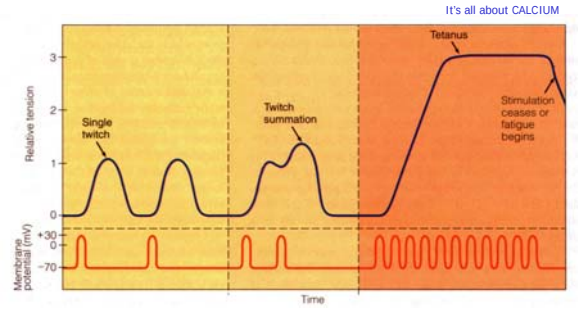
The eel generates electric charge in a battery of biological electrochemical cells, each cell providing about 0.15 V and an overall potential difference of ~ 700 V. Note that the eel's head is the cathode(+) and its tail the anode(-). The cells extend over the length of the eel.
Thanks to Professor Don Stevens, Zoology, for the picture and expert advice.

Control of Muscle Force

- Two primary factors can be adjusted to increase whole-muscle force:
  - the force developed by each contracting fiber (summation)
  - the number of muscle fibers contracting within a muscle (recruitment)

Summation

It's all about CALCIUM



Increase force by decreasing time between individual action potentials (increase rate of stimulation)

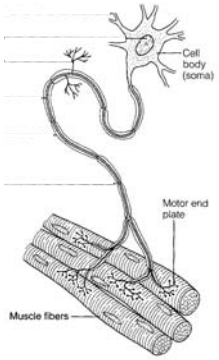
Control of Muscle Force

- Two primary factors can be adjusted to increase whole-muscle force:
  - the force developed by each contracting fiber (summation)
  - the number of muscle fibers contracting within a muscle (recruitment)

Motor Unit

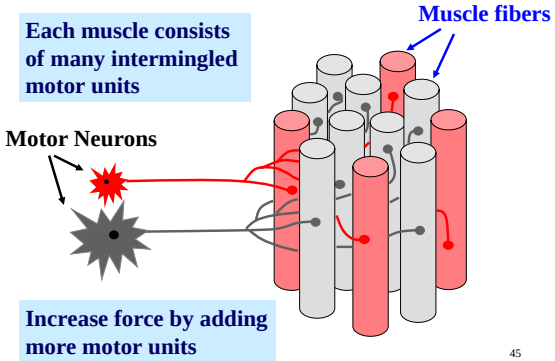
Motor unit = motor neuron and all of the muscle fibers it innervates

AP in motor neuron causes all innervated fibers to contract simultaneously



Recruitment

Each muscle consists of many intermingled motor units



Increase force by adding more motor units

Activating muscles

NERVOUS SYSTEM CONTROL:

- **cerebral cortex**
  - **frontal, parietal, temporal, occipital lobes**
- **Cerebellum**
- **basal ganglia**
- **brain stem**
- **spinal cord**
- **peripheral nerves**

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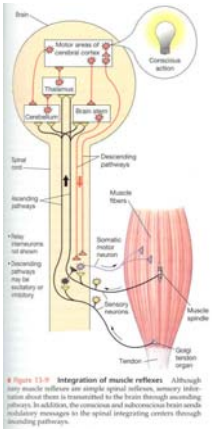

Silverthorn 2001

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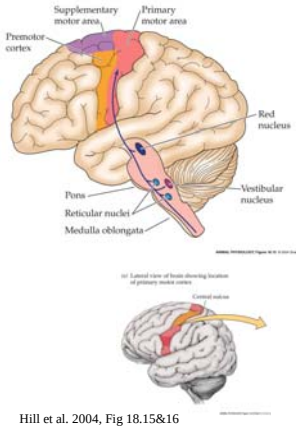
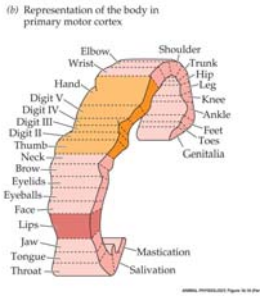


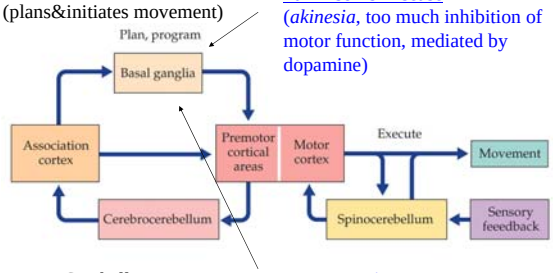
Major Motor Areas, Including
PRIMARY MOTOR CORTEX



Hill et al. 2004, Fig 18.15&16

Basal Ganglia
(plans&initiates movement)

Parkinson's Disease
(*akinesia*, too much inhibition of motor function, mediated by dopamine)

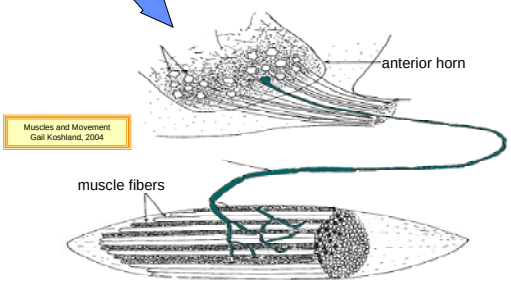


Cerebellum
(fine-tunes execution)

Huntington's Disease
(*chorea*, not enough inhibition of motor function)

Hill et al. 2004, Fig 18.19

A motor unit = the motoneuron + the muscle fibers that it innervates



Muscles and Movement
Gail Koshland, 2004

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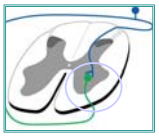
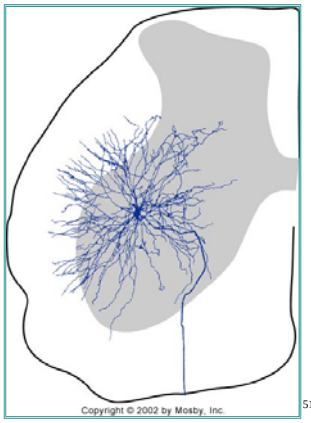
motoneuron in the spinal cord





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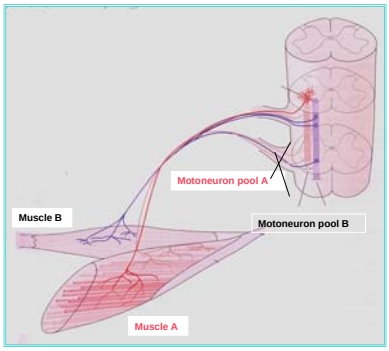
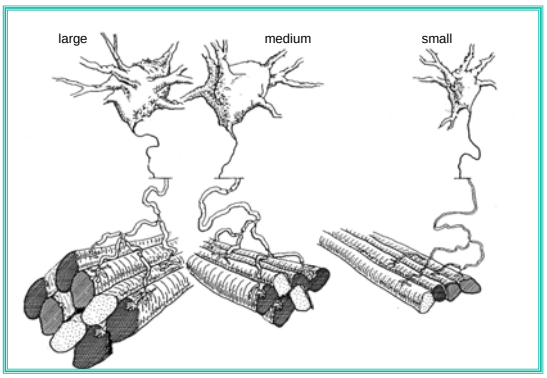
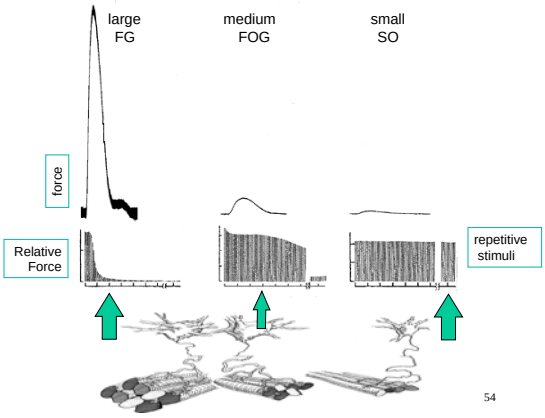
motoneuron pool = all motoneurons that innervate a single muscle

= 200 motoneurons

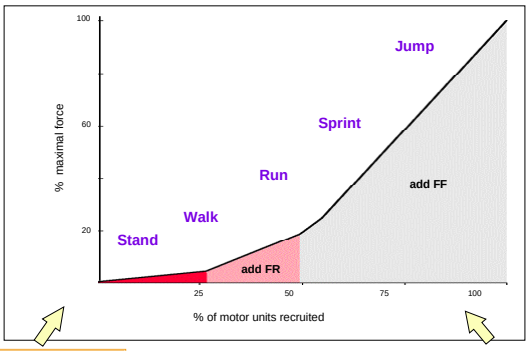




Motoneuron size = motor unit size



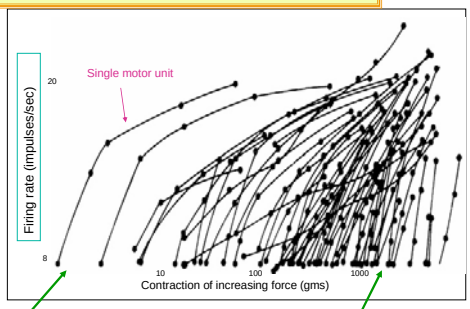
Size Principle



smallest MN's

largest MN's

Increasing firing frequency of recruited motor units



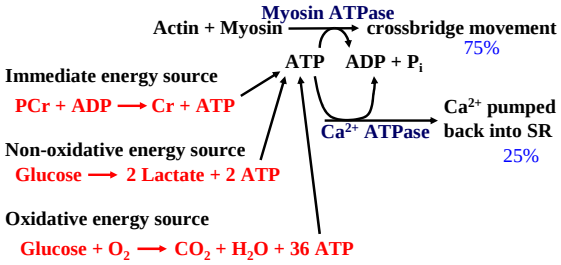
Small units, producing small amounts of force, are recruited first. Firing rate of these units increase as new units are recruited.

Large units, producing large amounts of force, are recruited later and also increase firing rate with more excitation

Muscle Energetics and Fatigue

http://homepage.mac.com/hopbailey/Swimming/Articles/Energy_and_fuel.html

Cellular Energetics



Energy systems differ in their rate of and capacity for producing ATP

Fatigue

Fatigue can result from many factors including;
- **-decreased motivation**
- **-failure of neuromuscular transmission**
- **-accumulation of metabolic end-products**
- **-dehydration**

Cause of fatigue depends on intensity & duration of exercise

Fatigue

- Continuous exercise at moderate speeds results in net accumulation of P_i

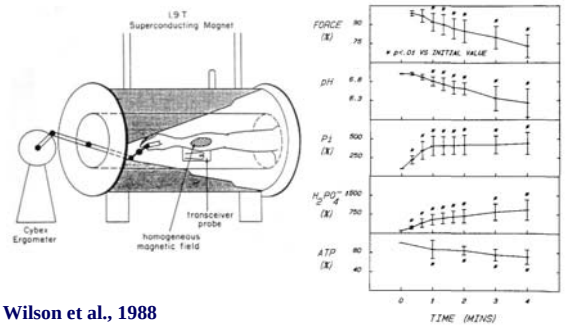
$PCr + ADP + H^+ \rightarrow Cr + ATP$

$ATP + H_2O \rightarrow ADP + P_i + H^+ + energy$

Exercise also produces net accumulation of lactic acid

Correlation vs. Causation

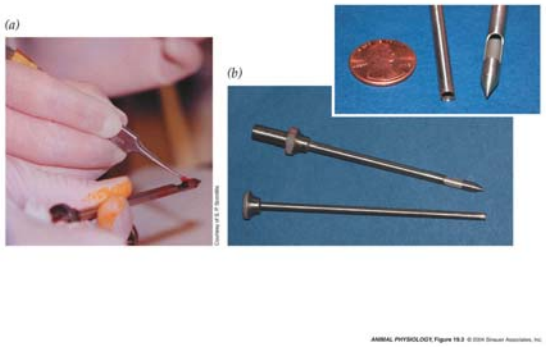
P_i accumulation is correlated with development of fatigue, as is lactic acid accumulation (drop in pH)



Wilson et al., 1988

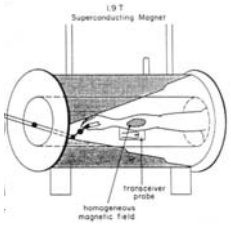
Muscle Biopsy

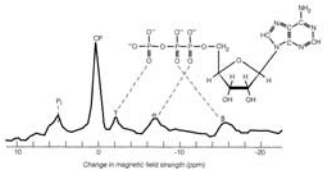
- prepare homogenate & perform enzymatic analysis of homogenate (e.g., creatine phosphate, ATP, P_i, lactate, glucose, glycogen)
  - Pros: low cost per assay
  - Cons: many samples required for time course



^{31}P-Magnetic Resonance Spectroscopy

- Intact muscle (e.g., creatine phosphate, ATP, P_i, pH)
  - Pros: multiple time points for each preparation
  - Cons: high cost per preparation





pH can be determined from position of P_i peak

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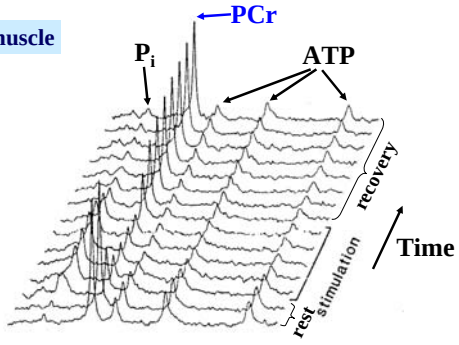
^{31}P-Magnetic Resonance Spectroscopy

Rat muscle



Kushmerick & Meyer, 1985

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Postulated Mechanisms of P_i Effect on Force

- Reduced cross-bridge force development
- Reduced Ca^{2+} release from sarcoplasmic reticulum
- Reduced Ca^{2+} sensitivity of myofilaments

Decreased pH (e.g., lactic acid) does not seem to have much effect on contractility - but may cause pain!

Cooke & Pate, 1985; Allen & Westerblad, 2001; Westerblad et al. 2002

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Muscle

Growth
Repair
Regeneration

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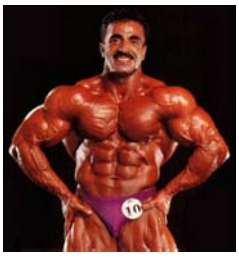
How did he get so BIG??



Muscle growth, repair and regeneration
Cindy Rankin
Dept of Physiology
(October 2004)

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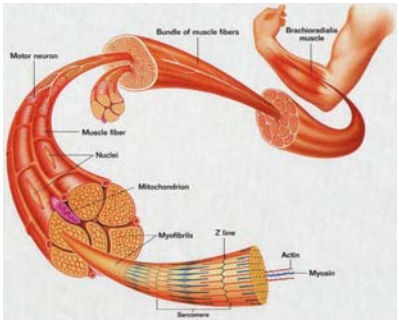

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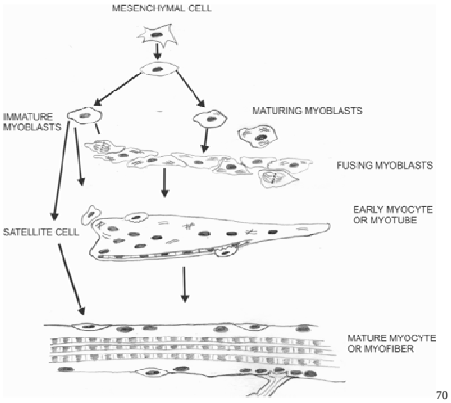

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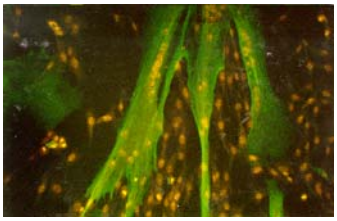
Muscle Growth in a Dish



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Factors influencing growth

- Genetics
- Location
- Tension
- Innervation
- Environment

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Factors cont.

- Environment:
  - Myogenic Regulatory Factors
    - Myo D, Myf5, Myogenin
  - Growth Factors
    - Insulin-like Growth Factor I (IGF-I)
    - Fibroblast Growth Factor (FGF)
    - Transforming Growth Factor (TGF- β)
    - Myostatin (MSTN)

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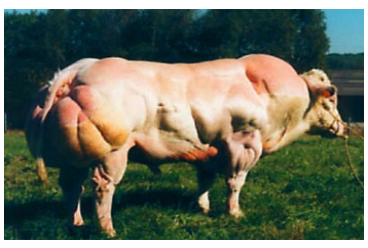
"Double-Muscling" myostatin deficient



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How to add Mass/Strength?

- Increase numbers of fibers:
  - Hyperplasia
- Increase size of existing fibers:
  - Hypertrophy

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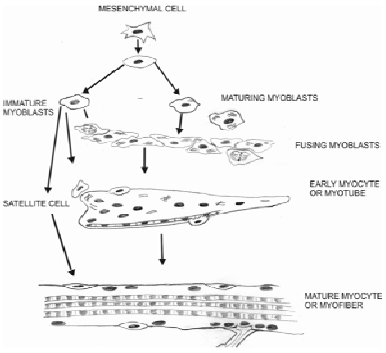

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Satellite Cell

- Adds nuclear material
- Stimulated to proliferate
- Fuses with existing fiber
- Fuses with other SC's to regenerate

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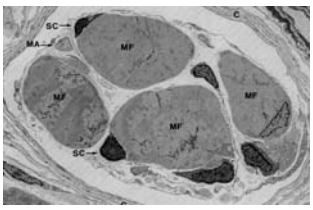
Satellite Cell



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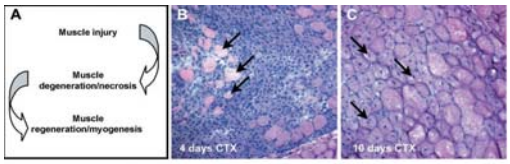
Factors affecting SC activity

- Damage
- Exercise

Process of repair



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Process of Repair

- Degeneration
  - Necrosis
  - Inflammation
    - Neutrophils
    - Macrophages
- Regeneration
  - Satellite Cells

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Factors affecting SC activity

- Damage
- Exercise
- Drugs (Androgenic Steroids)
- Loss of innervation
- Stretch
- Local anesthetics

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Atrophy → Amount of actin and myosin

Hypertrophy → Amount of actin and myosin

Age, disuse, denervation, suspension w/o load

Sarcopenia (# motor units down, remaining units large)

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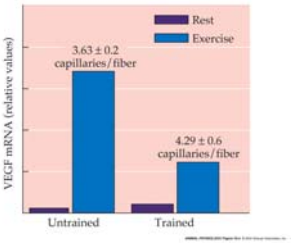
VEGF (vascular endothelial growth factor)
-secreted by working muscle

Angiogenesis
(e.g., type I with more capillaries and mitochondria)



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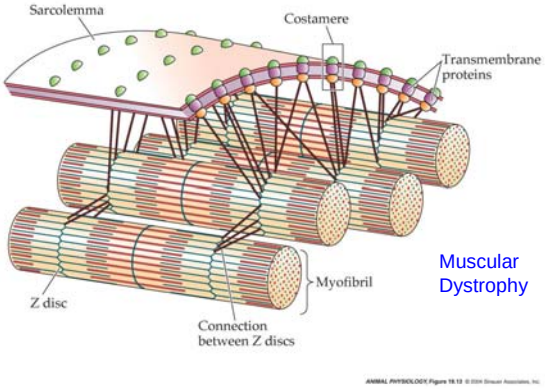
Dystrophin



Muscular Dystrophy