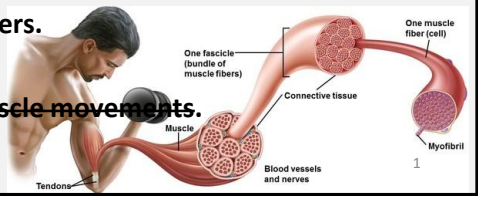
Ch 6: Muscle Physiology

Objectives:

1. Review 3 muscle types and how they are regulated.
2. Review muscle anatomy.
3. The neuromuscular junction
4. The sarcomere
5. Sliding filament theory of how muscles contract and relax.
6. Energetics of muscle contraction (ATP & ADP)
7. Types of muscle contraction.
8. Factors that influence muscle contractile strength.
9. Energetics of muscle use
10. Muscle growth & repair
11. Common muscle injuries & disorders.
- ~~Muscle sensory organs~~
- ~~Voluntary movement VS reflex muscle movements~~.



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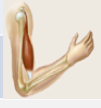
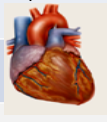
1. Differences in function of the 3 muscle types:

a) Skeletal Muscle	b) Cardiac Muscle	c) Smooth Muscle
Voluntary (somatic motor)	Involuntary (autonomic motor)	Involuntary (autonomic motor)
ACh nicotinic cholinergic	ACh muscarinic cholinergic; Epinephrine β1 adrenergic	
Fastest contraction speed	Intermediate contraction speed	Slowest contraction speed
Prone to fatigue	Fatigue resistant	Fatigue resistant


QUES:

Epineph. binding to β2-adrenergic receptors causes Bronchodilation; artery vasodilation to skeletal muscle

Epineph. binding to α-adrenergic receptors causes ↓ GI activity

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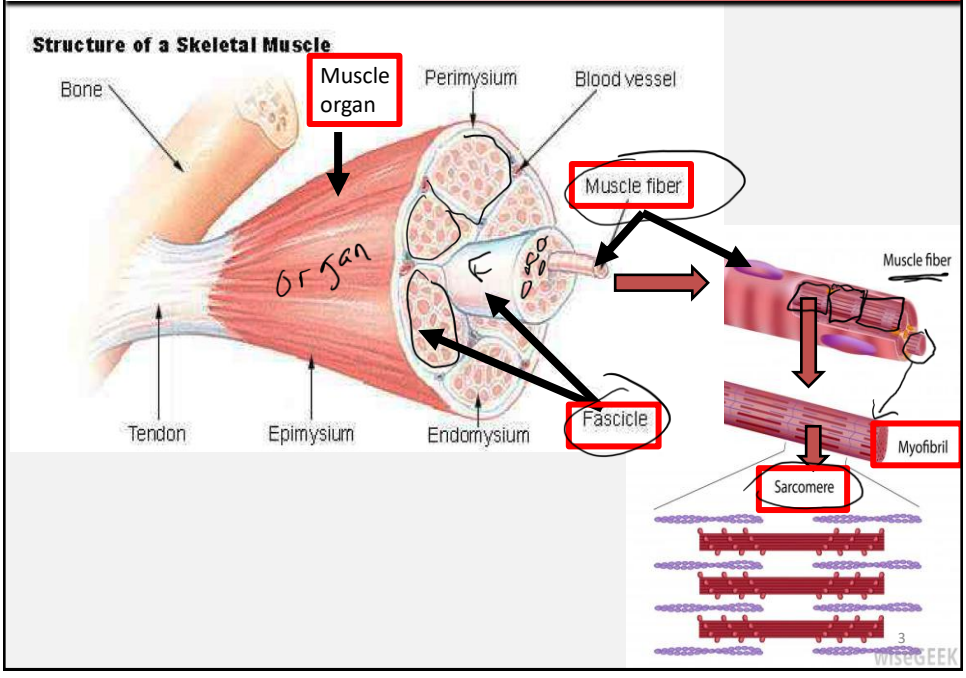
2. Review Anatomy of Skeletal Muscle: Pg 107



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2. Review Anatomy of Skeletal Muscle:

muscle organ = whole muscle group, made of muscle fascicles
(e.g. biceps brachii, triceps brachii)

fascicle = bundle of muscle fibers that make up muscle organ.

fiber = single muscle cell that a somatic motor neuron stimulates. Many fibers make up a muscle fascicle. Each fiber made of many muscle myofibrils.

myofibril = A fiber is made of many myofibrils. Each myofibril contains thousands of sarcomeres.

sarcomere = functional unit of muscle contraction. Has "myofilaments" actin and myosin.

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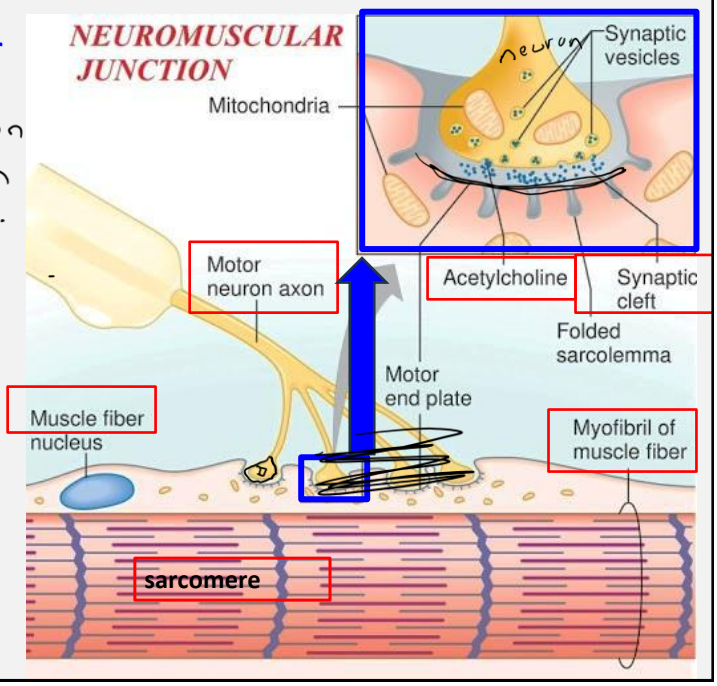
3. Neuromuscular Junction =

where a neuron synapses with a muscle cell.



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Review of Neuromuscular Junction (*review from Ch 4*)

Neuromuscular junction = between a single motor neuron and the muscle fiber it innervates.

If it's a somatic motor neuron stimulating a skeletal muscle cell the following happens:

- ACh ← what neurotransmitter? released by presynaptic motor neuron crossed the synapse
- binds to nicotinic cholinergic receptors on skeletal muscle fibers.
- Binding of receptor opens Na^+ ion channels
- Na^+ enters muscle cell & causes AP (or EPSP),
- AP causes Ca^{+2} release from **sarcoplasmic reticulum**.

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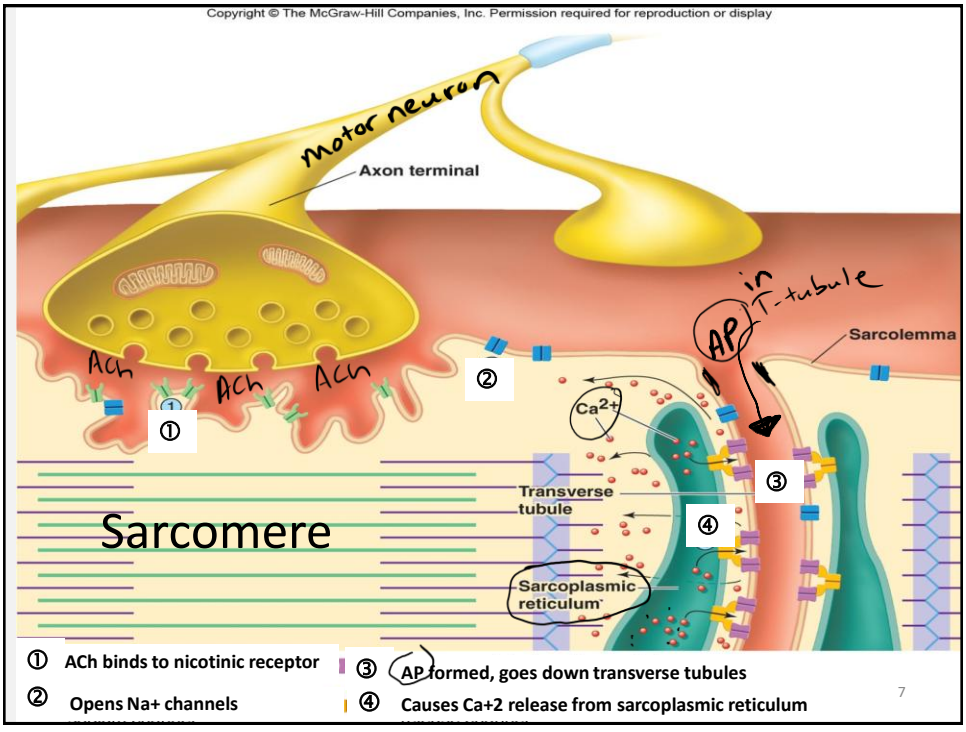

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4. Sarcomere contains myofilaments Actin & Myosin:

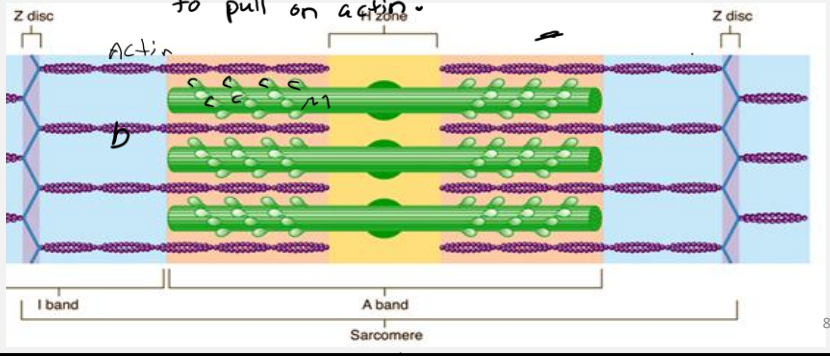
A) **Actin** = thin filament with active sites, and proteins troponin & tropomyosin.

> **active sites** = sites for myosin to bind.

> **troponin** = protein that binds to Ca^+, and causing it to move.

> **tropomyosin** = protein that blocks active sites of actin. When ~~tropomyo~~ troponin moves, it lifts tropomyosin off active sites so that myosin heads can

B) **Myosin** = has heads that grab active sites (crossbridge) attach to pull on actin.



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5. *Sliding Filament Theory of Muscle Contraction: the sequence of action.*

1. Somatic motor neuron releases Ach into synapse.
2. Ach binds to nicotinic cholinergic receptor on muscle cell
3. Opens Na^+ channels & Na^+ enters cell.
4. AP forms in muscle cell.
5. AP travels down T-tubules
6. Ca^+ release from sarcoplasmic reticulum.
7. Ca^+ binds to troponin
8. Moves tropomyosin off active sites on actin
9. myosin heads bind to active sites
10. myosin pulls on actin, shortens sarcomere, shortens muscle,

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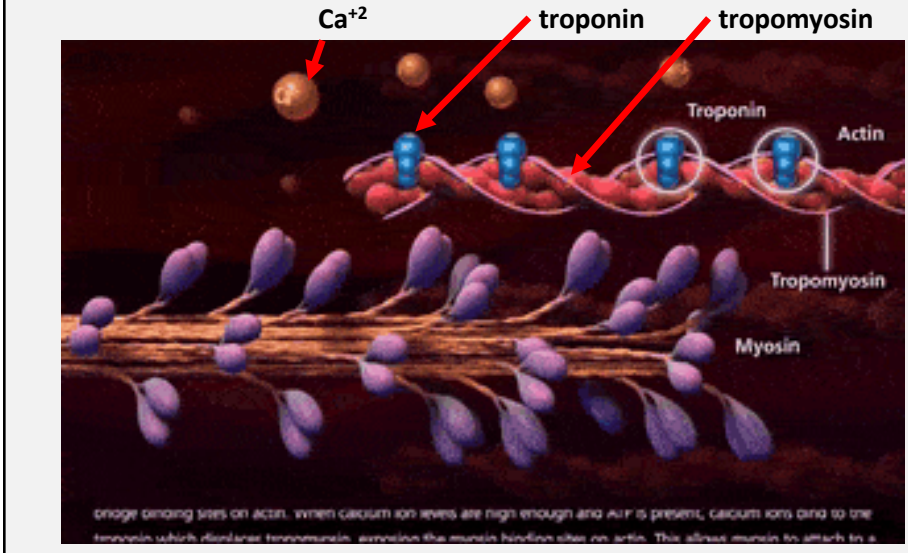

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6. Muscle Energetics - How ATP and ADP is used during muscle contraction

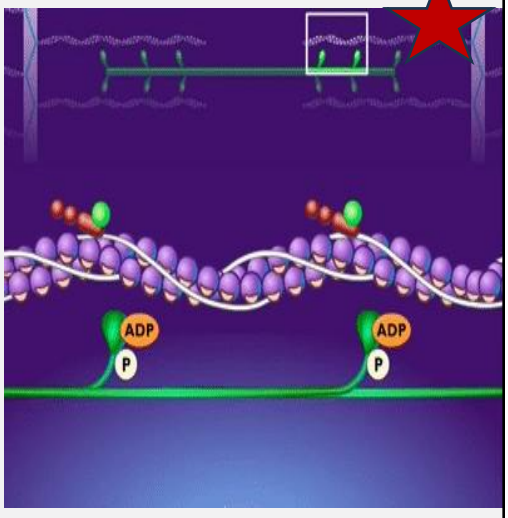
Myosin heads"pulling" on actin involves:
"Grip & Re-grip" Action

1) Myosin has ADP – forms crossbridge

2) ADP released = Power Stroke
(myosin pulls on actin)

3) ATP binds
-myosin breaks crossbridge
-ATP pumps Ca^{+2} into sarcoplasmic retic.

4) ATP converted to ADP
- Ready to bind again.



Click HERE for YouTube video

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Review

- Contrast how 3 muscle types function
- Muscle anatomy
  - organ, fascicles, fibers, myofibrils, and sarcomere arrangement of myofilaments (actin and myosin)
- Neuromuscular junction
- The sarcomere
- Sliding filament theory of muscle contraction
- The use of ATP and ADP in muscle contraction

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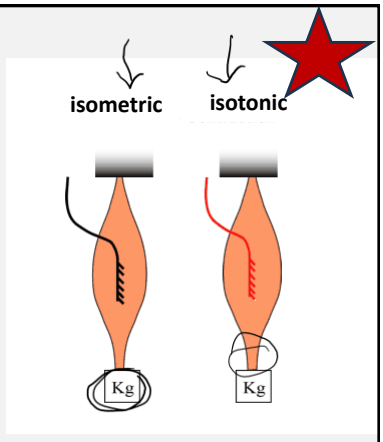
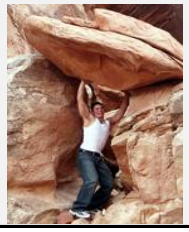
7. Types of muscle contractions



A) Isotonic contraction = muscle shorten

same measure

B) Isometric contraction = muscle has tension but no shortening.



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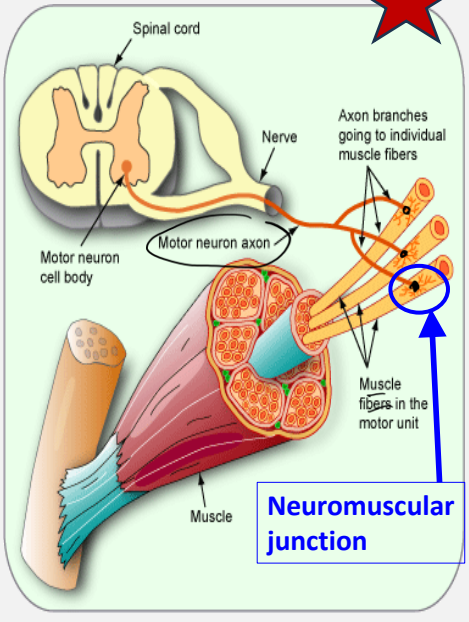
8. Factors Influencing Muscle Contractile Strength (Force):

How is the motor unit arranged?

Motor unit = one motor neuron & all the muscle fibers (cells) it connects to.

- There can be as many as 150 muscle fibers innervated by 1 motor neuron. It depends on the "Power versus Precision" principle (see later).



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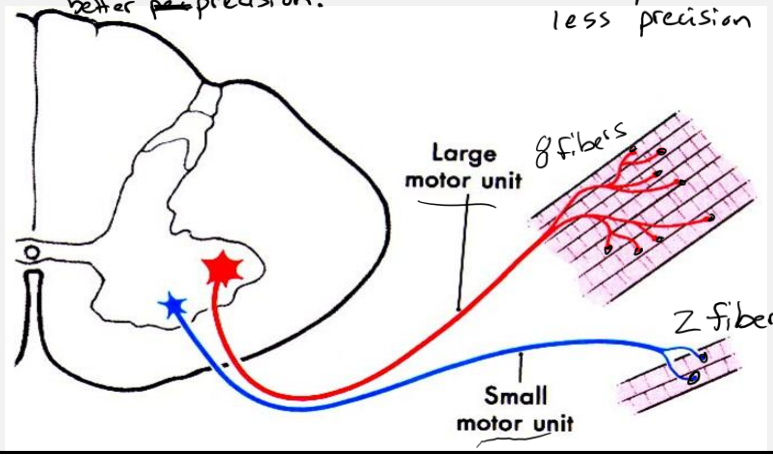
Muscle Contractile Strength Depends On: How is the motor unit arranged?

Tradeoff:

Muscle Precision **vs** **Muscle Power?**

= One motor neuron + few muscle fibers. less power better precision.

= One motor neuron + many muscle fibers Good power less precision



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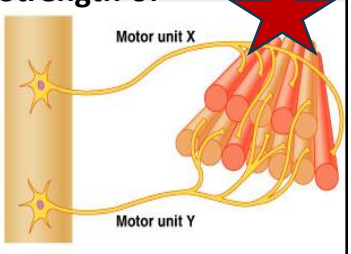
Muscle Contractile Strength Depends On: Strength of stimulation at the motor unit



A. The number of fibers responding:

> If more fibers respond = more force

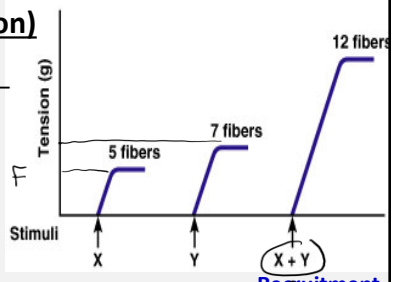
> If fewer fibers respond = less force

B. Strength of stimulus: (for 1 motor neuron)

> If stimulus strong = more force (a lot of ACh)

> If stimulus weak = less force (a little ACh)

"Graded potential"



> If stimulus VERY strong – get "recruitment"
- more than one motor neuron involved & all its muscle fibers.
- produced greater force than with 1 motor neuron.

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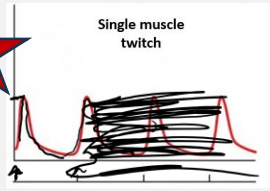
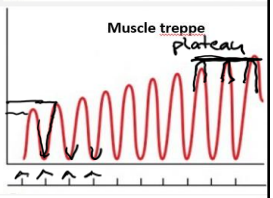
Muscle Contractile Strength Depends On:

C) Frequency of stimulus:

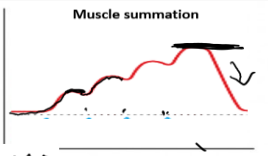
a) Muscle twitch = **Single stimulus** produces single muscle fiber contraction



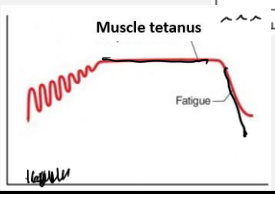
b) Muscle Treppe = muscle "warm up". After **repeated low frequency stimuli** each muscle contractile force increases until reaches max. force. Muscle can relax in between stimuli (force goes back to baseline).



c) Muscle Summation = **repeated high frequency stimuli** Result is each contraction has cumulative increase in force, BUT so rapid muscle cannot relax (don't go to baseline).



d) Muscle tetany = **repeated highest frequency stimuli** produces **greatest possible contractile force** *BUT* comes at cost. Sustained muscle contraction leads to muscle fatigue and failure.



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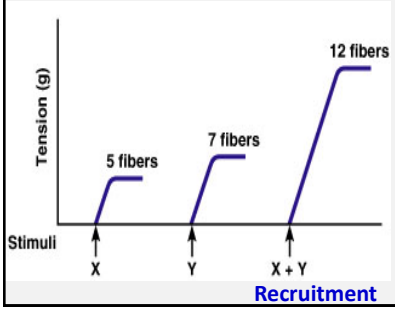
D) Muscle Contractile Strength Depends On: recruitment of different types of muscle fibers.

If have a heavy demand placed on muscles: **CNS stimulates Recruitment**

- more than one motor neuron involved & all its muscle fibers.
- recruit different types of muscle fibers depending on the need.
- produced greater force than with 1 motor unit alone.



Recruitment

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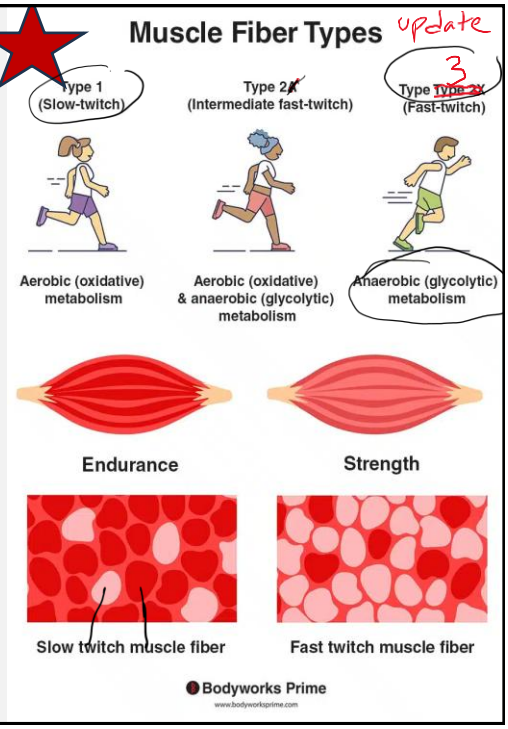
Recruitment of different muscle fiber types:

red muscle

Type 1 = **slow twitch (S).** For endurance aerobic activities

Type 2 = **fast twitch fatigue resistant (FR).** For more strenuous, endurance aerobic & anaerobic activities. *(Intermediate between type 1 & 2 for speed, strength **and** stamina.)*

Type 3 = **fast twitch subject to fatigue (FF).** For maximum power short bursts of activities. Muscles fatigue when forced into anaerobic metabolism



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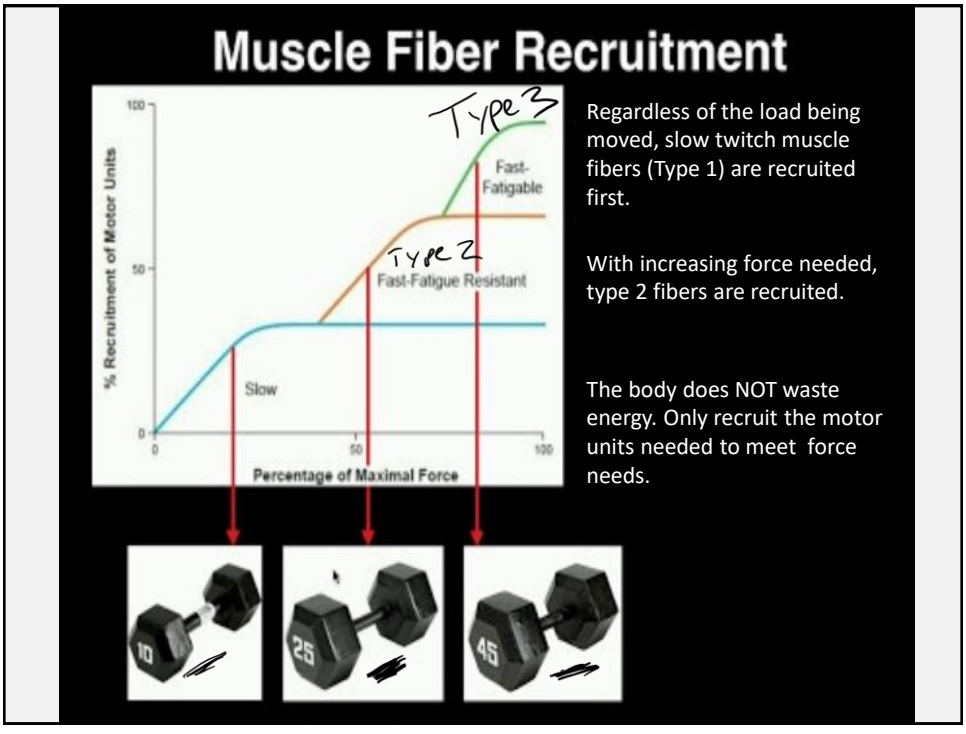

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Review

- **Types of muscle contraction contraction (isotonic vs isometric)**
- **What influences the strength of muscle contraction**
  - How motor unit is arranged (Muscle precision Vs power)
  - Strength of stimulation of motor units
    - Graded response of neurotransmitter stimulation
    - Frequency of neurotransmitter stimulation (muscle twitch, treppe, summation, and tetany)
    - Recruitment
      - Multiple motor units
      - Involves different muscle fiber types

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9. *The Energetics of Muscle Contraction (Muscle Fatigue)*

Muscle Fatigue

Depletion of:

- **O2**
- **ATP**
- **Glycogen**
- **Myoglobin**

Accumulation of:

- **CO2**
- **ADP**
- **Lactic acid**
- **Phosphate (from using creatine phosphate)**

QUES:
How is lactic acid removed from the bloodstream?

Cori cycle

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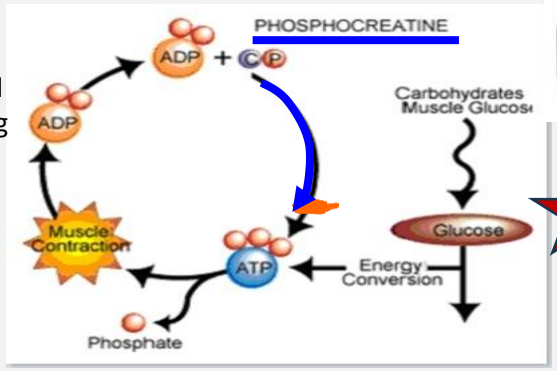
Phosphocreatine = natural molecule stored in large supply in resting muscle, is needed to convert ADP back into ATP. (donates a phosphate to ADP to make ATP)



Creatine phosphokinase (CK or CPK) = enzyme (in skeletal muscle, brain, and heart), which is needed to convert creatine into phosphocreatine.

Phosphocreatine is needed to make ATP in tissues requiring high ATP.

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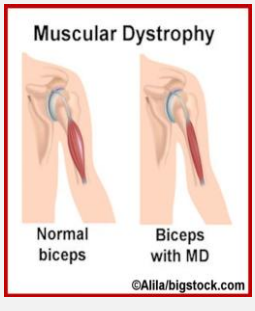
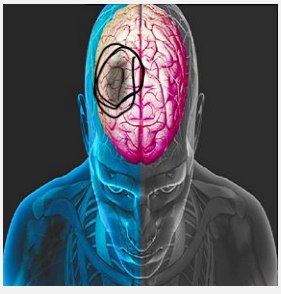
Different isoforms of CPK for different organs can be elevated due to death of tissues:

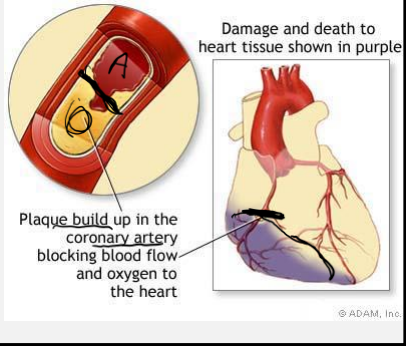
1. CPK-MM = elevated form associated with diseased **skeletal muscle,** like in muscular dystrophy. **Clinical App** ONLINE

2. CPK-BB = elevated form associated with **damaged brain**.

3. CPK-MB = elevated form associated with **damaged heart**.







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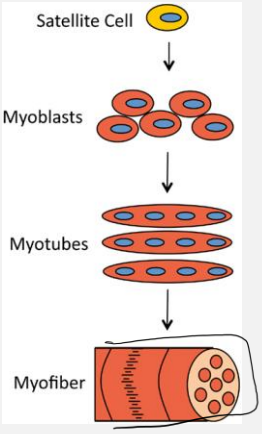
10. Muscle Growth & Repair

Muscle growth & repair:

Satellite cells = muscle stem cells that are activated with muscle injury. Makes new muscle fibers



Myostatin

= substance that inhibits Satellite cells

Elderly people with muscle atrophy have high myostatin levels.

When myostatin is inhibited – get excessive muscle growth!

The Belgian Blue has been bred to be predisposed towards myostatin blocking.

Wendy the whippet is the Schwarzenegger of dogs.

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Sleep Twitches

Sleep Twitch - **myoclonus or myoclonic jerk (a.k.a. hypnagogic massive jerk)**

= involuntary muscle movement as enter REM sleep.

Might be due to change in muscles as go from conscious to unconscious – involves GABA inhibition of muscles.

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11. Muscle Disorders

Muscle atrophy = shrinkage of muscle mass

Due to many possible factors:

- Lack of use (couch potatoes)
- Broken bone healing
- Injury or disease of muscle (e.g. MD, myasthenia gravis)
- Injury to nerves (e.g. ALS)

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11. Muscle Disorders

Pg 112-113

Muscle spasms = brief uncontrolled muscle contractions.

Muscle cramp = sustained painfull muscle contraction.

- after heavy workout
- dehydrated (lost electrolytes)

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11. Muscle Disorders – updated 6/10/25

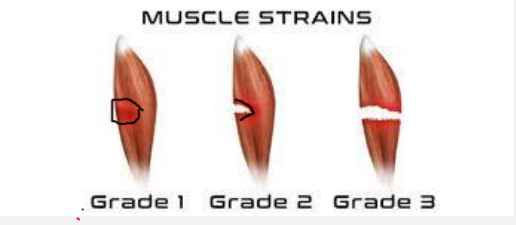
Pg 112-113

Muscle sprain = ~~S~~tretched or torn ligament.

Tx for sprain = RICE
Rest
Ice
Compression
Elevate

ACL tear (anterior cruciate ligament)

Muscle strain = pulled tendon or muscle



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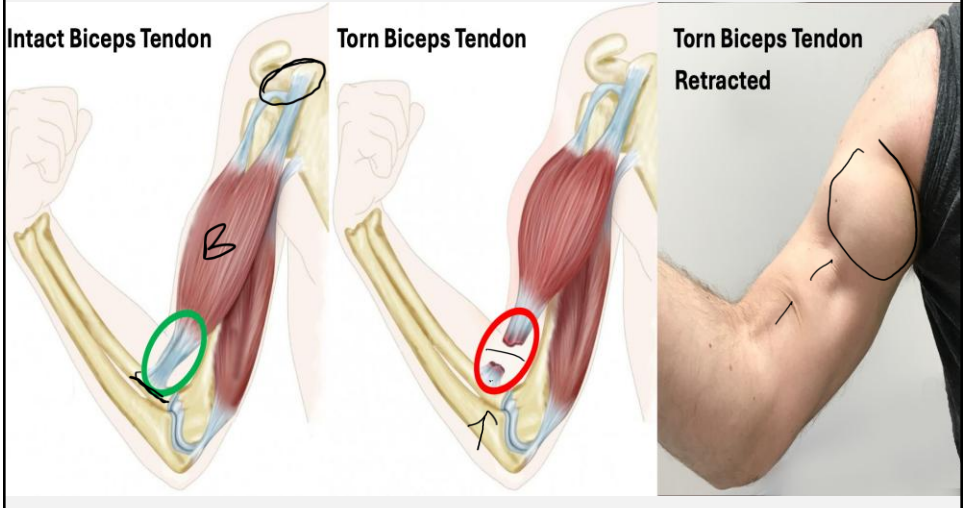
Added slide: Muscle strain example - Biceps tendon rupture



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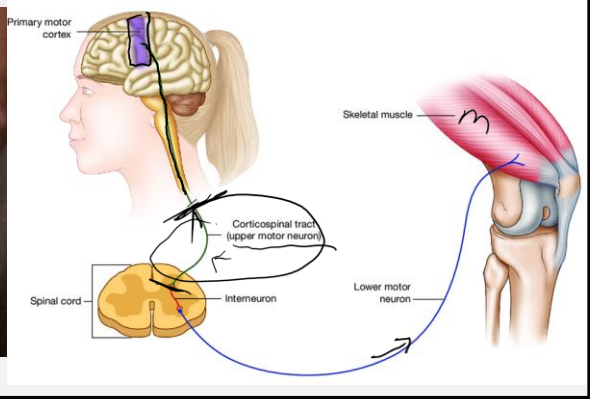
11. Muscle Disorders – slide updated 6/11/25

Muscle clonus = when nerve cells that control the muscles are damaged, causing involuntary muscle contractions or spasms.

Usually caused by lesions on upper motor neurons. Could also be problem in CNS like multiple sclerosis, cerebral palsy, Huntington disease, brain and spinal cord injuries, and stroke. Click **HERE** for video.



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11. Muscle Disorders

Dermatomyositis = (pronounce "dur·muh·tow·mai·uh·**sai**·tuhs "

= skin muscle inflammation = Chronic inflammation of skin & muscle.

> 1 / 100,000
> women predominantly

Presentation:

- Muscle weakness that progresses
- Affects muscles close to trunk (hip, shoulder, neck)
- Skin rashes

TX:

- anti-inflammatory
  - steroids (prednisone)
  - NSAIDs → non-steroidal anti-inflammatory
  - sunscreen to protect rashes.

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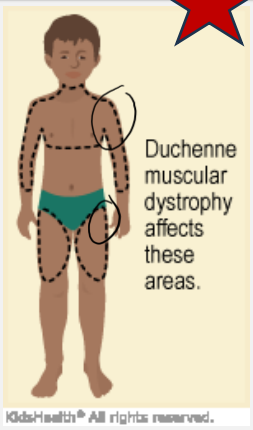
11. Muscle Disorders

2) Muscular Dystrophy (Duchenne's)



- Most common form of MD (1 / 3500 male births)

= Sex-linked disorder of progressive muscle weakness, starts at trunk muscles.

- Early onset in children = walking & balance problems. Muscle atrophy leads to loss of muscle function.

- Loss of dystrophin thought to influence.

"dystrophin" = protein needed for muscle function.

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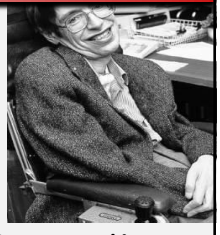
11. Muscle Disorders

3) ALS (Amyotrophic Lateral Sclerosis)

9 -10 / 100,00 people

a.k.a. Lou Gherig's disease

= ↓ loss or damage to motor neurons so that muscles are not stimulated. muscle atrophy



Steven Hawking

> Tends to start in motor neurons to hands and feet
> Eventually affects respiratory muscles.
> Life expectancy after diagnosis < 5 yrs.
> Reason?
- Loss of **superoxide dismutase** (an antioxidant that prevents cell death)
- **Glutamate toxicity** = excess brain stimulation
  > glutamate supposed to be taken up by astrocytes. (astrocyte problem?)
  > excess glutamate also thought to play role in Parkinson's & Alzheimers disease)

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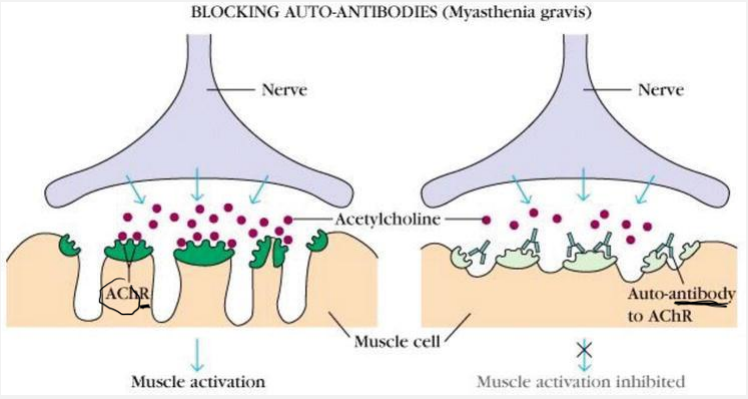
11. Muscle Disorders

REVIEW!

4) Myasthenia gravis = autoimmune attack on ACh receptors.

> Loss of motor neuron stimulation = muscle atrophy. 37 / 100,000 people



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Review

- **Energetics of muscle contraction**
  - Muscle fatigue and depletion vs accumulations of metabolic products
  - Phosphocreatine & Creatine phosphokinase
  - CPK (CPK-BB, CPK-MB, CPK-MM)
- **Muscle Growth & Repair**
  - Satellite cells vs Myostatin
- **Muscle Disorders:**
  > muscle atrophy, spasm, cramp, sprain, strain, clonus
  > Dermatomyositis
  > Duchenne's MD
  > ALS
  > Myasthenia gravis
  ~~Muscle disorder diagnosis & treatment with EMG & FES~~

End of Exam 3 material

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