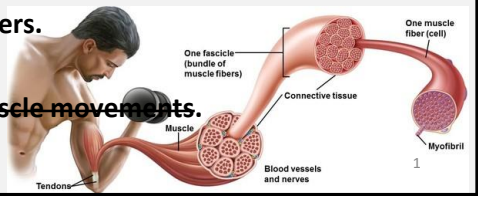
Ch 6: Muscle Physiology

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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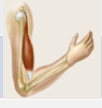
1. Differences in function of the 3 muscle types:

a) Skeletal Muscle	b) Cardiac Muscle	c) Smooth Muscle
Voluntary (somatic motor)	Involuntary (autonomic motor)	Involuntary (autonomic motor)
Neurotransmitter = Receptor = receptors for contraction & also Glycine & GABA with muscarinic receptors (Ch 4) **(for IPSPs – muscle relax)**	**Parasymp. Neurotrans.** = receptor to slow heart rate **Sympath. Neurotrans= receptor =** Effect = increased heart rate	**ACh with muscarinic cholinergic receptors, Epinephrine with B2 & α-adrenergic receptors**
Requires somatic motor neuron stimulus to contract (not "autorhythmic")	Is "autorhythmic", but HR influenced by ACh (↓HR) & epinephrine (↑HR)	Is "autorhythmic" – influenced by ACh or epinephrine
Fastest contraction speed	Intermediate contraction speed	Slowest contraction speed
Prone to fatigue	Fatigue resistant	Fatigue resistant



QUES:

Epineph. binding to β2-adrenergic receptors causes _____

Epineph. binding to α-adrenergic receptors causes _____

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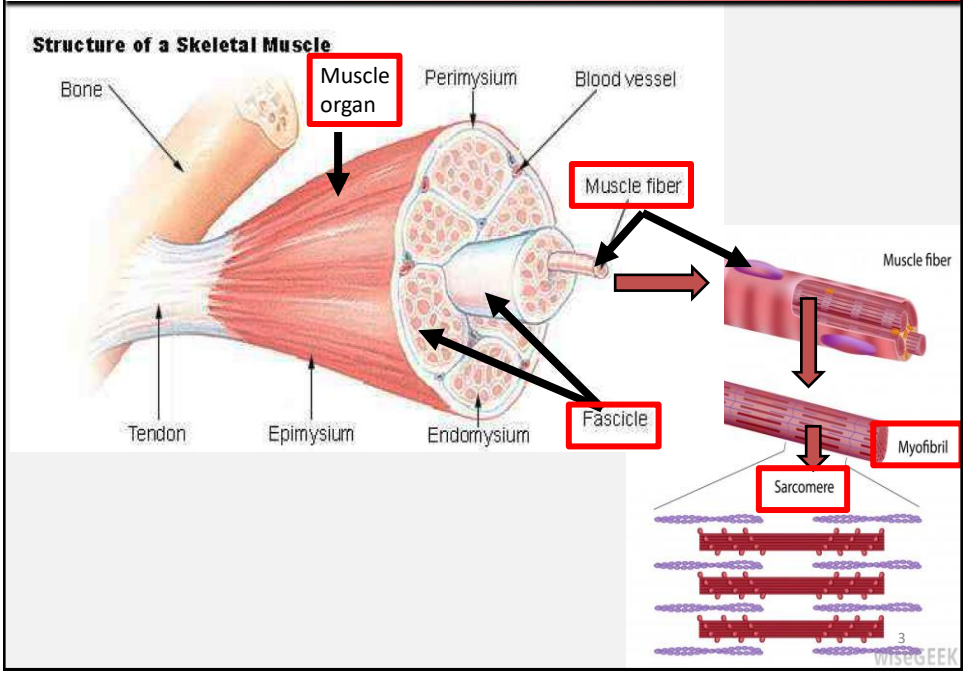
2. Review Anatomy of Skeletal Muscle: Pg 107



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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.

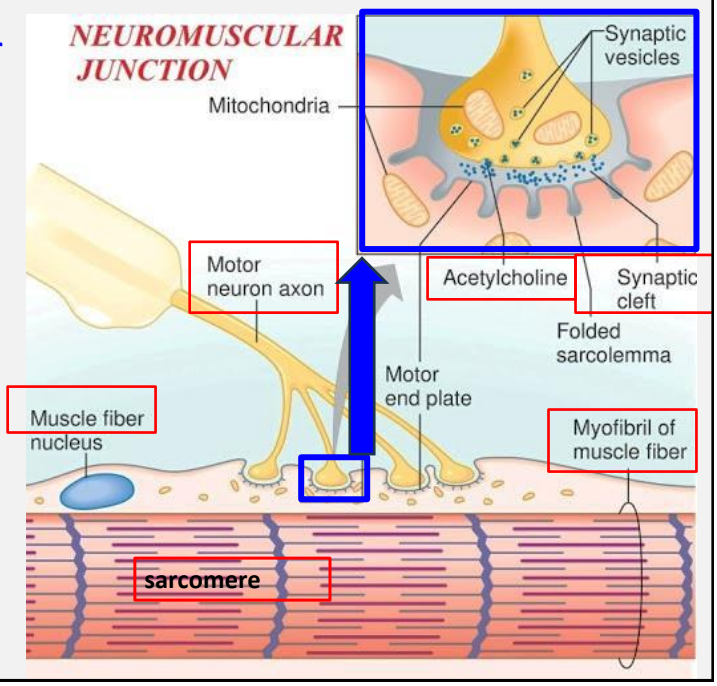
fiber = single muscle cell that a somatic motor neuron stimulates. Many fibers make up a muscle fascicle. Each fiber made of many muscle myofibrils.

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.

4

3. Neuromuscular Junction =



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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:

← what neurotransmitter?

- _____ released by presynaptic motor neuron crossed the synapse
- binds to _____ receptors on skeletal muscle fibers.
- Binding of receptor opens _____ ion channels
- _____enters muscle cell & causes AP (or EPSP),
- AP causes _____ release from **sarcoplasmic reticulum**.

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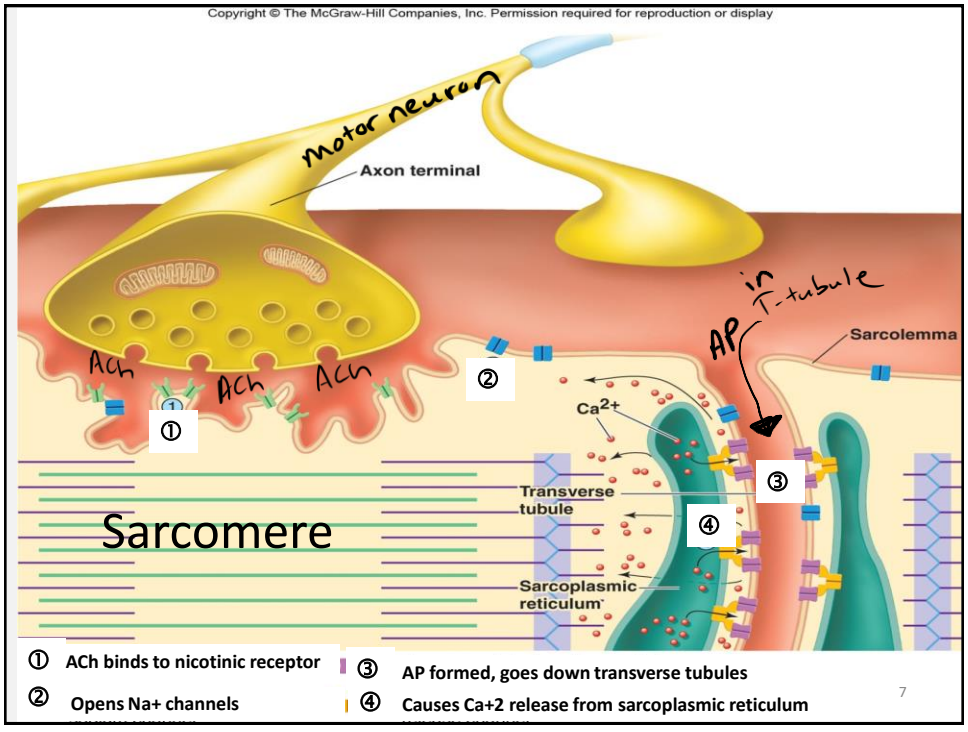

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4. Sarcomere contains myofilaments Actin & Myosin:

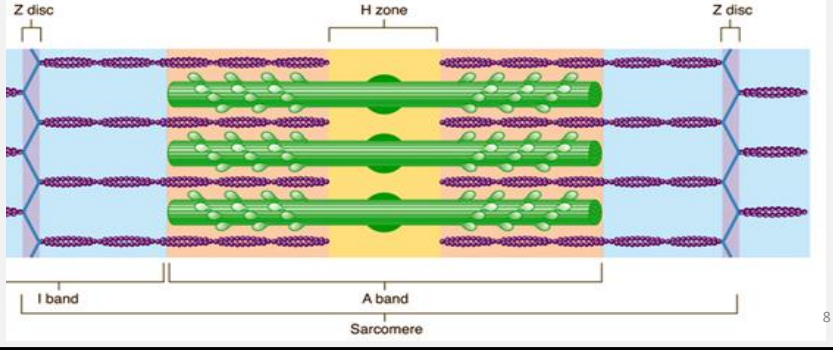
A) **Actin** = thin filament with active sites, and proteins troponin & tropomyosin.

> **active sites** =

> **troponin** =

>**tropomyosin** =

B) **Myosin** =



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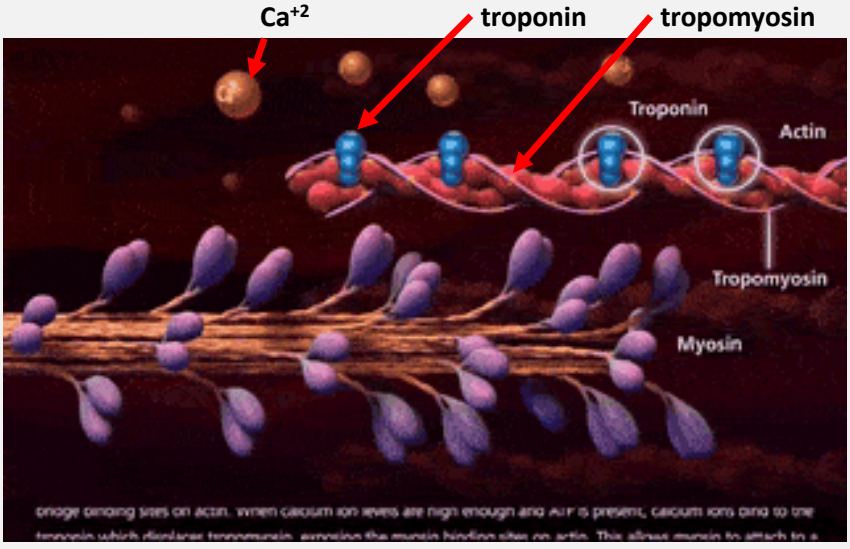

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6. Muscle Energetics - How ATP and ADP is used during muscle contraction

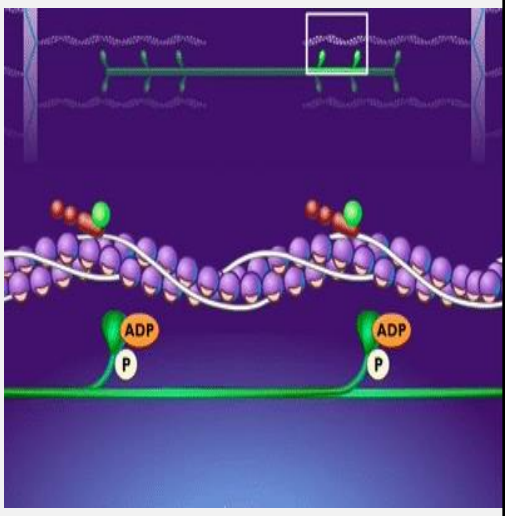
Myosin heads"pulling" on actin involves: "Grip & Re-grip" Action

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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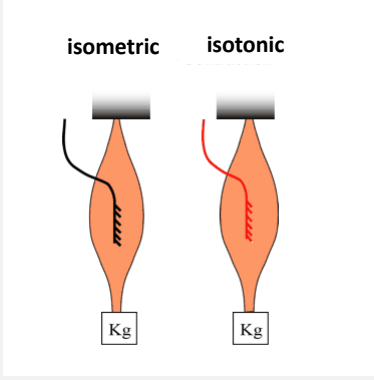
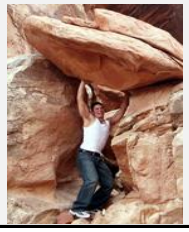
7. Types of muscle contractions



A) Isotonic contraction =

B) Isometric contraction =



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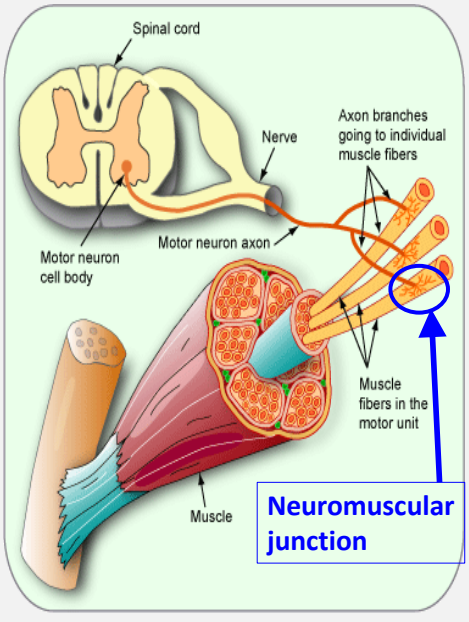
8. Factors Influencing Muscle Contractile Strength (Force):

How is the motor unit arranged?

Motor unit =

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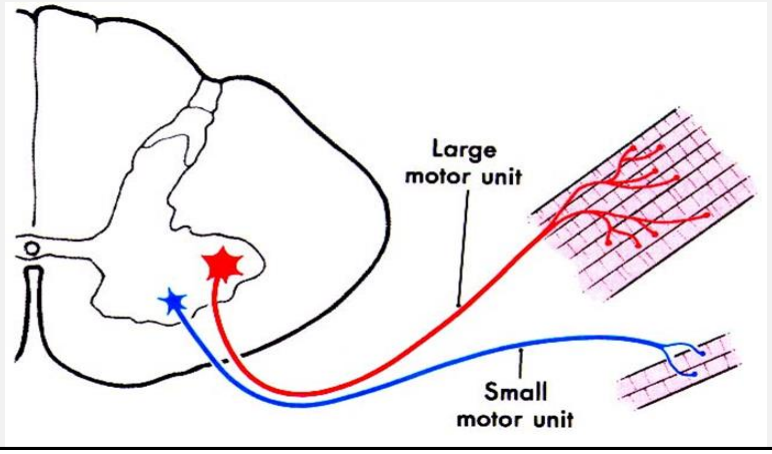
Muscle Contractile Strength Depends On: How is the motor unit arranged?

Muscle Precision **Tradeoff: vs** **Muscle Power?**

= =



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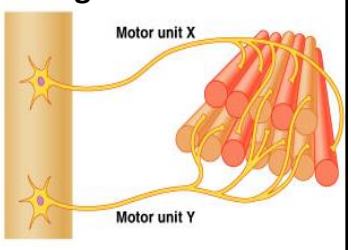
Muscle Contractile Strength Depends On: Strength of stimulation at the motor unit



A. The number of fibers responding:

> If more fibers respond = _____

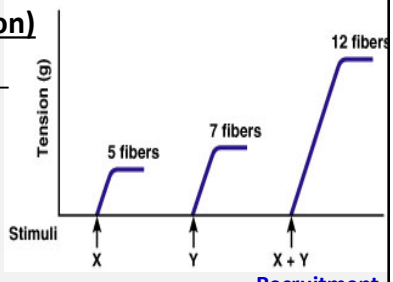
> If fewer fibers respond = _____

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

> If stimulus strong = _____
(a lot of ACh)

> If stimulus weak = _____
(a little ACh)

"Graded potential"



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

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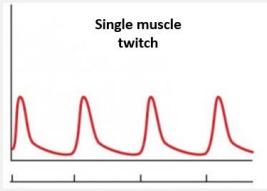
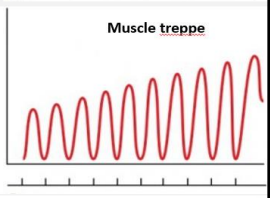
Muscle Contractile Strength Depends On:

C) Frequency of stimulus:

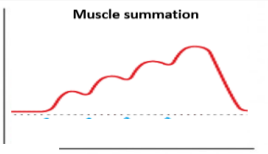
A) _____= **Single stimulus** produces single muscle fiber contraction



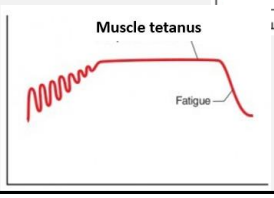
B) _____ = muscle "warm up". After **repeated low frequency stimuli** each muscle contractile force increases until reaches max. force. Muscle can relax in between stimuli (force goes back to baseline).



C) _____= **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) _____= **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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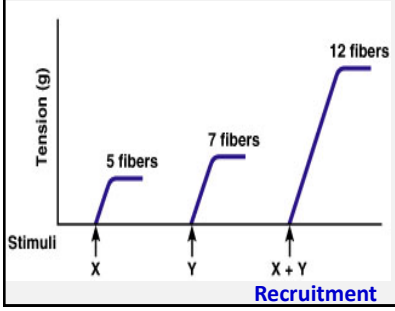
Muscle Contractile Strength Depends On: recruitment of different types of muscle fibers.

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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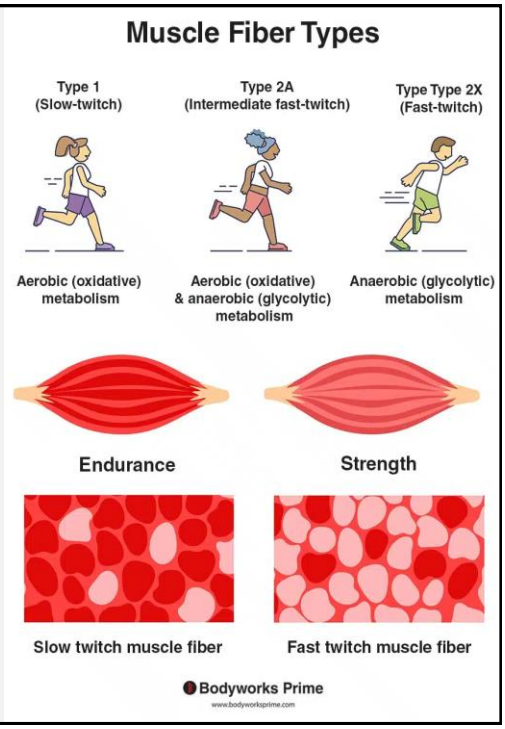
Recruitment of different muscle fiber types:

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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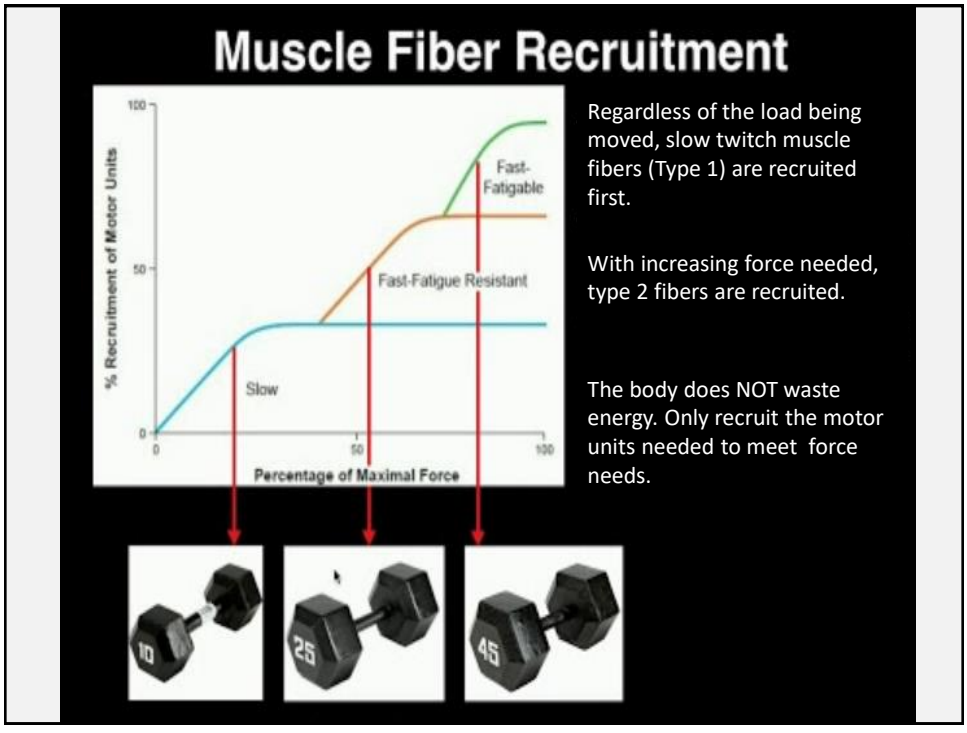

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Review

- **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?

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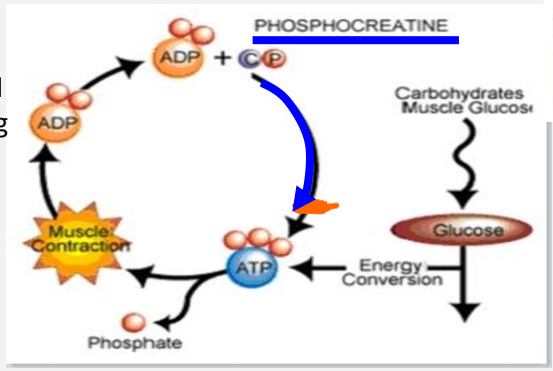
Phosphocreatine = natural molecule stored in large supply in resting muscle, is needed to convert ADP back into ATP. (donates a phosphate to ADP to make ATP)



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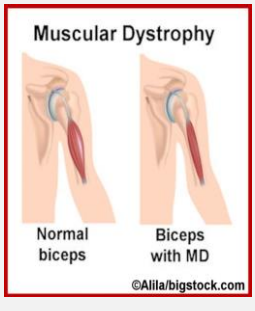
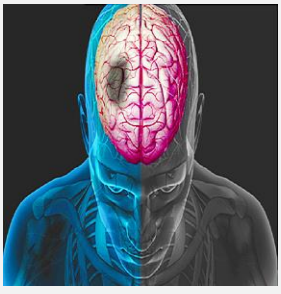
Different isoforms of CPK for different organs can be elevated due to death of tissues:

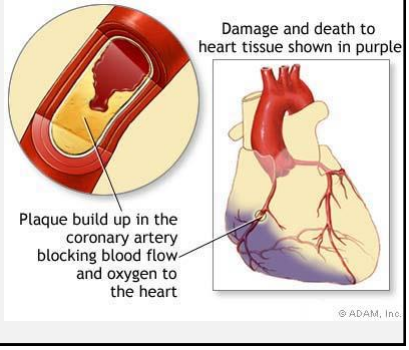
1. _____= elevated form associated with diseased **skeletal muscle,** like in muscular dystrophy. **Clinical App** ONLINE

2. _____= elevated form associated with **damaged brain**.

3. _____= elevated form associated with **damaged heart**.







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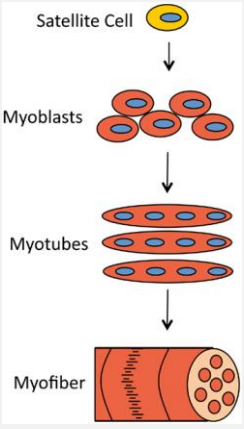
10. Muscle Growth & Repair

Muscle growth & repair:

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



Myostatin

=

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 =

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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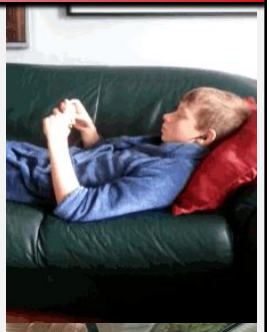
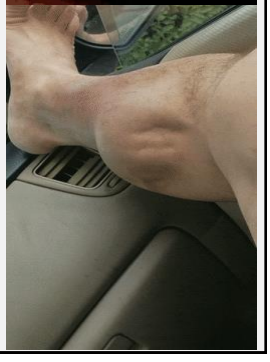
11. Muscle Disorders

Pg 112-113

Muscle spasms =



Muscle cramp =



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11. Muscle Disorders

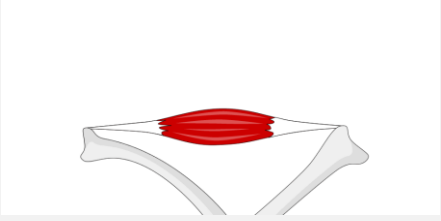
Pg 112-113

Muscle sprain =

Tx for sprain = RICE
Rest
Ice
Compression
Elevate

ACL tear (anterior cruciate ligament)

Muscle strain (pulled muscle) =



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11. Muscle Disorders

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

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

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11. Muscle Disorders

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

> 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
  - sunscreen to protect rashes.

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11. Muscle Disorders

2) Muscular Dystrophy (Duchenne's)

- Most common form of MD.

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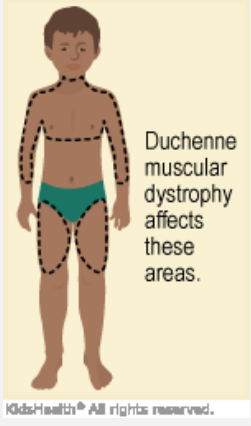
- Early onset in children = walking & balance problems. Muscle atrophy leads to loss of muscle function.

- Loss of dystrophin thought to influence.



"dystrophin" = protein needed for muscle function.

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11. Muscle Disorders

3) ALS (Amyotrophic Lateral Sclerosis)
a.k.a. Lou Gherig's disease

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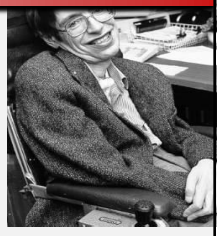

Steven Hawking

> 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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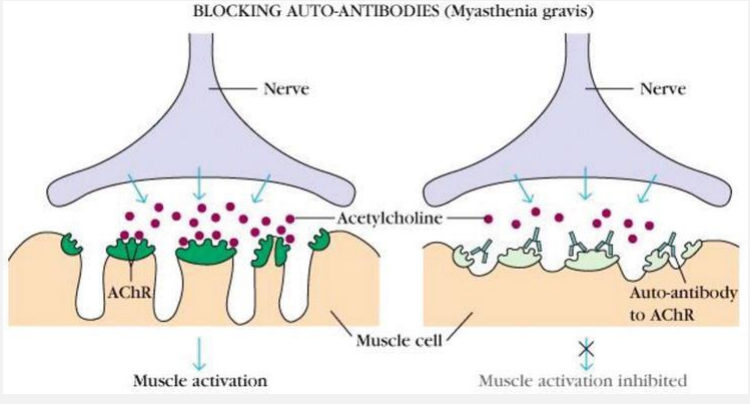
11. Muscle Disorders

REVIEW!

4) Myasthenia gravis =

> Loss of motor neuron stimulation = muscle atrophy.



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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~~

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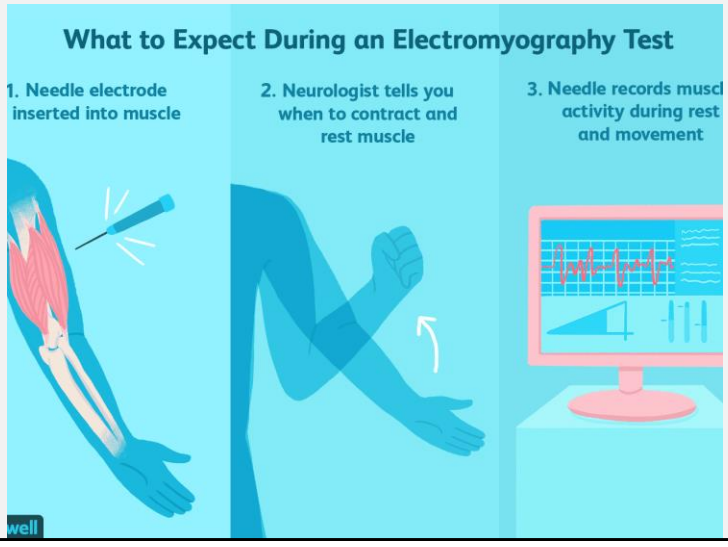
Muscle Electromyography (EMG)

EMG = looks at the electrical signals your muscles make when they are at rest and when they are being used.



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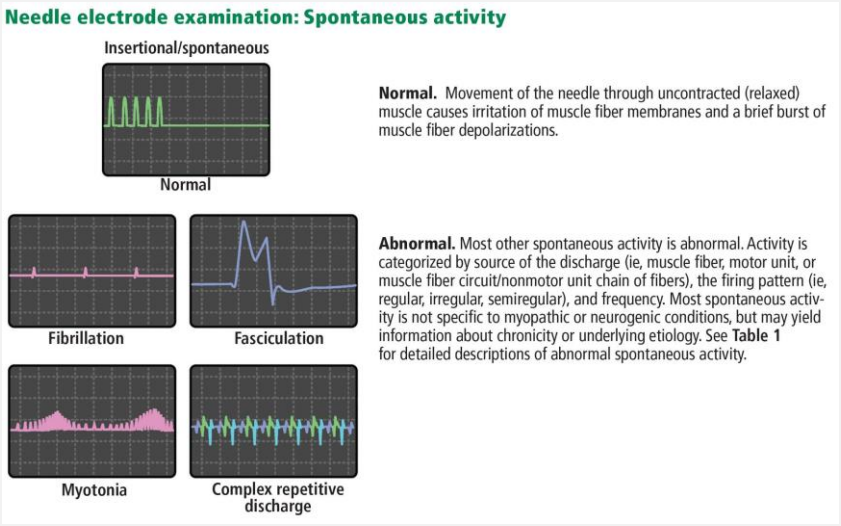
Muscle Electromyography (EMG)

EMG = looks at the electrical signals your muscles make when they are at rest and when they are being used.



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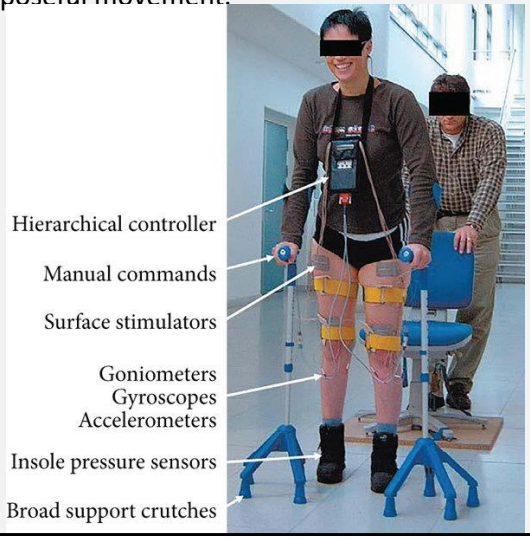
Functional Electrical Stimulations (FES)

FES = Rehabilitation technique that generates patterns of electrical stimulation in muscles of the limbs and trunk that are coordinated in such a way as to produce purposeful movement.



video

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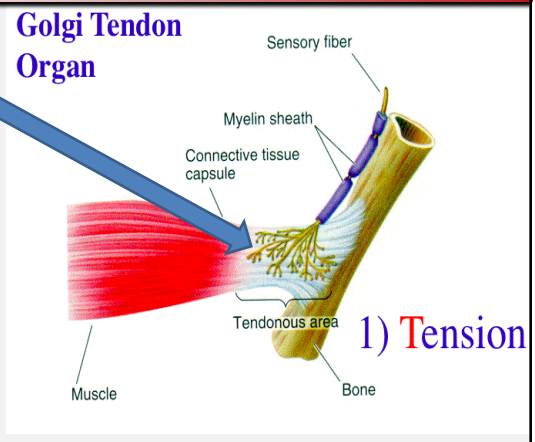
9. Muscle Sensory Organs Provide Sensory Feedback to Brain for Regulating Muscle Tone & Contraction.

2 types of Muscle Sensory Organs:

1. Golgi tendon organs:

- Sense **Tension (pull)** a muscle puts on a tendon.



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9. Muscle Sensory Organs Provide Sensory Feedback to Brain for Regulating Muscle Tone & Contraction.

2 types of Muscle Sensory Organs

1. Golgi tendon organs:

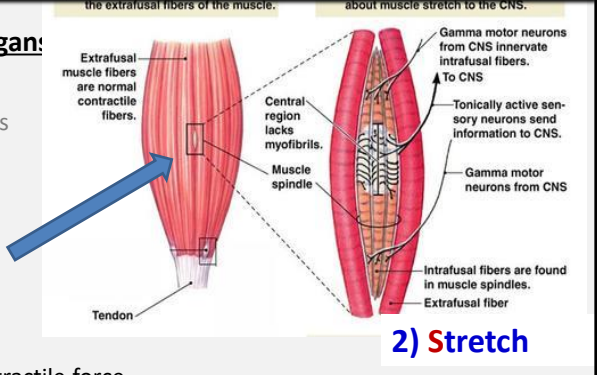
- Sense **Tension (pull)** a muscle puts on a tendon.

2. Muscle Spindle apparatus:

- Senses muscle **Stretch**

> Sudden rapid stretch = more contractile force

> slow stretch = less contractile force



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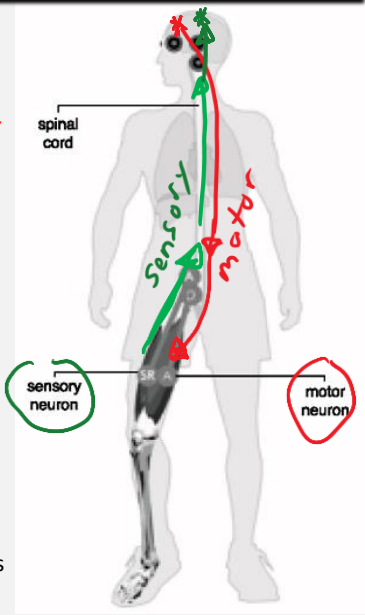
10. Voluntary vs Spinal Reflex Muscle Movement

Somatic Motor Neurons & Skeletal Muscle

- **Somatic neurons** synapse with **skeletal muscle fibers** at neuromuscular junctions for **VOLUNTARY movement**.

If someone tells you to contract your quadriceps muscles after they are touched:

- First, touch receptors on leg stimulated, send ascending info to sensory cortex.
- Sensory info shared with motor cortex. Motor command from motor neurons descends spinal cord.
- Somatic motor neurons (of spinal nerves) release ACh
  - Binds to nicotinic ACh receptors on skeletal muscles
  - Evokes EPSPs by opening Na+ channels
  - Causes contraction



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4 Spinal reflexes (Involuntary Movement):

I. Knee-jerk reflex

1) Tapping patellar tendon stretches tendon & quadriceps muscle - stimulates **spindle fiber** (stretch receptor) in muscle

2) Stimulating spindle fiber **evokes action potentials in sensory neuron**

3) Sensory neuron synapses *directly* with alpha somatic motor neuron in spinal cord.

4) Alpha motor neuron stimulates contractile muscle fibers

This is ex. of monosynaptic reflex

> Only one synapse is crossed (in spinal cord)

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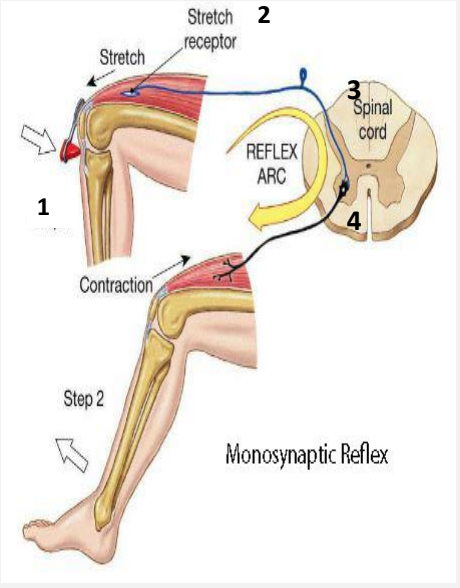

GIF

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II. Inhibitory Stretch Reflex (protects tendon from excessive muscle contractile force)

1) Muscle is stretched, muscle tendon is stretched, which stimulates AP in **Golgi tendon organ** (a sensory organ)

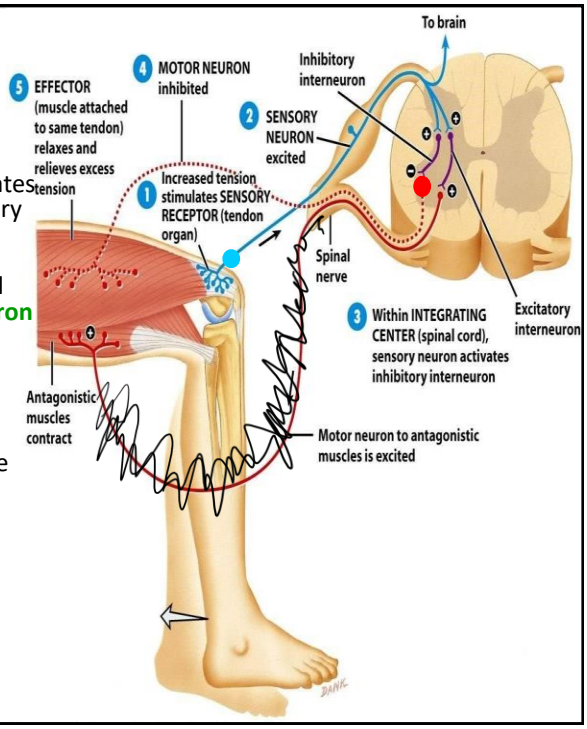
2) Sensory neuron goes into spinal cord & **stimulates (+) an interneuron**

3) Interneuron stim **inhibitory (-) neurotransmitter to alpha motor neuron**

4) Effect = motor neuron to muscle being stretched is inhibited

5) Muscle relaxes to reduces tension in tendon to prevent damage from excessive stretching

This is ex. of **disynaptic stretch reflex =** Two synapses are crossed in spinal cord



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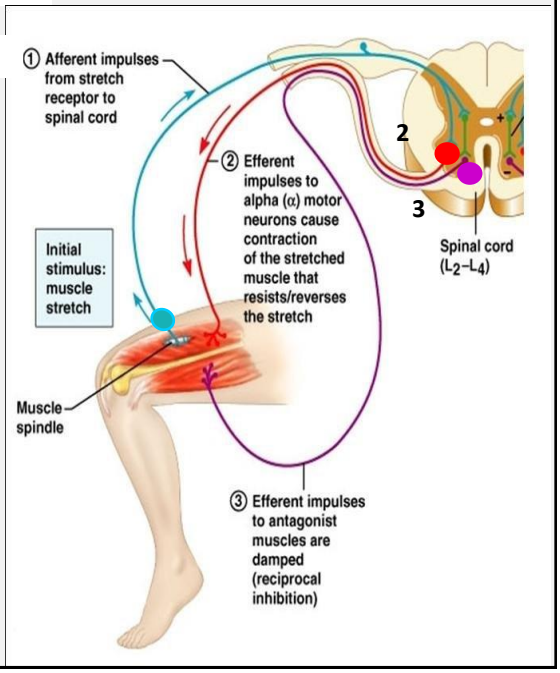
III. Reciprocal Innervation

How all our muscles work. Primary muscle is stimulated to contract while, simultaneously, the antagonist muscle is inhibited.

1) **Stretch of primary muscle & tendon stim. sensory neuron.** Sensory info enters dorsal spinal cord, crosses over to ventral horn & does two things:

2) **Positive (+) stim. of primary muscle to contract**.

3) **Inhibition (-) of antagonist muscle (stays relaxed).**



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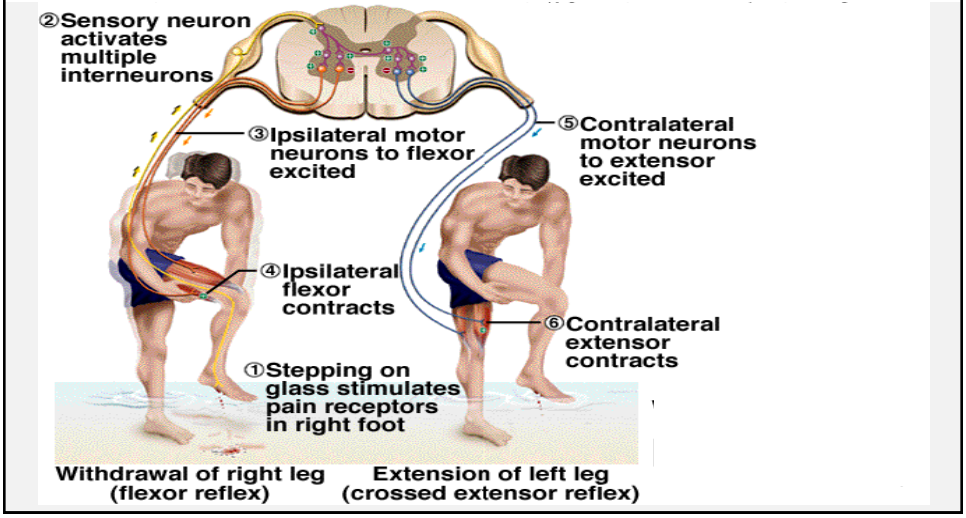
IV. Crossed Extensor Reflex or double reciprocal innervation

Ex. Painful stimulus on right foot **stim sensory neuron**, goes into dorsal horn spinal cord. Crosses to ventral horn on left and right sides of cord and **does two things**:

1) **Right leg Flexors contract (+)** and **extensors relax (-)** to withdraw injured foot on R.
2) **Left leg, Extensors contract (+)** and **flexors relax (-)** to put leg down & support body weight.



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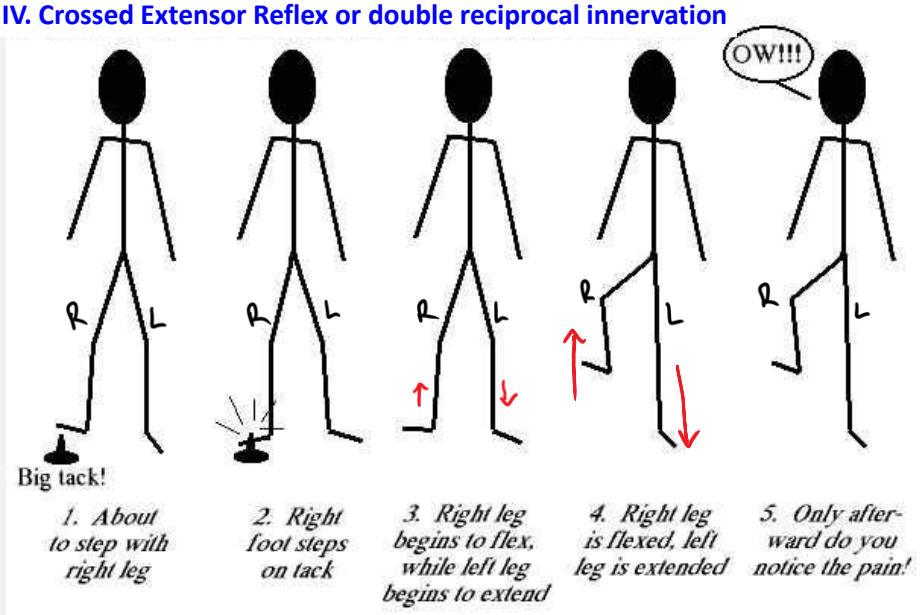
IV. Crossed Extensor Reflex or double reciprocal innervation



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Review

- **Muscle sensory organs:**
  - Golgi tendon organ
  - Spindle apparatus

- **Voluntary reflex**
  - Involves sensory neurons, spinal cord, brain, and motor neurons (longer, slower pathway)

- **Spinal reflex**
  - involves sensory neurons, spinal cord, and motor neurons
  - shorter, faster pathway under autonomic control

  Ex. Knee jerk reflex (monosynaptic)
  Inhibitory stretch reflex (disynaptic)
  Reciprocal innervation (contract one muscle & inhibit its antagonist)
  Crossed extensor reflex (usually in limbs supporting body)

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