MUSCULAR TISSUE

MUSCLE TISSUE

- **FUNCTIONAL CHARACTERISTICS**

- **Excitable** - Can generate an action potential; ability to respond to a stimulus - Like nerve tissue
- Unlike nerves, however, muscles are also:
  - **Contractible** (shorten)
  - **Extensible** (extend)
  - **Elastic** (return to their original shape)

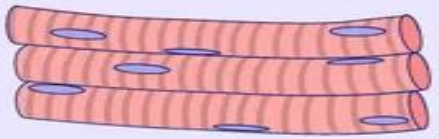
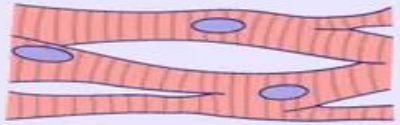
FUNCTION OF MUSCLE TISSUE

- **1)Create motion**
  - work with nerves, bones, and joints to produce body movements
  - Contraction causes movement
    - Of the body as a whole when connected to skeleton
    - Of materials through the body (blood)
- **2) Stabilize body positions** - includes maintaining posture & joint stabilization
- **3) Store & Move substances within the body-**
- Storage using sphincter muscles
  Movement by peristaltic contractions
- **4) Generate heat through thermogenesis**

TYPES OF MUSCULAR TISSUE

- Skeletal
  - Found in skeleton; movement, heat & posture; **Striated**, **multinucleated**, parallel fibres; **voluntary** control
- Cardiac
  - Heart; pump blood; **Striated, one central nucleus**; **involuntary** control
- Visceral AKA Smooth
  - Ex. GI Tract; peristalsis, blood pressure, pupil size; **no striations, one central nucleus, involuntary**

3 types of muscle tissue

	Main features	Histology
Skeletal muscle	• Fibers: striated, tubular and multi nucleated • Voluntary • Usually attached to skeleton	
Smooth muscle	• Fibers: non-striated, spindle-shaped, and uninucleated • Involuntary • Usually covering wall of internal organs	
Cardiac muscle	• Fibers: striated, branched and uninucleated • Involuntary • Only covering walls of the heart	

Jack Westin

Muscle Cells are called Myocytes

Special Terminology:

- **Sarcolemma** - the cell membrane surrounding a muscle cell
- **Sarcoplasm-** the cytoplasm of muscle cells. It contains **glycogen** - which can be broken down to glucose for energy & **myoglobin -** a protein that binds oxygen
- **Sarcoplasmic reticulum -** specialized type of smooth endoplasmic reticulum found in muscle cells. Dedicated to **Calcium** handling. Muscle requires a lot of calcium for the cycle of contracting & relaxing.
- **Sarcomere-** In striated muscle (cardiac & Skeletal), a sarcomere is the *functional* unit of muscle between two striations or stripes.

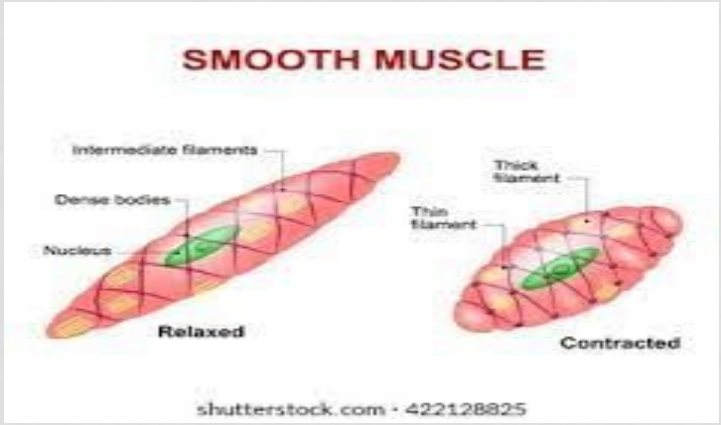
Smooth Muscle AKA Visceral or Involuntary

Smooth muscle cells - smallest cell size of the 3 types.

Involuntary Contractions, including **peristalsis** of the GI system

- Found in walls of blood vessels & hollow organs allowing stretch
- Also found in the eye to change focus of the lens
- Spindle- shaped. No striations, no T Tubules
- Contractions are Slow & long lasting
- Only fascia is the Endomysium

-Capacity for regeneration: Highest of the muscle cells

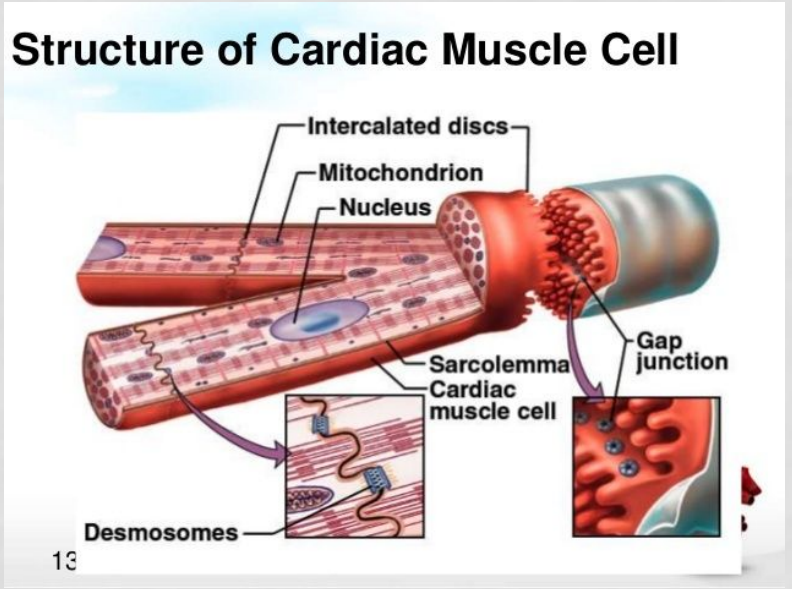


Cardiomyocytes

- Only found in the heart (myocardium)
- Larger fibres than smooth muscle, smaller than skeletal muscle.
- 1 nucleus, **branched** fibers, striated
- **Intercalated discs** are unique to heart muscle - they contain desmosomes to attach fibres together & gap junctions which allow muscle action potentials to travel between myocytes
- **Fascia**: Cardiac muscle has an endomysium & perimysium
- Capacity for regeneration is very limited

Cardiomyocytes cont.

- Contracts when stimulated by its own autorhythmic fibers - the *Cardiac Conduction System*
- Contains the **most & largest mitochondria** because of its constant workload. Cardiac muscle **must** have a regular supply of oxygen, so it can use aerobic respiration to make ATP
- Each contraction is 10- 15 x longer than a skeletal muscle twitch



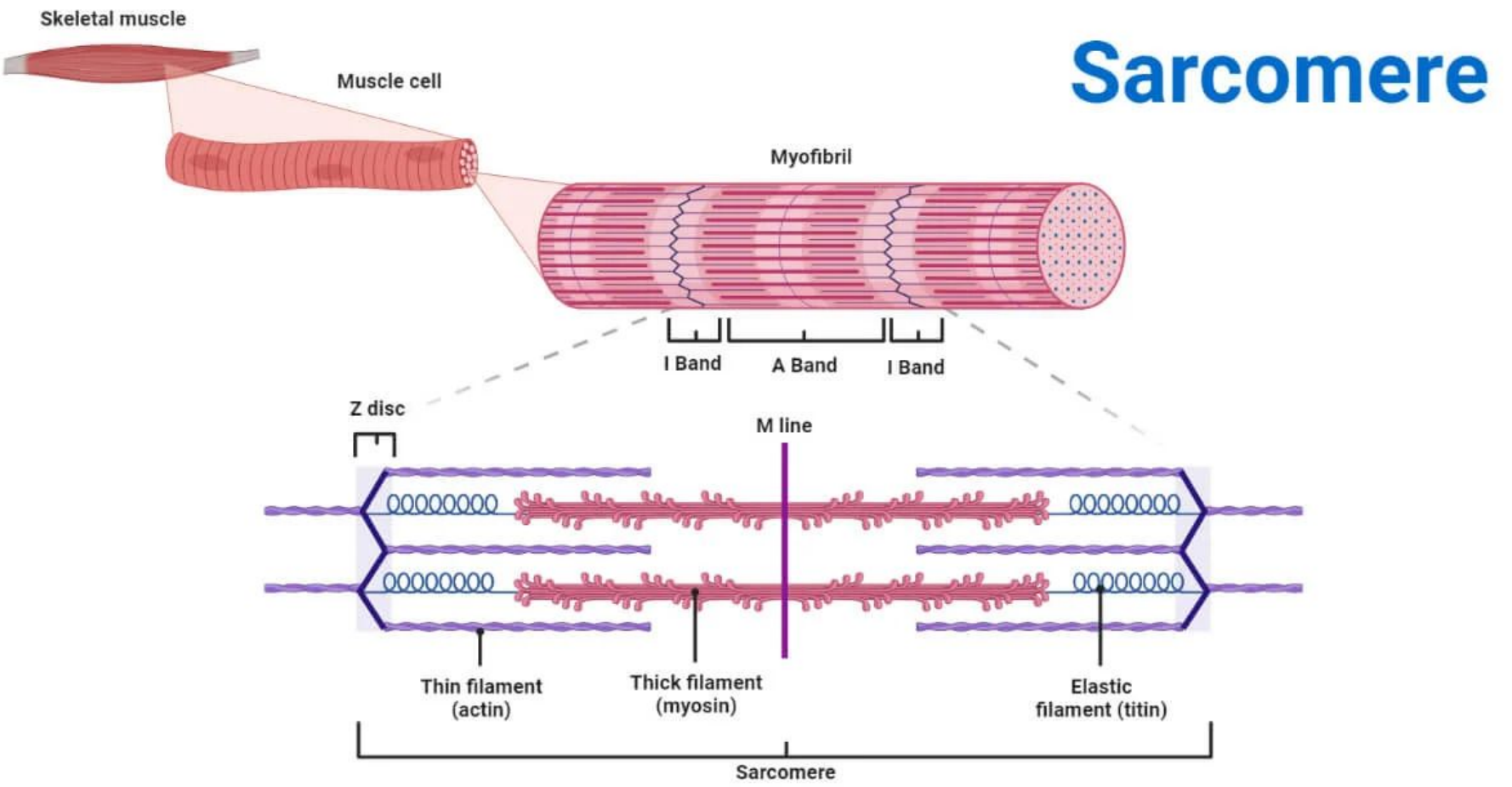
Skeletal Muscle Cells AKA Voluntary

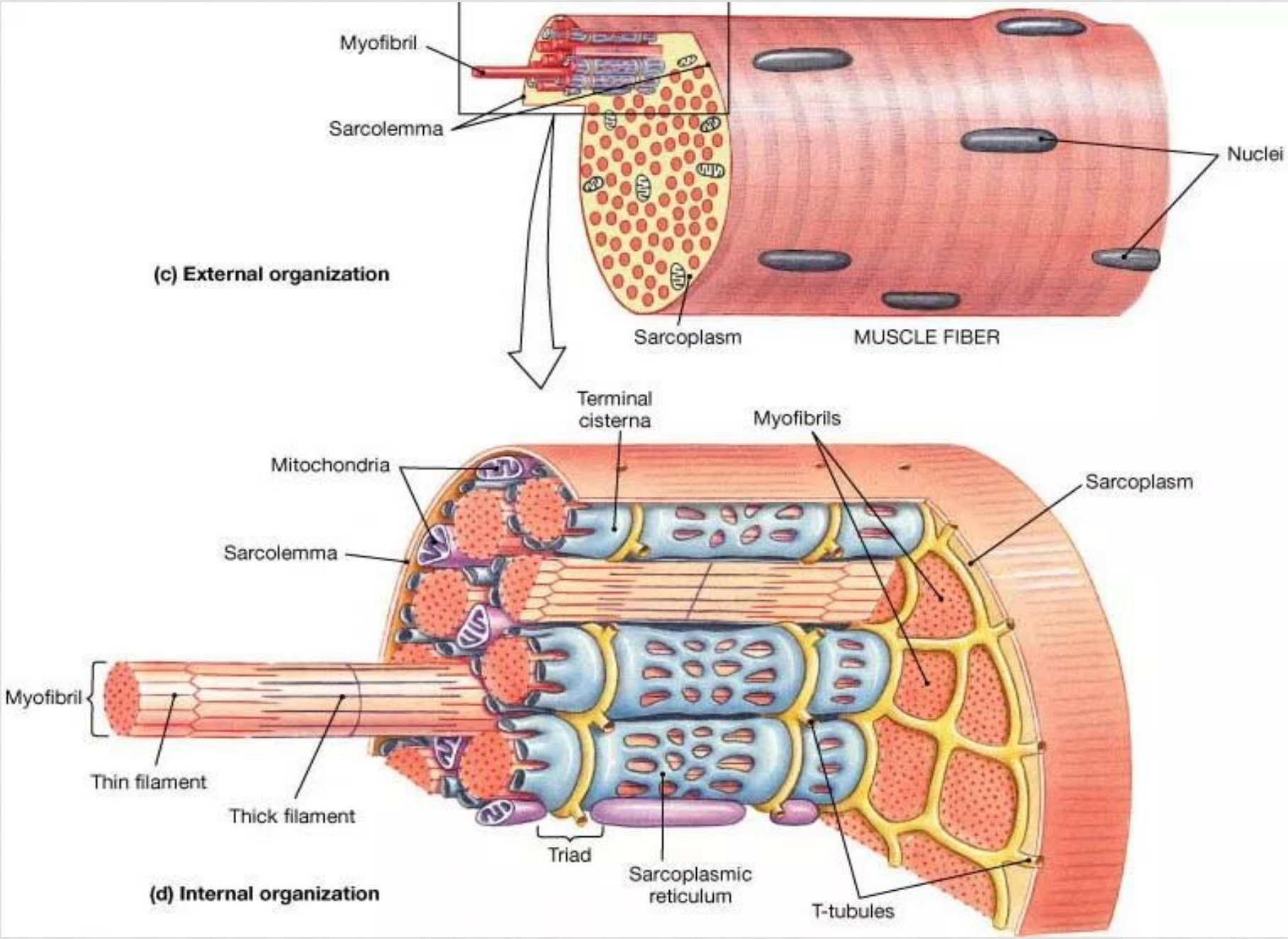
- When skeletal muscles fibers are forming during embryological development, several myoblasts fuse together to make a **long** (up to 30 cm), **multinucleated** skeletal muscle fiber.
- Skeletal muscles are usually attached to bones by tendons
- **Fascia:** skeletal muscle has an endomysium, perimysium & epimysium
- Fastest contraction speed
- Capacity for regeneration is limited, via satellite cells.

The Sarcomere in Skeletal Muscle

- Within the sarcolemma of all muscle cells are many types of proteins or filaments, such as the thick & thin filaments. In striated muscles, those filaments don't extend the length of the whole muscle cell, they are in compartments called **sarcomeres.** At the end of each sarcomere is a dense protein disc called a **Z disc.**
- The sarcolemma contains many **T tubules** - areas where the sarcolemma tunnels in towards the centre of the cells. Interstitial fluid is present in the T tubules.
- Muscle contraction takes place in the sarcomeres

Sarcomere


Skeletal muscle
Muscle cell
Sarcomere
Myofibril
I Band
A Band
I Band
Z disc
M line
Thin filament
(actin)
Thick filament
(myosin)
Elastic
filament (titin)
Sarcomere


Myofibril
Sarcolemma
Nuclei
(c) External organization
Sarcoplasm
MUSCLE FIBER
Terminal cisterna
Myofibrils
Mitochondria
Sarcoplasm
Sarcolemma
Myofibril
Thin filament
Thick filament
Triad
Sarcoplasmic reticulum
T-tubules
(d) Internal organization

MUSCLE PROTEINS

- As we look closer into the sarcolemma of muscle cells we will see myofibrils. Myofibrils are built from three groups of proteins.
  - **Contractile protein**
    - generate force during contraction.
    - Include **Actin & Myosin**
  - **Regulatory protein**
    - Control Contraction process
    - Include **Tropomyosin & Troponin** (on the thin filament)
  - **Structural protein**
    - keep the thick and thin filaments in proper alignment and link the myofibrils to the sarcolemma and extracellular matrix
    - Include **Titan & Dystrophin**

CONTRACTILE PROTEINS- ACTIN & MYOSIN

- In the **thin filaments actin** proteins are strung together like a bead of pearls. Thin filaments also contain the regulatory proteins ***troponin & tropomyosin***.
- 
- In the **thick filaments myosin** proteins look like golf clubs bound together or cobra heads

Structural PROTEINS

- muscle contains about a dozen structural proteins which contribute to the alignment, stability, elasticity, and extensibility of myofibrils
  - **Titan** - ***third most plentiful protein*** in muscle, after actin and myosin - it extends from the Z disc and accounts for much of the elasticity of myofibrils
  - **Dystrophin** - provides a structural link between the muscle cytoskeleton and extracellular matrix to maintain muscle integrity. This protein has various abnormalities in the different types of the disease ***Muscular Dystrophy.***

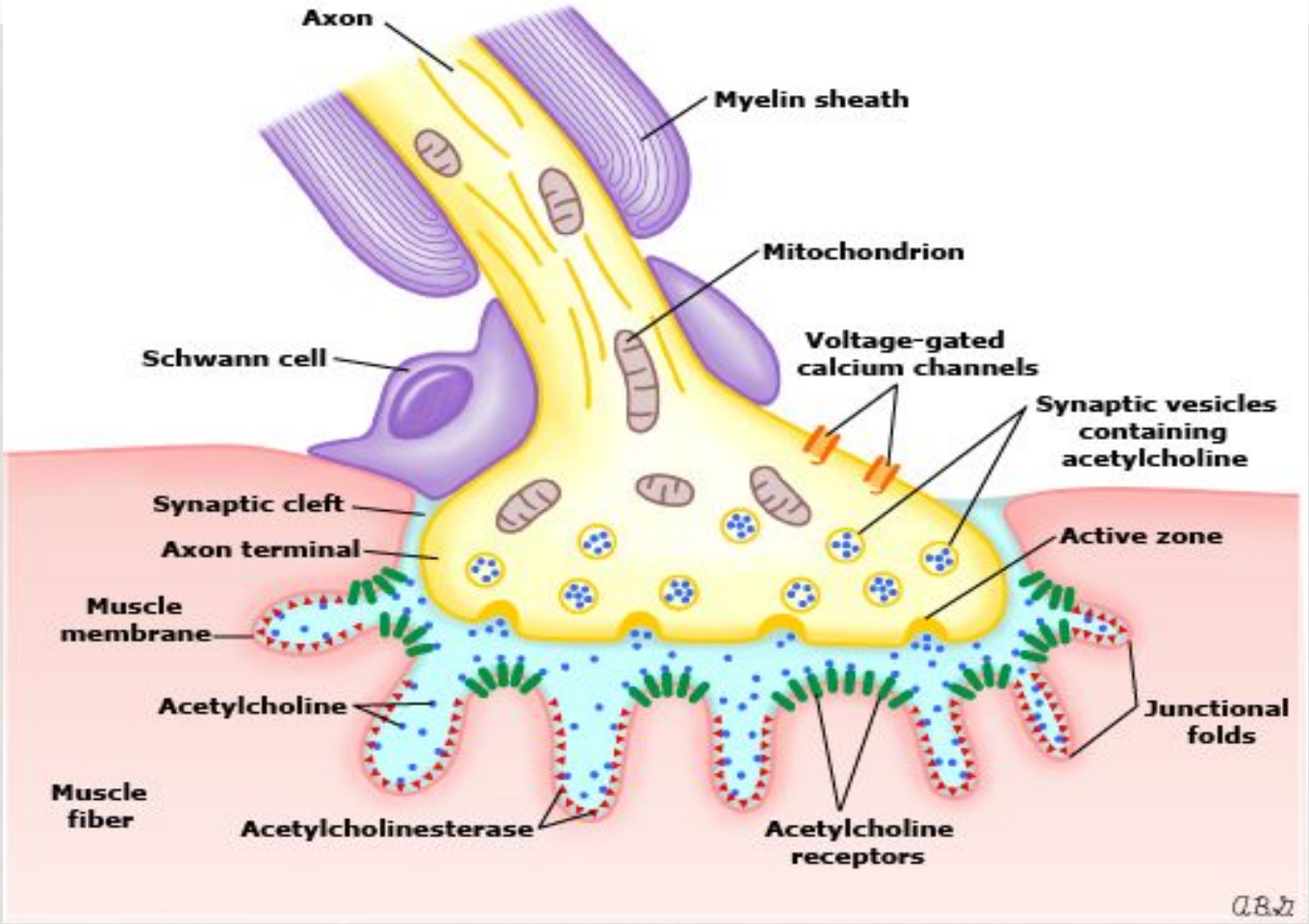
CONTRACTION

- When an individual muscle fiber is stimulated to depolarization, and an action potential is propagated along its sarcolemma, it must contract to it's full force—it can't partially contract. Also, when a single motor unit is recruited to contract, all the muscle fibers in that motor unit must all contract at the same time
- **Motor Unit =** 1 nerve ending & all the fibers that it affects.
- Each muscle will have several motor units.

EXCITATION – CONTRACTION COUPLING

- Involves events at the junction between a motor neuron and a skeletal muscle fiber
  - ***Presynaptic membrane is on the neuron***
  - ***Postsynaptic membrane is the motor end plate on the muscle cell***
  - ***Two membranes are separated by a space, or "cleft" = Synapse or synaptic cleft***
- EC Coupling involves
  - Conscious thought results in activation of a motor neuron, and release of the neurotransmitter ACH at the NMJ
  - plasma membrane on the "far side" of the NMJ belongs is known as the motor end plate
  - The receptors for ACh are on the ligand-gated sodium channels on the motor end plate.
  - acetylcholinesterase breaks down ACh after a short period of time
  - The chemical events at the NMJ transmit the electrical events of a neuronal action potential into the electrical events of a muscle action potential
  - **The signal is electrical (in neuron) to Chemical (at NMJ) to electrical (in muscle cell)**

The Neuromuscular Junction



Where the motor neuron communicates with the muscle fiber.
https://youtu.be/4GzN4p_xWj4

Sliding Filament Contraction/Relaxation

Steps for how a sarcomere contracts, then relaxes:

1) A nerve impulse arrives at the axon terminal of a ***motor neuron,*** triggering the release of ***Acetylcholine***
2) Ach binds to its receptors on the motor end plate of the muscle, triggering a muscle action potential
3) ***Muscle action potential travels along the sarcolemma & T tubules***, triggering the release of **Calcium** ions from the sarcoplasmic reticulum
4) ***Calcium binds*** to the regulatory protein **troponin** on the **thin filament** which exposes sites on actin for myosin to bind to.
5) ***Myosin heads bind to actin*** using ATP for energy,forming a **cross *bridge*** & contracting the sarcomere by pulling the thin filaments towards the centre of the sarcomere in a ***power stroke***.
6) When the stimulation of the nerve stops or no more ATP is available, Myosin & Actin release from each other, Calcium gets reabsorbed into the sarcoplasmic reticulum

https://youtu.be/D6xzeC30aow

MUSCLE ACTION POTENTIAL

- The muscle AP is propagated over the sarcolemma via voltage gated Na+ and K+ channels.
  - **Na+ gates open during the depolarization phase**
  - **K+ gates open during the repolarization phase**
- Generating an AP on the muscle membrane involves the transfer of information from an **electrical** signal (down the neuron), **to** a **chemical** signal (at the NMJ), back **to** an **electrical** signal (depolarization of the sarcolemma)
- **Resting action potential** is around -90 to -75mV
- **Threshold action potential** is about 15-20 mV higher than resting, so -75 to -55mV
- There is a very short **Latent period** between when the action potential is generated and when the sarcomere begins contracting
- There is a **refractory period** where another action potential cannot be generated. It is very short (about 5 msec) in skeletal muscle vs about 300 msec for cardiac muscle

Regulation of Contraction in Different Muscle Types

Skeletal Muscle- As we have been discussing, ***Ach*** release ***from motor neurons*** initiate & regulate skeletal muscle contraction

Cardiac- Ach (parasympathetic) or Norepinephrine (sympathetic) released by autonomic motor neurons and concentration of several hormones

Smooth- Ach or Norepinephrine released by autonomic motor neurons, several hormones, local chemical changes (such as pH) & stretching

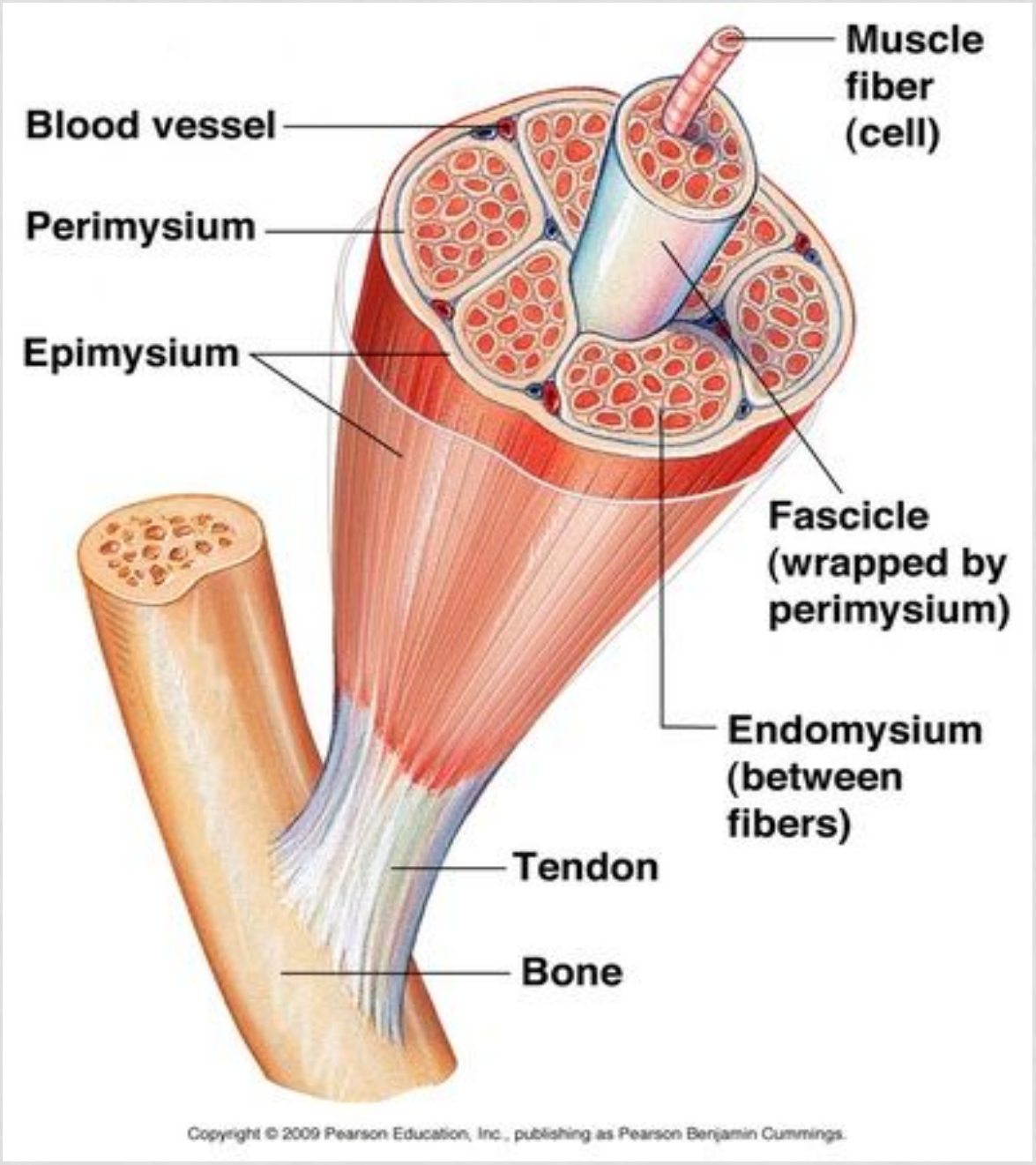
ORGANIZATION OF MUSCLE TISSUE & FASCIA

- The **hypodermis** is a layer of connective tissue (loose alveolar & adipose) separating skin from muscle
- **Endomysium -** Thin layer of reticular fibers separating each individual muscle fibers (myocytes) from each other
- **Perimysium-** surrounds a **fascicle**, which is a group of 10 - 100 muscle fibers. Also consists of dense irregular CT.
- **Epimysium** - outermost layer of connective tissue (dense irregular)that encloses the entire muscle, Becomes continuous with the tendon attaching the muscle to bone (only present on skeletal muscle)

FASCIA cont.

- In groups of muscles the epimysium continues to become thicker, forming fascia which covers many muscles .
  - ***fascia lata*** enveloping the entire group of quadriceps and hamstring muscles in the thigh.
  - Many large muscle groups are encased in both a superficial and a deep fascia

- **Aponeurosis** is thick, flat band of fascia that connects two muscle Bellies. Acts as a non-bony muscle attachment site.
  - Eg. epicranial aponeurosis connects the muscle bellies of the occipitalis and the frontalis



SOURCES OF MUSCLE ENERGY

- **1) Stored ATP** - only enough for a few seconds of activity
- **2) ATP from stored creatine phosphate**- This type of energy production occurs ONLY in muscle cells. When muscle cells are relaxed, they produce more ATP than needed, which is then combined with creatine to be stored as Creatine phosphate. Produces enough ATP for about 15 seconds of contraction
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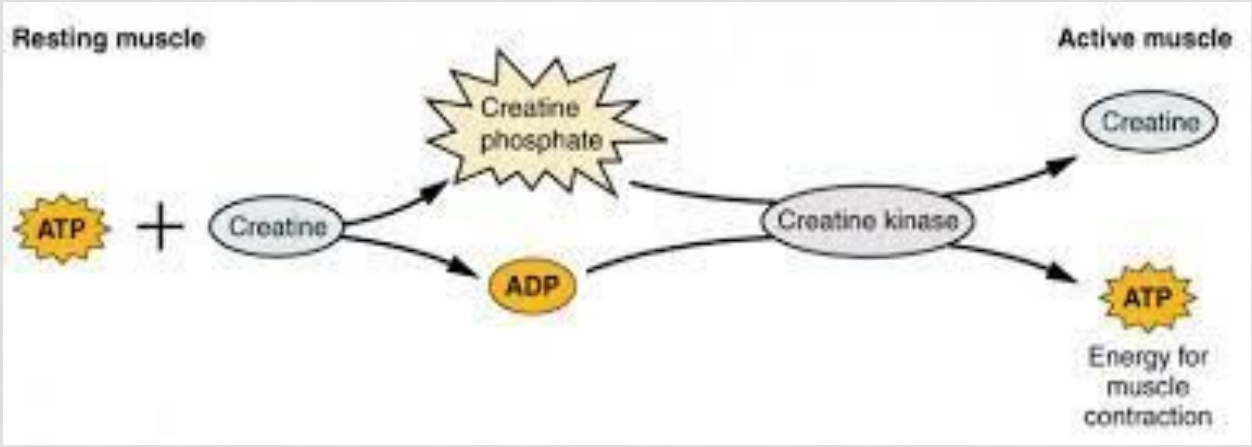


Sources of Muscle Energy

3) Anaerobic glycolysis-

Glucose is available to make ATP from 2 sources: The ***breakdown of muscle glycogen*** & the ***bloodstream.***

Remembering the *Krebs Cycle*, this glucose is broken down into ***two*** molecules of ***pyruvic acid*** and ***two ATP.*** in the sarcoplasm of the cells & does ***NOT*** require oxygen.

If enough oxygen is present, the pyruvic acid will go on to ***aerobic respiration*** in the ***mitochondria.***

If not enough oxygen is present, the pyruvic acid will break down to **2** molecules of **lactic acid** & **two ATP**.

This generates enough ATP for about 2 mins of energy.

Sources of Muscle Energy

4) Aerobic Respiration- If enough oxygen is present, the glucose can go through aerobic respiration (including the Krebs cycle & electron transport chain) in the mitochondria of the myocytes, generating **30 -32 ATPs** per glucose molecule.

Muscle cells get oxygen directly from the *bloodstream* as well as from *myoglobin* present within the muscle cells.

The energy produced through aerobic respiration can last minutes to hours.

SKELETAL MUSCLE METABOLISM

- In a state of homeostasis, muscle use of O2 and nutrients is balanced by the production of manageable levels of waste products like
  - CO2 - Carbon Dioxide
  - Heat - 70-80% of the energy used by muscles is lost as heat - muscle activity is important for maintaining body temperature
  - Lactic acid - produced when their is NOT enough oxygen to meet demand (anaerobic). Remember the Krebs cycle.

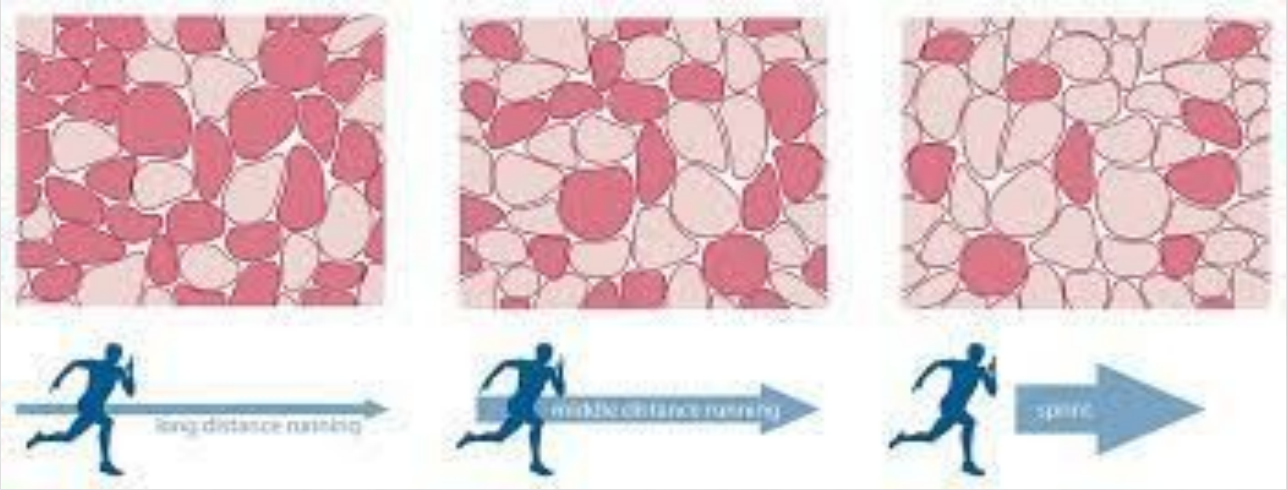
    Lactic acid makes your muscles feel sore 1 - 3 days after exertion

CARDIAC AND SMOOTH MUSCLE METABOLISM

- In response to a single AP, cardiac muscle contracts 10-15 times longer than skeletal muscle, and must continue to do so, without rest, for the life of the individual
- To meet this constant demand, cardiac muscle generally uses the rich supply of O2 delivered by the extensive coronary circulation to generate ATP through aerobic respiration.
- Like cardiac muscle, smooth muscle is autorhythmic and is not under voluntary control
- smooth muscle has a low capacity for generating ATP and does so only through anaerobic respiration (glycolysis)

SKELETAL MUSCLES BY APPEARANCE

- **Red** muscle fibers have a **high myoglobin** content, **more** mitochondria, more energy stores, and a greater blood supply.
- **White** muscle fibers have **less** myoglobin, mitochondria, and blood supply.

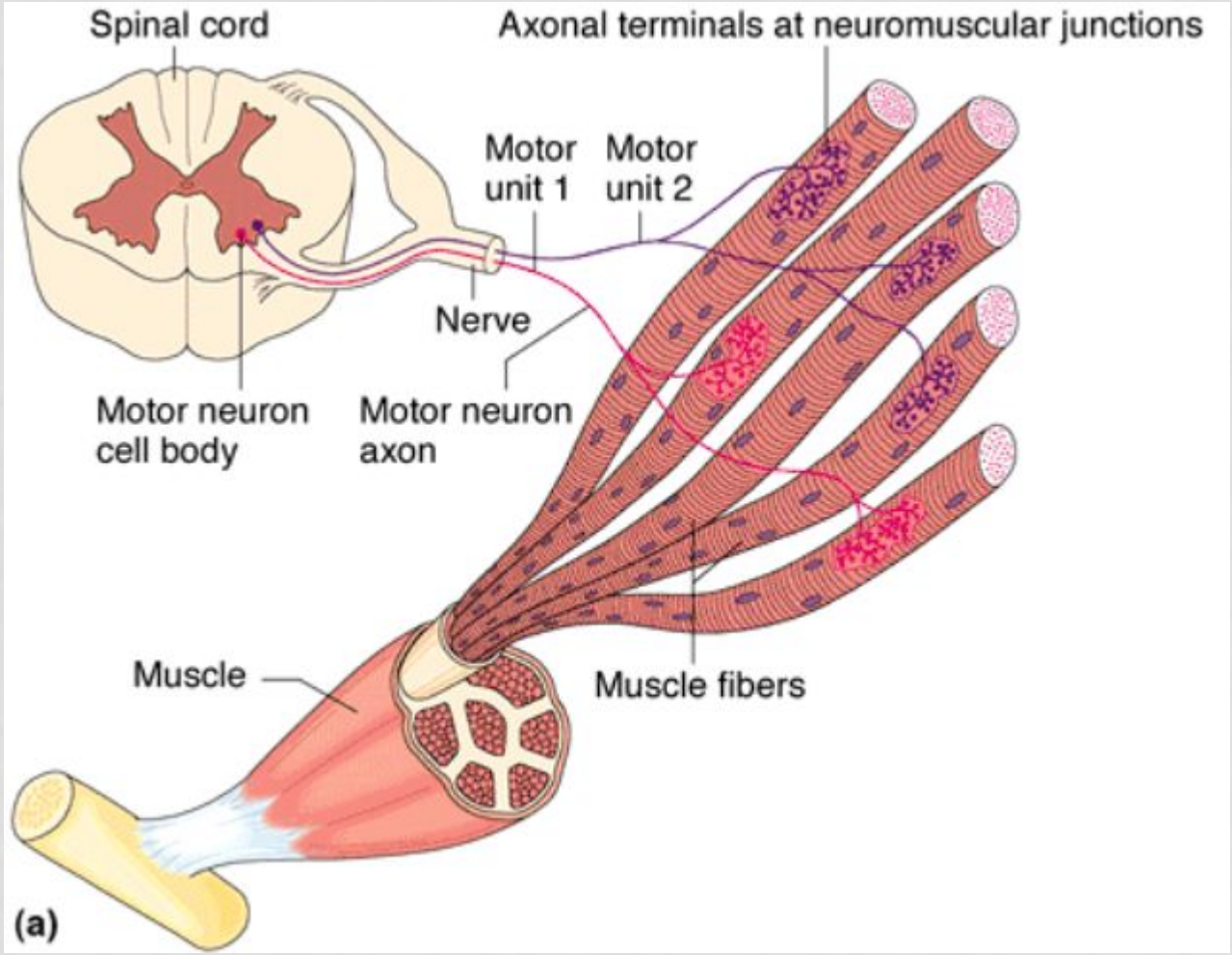


SKELETAL MUSCLE FIBERS BY FUNCTION

- **Slow oxidative fibers** (SO) small, appear dark red
  - the least powerful type, very fatigue resistant
  - Used for endurance like maintaining posture, running a marathon
- **Fast oxidative-glycolytic fibers** (FOG) are intermediate in size, appear dark red,
  - moderately resistant to fatigue. Used for walking, medium distance running
- **Fast glycolytic fibers** (FG) are large, white
  - Powerful
  - Suited to intense **anaerobic** activity of short duration - sprinting

- Most skeletal muscles are a mixture of all three types of skeletal muscle fibers; about half the fibers in a typical skeletal muscle are slow oxidative (SO) fibers. Postural muscles contain more SO fibers while action muscles contain more FG fibers.
- **Within a particular motor unit all the skeletal muscle fibers are the same type.** Remember, motor unit = 1 nerve and all the muscle fibers that it innervates

Motor Units



Ratios of Motor Neurons to Muscle Fibers

Eye Muscles - 1 :1-3

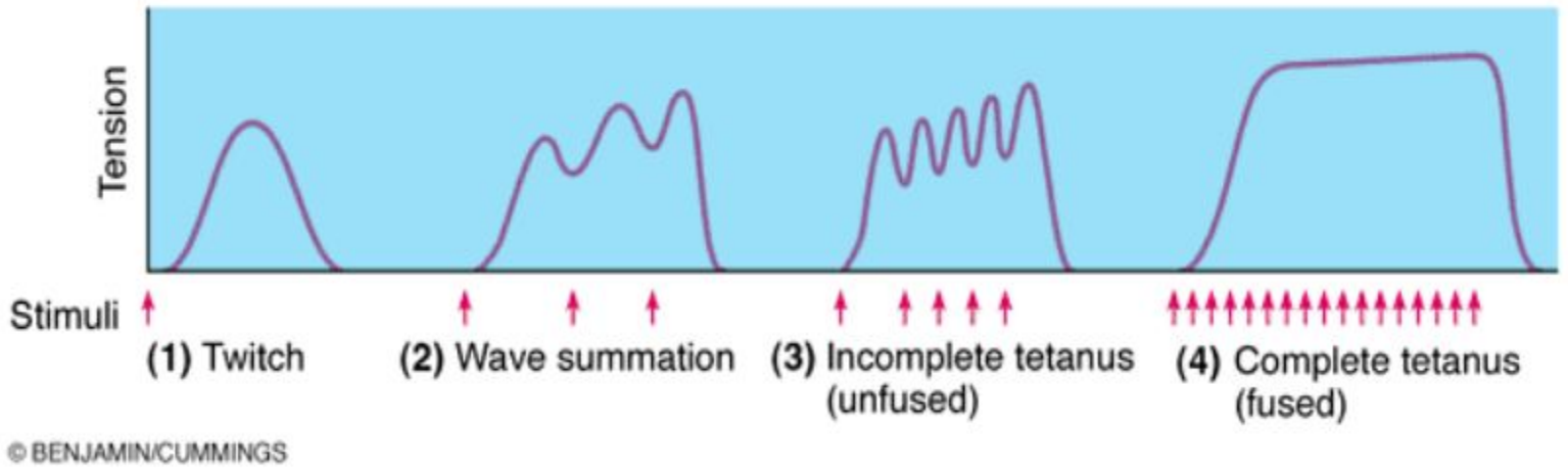
Soleus - 1;180

Gastrocnemius- 1:1000-2000

TENSION IN A MUSCLE

- There is a brief delay called the **latent period** as the AP sweeps over the sarcolemma and Ca2+ ions are released from the sarcoplasmic reticulum (SR)
- During the next phase the fiber is actively contracting
- This is followed by relaxation as the Ca2+ ions are re-sequestered into the SR and myosin binding sites are covered by tropomyosin
- Temporary loss of excitability is called the **refractory period** – All muscle fibers in a motor unit will not respond to a stimulus during this short time.
- A **twitch** is recorded when a stimulus that results in contraction (force) of a single muscle fiber is measured over a very brief millisecond time frame
- **Tetanus or Tetanic Contraction -** sustained muscle contraction resulting from action potentials coming at a very high rate. Usually normal, contributing to **muscle tone**, needed to maintain posture, crouching, holding a heavy box etc.

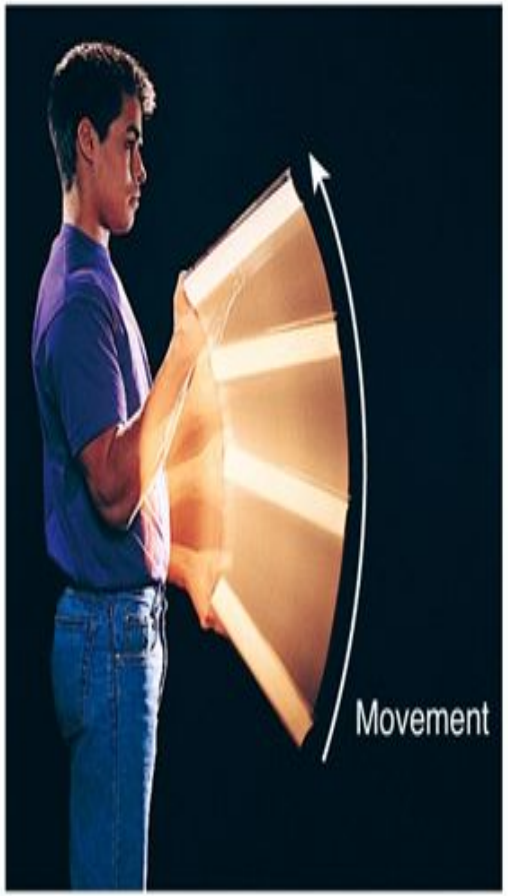
Twitch & Tetanus



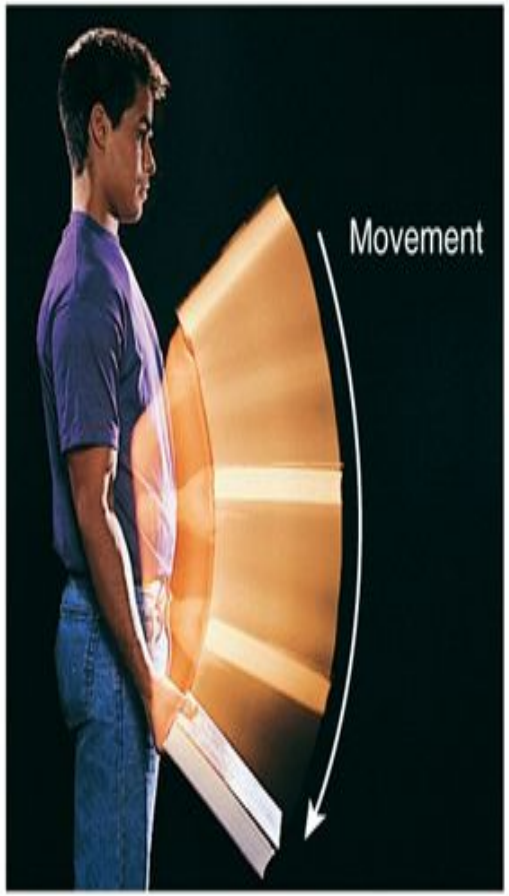
Muscle Tone- The continuous and passive partial contraction of the muscles. It helps us to maintain posture. Low tone generally corresponds to greater flexibility & less strength, while high tone is associated with the opposite set of circumstances.

TYPES OF MUSCULAR CONTRACTIONS

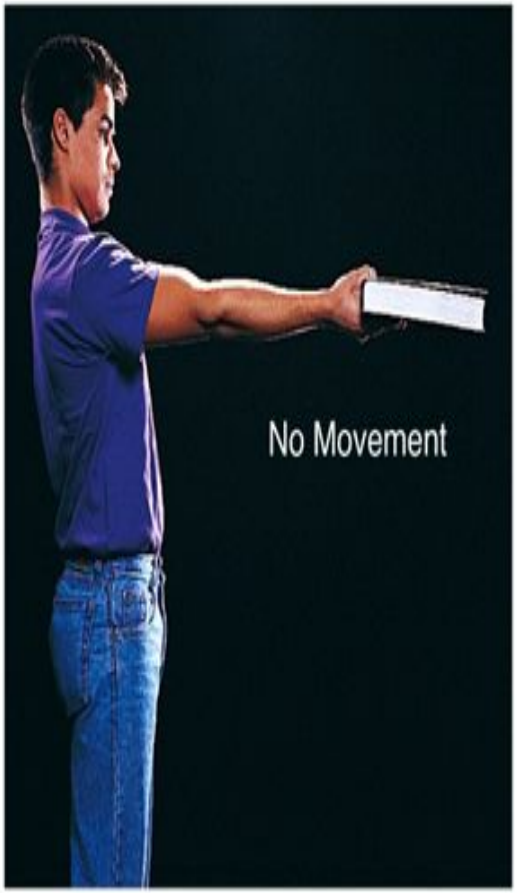
- **Isotonic** contractions results in **movement**
  - **Concentric** isotonic is a type of muscle contraction in which ***the muscle shorten*** while generating force
  - **Eccentric** isotonic is a contraction in which muscle tension is less than the resistance (***the muscle lengthens***)
- **Isometric** contractions results in **no movement**
  - Muscle force and resistance are equal
  - Supporting objects in a fixed position and maintaining posture



(a) Concentric contraction while picking up a book



(b) Eccentric contraction while lowering a book



(c) Isometric contraction while holding a book steady

Effects of Exercise

- **Exercise-induced muscle damage**
  - After intense exercise electron micrographs reveal considerable muscle damage including torn sarcolemmas and disrupted Z-discs
  - Blood levels of proteins normally confined only to muscle (including myoglobin and the enzyme creatine kinase) increase as they are released from damaged muscle
  - **Rhabdomyolysis -** a serious muscle injury after extreme exercise. It can be fatal due to the proteins and electrolytes released from the damaged muscles causing injury to the heart & kidneys.

Muscle Hypertrophy - Growth in skeletal muscles as a result of resistance training. Each myofibril increases in size, the number of cells remains the same. Can also happen in cardiac muscle to a lesser degree.

https://youtu.be/2tM1LFFxeKg

Disorders of Muscle Tissue

Hypotonia - abnormally low muscle tone, resulting in ***flaccidity*** where the muscle takes on a floppy appearance. Stretch reflexes & resistance to passive movement is decreased.

Can occur with
Genetic conditions like
Down Syndrome and
Muscular Dystrophy,
and Lower Motor Neuron
diseases such as Polio & ALS.

Disorders of Muscle Tissue

Hypertonia- abnormally high muscle tone. This can be temporary such as with ***spasms or cramps,*** or permanent such as in Upper Motor Neuron diseases.

Spasm- any involuntary muscle contraction. May or may not be painful.

Cramp- involuntary, painful contraction of a muscle.

Dystonia - causes twisting movements of the limbs, head, or upper body. It can fluctuate in severity & presence.

Spastic hypertonia - involves uncontrollable spasms, stiffening or straightening out of muscles. Can be seen with cerebral palsy, stroke & upper motor neuron lesions.

Rigid Hypertonia - stiffness/inflexibility of the muscles. Often seen in Parkinson's disease.

Hypertonia/Spasticity

Common Limb Deformities in Upper Limb Spasticity

*In the **adducted/internally rotated shoulder**, the arm is held closely against the side, elbow bent, with the forearm applied across the front of the chest.*

***Flexion of the wrist** is caused by hypertonicity of the wrist flexor muscles that seem to easily overpower their antagonists of wrist extension, so that this is the most common attitude.*

*The **flexed elbow** is bent into flexion and this posture may dramatically worsen with ambulation, causing more-severe angle flexion.*

DISEASE STATES AND DISORDERS

- **Fibrosis** (myofibrosis)
  - Replacement of muscle fibers by excessive amounts of connective tissues (fibrous scar tissue)
  - When muscle is damaged, it is repaired by both myoblasts that will become muscle cells, as well as fibroblasts that will become connective tissue
- **Myosclerosis**
  - Hardening of the muscle caused by calcification
- Both myosclerosis and muscle fibrosis can occur as a result of trauma and various metabolic disorders

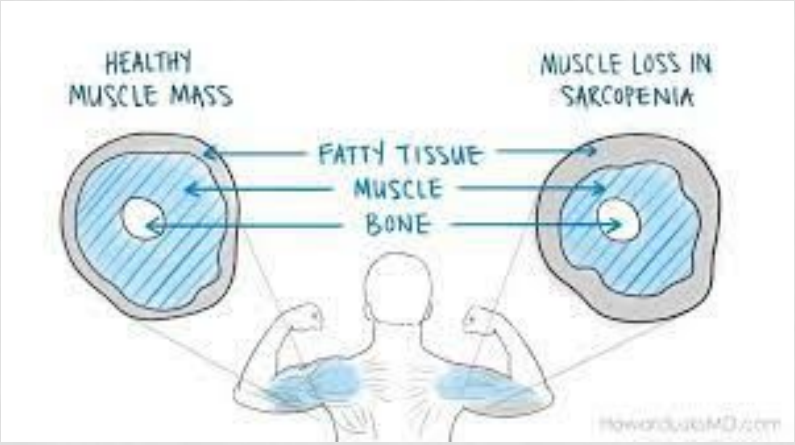
  https://youtu.be/IMixU0Z8Un4

Atrophy

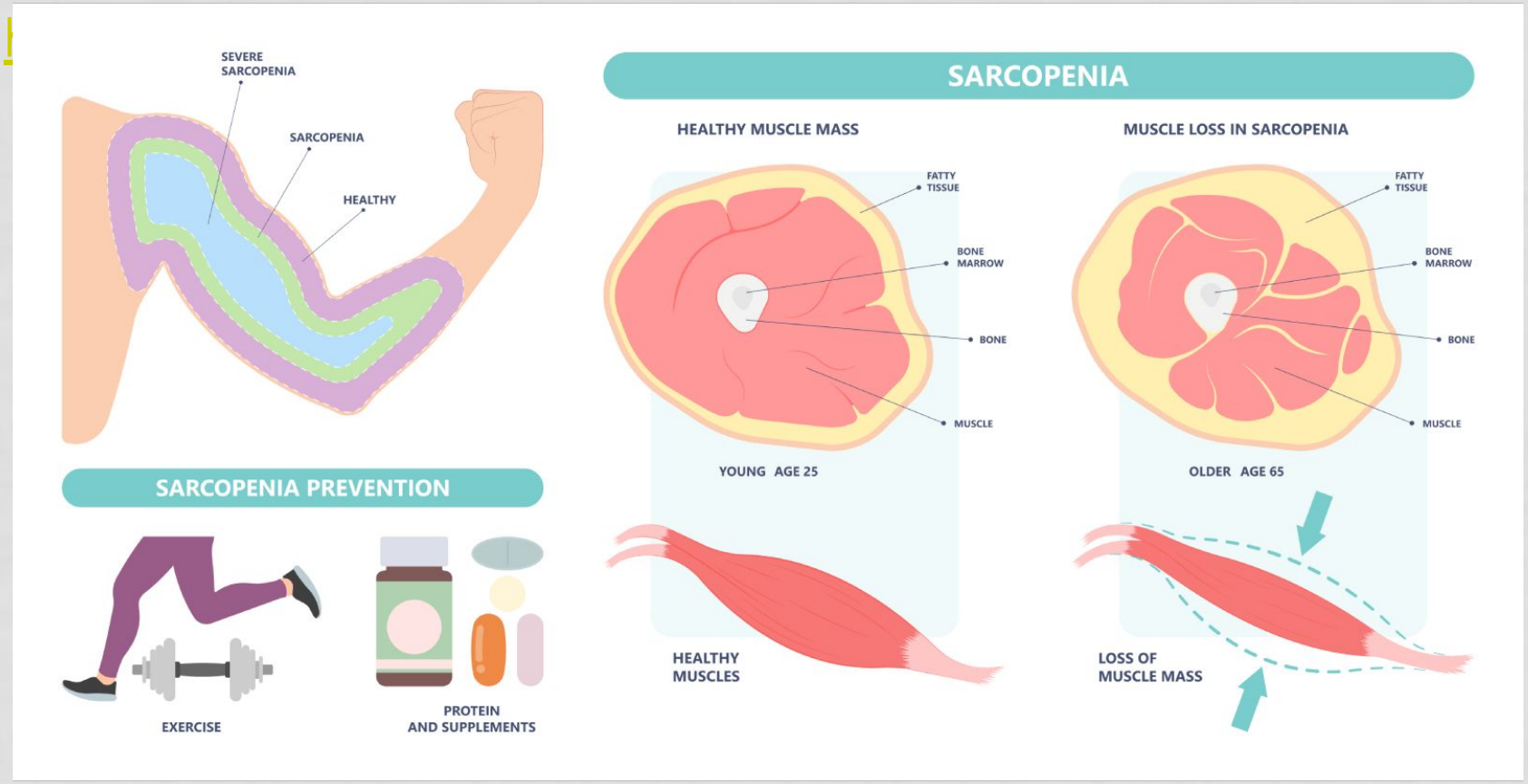
Atrophy- AKA Muscle wasting. This is the decrease in size of a muscle as a result of disuse. Can be temporary, such as when a limb is immobilized in a cast or permanent, such as when a nerve injury causes its corresponding muscle to receive no stimulation.

Sarcopenia

Sarcopenia - Muscle tissue decrease associated with age & a sedentary lifestyle. After age 30, muscle tissue can decline & start to be replaced by adipose & other connective tissues. This process can be reversed by proper diet and exercise, especially resistance exercises.



Sarcopenia



https://youtu.be/zTQ31Allma8

The End