Muscle Tissue

Muscle Tissue

•Muscle tissues are specialized to contract.

•Muscle cells are connected together, primarily by collagen fibers

•When a muscle cell contracts it pulls on the collagen fibers creating **tension** (tension is an active force that requires energy)

•Tension can cause movement if it overcomes resistance.

The Muscular System

3 types of muscle tissue:

1. **skeletal muscle**: move the body by pulling bones of the skeleton
2. **cardiac muscle**: muscle of the heart, push blood around the body
3. **smooth muscle**: in the walls of organs, performs a variety of tasks

Skeletal Muscle

•Directly or indirectly attached to bones of the skeleton

Perform the following 5 functions

1. Produce skeletal movement:

•Movements in skeletal muscles pull tendons and move bones.

2. Maintain posture & body position:

•Standing, sitting, holding your head up. All require skeletal muscle movement.

3. Support soft tissue:

- Abdominal wall and floor of pelvic cavity and skeletal muscle. They support the weight of visceral organs and help protect them

4. Guard Entrances & Exits:

- Openings of the digestive and urinary tracts are closed with sets of skeletal muscles, providing voluntary control over the passage of food and waste.

5. Maintain Body Temperature:

- The contractions of muscles produce heat which is transferred to the body and causes a slight rise in body temperature.

Gross Anatomy of Skeletal Muscle

Skeletal Muscle contains:

•Connective tissue

•Blood vessels

•Nerves

•Skeletal muscle tissue

Connective Tissue organization

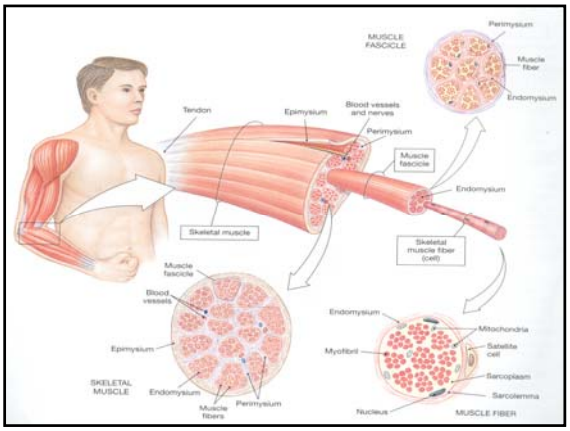
There are 3 layers:

1. The entire muscle is surrounded by a dense layer of collagen fibers called the **epimysium**.
2. The **perimysium** divides the skeletal muscles into compartments, each containing bundles of muscle fibers called a **fascicle**.
3. Fascicles are made of individual skeletal muscles fibers surrounded by a connective tissue called **endomysium**.

•**Satellite cells** also exist in the endomysium. These are embryonic stem cells used for repair & maintenance.

•The fibers of the endo & peri mysiums blend together.

•At the end of the muscle s all three connective tissues intertwine to become a **tendon** (bundle-like) or **aponeurosis** (broad-sheet).



Blood vessels & Nerves

•The epimysium & perimysium contain blood vessels & nerves that service muscle tissue.

•Contracting takes lots of energy, so a large vascular network must supply the muscles with O_2 & nutrients and carry away waste.

•Blood vessels & nerves follow the same branching pattern.

Microscopic Structure

•***Muscle cells*** (aka muscle fibers) - Huge cylindrical cells 10 - 100 mm wide, and can reach 30 cm in length. Hundreds of embryonic cells (**myoblasts)** fuse together forming a ***syncytium***. Thus, mature skeletal muscle cells are multinucleated.

•Unfused myoblasts remain in the skeletal muscles as satellite cells.

•The nuclei lie just beneath the plasma membrane which is called the ***sarcolemma***. ***Sarcoplasm*** differs from cytoplasm in that it contains a red, oxygen storing, pigment called ***myoglobin***. The myoglobin is responsible for the reddish brown color of meat.

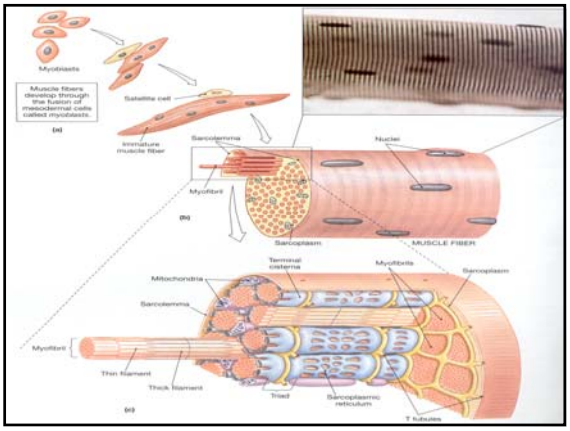
•***Transverse tubules*** are invaginations of the sarcolemma and thus can transfer a muscle impulse (**action potential**) to the deeper regions of the cell. These tubules penetrate deep into the cell perpendicular to the ***sarcoplasmic reticulum***. The T-tubules along with two cisternae of the SR form a ***triad***. The SR has a high concentration of Ca^{+2} which are released in response to an impulse.

•***Myofibrils*** - Each muscle cell contains many of these parallel rodlike structures that run the length of the cell. Each myofibril is 1 - 2 mm in diameter. Mitochondria, etc.are squeezed between them. Myofibrils have a banded (striated) appearance. This banding is due to an arrangement of even smaller structures called *myofilaments*.

Myofilaments - Two types exist in muscle cells.

1) **Thick filaments** (16 nm) - The thick filaments are made of many (around 200)proteins called ***myosin***. A myosin molecule has a tail and two globular heads. The heads are often called ***cross bridges***.

2) **Thin filaments** (7 - 8 nm) - The thin filaments are composed mostly of a double strand of the protein ***actin***. Sites are present to which the cross bridges attach during contraction. Actin is associated with two other proteins.**Tropomyosin** form strands that loosley attach to the actin and **troponin** which is bound to the tropmyosin (forming a *tropomyosin-troponin complex*).The troponin has binding sites for Ca^{2+}



SARCOMERE ANALYSIS & THE SLIDING FILAMENT THEORY OF CONTRACTION

Sarcomere- the smallest contractile unit of a striated muscle cell
(1 myofibril is made is made up of ≈ 10,000 sarcomeres)

•***A bands*** - Dark bands (where the thick filaments are located) (**dArk**)

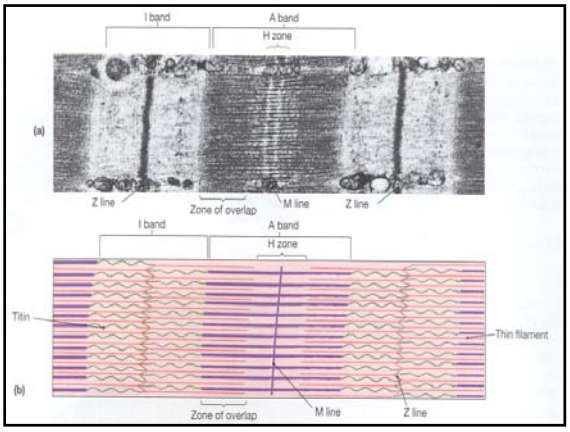
•***I bands*** - Light bands (where the thin filaments are located) (**Ilght**)
*Alternating A and I bands are what gives striated muscle its look!

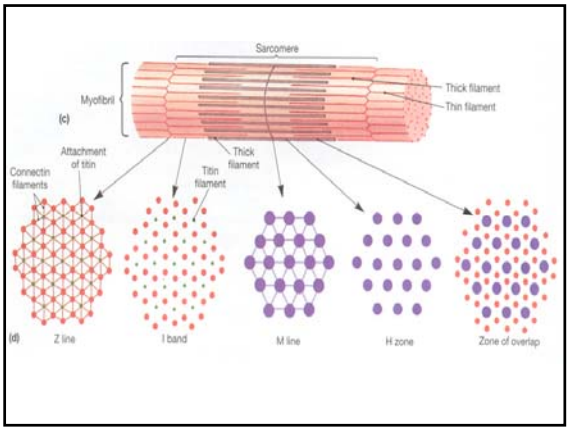
•***H zone*** - Found in the midsection of an A band. H zones are visible in relaxed muscle only.

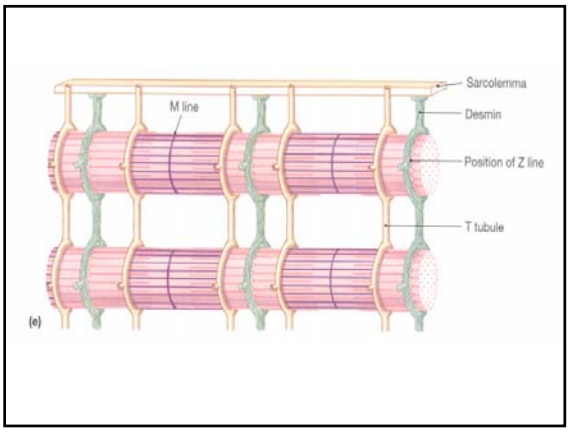
•***M line*** - Found in the middle of an H zone. This is an area where the thick filaments are cross connected.

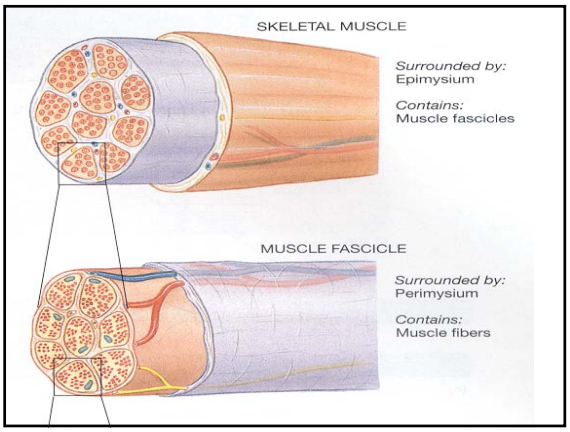
•***Z line*** - Found in the middle of an I band. The thin filaments are cross connected here.

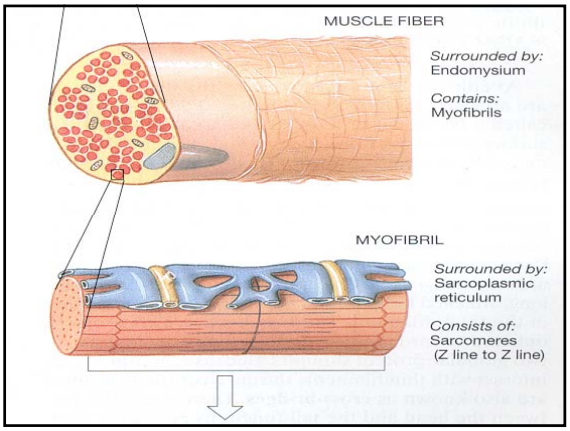
Z line to Z line = 1 sarcomere

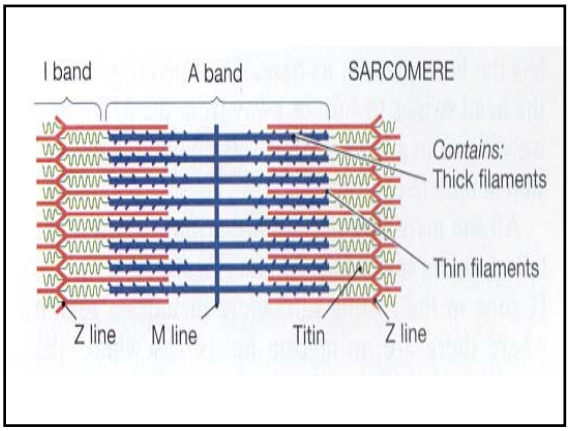


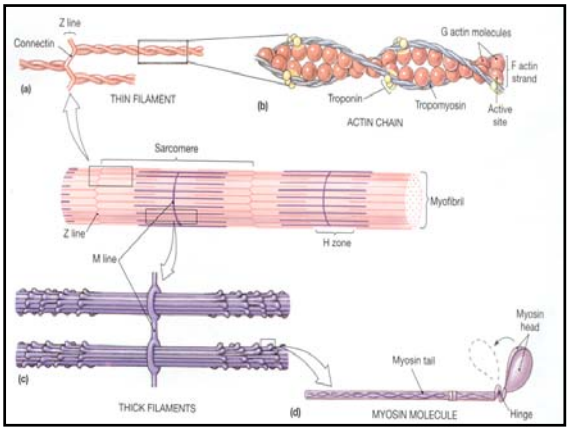












•The ***sliding filament theory*** states that during a contraction, the thin filaments slide past the thick ones overlapping to a greater degree than during the relaxing period.

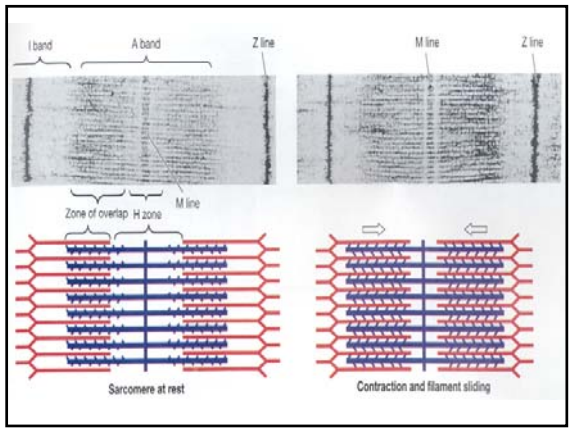
The results are . . . .

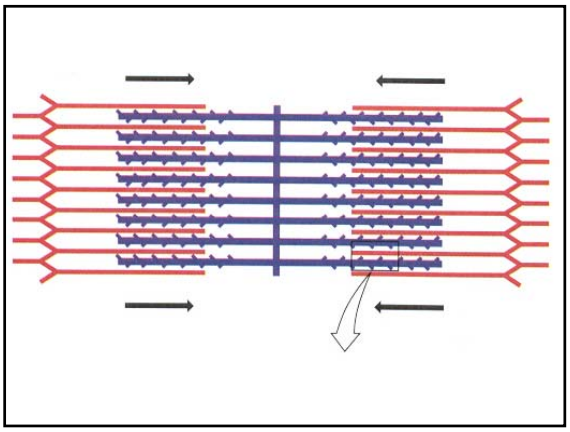
1) During contraction the distance between Z lines is reduced.

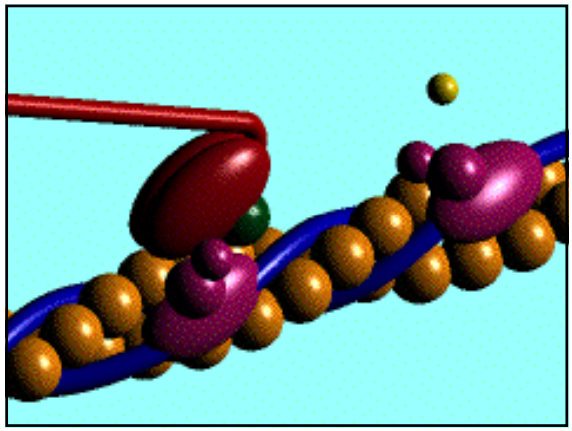
2) The I bands shorten.

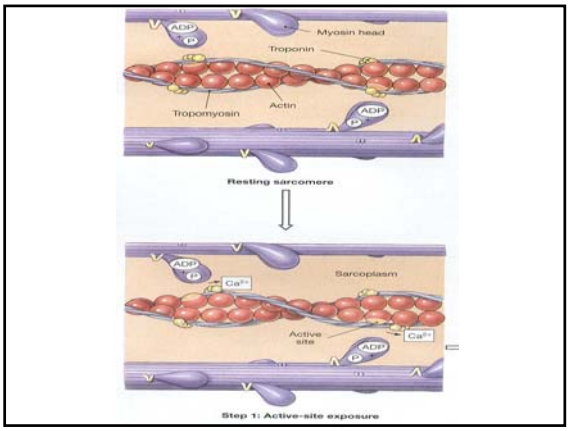
3) The H zones disappear.

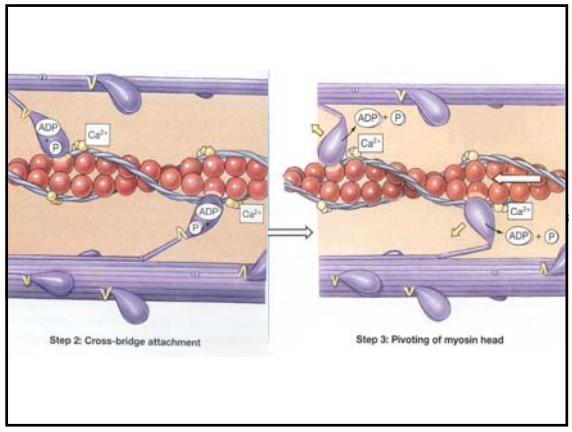
4) The A bands move closer together but do not change in length.

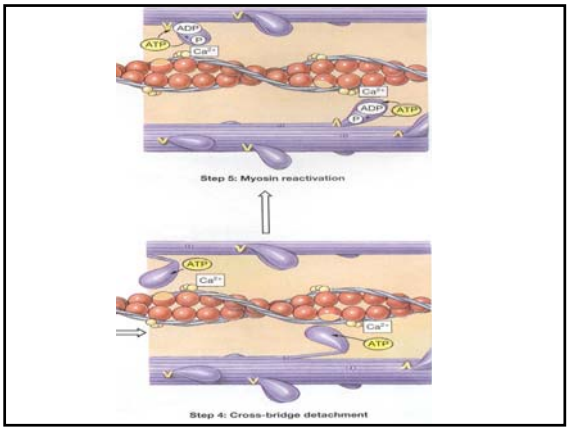

I band
A band
Z line
M line
Z line
M line
Zone of overlap
H zone
Sarcomere at rest
Contraction and filament sliding






ADP
P
Myosin head
Troponin
Actin
Tropomyosin
ADP
P
Resting sarcomere
ADP
P
Ca2+
Sarcoplasm
Active site
Ca2+
ADP
P
Step 1: Active-site exposure


ADP
P
Ca2+
ADP
P
Ca2+
Step 2: Cross-bridge attachment
ADP + P
Ca2+
Ca2+
ADP + P
Step 3: Pivoting of myosin head


ADP
P
ATP
Ca2+
Ca2+
ADP
P
ATP
Step 5: Myosin reactivation
ATP
Ca2+
Ca2+
ATP
Step 4: Cross-bridge detachment

PHYSIOLOGY OF CONTRACTION

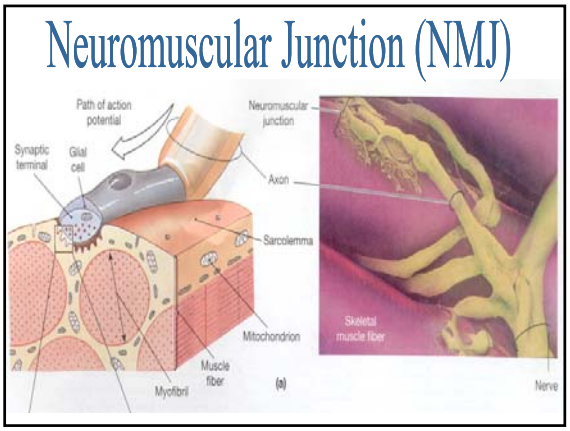
What causes the sliding?

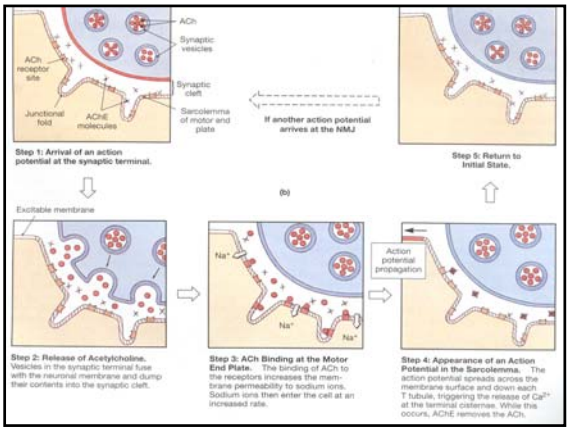
•When a muscle fiber is relaxed, the concentration of ATP is high and the concentration of Ca^{2+} is low. The ions are stored in the SR. The myosin heads are not able to contact the actin receptor sites because of the presence of the tropomyosin-troponin complex.

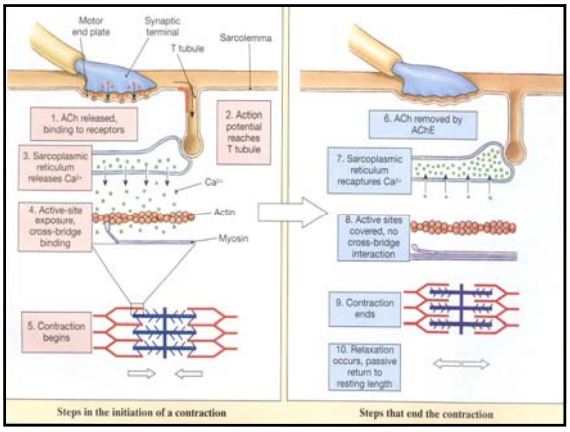
•The release of ***acetylcholine*** (ACh) by the neurons will eventually cause the SR to release Ca^{2+}. The presence of Ca^{2+} and energy from ATP causes the tropomyosin-troponin complex to change shape and move. This allows a binding of the myosin heads to exposed sites on the actin. Energy from ATP allows for a flexing of the cross bridges (like a ratchet). One flex shortens the muscle by 1%. Therefore, many flexes are required.

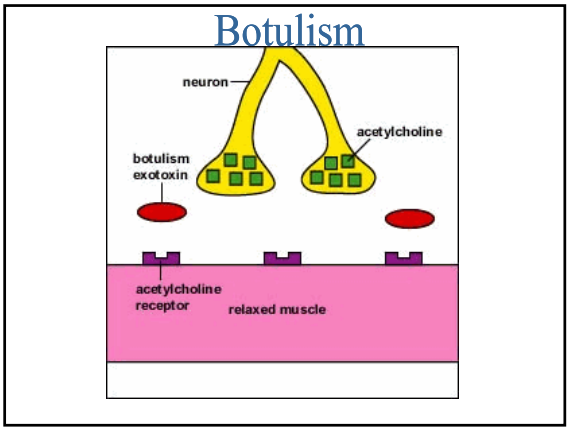
•The muscle cell will relax when the acetylcholine is destroyed by ***acetylcholinesterase*** and Ca^{2+} are moved back into the SR by way of an active transport mechanism. More ATP is needed to release the myosin heads from the actin. Lack of ATP will result in the cross bridges remaining attached and muscle stiffness to occur.

•This is what occurs in the hours after death. The condition is called ***rigor mortis***. Rigor mortis dissipates as the proteins begin to break down.









Tension production

•These are the coordinated contractions of the entire muscle

•The amount of tension produced depends solely on the number of cross-bridge interactions within a given muscle fiber.

•A muscle fiber when stimulated will always produce the same tension. It is either on (contracted) or off (relaxed).

- This is also known as the ALL OR NONE PRINCIPLE

So the amount of tension given by a whole muscle is determined by two things

1. The frequency of stimulation
2. Number of muscle fibers stimulated

Frequency of Stimulation

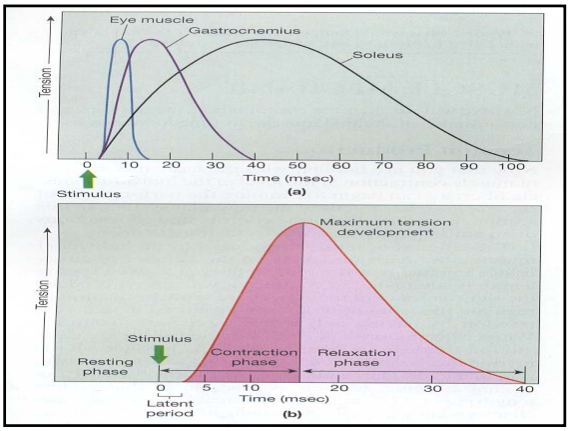
•A **twitch** is the result of a single stimulus a contraction/relaxation event in a single muscle fiber.

•Twitches can last for various durations

7.5 msec for an eye muscle fiber
↓
100 msec for a calf muscle

•A **Myogram** is a graph of muscle tension development during a twitch

•Twitches in skeletal muscles do not accomplish anything useful. All normal activities involve sustained muscle contractions



Wave Summation / Incomplete Tetanus

•If a 2nd nerve impulse comes before the completion of the relaxation phase, a second (more powerful) contraction occurs. This becomes a summation of twitches, or a **wave summation**

•If the nervous stimulation continues, the contraction will reach a peak. This is known as **incomplete tetanus**.
i.e.- shivering

If a twitch lasts 20 msec (1/50 sec)

Stimulation at < 50/sec: twitches

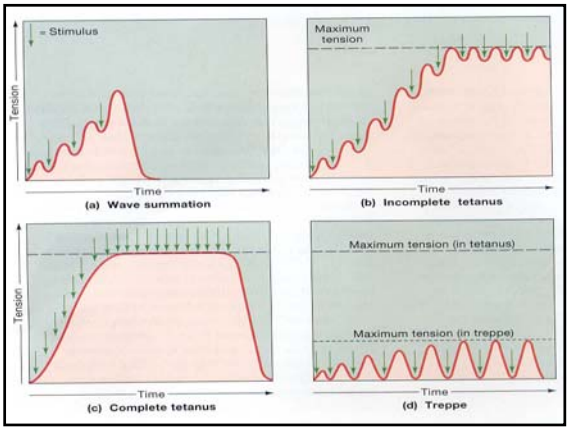
Stimulation at > 50/sec: wave summation

Complete Tetanus

•If the stimuli to the muscle come so fast that there is NO RELAXATION PHASE, then the sarcomere does not have time to reclaim Ca^{2+} so there is a sustained STRONG contraction called **complete tetanus**.

Treppe

•For the first 30-50 rapid contractions (complete tetanus) of a muscle, the tension is at the maximum. After that, tension in the muscle will be only 25% of what it is maximally. This condition is called **Treppe**.



Internal vs. External Tension

Internal Tension is generated when the myofibrils contract, but since the myofibrils are not directly connected to bone there is other stretching going on.

•The extracellular fibers of muscle attachment act like rubber bands and stretch as the internal tension builds until they can no longer stretch and begin to pull. The tension in these extracellular fibers is called **external tension**.

***finger-rubber band-binder analogy**

•Twitches are so short, there is not enough time to build up external tension, so twitching provides no mechanical function.

Tetanus (Lock-Jaw)

•Caused by a poison produced by the bacterium *Clostridium tetani*

•Very common but can only live in tissue with low O_2 conc. (deep wounds)

•The toxin suppresses the regulation mechanism for motor neuron activity, so get sustained powerful contractions of skeletal muscles throughout the body.

•Incubation period is < 2 weeks

1st : headache, muscle stiffness, difficulty swallowing

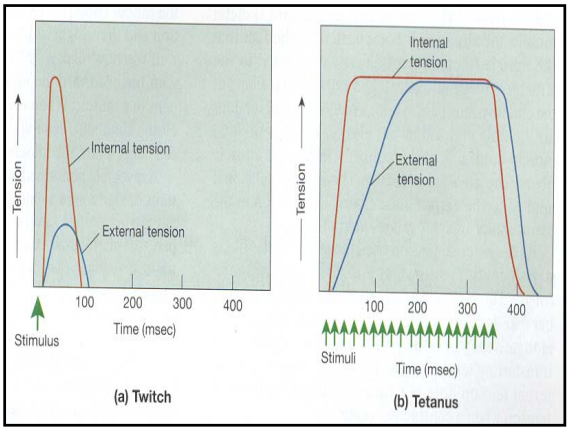
2nd : widespread muscle spasms. Start 2-3 days after 1st symptoms, last for a week

3rd : complete recovery 2-4 weeks or DEATH

•Severe tetanus has 40-60% mortality rate

•500,000 cases worldwide / year only ≈ 100 in U.S. / year

•Due to tetanus shot /booster program in U.S..



Motor Units

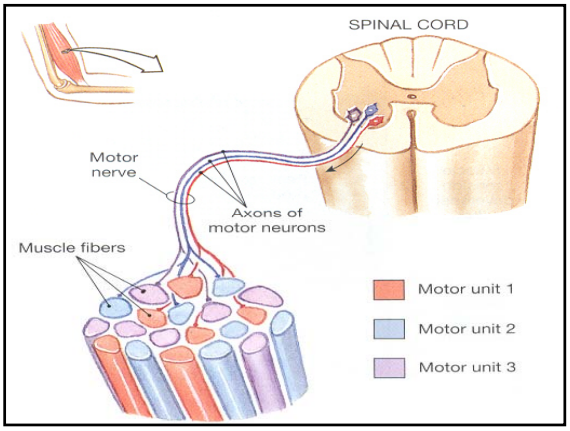
•Generally each neuron that innervates a muscle controls hundreds of muscle fibers. The nerve and the fibers it controls is known as a **motor unit**.

•The # & size of a muscle's motor units indicate how precisely controlled it movements are.

precise control required in eye: motor neuron controls 4 - 6 fibers

gross control required in legs: motor neuron controls 1,000 - 2,000 fibers

•The smooth, steady increase of muscle tension produced by bringing more motor units "on-line" is called **recruitment** or multiple motor unit stimulation.



Muscle Tone

•Some motor units within any particular muscle are always active.

•These contractions don't produce movement, but they do dense and firm the muscle.

•This resting tension in skeletal muscles is called **muscle tone**.

Little **MT**: appears weak & flaccid

Moderate **MT**: appears firm & solid

•These motor units change often so tension on tendons is constant, but individual fibers can rest.

Muscle Tone

•Maintains body position

•Prevents sudden change in position of joint

•Act as a shock absorption system

•Heightened muscle tone stimulates recruitment.

ISOTONIC AND ISOMETRIC CONTRACTIONS

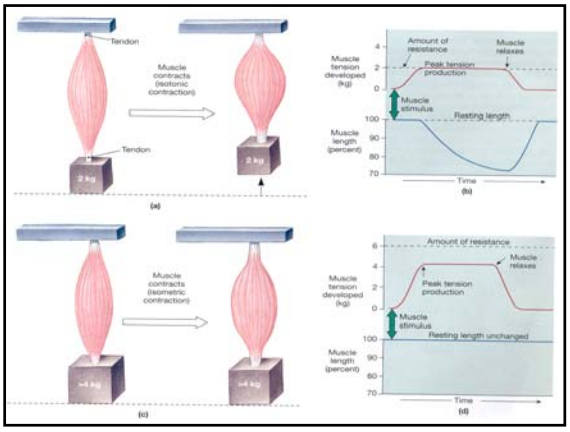
Isotonic = Same tension. The muscle changes in length and moves the load. The tension remains constant through most of the period.

i.e.- Lifting a book.

Isometric = Same measure. The tension increases but the muscle neither shortens nor lengthens.

i.e.-Trying to lift a piano.

•The cross bridges are unsuccessful in moving the thin filaments. (Like spinning their wheels!)



Types of Skeletal Muscle Fibers

Fast Fibers- contract .01 sec or less after stimulation
*Most skeletal muscle fibers)

*Large diameter

*Fatigue rapidly

Slow Fibers- contract .03 sec or more after stimulation
*½ diameter of fast fibers

*Specialized to contract for long periods

Intermediate Fibers
*Intermediate properties

Genetics can predispose a world class athlete to a particular event.

•Marathon runners can have up to 80% slow twitch.

•Sprinters can have up to 60% fast twitch.

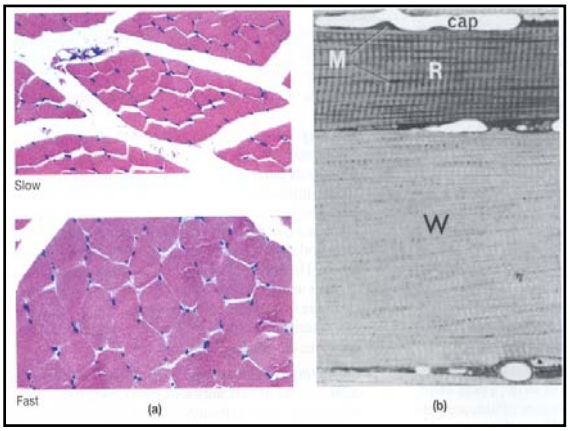
Muscle have a mixture of fibers in them that varies according to the tasks they perform

Fast fibers are light in color so appear as "white" muscles
i.e.- chicken breasts

Slow fibers are red in color so appear as "dark red" muscles
i.e.- chicken thighs

*Most human muscles are a good mixture of both types and are called "pink" muscles
eye & hand: most fast fibers

calf & back: most slow fibers



Hypertrophy & Atrophy

Muscular Hypertrophy – weight training to max. tension, increases the diameter (not number) of fibers making the muscle bigger and stronger.

Muscular Atrophy- muscles that are not stimulated on a regular basis, the muscle becomes flaccid and muscle fiber become smaller and weaker.

Aging & The Muscular System

As the body ages:

1. skeletal muscle fibers become smaller in diameter (reduction in size, strength, & endurance of muscle)

2. skeletal muscle become less elastic
increasing amt. of fibrous tissue (**fibrosis**)

3. tolerance for exercise decreases
*rapid fatigue

*muscle overheat (loss of thermoregularity)

4. ability to recover from muscular injuries decreases
*# of satellite cells decreases

*Repair ability becomes limited

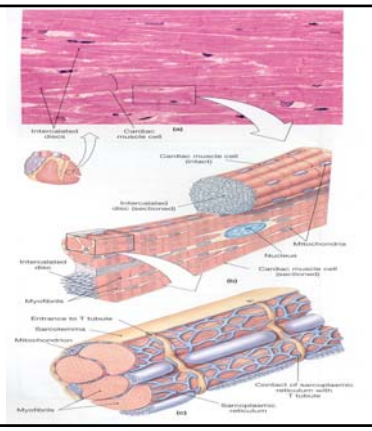
Note to self: STAY HEALTHY NOW!

Cardiac Muscle

•a.k.a. cardiomyocytes

•relatively small 10 – 20 µm x 50-100 µm

•found only in the heart



Important Functional Difference

1. Contract automatically (w/o neural stimulation) timing by pacemaker cells

2. Innervation by nervous system can
a. change pace
b. change tension

3. Contractions last ≈ 10x longer than skeletal muscle contractions

4. Individual cardiac cells cannot undergo wave summation

Smooth Muscle Tissue

•Range in size from:

5-10 µm diameter x 30-200 µm in length

•Cell is spindle shaped

•Single Nucleus

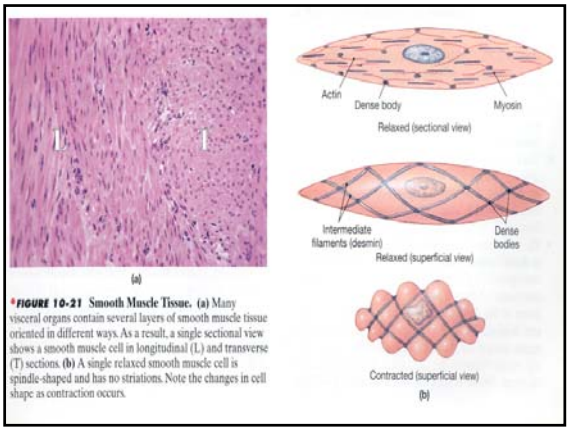


FIGURE 10-21 Smooth Muscle Tissue. **(a)** Many visceral organs contain several layers of smooth muscle tissue oriented in different ways. As a result, a single sectional view shows a smooth muscle cell in longitudinal (L) and transverse (T) sections. **(b)** A single relaxed smooth muscle cell is spindle-shaped and has no striations. Note the changes in cell shape as contraction occurs.