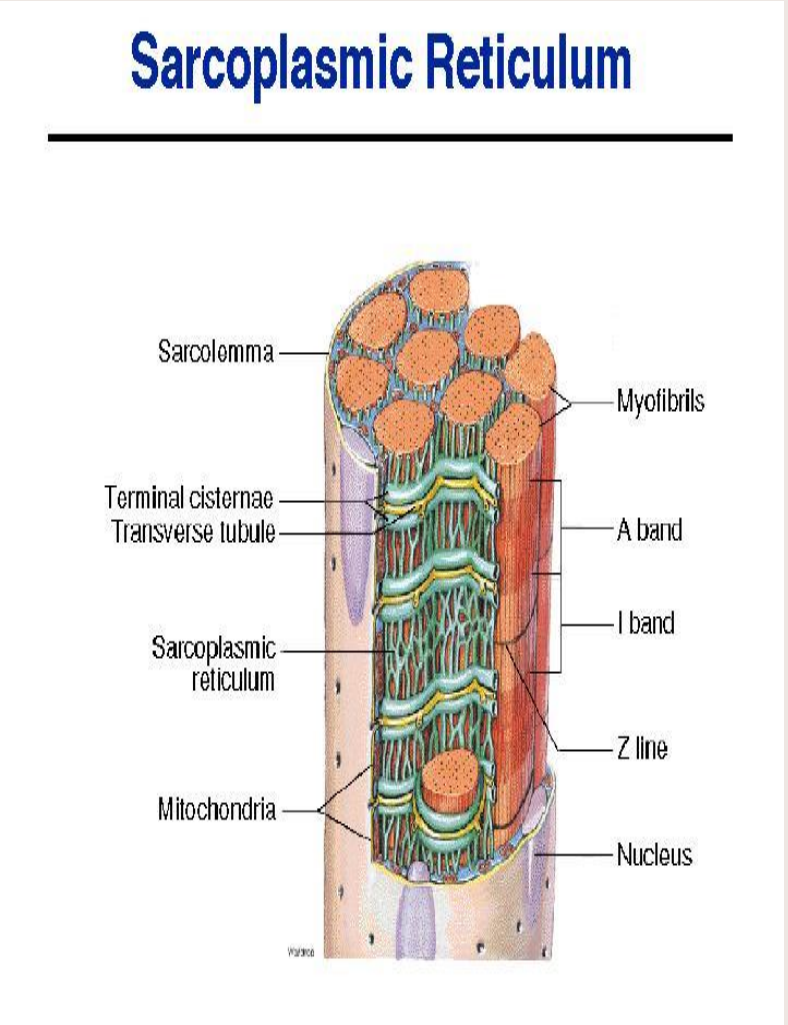
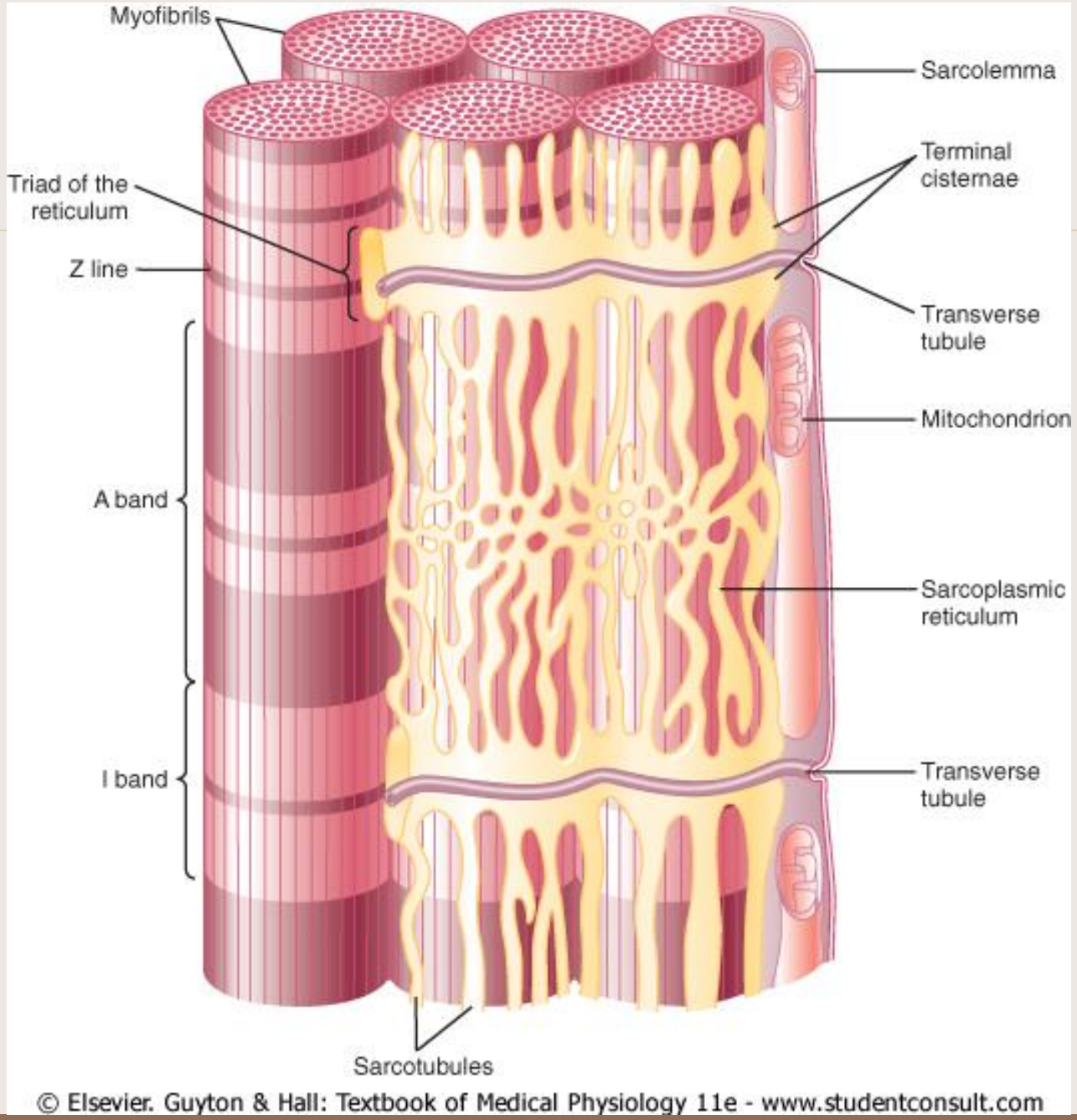
- The function of T-TUBULES is to conduct impulses from the surface of the cell (SARCOLEMMA) down into the cell and, specifically, to another structure in the cell called the SARCOPLASMIC RETICULUM.
- As they open to the exterior, the extracellular fluid runs through their lumen.




Myofibrils
Sarcolemma
Terminal cisternae
Triad of the reticulum
Z line
Transverse tubule
Mitochondrion
A band
Sarcoplasmic reticulum
I band
Transverse tubule
Sarcotubules
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L TUBULES – SARCOPLASMIC RETICULUM

- Extend throughout the sarcoplasm.
- Together called sarcoplasmic Reticulum.
- Runs in long axes of the muscle fiber and hence called longitudinal tubules or “L tubules”.
- Form a closed tubular system around each myofibril.
- They do not open to exterior like T tubules.
- It cones ponds to the endoplasmic reticulum of other cells regular intervals, throughout the length of the myofibrils, the L tubules delate to form a pair of lateral sacs called terminal cisternae.
- Each pair of terminal cisternal is in close contact with T tubule. (The T tubule along with cisterae on either side is called the triad of skeletal muscle).

FUNCTIONS OF T TUBULES

- Responsible for rapid transmission of impulse in the form of action potential to the myofibrils.

FUNCTION OF L TUBULES

- Store a large quantity of calcium ions.
- When the action potential reaches the cisterval of “L” tubule, these calcium ions are released into the sarcoplasm, which trigger the processes involved in the contraction of the muscle this process is called excitation contraction coupling.

Sarcoplasmic and Endoplasmic reticulum.

- Sarcoplasmic Reticulum is from the greek sarx ‘flesh’ is a special type of smooth endoplasmic reticulum found in smooth, striated muscles.
- SR is greyish blue in colour and wrapped around the myofibril.
- Terminal cisternae is a part of the SR
- S R stores and pumps Ca ions.

- E R synthesizes protein molecules.
- ER causes facilitation of protein folding and transport of synthesized proteins in sacs called Cisternae.

Sarcoplasmic reticulum

- Sarcoplasmic reticulum is very abundant in skeletal muscle cells and is closely associated with the MYOFIBRILS (and, therefore, the MYOFILAMENTS).
- The membrane of the SR is well-equipped to handle calcium: there are "pumps" (active transport) for calcium so that calcium is constantly being "pumped" into the SR from the cytoplasm of the muscle cell (called the SARCOPLASM).
- As a result, in a relaxed muscle, there is a very high concentration of calcium in the SR and a very low concentration in the sarcoplasm (and, therefore, among the myofibrils & myofilaments).
- In addition, the membrane has special openings, or "gates", for calcium.
- In a relaxed muscle, these gates are closed and calcium cannot pass through the membrane. So, the calcium remains in the SR.
- However, if an impulse travels along the membrane of the SR, the calcium "gates" open &, therefore, calcium diffuses rapidly out of the SR & into the sarcoplasm where the myofibrils & myofilaments are located.

COMPOSITION OF MUSCLE

- Skeletal muscle is formed by 75% of water, 20% of proteins and 5% of organic substances other than proteins and some inorganic substances.

MUSCLE PROTEINS

- Following are the protein present in the muscle.

1. Myosine
2. Actin
3. Tropomyosin
4. Troponin
5. Actinin
6. Titin
7. Desmin
8. Myogen (Sarcoplasm of the muscle cell).
9. Myoglobin (Sarcoplasm)

This myoglobin is also called myohemoglobin. Its function is similar to haemoglobin that is to carry O_2.

SKELETAL MUSCLES

- Skeletal muscle has Cross Striations
- Skeletal muscle are the Voluntary muscles.
- Skeletal muscles are in Association with bones forming the skeletal system.
- Skeletal muscles form 40 to 50% of body mass.
- Skeletal muscles are Supplied by somatic nerves.

PROPERTIES OF SKELETAL MUSCLES EXCITABILITY

- Is defined as the reaction or response of a tissue to the irritation or stimulation.
- The muscle can be excited by both **direct stimulation** and **indirect (through its nerve) stimulation**.
- Four types of stimulus, which can excite a living tissue.
  - ✓Mechanical stimulus (Prnching)
  - ✓Electrical stimulus (Electric Shock)
  - ✓Thermal stimulus (by applying heated glass rod or wire)
  - ✓Chemical Stimulus (acids)
  - The stimulus whose strength (or voltage) is sufficient to excite the tissue is called threshold or minimal stimulus.
  - For a week stimulus, the duration be longer and for a stronger stimulus the duration is short.

EXCITABILITY CURVE OR STRENGTH DURATION CURVE

- In this curve, the strength of the stimulus is plotted (in volts0 vertically and the duration in (milliseconds) horizontally.
- To start with a stimulus with higher strength or voltage (4 to 5) is applied. The minimum duration during which the stimulus must be applied to excite the tissue is determined.
- Strength of the stimulus is reduced and the duration is found.
- **Rheobase:** This is the least possible i.e. ***minimum strength*** (voltage) which can excite the tissue, what ever may be the duration of stimulus.
- **Utilization time:** Is the **minimum time** required to excite the tissue.
- **Chronaxic:** It is the minimum time, at which a stimulus with double the theobasic strength (votltage) can excite the tissue.

IMPORTANCE OF CHRONAXIE

- Is used to compare the excitability in different tissues.
- Longer the chronaxie, lesser is the ecitability.
- Chronaxie in human Skeletal muscle varies from 0.8 millisec to 0.32 milli seconds and 10 times more in skeletal muscle of infants then in the skeletal muscles of adults.
- Chronaxie is longer in paralyzed muscles than the normal muscle.
- In the neural diseases it is prolonged gradually.
- Chronaxie is shortened in increased temperature and shorter in red muscles then in white muscle.

CONTRACTILITY

- Skeletal muscle gives response to a stimulus in the form of contraction.
- **Contraction:** Can be defined as the interval events of the muscle, which are manifested by change in either the length of the muscle fibers or the tension.
- **Isotonic Contraction:** In this type of contraction the tension remains the same whereas the change occurs in the length of the muscle fiber (ISO = same tonic = tension)
- Example is simple flexion of arm
- **Isometric contraction:** In this type, the length of muscle fibers remains the same and the tension is increased. Example is pulling any heavy object.

Isometric contraction

- The force exerted on an object by contracting muscle is known as muscle tension,and the force exerted on the muscle by an object(usually its weight) is the load.
- Muscle tension and load are opposing forces.
- When a muscle develops tension but does not shortens(or lengthens),the contraction is called isometric(constant length)

Isometric contraction(continued)

- Isometric Contractions, on the other hand, are situations where the muscle TRIES to contract, but cannot. An example of this is if you tried to lift an immoveable object. Holding a weight at arm's length would be another.
- An **isometric contraction** of a muscle generates force without changing length. An example can be found when the muscles of the hand and forearm grip an object; the joints of the hand do not move, but muscles generate sufficient force to prevent the object from being dropped.

(a) Isometric contraction

Muscle tension is less than the resistance. Although tension is generated, the muscle does not shorten, and no movement occurs.

(b) Isotonic contraction

Muscle tension equals or is greater than the resistance. The muscle shortens, and movement occurs.

Isometric exercise

- Isometric exercise, is a strength training activity in which your muscle length and joint angles do not change.
- Isometric exercises strengthen and condition muscles, and increase muscle size. Isometrics are often performed in yoga workouts. They are also used in rehabilitation and for sport-specific training.

EXERCISE A IS AN ISOTONIC CONTRACTION, EXERCISE B IS ISOMETRIC

Isotonic contraction

- A contraction in which the muscle changes length, while the load on the muscle remain constant is isotonic(constant tension)
- Exercises which utilize isotonic contractions are, Swinging a bat, throwing a ball or lifting a weight are all isotonic movements.
- Anatomy wise, an isotonic movement is one in which a muscle is shortened and the body part it is attached to moves as well.
- If you perform a bicep curl, the process of shortening the bicep is what moves the arm
- isotonic contraction can be associated with either shortening or lengthening of a muscle when tension exceeds a load, shortening occurs and it is referred to as **concentric contraction**

Isotonic contraction

- On the other hand if an unsupported load is greater then the tension generated by cross bridges the result is a lengthening contraction **(eccentric contraction).**
- In this situation, the load pulls the muscle to a longer length inspite of the opposing force produced by the cross bridges.

Difference between isometric and isotonic contraction

- Isometric cortraction occurs when a muscle contracts against an immovable load
- Actin filaments are unable to slide on myosin filaments
- Tension rises during contraction
- No shortening occurs ,hence no external work is done

- Isotonic contraction occurs when a muscle contracts against zero load.
- Actin filaments easily slide on myosine filaments.
- Tension remains unchanged during contraction.
- Shortening occurs and external work is done.

Difference between isometric and isotonic contraction.

- Occurs at the beginning and end of all contraction.
- Isometric contraction increases when load increases.
- Heat released is less hence, more energy-efficient.
- An isometric twitch has a shorter latent period. The tension peaks quickly and relaxation is slow.

- Occurs in the middle of a contraction.
- Isotonic contraction decreases when load increases.
- Heat released is more hence, less energy-efficient.
- An isotonic twitch has a longer latent period. The shortening peaks somewhat later and relaxation is quicker.

Isometric-Isotonic contractions have their benefits.

- Isotonic movements typically are much **more vigorous,** which is better for the heart.
- Due to their **vigorous nature, isotonic exercises are usually better at burning calories** and therefore **greatly aid in weight reduction.**
-

- Isometrics only work the heart indirectly.
- Isometric exercises **are static position exercises** that don't require the worked muscle to move.
- isometrics, you **merely contract muscles while keeping a particular body part still.**
- Isometric exercises **are not great for strength development but are ideal for aiding in rehabilitation**.
- It help the **entire body and help maintain your strength.**

Isometric exercise

Comparison

Anaerobic exercises

- Use fast twitch fibres
- Weight lifting, push up exercises.
- Depletes Oxygen reserve in the muscle cells quickly.
- To reply the oxygen Dept human breath quickly which restores oxygen level.
- Creates excess of Lactic acid(a waste product) increase oxygen intake the liver cells can convert the excess lactic acid into glucose used in cellular metabolism.

Aerobic exercises

- Uses slow twitch muscle
- Include activities that are prolonged and requires constant energy
- Long distance running and cycling are examples of aerobic exercise.
- The muscle cell requires the same amount of oxygen that the body supplies. The oxygen debt is slashed and lactic acid is not formed.

LATENT PERIOD

- Is the time taken for the impulse to travel along the nerve from the place of stimulation to the muscle.
- It is the time taken for initial chemical changes in the muscle to start with.
- Latent period is not constant. It decreases in high temperature and increases in low temperatures.

CONTRACTION TIME (Total Twitch Period)

- Based on the contraction time, the skeletal muscles are classified into two types, the red muscles and white muscles.
- Similarly, depending upon contraction time and myosin ATPase activity the muscle fibers are also divided into two types.
- Type 1 fibers (slow twitch fibers) having small diameters.
- Type 2 fibers (fast twitch fibers) having Large diameter.

TABLE 30-1: Features of red and white muscles

Red (slow) muscle	White (fast) muscle
1. Myoglobin content is more. So, it is red	Myoglobin content is less. So, it is pale
2. Sarcoplasmic reticulum is less extensive	Sarcoplasmic reticulum is more extensive
3. Blood vessels are more extensive	Blood vessels are less extensive
4. Mitochondria are more in number	Mitochondria are less in number
5. Response is slow with long latent period	Response is rapid with short latent period
6. Contraction is less powerful	Contraction is more powerful
7. This muscle is involved in prolonged and continued activity as it undergoes sustained contraction	This muscle is not involved in prolonged and continued activity as it relaxes immediately
8. Fatigue occurs slowly	Fatigue occurs quickly
9. Depends upon cellular respiration for ATP production	Depends upon glycolysis for ATP production

Red and white muscle fibers

- red muscle fibers initiate all movement while white fibers activate only when intensity surpasses a given level
- White muscle fibers create high-intensity actions lasting fewer than 30 seconds, such as jumping and lifting loads greater than 70 percent of your maximal ability.

Red and white muscle fibers

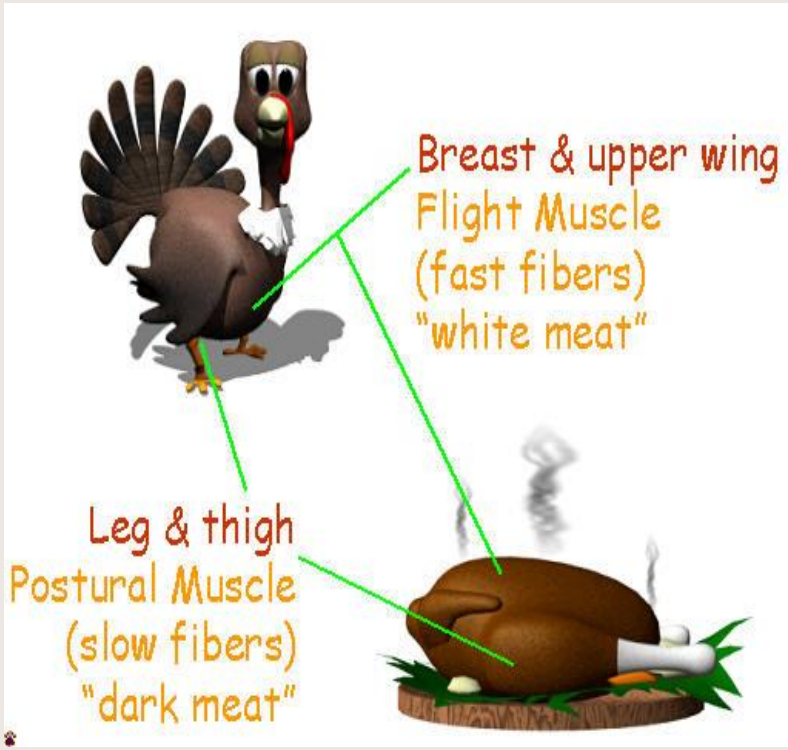
- red muscle fibers specialize in long-duration, low-intensity movement, such as walking, standing or lifting loads below 70 percent of your maximal ability.
- Red fibers fatigue slowly
- dominate muscle composition in the human body.
- red fibers contribute to all muscular contractions, they are easier to target with exercise. For example, any repetitive, weight-bearing action
- Designed for quick movements (like the muscles in your hands & for moving your eyes)
- More SR in these fibers, so they are better equipped for quick release and re-uptake of calcium ions
- Myosin heads have a slight molecular difference that makes them faster and more efficient at hydrolyzing ATP.
- Because of this, they can run through the cross-bridge cycle faster.More likely to fatigue (due to lactic acid build up)

Red and white muscle fibers

- More mitochondria & myoglobin
- better blood supply. Two major advantages of this:rather than making ATP and having lactic acid build up, the pyruvate is better able to enter the mitochondria and be broken down further there... all you need is plenty of mitochondria and plenty of myoglobin.slow muscle fibers are less likely to fatigue (because of a slower build-up of lactic acid)
- Note that since myoglobin is a red pigment molecule (like hemoglobin is), these fibers tend to look redder (or darker) than fast muscle fibers

- The red muscles are aerobic while the white muscle is mostly anaerobic.

Red and white muscle fibers



SOURCES OF ENERGY FOR MUSCLE CONTRACTION

- Muscle contraction depends on energy supplied by ATP.
- Energy is required to activate the walk along mechanism by which the cross bridges pull the actin filaments.
- Small amounts are required for pumping calcium from the sarcoplasm into the sarcoplasmic reticulam after the contraction is over.
- Pumping sodium and potassium ions through the muscle fiber membrane to maintain an appropriate ionic enviroment for propagation of muscle fiber action potential.

Energy sources

- Energy is converted from fuel molecules in the mitochondria
- Muscle fibers have many mitochondria to provide their high energy needs
- Muscle fibers are specialized for producing energy efficiently

SOURCES OF ENERGY FOR MUSCLE CONTRACTION

- The concentration of ATP in the muscle fiber, about 4 millimolar,is sufficient to maintain full contraction for only 1 to 2 seconds at most.
- After this,ATP is split to form ADP.
- The ADP is rephosphorylated to form new ATP within another fraction of a second,which allows the muscle to continue its contraction.

SOURCES OF ENERGY FOR MUSCLE CONTRACTION

- The first source of energy that is used to reconstitute the ATP is the substance **phosphocreatine** ,which carries a high energy phosphate bond similar to the bond of ATP.
- The high energy phosphate bond of phosphocreatine has a slightly higher amount of free energy than that of the ATP bond.
- Therefore phosphocreatine is instantly cleaved,and the released energy causes bonding of a new phosphate ions to ADP to reconstitute the ATP.

SOURCES OF ENERGY FOR MUSCLE CONTRACTION

- Total amount of phosphocreatine in the muscle fiber is also very little,only five times as great as the ATP.
- Therefore, the combined energy of both the **stored ATP** and the **phosphocreatine** in the muscle is still capable of causing maximal muscle contraction for only 5 to 8 seconds.

SOURCES OF ENERGY FOR MUSCLE CONTRACTION

- The second important source of energy,which is used to reconstitute both ATP and phosphocreatine, is glycogen previously stored in the muscle cells
- Rapid enzymatic breakdown of the glycogen to pyruvic acid and lactic acid liberates energy that is used to convert ADP to ATP can then be used directly to energize muscle contraction or to reform the stores of phosphocreatine.

IMPORTANCE OF GLYCOLYSIS MECHANISM

- Can occur in the absence of oxygen
- The rate of formation of ATP by glycolytic process is 2 and a half times as rapid as ATP formation when cellular food stuffs react with oxygen.
- After about 1 min glycolysis loses the capacity to sustain maximum muscle contraction because the end products of glycolysis accumulate in the muscle cells

FINAL THIRD SOURCE OF ENERGY

- Is oxidative metabolism.this means the combining of oxygen with various cellular foodstuffs to liberate ATP.

Functional characteristics of muscle fibers

- Excitable
- Contractile
- Extensible
- Elastic

TABLE 28-1: Features of skeletal, cardiac and smooth muscle fibers

Features	Skeletal muscle fiber	Cardiac muscle fiber	Smooth muscle fiber
Location	In association with bones	In the heart	In the visceral organs
Shape	Cylindrical and unbranched	Branched	Spindle shaped and unbranched
Length	1–4 cm	80–100 μ	50–200 μ
Diameter	10–100 μ	15–20 μ	2–5 μ
No. of nucleus	One or more	One	One
Cross striations	Present	Present	Absent
Myofibrils	Present	Present	Absent
Sarcomere	Present	Present	Absent
Troponin	Present	Present	Absent
Sarcotubular system	Well developed	Well developed	Poorly developed
'T' tubules	Long and thin	Short and broad	Absent
Depolarization	Upon stimulation	Spontaneous	Spontaneous
Fatigue	Possible	Not possible	Not possible

TABLE 28-1: Features of skeletal, cardiac and smooth muscle fibers

Fatigue			
Summation	Possible	Not possible	Possible
Tetanus	Possible	Not possible	Possible
Resting membrane potential	Stable	Stable	Unstable
For trigger of contraction, calcium binds with	Troponin	Troponin	Calmodulin
Source of calcium	Sarcoplasmic reticulum	Sarcoplasmic reticulum	Extracellular
Speed of contraction	Fast	Intermediate	Slow
Neuromuscular junction	Well defined	Not well defined	Not well defined
Action	Voluntary action	Involuntary action	Involuntary action
Control	Only neurogenic	Myogenic	Neurogenic and myoge
Nerve supply	Somatic nerves	Autonomic nerves	Autonomic nerves
Starling's law	Applicable	Applicable	Not applicable

Muscle fatigue

- When a skeletal muscle fiber is repeatedly stimulated, the tension the fiber develops eventually decreases even though the stimulation continues.
- This decline in muscle tension as a result of previous contractile activity is known as muscle fatigue.

Characteristics of fatigued muscle are

- A decreased shortening velocity and slower rate of relaxation.

Factors involved in skeletal muscle fatigue

- **Conduction failure**:The muscle action potential can fail to be conducted into the fiber.
- Conduction failure results from the buildup of potassium ions in the T tubules during the repolarization of repitative action potential.
- Elevated external K concentration leads to a persistant depolarization of the membrane potential and eventually cause a failure to produce action potential in the T tubular membrane (due to inactivation of sodium channels)

Factors involved in skeletal muscle fatigue

- **Lactic acid buildup:Elevated H ions concentration alters protein confirmation and activity.**
- **Thus acidification of muscle by lactic acid may alters a number of muscle protein including actin and myosin as well as proteins involved in calcium release.**

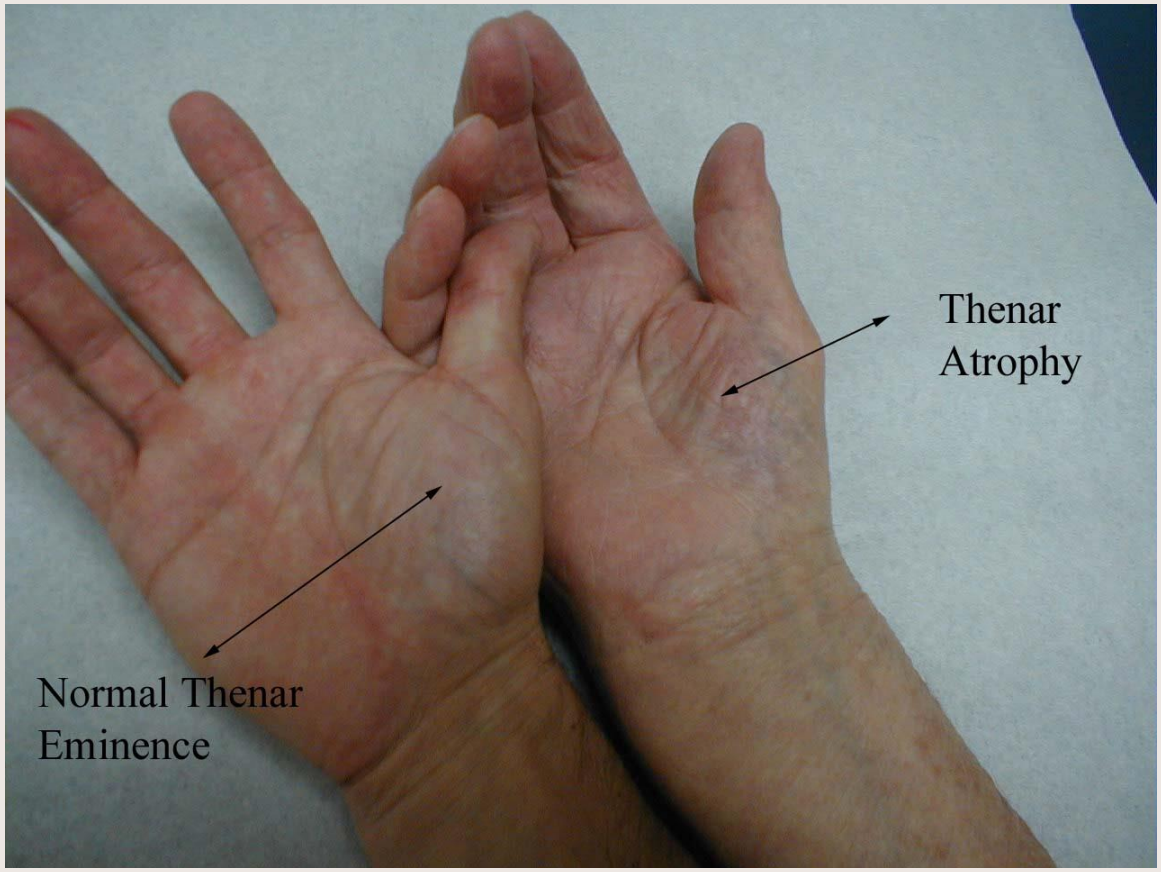
Factors involved in skeletal muscle fatigue

- **Inhibition of cross bridge cycling**: high intensity exercise cause impaired relaxation observed in muscles as a result there is delay with cross bridge detachment from actin filaments.
- **ATP depletion in not a cause of fatigue**.
- The decease in muscle glycogen which supplied fuel for contraction correlates closely with the fatigue on set.
- Low blood glucose and dehydration have been demonstrated to increase fatigue.

Atrophy of the skeletal muscles

Atrophy is are of two types

1.**DENERVATION ATROPHY**: If the neurons to a skeletal muscle are destroyed or the neuromuscular junctions become nonfunctional, the denervated muscle fibers will progressively smaller in diameter,and the amount of contractile proteins they contain will decrease.This condition is known as denervation atrophy.


Thenar
Atrophy
Normal Thenar
Eminence

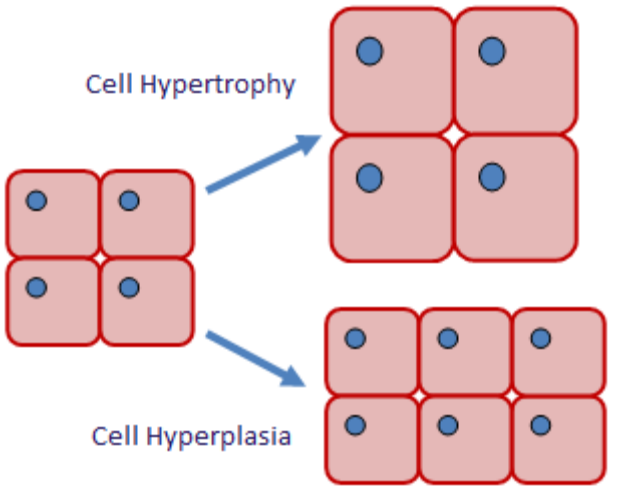
Atrophy of the skeletal muscles

DISUSE ATROPHY:A muscle can also atrophy with the nerve supply intact, if the muscleis not used for a long period of time as when a broken arm or leg is immobilized in a cast.This condition is known a disuse atrophy.

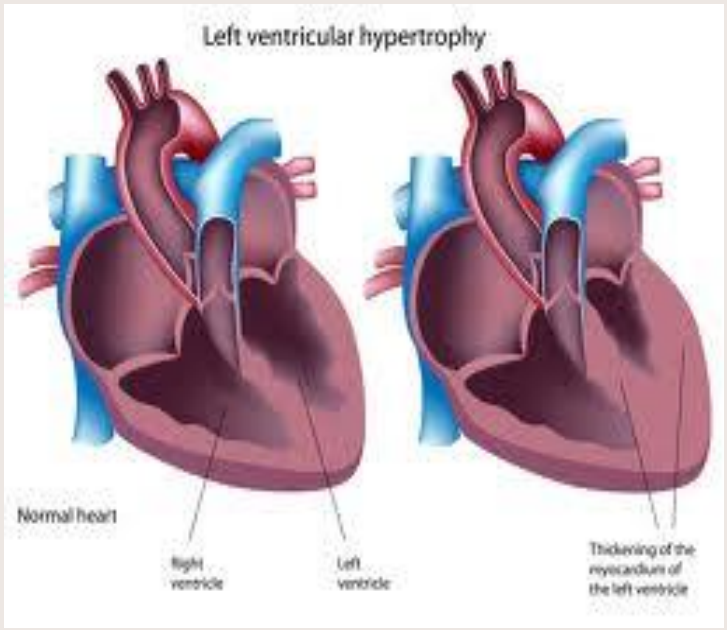
Muscle Hypertrophy

- Increase muscle size due to forceful muscular activity for a long period of time,is called muscle hypertrophy.
- Cause are increase in diameter of muscle fiber.
- Increase in number of muscle fiber(hyperplasia).

Difference between Hyperplasia and hypertrophy



Difference between physiological and pathological hypertrophy



Effect of exercise on skeletal muscles

- An increase in the size(hypertrophy) of muscle fibers as well as changes in their capacity for ATP production.
- Exercise of relatively low intensity but longer duration(popularly called Aerobic exercise) such as running or swimming produce increase in the number of Mitochondria in the fibers that are recruited in this type of activity.

Effect of exercise on skeletal muscles

- The **number of capillaries around these fibers** also increases.
- Exercise **increases the capacity for endurance activity with a minimum of fatigue**.(Endurance means the power to withstand hardship)
- Exercise **improves the delivery of oxygen and fuel molecules to the muscle**.

Muscle Cramps

- Involuntary tetanic contraction of the skeletal muscles produces muscle cramps.
- During cramping ,action potentials fire at abnormally high rates, a much greater rate then occurs during maximum voluntary contraction.

Summation of muscle contraction

- Adding together of individual muscle contraction to give a strong muscle contraction, is called summation.

There are two types of summation

- **Multiple motor unit summation**:In this number of motor units contracting simultaneously is increased
- **Wave summation**: In this frequency of contraction of individual motor is increased .

Hypocalcemic Tetany

- Is involuntary tetanic contraction of skeletal muscle that occurs when the extracellular calcium concentration falls to about 40% of its normal value.
- Hypocalcemia opens the Na channels in excitable membranes ,leading to membrane depolarization and spontaneous firing of action potential causing increase muscle contraction

EXAMINATION TIP

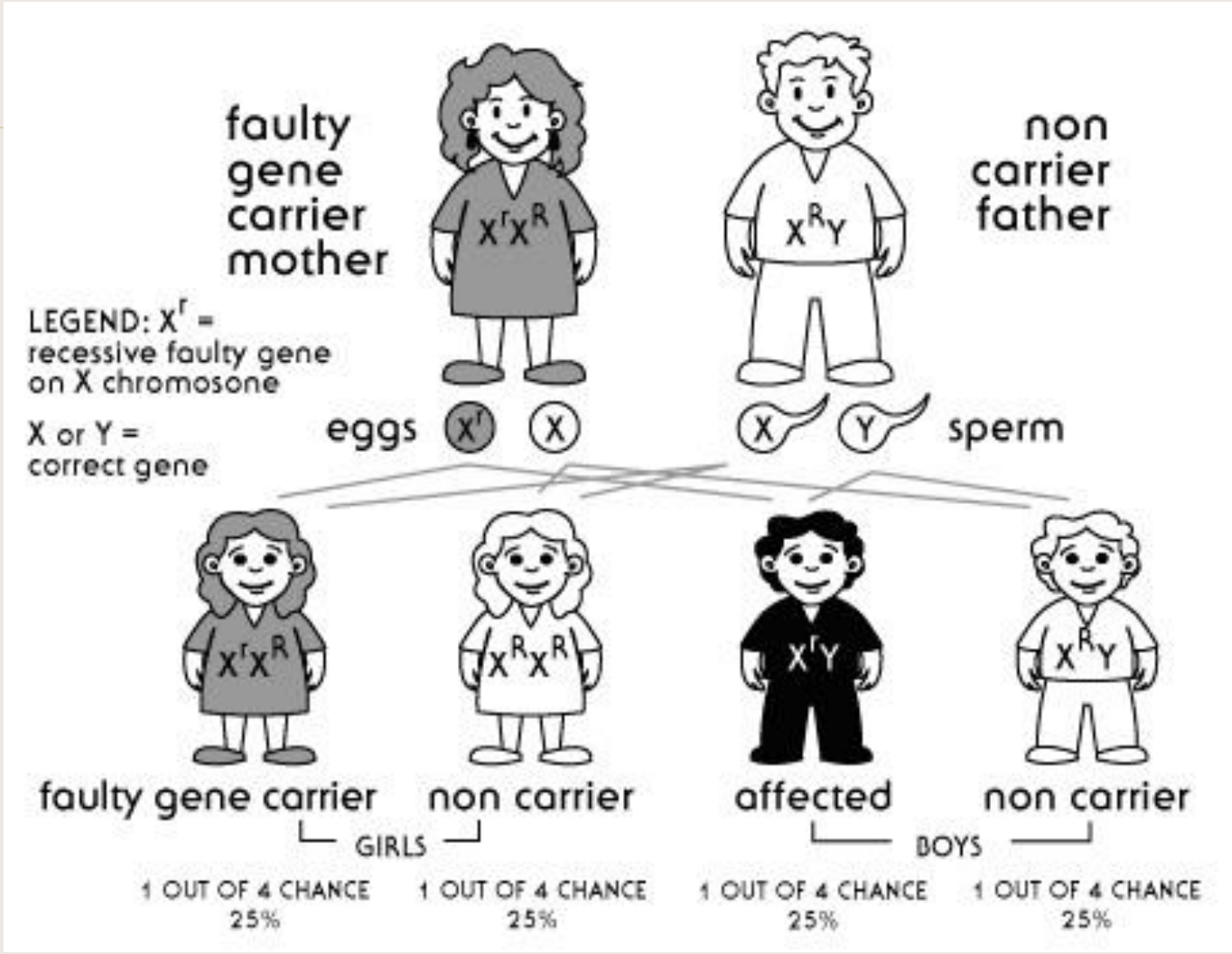
Recognizing carpopedal spasm

In the hand, carpopedal spasm involves adduction of the thumb over the palm, followed by flexion of the metacarpophalangeal joints, extension of the interphalangeal joints (fingers together), adduction of the hyperextended fingers, and flexion of the wrist and elbow joints. Similar effects occur in the joints of the feet.

Muscular Dystrophy

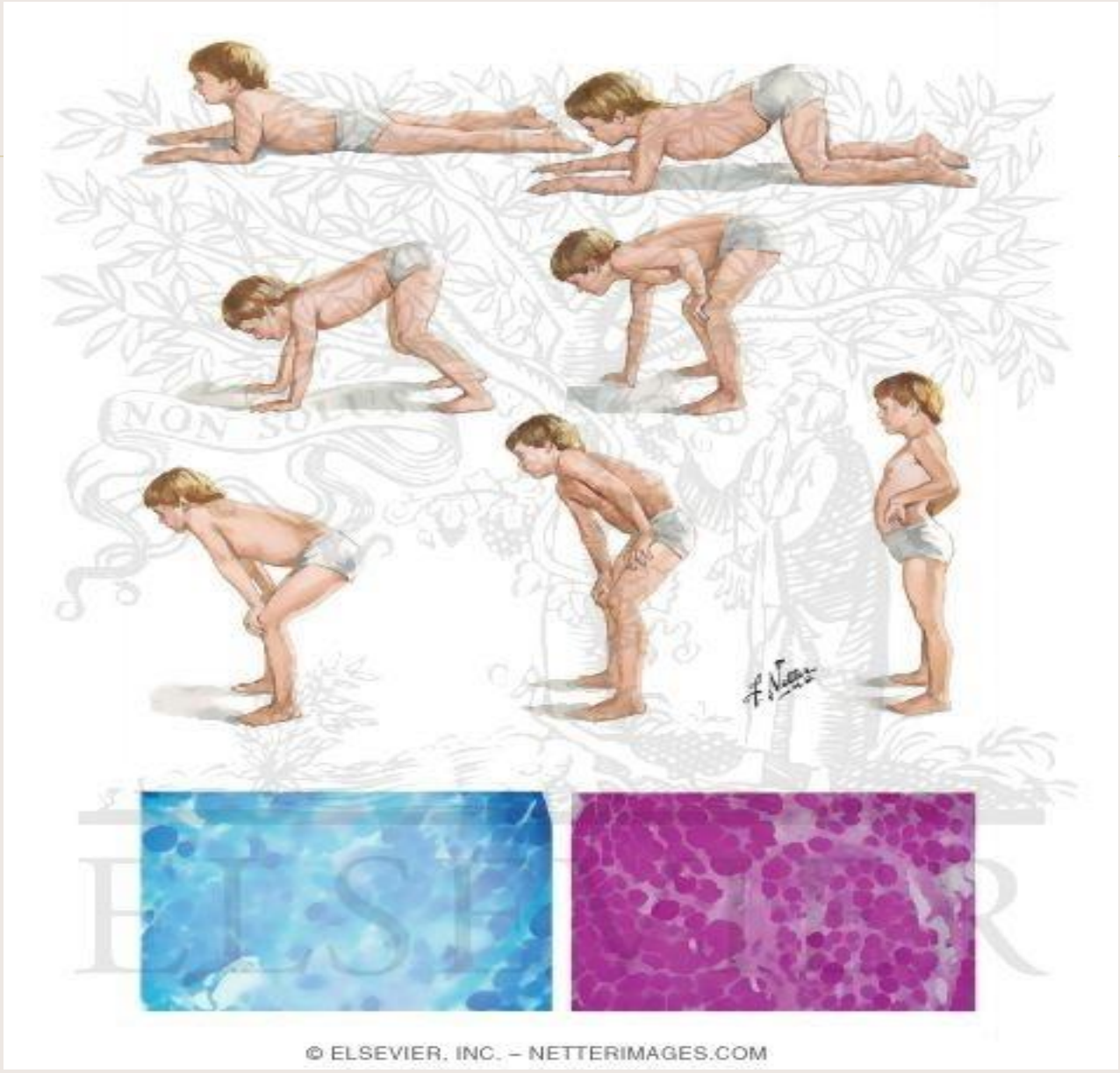
- Genetic disease.
- Affecting one in every 3500 males(but many fever females)
- It is associated with the progressive degeneration of skeletal and cardiac muscle fibers, weakening the muscles and leading to death from respiratory and cardiac failure.
- The symptoms become evident at about 2 to 6 years of age.
- Most affected individuals do not survive far beyond age of 20.

Muscular dystrophy is a disease in which muscles of the body get weaker and weaker and may slowly stop working.


faulty gene carrier mother
non carrier father
LEGEND: X^r = recessive faulty gene on X chromosone
X or Y = correct gene
eggs
sperm
faulty gene carrier
non carrier
affected
non carrier
GIRLS
BOYS
1 OUT OF 4 CHANCE 25%
1 OUT OF 4 CHANCE 25%
1 OUT OF 4 CHANCE 25%
1 OUT OF 4 CHANCE 25%

Muscular Dystrophy

- The recessive gene responsible for a major form of muscular dystrophy(duchenne muscular dystrophy) has been identified on the X chromosome.
- It is thus a sex linked recessive disease, girls have two X chromosomes and boys only have one
- Consequently with one abnormal X chromosome and one normal one will not generally develop the disease. This is why the disease is more common in boys.
- This gene code for a protein known as dystrophin, which is present in a non functional form or absent in patients with the disease.

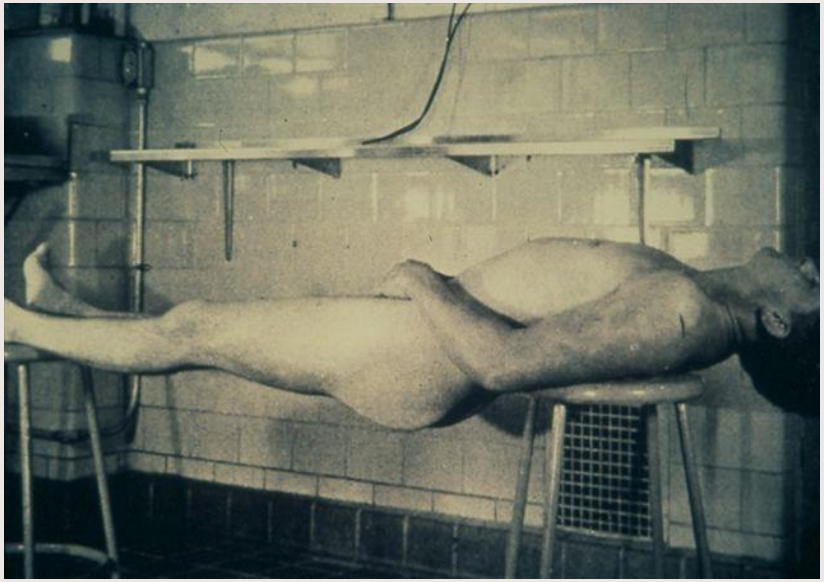


Muscular Dystrophy

- Dystrophin is a large protein that links Cytoskeletal proteins to membrane Glycoproteins
- It resemble other known cytoskeletal proteins and may be involved in maintaining the structural integrity of the plasma membrane,or of elements within the membrane,such as ion channels.
- In its absence ,fibers subjected to repeated structural deformation during contraction and susceptible to membrane rupture and cell death.

Rigor mortis

- After death muscle contract and become rigid ,this is called rigor mortis.
- Cause of rigor mortis is loss of ATP which is needed for separation of cross bridges from actin filament



Neuromuscular Junction

- The skeletal muscle fibers are innervated by a large ,myelinated nerve fibers that originate from large motor neurons in the anterior horns of spinal cord.
- Each nerve fiber ,before entering the muscle,normally branches and stimulates from three to several hundred muscle fibers.

Motor end plate

- Each terminal branch of nerve fiber(axon terminal) when comes close to the muscle fiber it loses the myelin sheath ,and innervates into the surface fiber,this portion is expanded.This entire structure is called motor end plate .It is covered by one or more schwann cells that insulate it from the surrounding fluid.