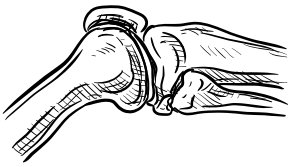
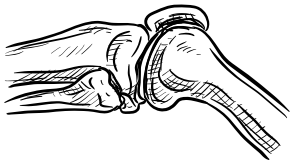
بسم الله الرحمن الرحيم

وَإِن تَتَوَلَّوْا يَسْتَبْدِلْ قَوْمًا غَيْرَكُمْ ثُمَّ لَا يَكُونُوا أَمْثَالَكُم

اللهم استعملنا ولا تستبدلنا



PHYSIOLOGY



MID | Lecture # 4

Skeletal muscle mechanics

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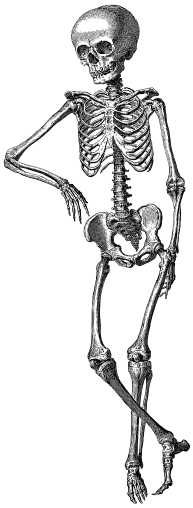
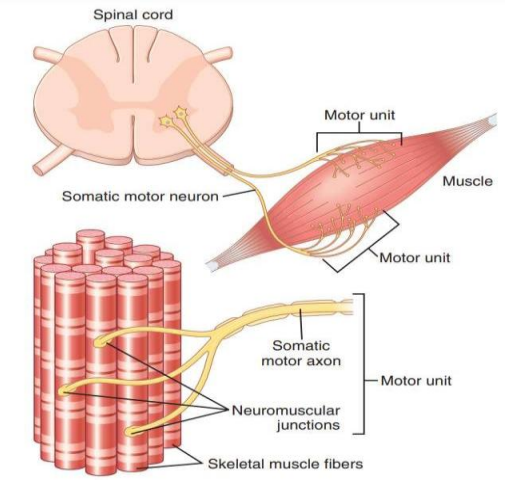


رَمَضَانُ مُبَارَكٌ

بدايةً: بما أننا سوف ندرس هذه المحاضرة في جميع الأحوال، ثانيةٌ واحدةٌ قبل بدئك بها تستحضر و تجدد فيها نيّتك بدراسة هذه المحاضرة نصرةً لدينك و إعلاءً لكلمة الله تخرجها من كونها عملًا دنيويًا خالصًا الى طاعةٍ قد تكون هي منجيتك يوم القيامة، فاجعلها بنيةٍ خالصة لوجه الله تعالى.

QUIZ ON THE LAST LECTURE HERE

Motor Unit



- ✓ Each lower motor neuron (motoneuron) innervates **multiple muscle fibers**, with the number of fibers innervated depending on the **type of muscle**. (Therefore, a muscle is made up of multiple motor units, each controlling a specific group of muscle fibers within that muscle.)
- ✓ All the muscle fibers innervated by a single nerve fiber are called a **motor unit**.
- ✓ **Smaller muscles** that react rapidly and whose control must be exact (responsible for fine, precise and delicate movement) have more nerve fibers for fewer muscle fibers (for instance, as few as two or three muscle fibers per motor unit in some of the laryngeal muscles).
- ✓ **Large muscles** that do not require fine control, such as the soleus muscle (one of the calf muscles that is responsible for maintaining posture), may have **several hundred muscle fibers per motor unit**.

- ✓ The muscle fibers within each motor unit are **not bunched together in the muscle** but are but overlap other motor units in microbundles of 3 to 15 fibers.

These muscle fibers within a single motor unit are not grouped and bundled all together, but instead spread out and interdigitated with fibers from other motor units in small clusters of 3 to 15 fibers.

- ✓ This interdigitation of the motor units allows the separate motor units to contract in support of one another rather than entirely as individual segments.

A muscle contraction that is uniformly spread across muscle for smooth contraction rather than jerky one.

Motor Unit Recruitment

- ✓ Motor unit recruitment is the process where the number of active motor units increases is called **motor unit recruitment**.
- ✓ Typically, the different motor units of an entire muscle are not stimulated to contract in unison. While some motor units are contracting, others are relaxed.

In submaximal contractions, the muscle does not recruit all motor units synchronously, but rather some are contracting, while others are resting. For weak contractions, few motor units are recruited, however, for stronger contractions, more motor units are activated to increase the strength/force of muscle contraction.

- ✓ This pattern of motor unit activity delays muscle fatigue and allows contraction of a whole muscle to be sustained for long periods.
- ✓ Recruitment is one factor responsible for producing smooth movements rather than a series of jerks.

This alternative and gradual pattern of motor unit recruitment, alongside interdigitation, produces smooth contraction across muscle instead of jerky one. Motor unit recruitment as well helps prevent muscle fatigue and allows muscles to keep working for long periods.

- ✓ The number of muscle fibers innervated by one motor neuron varies greatly. Precise movements are brought about by small changes in muscle contraction.
- ✓ Therefore, the small muscles that produce precise movements are made up of small motor units.
- ✓ By contrast, large motor units are active when a large amount of tension is needed and

The number of muscle fibers per motor unit varies between muscles depending on the size and function.

For smaller muscles that have smaller motor units, that is, fewer muscle fibers per motor neuron, when additional motor unit is recruited, only small increment in the muscle tension/force of contraction occurs, this applies to laryngeal or extraocular muscles for instance, where precise, fine and delicate movements are required.

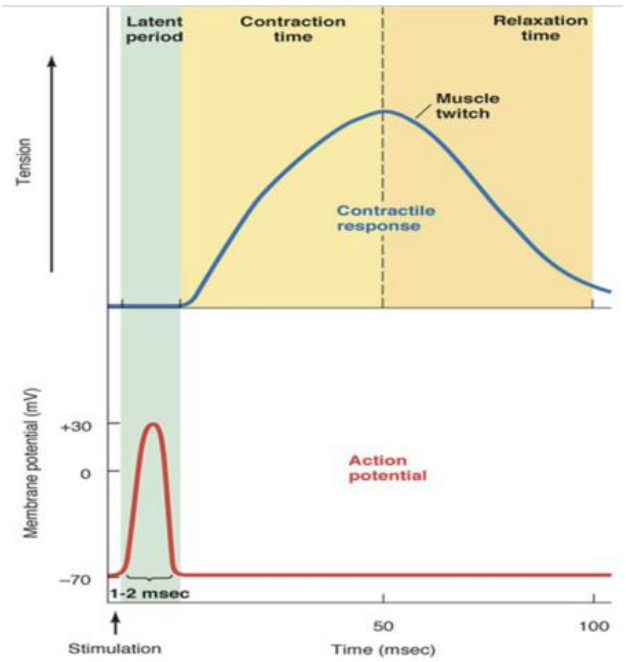
On the other hand, larger motor units are found within larger muscles in the body, great increment in the tension occurs when additional motor unit is activated, and this applies to soleus or quadriceps muscles for example, where powerful and less precise movements are needed.

Muscle Twitch and Contraction

A muscle twitch is a **weak contraction of muscle in response to a single action potential**. Typically, action potential lasts for barely **1-2ms**, where muscle twitch takes as long as **100ms** in general (it is variable between different muscles), which means that the action potential is over before the contraction even commences **(see the figure below)**. Muscle twitch occurs in three distinct phases:

1. Latent Period:

- ✓ The time between the stimulus (nerve impulse) and the initiation of muscle contraction.
- ✓ The delay in this phase is due to the time that the calcium (Ca^{2+}) needs to be released from the sarcoplasmic reticulum in response to the action potential as a part of the coupling mechanism between excitation and contraction.



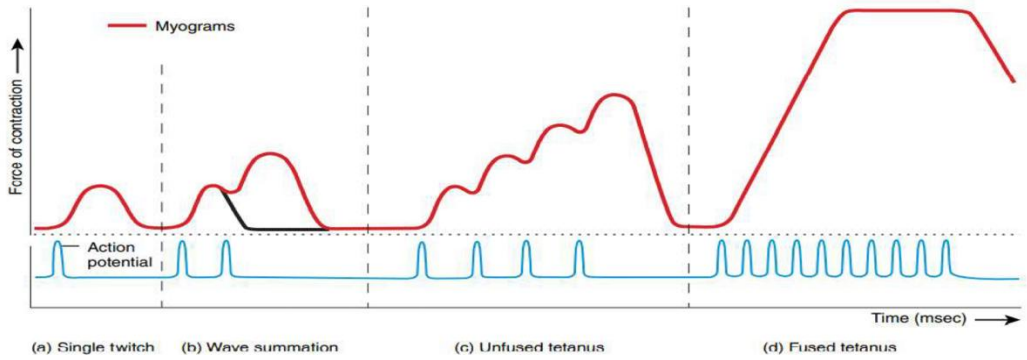
2. Contraction Phase:

- ✓ Cross-bridge formation occurs as actin and myosin filaments slide past each other.
- ✓ The muscle shortens and generates tension.

3. Relaxation Phase:

- ✓ Calcium is pumped back into the sarcoplasmic reticulum. The muscle returns to its resting state, and tension decreases.

➢ Twitch summation and tetanization.



1. Wave Summation:

- ✓ Occurs when a second stimulus arrives **before the muscle fully relaxes from the first twitch.** The next twitch starts at a higher tension because some calcium **(Ca^{2+})** ions from the previous action potential are not pumped back to the sarcoplasmic reticulum maintaining increasing concentration of **(Ca^{+2})**
- ✓ The two twitches from the successive stimuli are said to add together yielding a stronger contraction compared to a single twitch.
- ✓ This summation is termed **frequency summation**. Another type of summation is **multiple fiber summation (further discussed in the lab lecture)**.
- ✓ one crucial concept here is that muscle twitches are being summed not the actual action potentials, due to the refractory period that prevents restimulation of the sarcolemma until the end of the action potential.

2. Unfused (Incomplete) Tetanus:

- ✓ This happens when stimuli are given at a **high frequency**, therefore the muscle partially relaxes between stimuli.
- ✓ The muscle exhibits a **wavy**, **fluctuating** contraction pattern, but there is still partial relaxation between successive stimuli.

3. Fused (Complete) Tetanus:

- ✓ This occurs when stimuli are delivered at a **very high frequency**, preventing the muscle from relaxing at all between successive impulses.
- ✓ Calcium levels stay at their maximum level, and the muscle remains in constant and maximal contraction.

Muscular tissue Properties

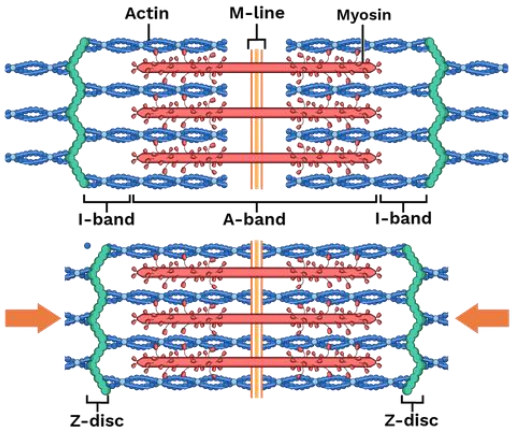
- ✓ Muscular tissue has four special properties that enable it to function and contribute to homeostasis:
- ✓ **Electrical excitability**, a property of both muscle and nerve cells, is the ability to respond to certain stimuli by producing electrical signals called action potentials (impulses).

- ✓ **Contractility** is the ability of muscular tissue to contract forcefully when stimulated by an action potential. When a skeletal muscle contracts, it generates tension (force of contraction) while pulling on its attachment points. If the tension generated is great enough to overcome the resistance of the object to be moved (load/opposing force), the muscle shortens, and movement occurs.

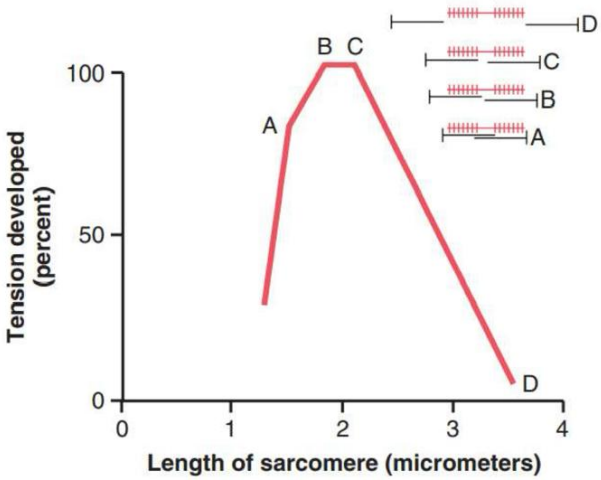
- ✓ **Extensibility** is the ability of muscular tissue to stretch, within limits, without being damaged. The connective tissue within the muscle limits the range of extensibility and keeps it within the contractile range of the muscle cells. Normally, smooth muscle is subject to the greatest amount of stretching.

- ✓ **Elasticity** is the ability of muscular tissue to return to its original length and shape after contraction (shortening) or extension.

Remember:



Length-Tension Relationship



- ✓ The figure on the right depicts the relationship between the length of a single sarcomere or single muscle fiber (not a whole muscle) and the **active tension** developed, this can be later reflected to the contraction of the entire muscle mass.
- ✓ The amount of **actin and myosin filament overlap** (possible cross-bridge interaction) determines **active tension** developed by the contracting muscle.
- ✓ At point D in the diagram, the actin filament has pulled all the way out to the end of the myosin filament, with no actin-myosin overlap. At this point, the tension developed by the activated muscle is zero.
- ✓ The sarcomere shortens and the actin filament begins to overlap the myosin filament, the tension increases progressively until the sarcomere length decreases to about 2.2 micrometers.

- ✓ At point C (2.2 micrometers) the actin filament has already overlapped (attached) with all the cross-bridges of the myosin filament but has not yet reached the center of the myosin filament. (M line of band A).

- ✓ With further shortening, the sarcomere maintains full maximal tension until point B is reached, at a sarcomere length of about 2 micrometers. At this point, the ends of the two actin filaments begin to overlap each other in addition to overlapping the myosin filaments.

Sarcomere length of **(2-2.2) micrometers** is referred to as the **optimal length**. It is basically the sarcomere length with which **maximal tension** can be achieved. Beyond this critical length, the **tension** developed decreases gradually approaching zero.

- ✓ As the sarcomere length decreases from 2 micrometers down to about 1.65 micrometers, at point A, the strength of contraction decreases rapidly. After that, the two Z disks of the sarcomere abut (in a very close proximity to one another) the ends of the myosin filaments.

- ✓ Then, as contraction proceeds to still shorter sarcomere length, the ends of the myosin filaments are crumpled, and the strength of contraction approaches zero, but the sarcomere has now contracted to its shortest length.

Isometric vs isotonic contraction

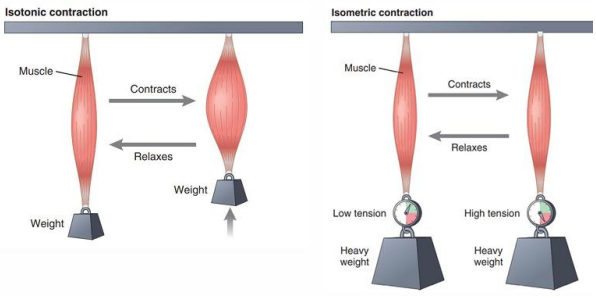
- ✓ Muscle contraction is said to be **isometric** when the muscle does not shorten during contraction, the skeletal muscle length is fixed, and the joint angle does not change.
- ✓ **Isotonic** when it does shorten but the tension on the muscle remains constant throughout the contraction. Thereupon movement occurs and the joint angle does change.

Isotonic contraction

- ✓ Isotonic contractions are used for body movements and for moving objects. The two types of isotonic contractions are **concentric and eccentric.**
- ✓ If the tension generated in a concentric isotonic contraction is **great enough to overcome the resistance of the object to be moved**, the muscle shortens and pulls on another structure, such as a tendon, to produce movement and to reduce the angle at a joint.
- ✓ Picking up a book from a table involves concentric isotonic contractions of the biceps brachii muscle in the arm.

- ✓ Isotonic contraction refers to a type of muscle contraction where the muscle changes length while maintaining a constant tension throughout the movement.
- ✓ There are two types of isotonic contractions:
- ✓ **Concentric**: The muscle shortens as it contracts since the tension outweighs the opposing force (e.g., lifting a weight).

Isometric vs isotonic contraction



- ✓ **Eccentric**: The muscle lengthens while contracting since the opposing force outweighs the tension developed (e.g., lowering a weight).

Isometric contraction

- ✓ In an isometric contraction, **the tension generated is not enough to exceed the resistance of the object to be moved**, and the muscle does not change its length.

There is contraction and sarcomere shortening producing tension, but the overall muscle does not change length nor produce any movement.

- ✓ An example would be holding a book steady using an outstretched arm. These contractions are important for **maintaining posture** and for supporting objects in a **fixed position**.

It provides stationery and steady contractions.

- ✓ Although isometric contractions do not result in body movement, energy is still expended.

- ✓ The book pulls the arm downward, stretching the shoulder and arm muscles. The isometric contraction of the shoulder and arm muscles counteracts the stretch.

- ✓ Isometric contractions are important because they **stabilize some joints** as others are moved.

✓ Most activities include both isotonic and isometric contraction.

Bodily activities are complex mechanical systems, therefore both isometric and isotonic contraction must curry out in harmony most of the time.

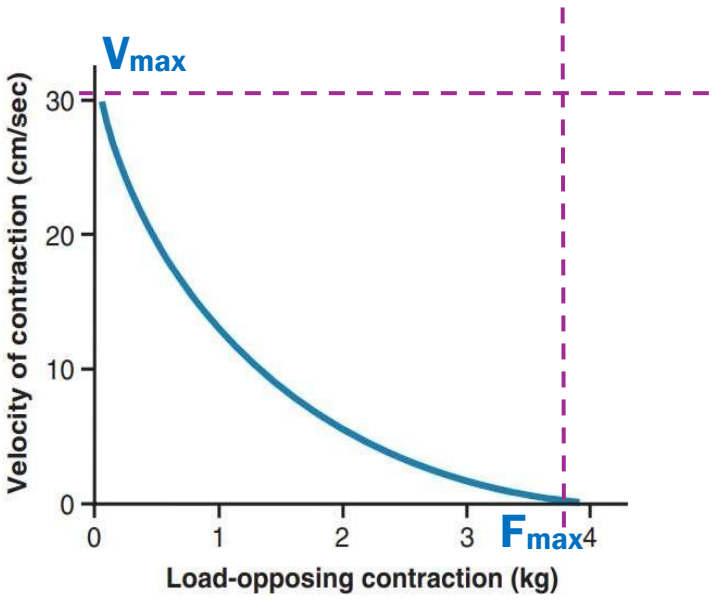
Isometric vs isotonic contraction

✓ **Isotonic contraction** occurs when the force of the muscle contraction is greater than the load and the tension on the muscle remains constant during the contraction; when the muscle contracts, it shortens and moves the load.

✓ **Isometric contraction** occurs when the load is greater than the force of the muscle contraction; the muscle creates tension when it contracts, but the overall length of the muscle does not change

Contraction Velocity-Load Relationship

- ✓ A skeletal muscle contracts rapidly with maximal velocity **(V_{max})** when it contracts against no load.
- ✓ When loads are applied, the velocity of contraction becomes **progressively less** as the load increases.
- ✓ When the load has been increased to **equal the maximum force (F_{max}) that the muscle can exert**, the velocity of contraction becomes zero and no contraction results, despite activation of the muscle fibers.
- ✓ This decreasing velocity of contraction with load is caused by the fact that a load on a contracting muscle is considered a **reversed force that opposes the contractile force** caused by muscle contraction.
- ✓ Therefore, the net force that is available to cause velocity of shortening is correspondingly reduced when there is load on the muscle.



Muscle tone

- ✓ Even when muscles are at rest, a certain amount of tension usually remains, which is called **muscle tone**.
- ✓ Because normal skeletal muscle fibers do not contract without an action potential to stimulate the fibers, skeletal muscle tone results entirely from a low rate of nerve impulses coming from the spinal cord**.**
- ✓ These nerve impulses, in turn, are controlled partly by signals transmitted from the brain to the appropriate spinal cord anterior motoneurons and partly by signals that originate in muscle spindles (those are **sensory receptors** that sense stretching of muscle tissue) located in the muscle itself.

We can define it as: "**constant, involuntary and low level** of muscle tension that is maintained at rest, controlled by complex neural circuits in the brain, spinal cord, and muscle spindles, it is responsible for maintaining posture and eliciting spinal reflexes, Skeletal muscle tone is due to both elastic properties of the muscle that resist passive stretching and continuous, minimal stimulation by motor neurons that produces a constant state of partial muscle contraction"

- ✓ When the motor neurons serving a skeletal muscle are damaged or cut, the muscle becomes flaccid, a state of limpness in which muscle tone is lost.
- ✓ To sustain muscle tone, small groups of motor units are alternatively active and inactive in a constantly shifting pattern.

It is a weak state of alternative pattern of contractions and relaxations of motor units.

- ✓ Muscle tone keeps skeletal muscles firm, but it does not result in a force strong enough to produce movement.

Muscle tone helps keep muscle tissue firm (tight and strong enough), without which, the muscle would be floppy and lax, however, the tension produced is too weak to produce any movement. Of course, more forceful and purposeful contractions can be commanded at any time to produce movements.

- ✓ Muscle tone also is important in **smooth muscle tissues**, such as those found in the gastrointestinal tract, where the walls of the digestive organs maintain a steady pressure on their contents.
- ✓ The tone of smooth muscle fibers in the walls of blood vessels plays a crucial role in maintaining blood pressure.

Clinical connection: muscle tone examination

Click on the image to see the video or use the link. Muscle tone

This is clinical assessment of muscle tone, where examiner stretches patient's hand passively and feels resistance, evaluating muscle firmness and range of motion at the wrist or elbow joint for instance, to check for neurological or muscular disorders that result in hypertonia or hypotonia where there is abnormal increase or decrease in muscle tone respectively. Examiners must also check for spinal or tendon reflexes like stretch reflexes, just by tapping and knocking muscle tendon by a medical hammer, a sudden movement occurs across the joint, this indicates healthy muscle. These reflexes might be lost, reduced or exaggerated if an underlying problem is present.

- ✓ **Normal Tone** → Firm, smooth muscle and slight resistance present.
- ✓ **Hypotonia (Low Tone)** → Floppy, lax and flaccid muscle with decreased resistance.
- ✓ **Hypertonia (High Tone)** → Rigid, stiff and spastic muscle with Increased resistance.

Hypotonia

- ✓ Hypotonia refers to decreased or lost muscle tone. Such muscles are said to be **flaccid**.
- ✓ Flaccid muscles are loose and appear flattened rather than rounded. Caused by certain disorders of the nervous system and disruptions in the balance of electrolytes (especially sodium, calcium, and, to a lesser extent, magnesium) may result in flaccid paralysis which is characterized by loss of muscle tone, loss or reduction of tendon reflexes, and atrophy (wasting away) and degeneration of muscles**.**

The best example to remember hypotonia is facial nerve palsy due to a lower motor neuron lesion (Bell's palsy).

Hypertonia

- ✓ Hypertonia refers to increased muscle tone and is expressed in two ways:
- ✓ **Spasticity** is characterized by increased muscle tone (**stiffness**) associated with an increase in tendon reflexes and pathological reflexes.

Hypertonia & Hyperreflexia (increased tendon reflexes) are present.

- ✓ **Rigidity** refers to increased muscle tone in which reflexes are not affected.

Only hypertonia is present.

Muscle fatigue

- ✓ Prolonged and strong contraction of a muscle leads to the well-known state of muscle fatigue.
- ✓ Studies have shown that muscle fatigue increases in almost direct proportion to the rate of depletion of muscle glycogen.
- ✓ Fatigue results mainly from **inability of the contractile and metabolic processes of the muscle fibers to continue supplying the same work output.**

Fatigue is a decline in the ability of the muscle to respond to stimulation, which occurs after prolonged and strong contraction. Depletion of metabolites like ATP, glycogen, Ca+2, electrolyte imbalance in general and oxygen supply are the main causes of this condition.

- ✓ **Interruption of blood flow** through a contracting muscle leads to almost complete muscle fatigue within 1 or 2 minutes because of the loss of nutrient supply, especially the loss of oxygen.

Fatigue of NMJ

- ✓ Stimulation of the nerve fiber at rates greater than 100 times per second for several minutes often diminishes the number of acetylcholine vesicles so much that impulses fail to pass into the muscle fiber.
- ✓ This situation is called **fatigue of the neuromuscular junction.**

(Depletion of acetylcholine)

CNS fatigue

- ✓ Originates from the central nervous system and affects the neural drive to muscles leading to generalized tiredness and decreased overall performance.

This condition might be Due to:

1. Neurotransmitter imbalance.
2. Impairing of the nerve signals.
3. Intensive exercises, because our body takes "**CNS fatigue"** as a **protective mechanism**, to increase the inhibitory effect or protect the muscle from damage, so CNS commands the muscles to relax.

Remodelling of muscle to match function

- ✓ All the muscles of the body are continually being remodeled to match the functions that are required of them.
- ✓ Their diameters, lengths, strengths, and vascular supplies are altered, and even the types of muscle fibers are altered at least slightly.

Muscle hypertrophy

- ✓ The increase of the total mass of a muscle is called **muscle hypertrophy**.
- ✓ Virtually all muscle hypertrophy results from an increase in the number of actin and myosin filaments in each muscle fiber, causing enlargement of the individual muscle fibers; this condition is called simply **fiber hypertrophy**.
- ✓ Along with the increasing size of myofibrils, the enzyme systems that provide energy also increase. This increase is especially true of the enzymes for glycolysis, allowing rapid supply of energy during short-term forceful muscle contraction.
- ✓ **Adjustment of Muscle Length**. Another type of hypertrophy occurs when muscles are stretched to greater than normal length.
- ✓ This stretching causes new sarcomeres to be added at the ends of the muscle fibers, where they attach to the tendons, increasing muscle length.

Muscle atrophy

"If you don't use it, you lose it"

- ✓ When a muscle remains unused for many weeks, the rate of degradation of the contractile proteins is more rapid than the rate of replacement. Therefore, **muscle atrophy** occurs (a decrease in total mass).
- ✓ The pathway that appears to account for much of the protein degradation in a muscle undergoing atrophy is the **ATP-dependent ubiquitin-proteasome pathway**.

Pay attention to this image.

If it happens to have your arm broken (God forbid), you will notice after taking the cast off how your arm muscles are, however with continuous exercise and stretching, they will get back to their normal size.

In case of nerve injury, physical therapy and rehabilitation are required to restore normal function and size at least partially if not completely.

Muscle Denervation

- ✓ Causes Rapid Atrophy.
- ✓ When a muscle loses its nerve supply, it no longer receives the contractile signals that are required to maintain normal muscle size. Therefore, atrophy begins almost immediately.
- ✓ After about 2 months, degenerative changes also begin to appear in the muscle fibers.

carrying out blood tests will reveal high concentration of skeletal muscle proteins and enzymes in the plasma.

Click on sambosa or minibancakes stuffed with walnuts to go to a quick quiz on this lecture or use this link.

Enjoy.

Additional Resources:

رسالة من الفريق العلمي:

أدعو لنا ولوالدينا بالرحمة والمغفرة، وأن يجزل الله لهما الثواب.

أَيَّ مَحَلٍّ أَرتَقي

أَيَّ عَظيمٍ أَتَّقي

وَكُلُّ ما قَد خَلَقَ الـ

ـلاهُ وَما لَم يَخلُقِ

مُحتَقَرٌ في هِمَّتي

كَشَعرَةٍ في مَفرِق

For any feedback, scan or click the code.

Versions	Page #	Before	After
V0 → V1			**Some info. is deleted under these headings:** **Muscular tissue Properties** **Lengthen-tension relationship** **Isometric vs isotonic** **Velocity-load relationship**
V1 → V2			