MSS

Physiology

|Modified slides

Written by: Laith Sami
Correction: Dr.Fatima Ryalat
Doctor: Dr.Fatima Ryalat

Skeletal muscle physiology for medical students 2022

Skeletal muscle contraction-2

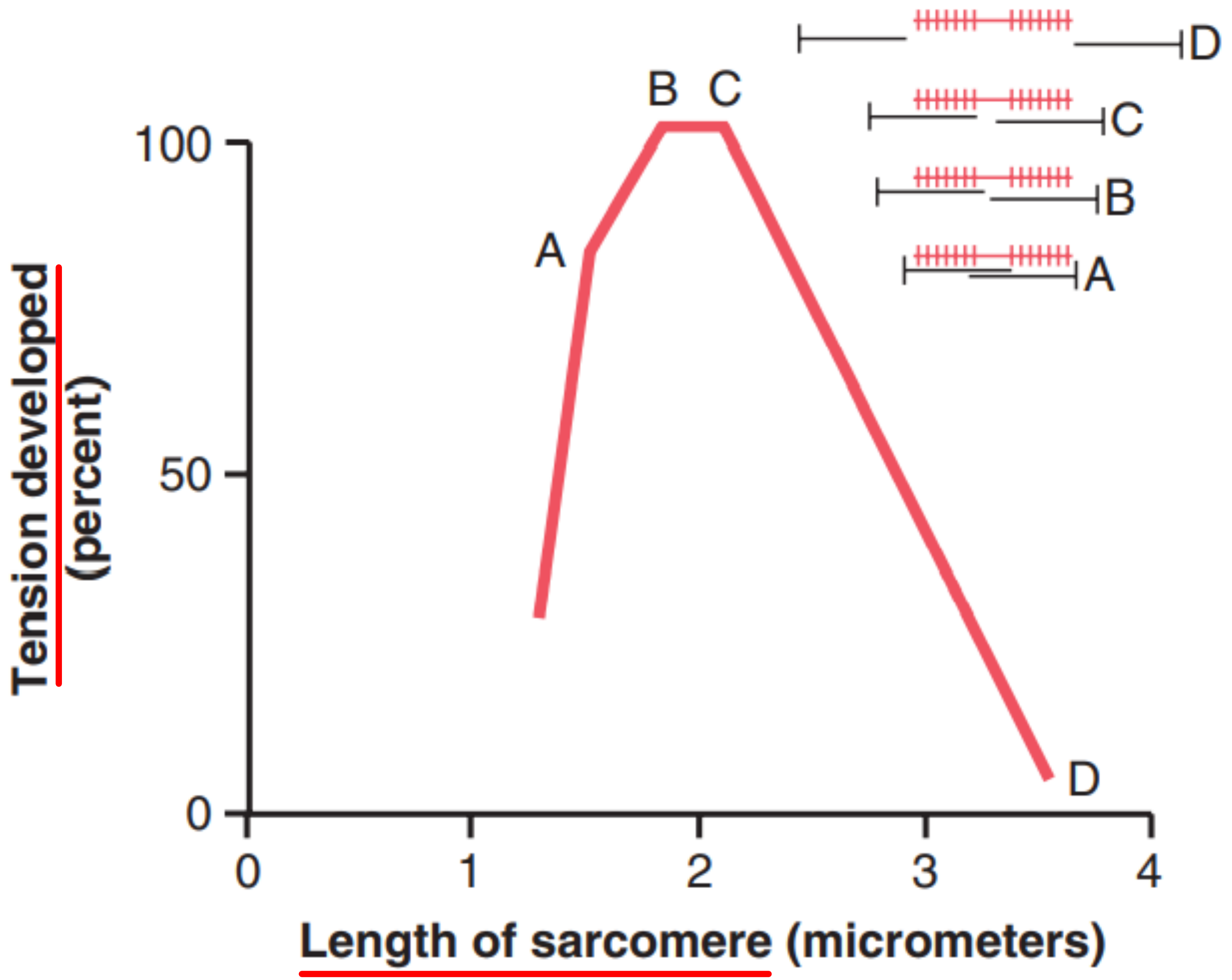
Fatima Ryalat, MD, PhD

Assistant professor,
Physiology and Biochemistry Department,
School of Medicine, University of Jordan.

Outline

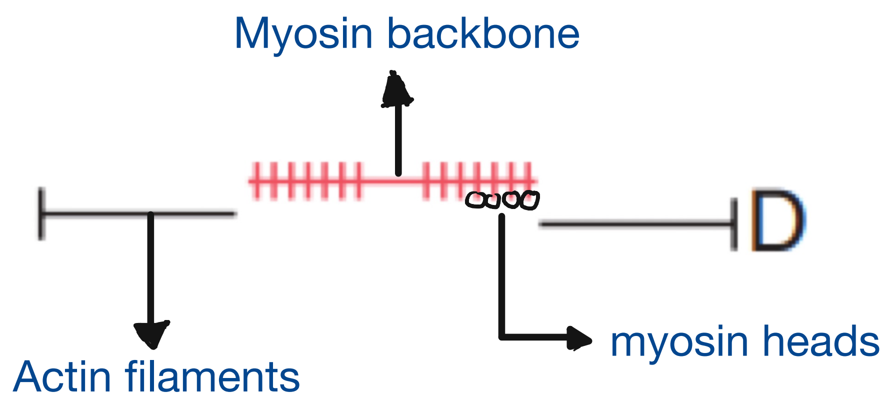
- Length- tension relationship
- Load- velocity relationship
- Motor unit
- Types of contraction
- Fatigue
- Remodeling of the muscle
- Skeletal, smooth and cardiac muscles

Length-tension relationship



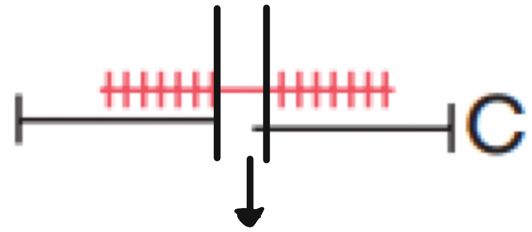
In the previous lecture, we talked about the sources that provide us with the energy needed to perform muscle contraction, as we mentioned that muscle contraction does not occur unless there is an overlap between actin and myosin filaments and the sarcomere becomes shorter.

There are two important factors that control muscle contraction, length and tension



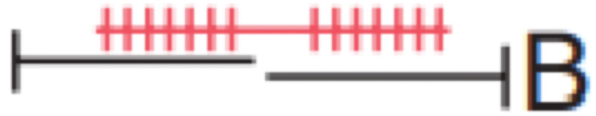
In this case, (D) ,the sarcomere is extended and there is no overlap between the actin and myosin filaments, meaning that the myosin heads are not connected to their positions on the actin filaments, and the tension is equal to zero.

In this case, (C), the sarcomere begins to shorten and an overlap between the actin filaments and the myosin heads appeared, and the overlap continued until all myosin heads became attached to their positions on the actin filaments, and then the so-called (Maximum Cross Bridges)occurred, and accordingly the tension becomes at its highest.



(H)zone ,doesn't have myosin head

In this case,(B),the number of myosin heads attached to the actin filaments remains constant, the tension also remains constant, but the length of the sarcomere decreases.



In this case,(A),the length of the sarcomere decreases more and more, and the actin filaments slip between each other and as a result, the connection between the myosin heads and the actin filaments decreases, and the tension also decreases.

- At point D on 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.

- as 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 this point, the actin filament has already overlapped all the cross-bridges of the myosin filament but has not yet reached the center of the myosin filament.

- With further shortening, the sarcomere maintains full 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.

- As the sarcomere length decreases from 2 micrometers down to about 1.65 micrometers, at point A, the strength of contraction decreases rapidly. At this point, the two Z disks of the sarcomere abut the ends of the myosin filaments.

- Then, as contraction proceeds to still shorter sarcomere lengths, 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.

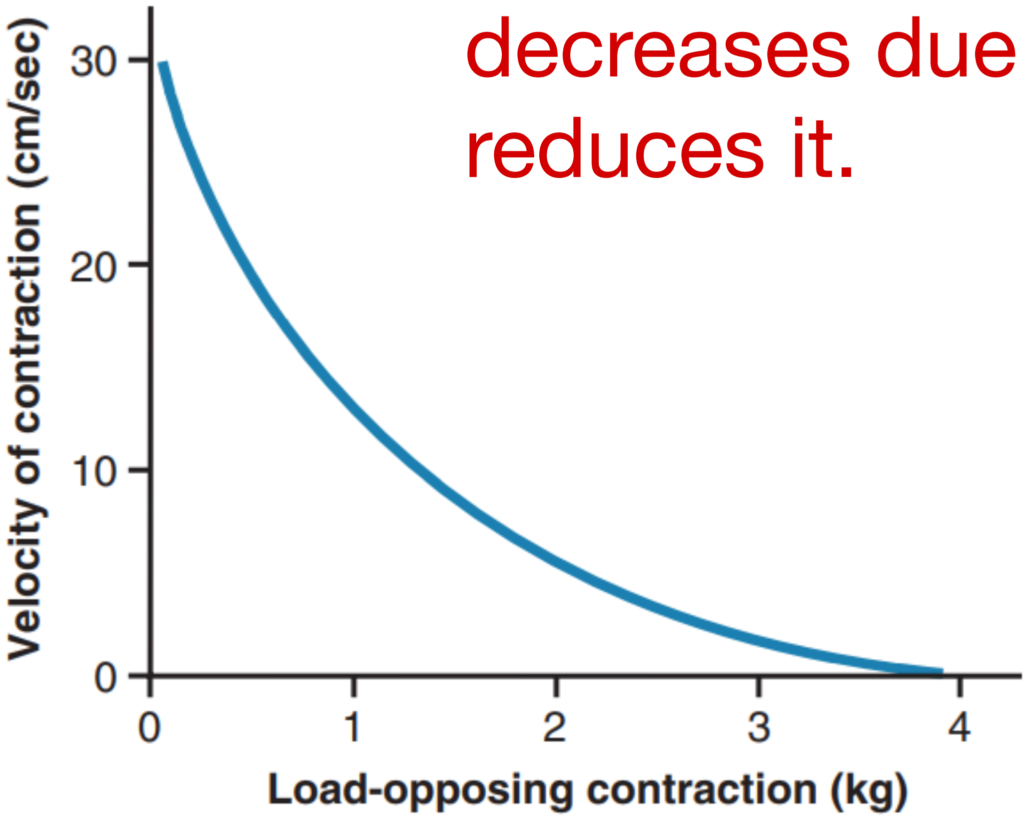
The amount of actin and myosin filament overlap determines tension developed by the contracting muscle.

Effect of muscle length on force of contraction in the whole intact muscle

- The whole muscle has a large amount of connective tissue in it; in addition, the sarcomeres in different parts of the muscle do not always contract the same amount. Therefore, the curve has somewhat different dimensions from the individual muscle fiber, but it exhibits the same general form for the slope in the normal range of contraction.

Contraction velocity- load

As the load increases, the speed decreases due to the resistance that reduces it.



Contraction velocity- load

- A skeletal muscle contracts rapidly when it contracts against no load.

- When loads are applied, the velocity of contraction becomes progressively less as the load increases.

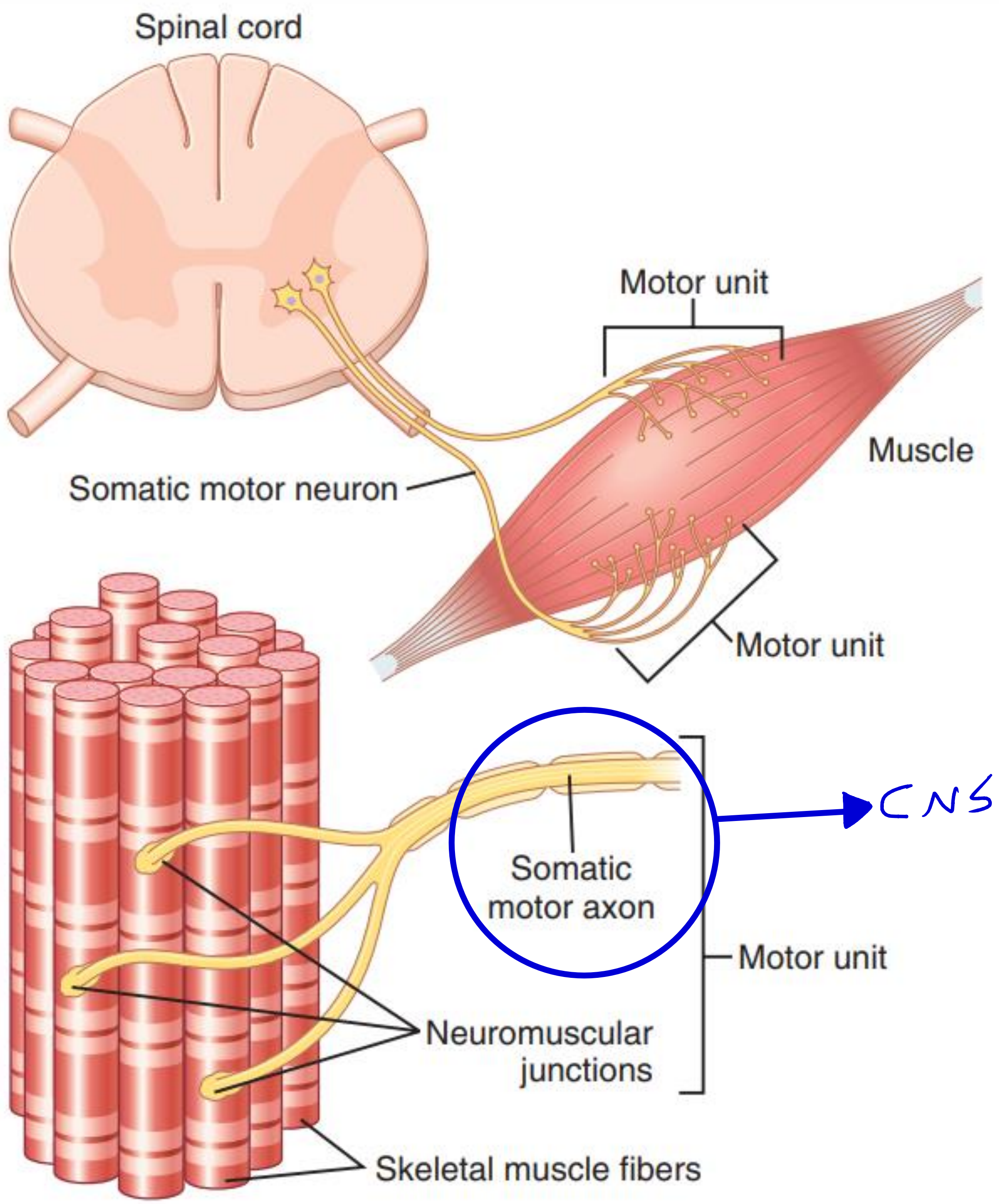
- when the load has been increased to equal the maximum force that the muscle can exert, the velocity of contraction becomes zero and no contraction results, despite activation of the muscle fiber.

Contraction velocity- load

- This decreasing velocity of contraction with load is caused by the fact that a load on a contracting muscle is a reverse 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.

Somatic motor neuron

Motor unit



Motor unit

- Each lower motor neuron (motoneuron) innervates multiple muscle fibers, with the number of fibers innervated depending on the type of muscle.

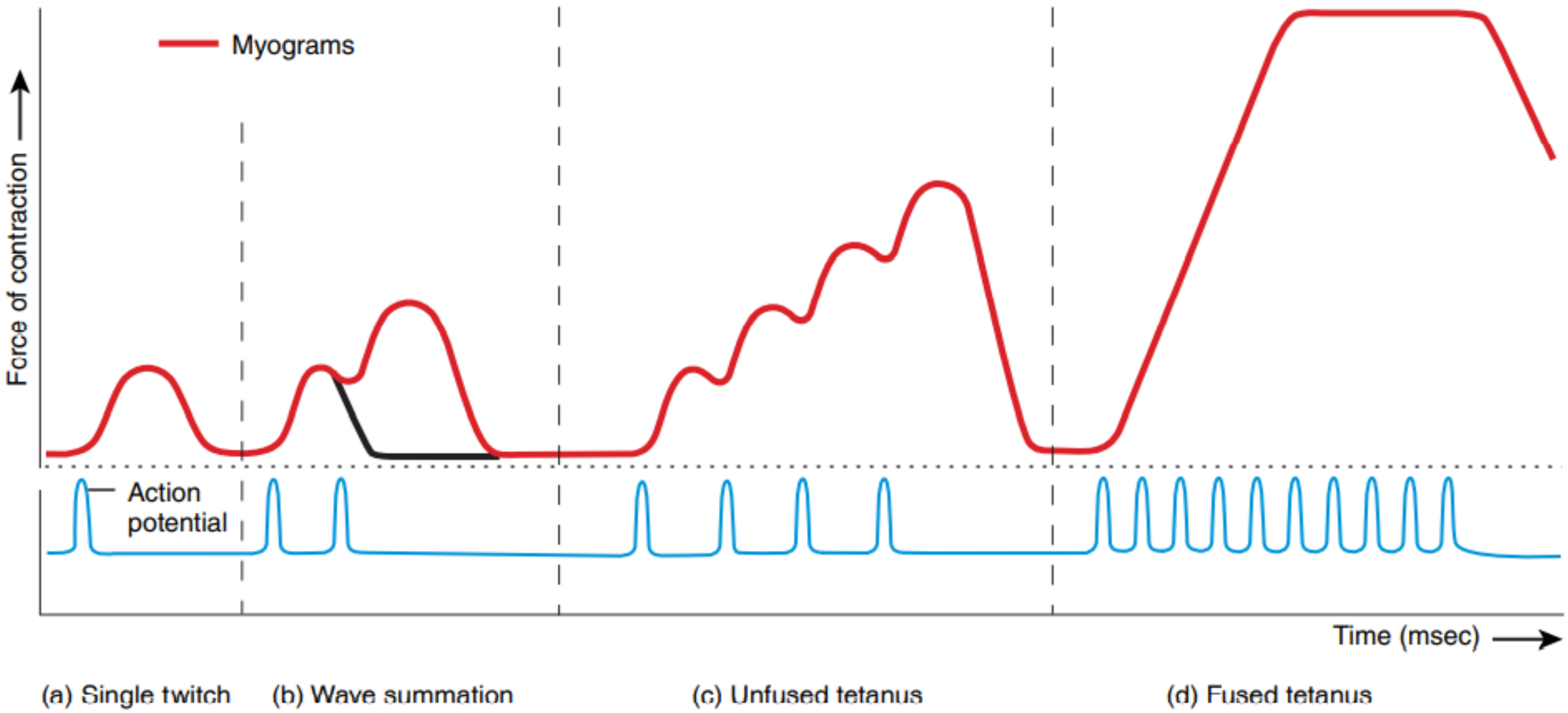
- All the muscle fibers innervated by a single nerve fiber are called a **motor unit**.

Motor unit

- In general, smaller muscles that react rapidly and whose control must be exact 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).

- Conversely, large muscles that do not require fine control, such as the soleus muscle, may have several hundred muscle fibers in a motor unit.

Physiology lab



Motor unit

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

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

Motor unit recruitment

- The process in which 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. 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.

Motor unit recruitment

- 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 precision is less important.

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 located in the muscle itself.

Muscle tone

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

Muscle tone

- 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

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Hypotonia flaccidity

- 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. 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.

Hypertonia

- Hypertonia refers to increased muscle tone and is expressed in two ways:

- **spasticity or rigidity**. Spasticity is characterized by increased muscle tone (stiffness) associated with an increase in tendon reflexes and pathological reflexes.

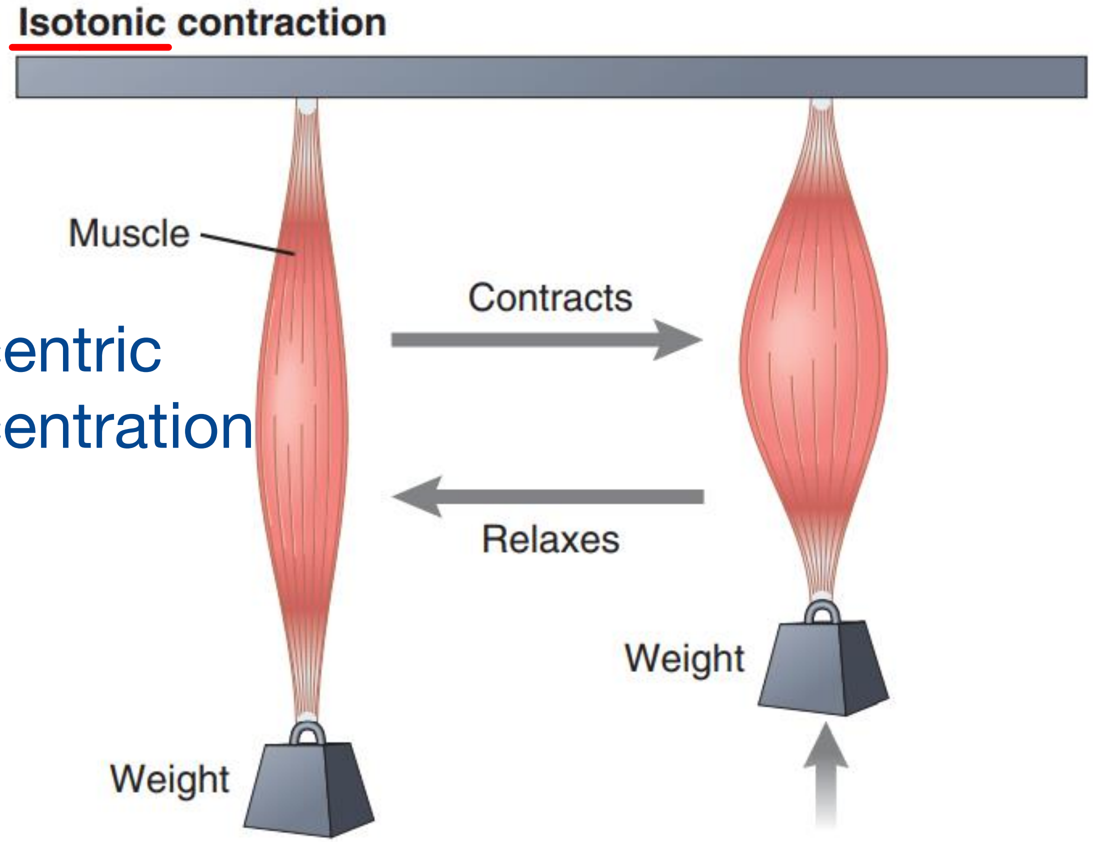
- Rigidity refers to increased muscle tone in which reflexes are not affected.

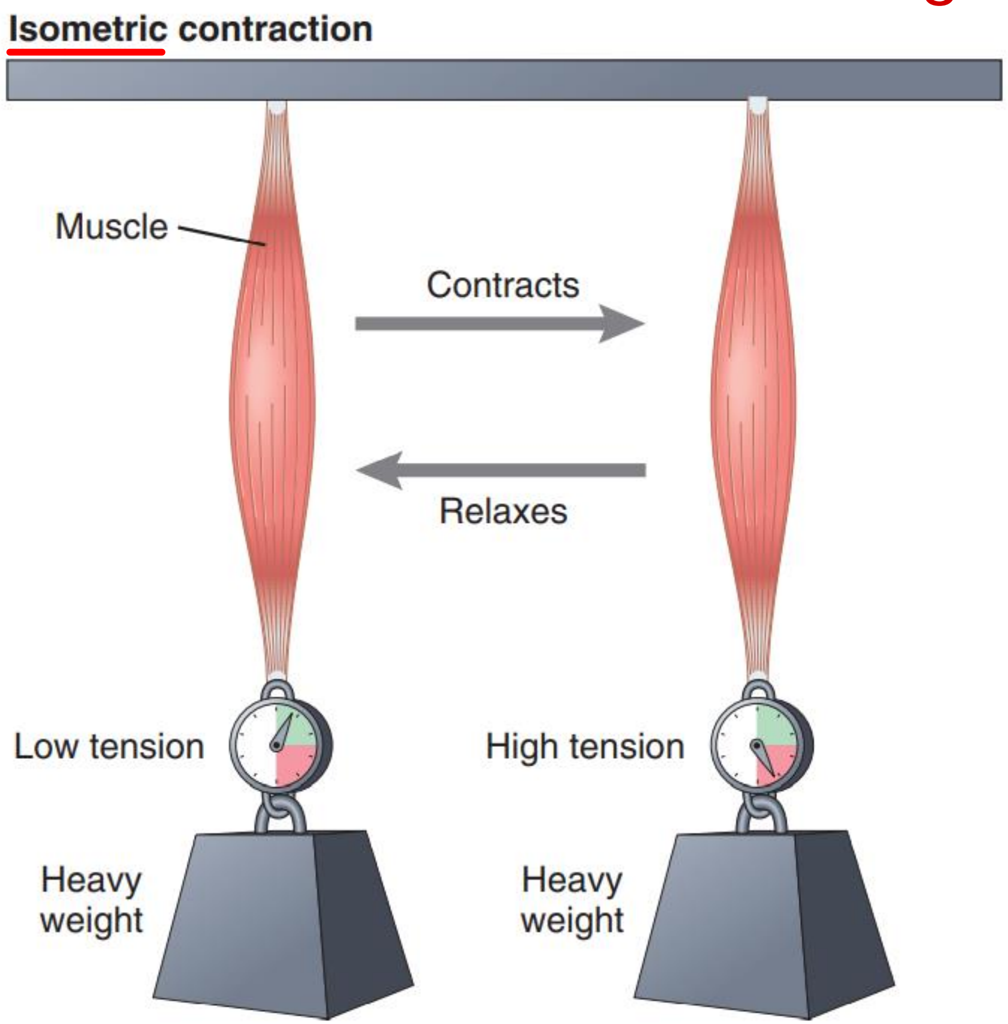
Isometric vs isotonic contraction

The tension is constant, but the length changes

The length is constant, but the tension changes

concentric
concentration





Isometric vs isotonic contraction

- Muscle contraction is said to be isometric when the muscle does not shorten during contraction,

- and isotonic when it does shorten but the tension on the muscle remains constant throughout the contraction.

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. By contrast, as you lower the book to place it back on the table, the previously shortened biceps lengthens in a controlled manner while it continues to contract. When the length of a muscle increases during a contraction, the contraction is an eccentric isotonic contraction. During an eccentric contraction, the tension exerted by the myosin cross-bridges resists movement of a load (the book, in this case) and slows the lengthening process.

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. 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. 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.

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.

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. Therefore, fatigue results mainly from **inability of the contractile and metabolic processes of the muscle fibers to continue supplying the same work output**.

- **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

- However, 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**.

CNS fatigue

CNS fatigue,for example when you feel that your muscles are tired and want to drop the load before you actually do so.The CNS integrates the information from different sensory receptors including muscle spindle (stretch receptor) and golgi tendon organ (tension receptor , and decide to stop exciting that muscle sometimes as a protective mechanism from muscle injury.The mechanism is not clear yet.

Remodeling 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.

Athletes, such as swimmers and soccer players, have larger muscles than normal people, and the number of sarcomeres is large because of the large size of the muscles.

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**.

Muscle 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.

Muscle atrophy

- 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.

Clinical connection

https://www.medindia.net/

- **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.

- **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.

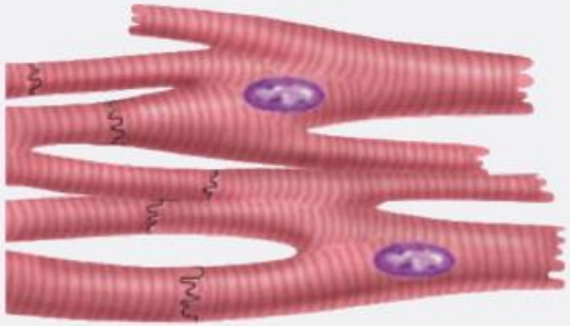
- **Muscular tissue has four special properties** that enable it to function and contribute to homeostasis:

- 1. **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).

- 2. **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, the muscle shortens and movement occurs.

- 3**. 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.

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

CHARACTERISTIC	SKELETAL MUSCLE	CARDIAC MUSCLE	SMOOTH MUSCLE
Microscopic appearance and features	Long cylindrical fiber with many peripherally located nuclei; unbranched; striated.	Branched cylindrical fiber with one centrally located nucleus; intercalated discs join neighboring fibers; striated.	Fiber thickest in middle, tapered at each end, and with one centrally positioned nucleus; not striated.
The doctor said they are not required and did not explain them			
Location	Most commonly attached by tendons to bones.	Heart.	Walls of hollow viscera, airways, blood vessels, iris and ciliary body of eye, arrector pili muscles of hair follicles.
Fiber diameter	Very large (10–100 μm).	Large (10–20 μm).	Small (3–8 μm).
Connective tissue components	Endomysium, perimysium, and epimysium.	Endomysium and perimysium.	Endomysium.
Fiber length	Very large (100 μm–30 cm = 12 in.).	Large (50–100 μm).	Intermediate (30–200 μm).
Contractile proteins organized into sarcomeres	Yes.	Yes.	No.

Sarcoplasmic reticulum	Abundant.	Some.	Very little.
Transverse tubules present	Yes, aligned with each A–I band junction.	Yes, aligned with each Z disc.	No.
Junctions between fibers	None.	Intercalated discs contain gap junctions and desmosomes.	Gap junctions in visceral smooth muscle; none in multi-unit smooth muscle.
Autorhythmicity	No.	Yes.	Yes, in visceral smooth muscle.
Source of Ca^{2+} for contraction	Sarcoplasmic reticulum.	Sarcoplasmic reticulum and interstitial fluid.	Sarcoplasmic reticulum and interstitial fluid.
Regulator proteins for contraction	Troponin and tropomyosin.	Troponin and tropomyosin.	Calmodulin and myosin light chain kinase.
Speed of contraction	Fast.	Moderate.	Slow.
Nervous control	Voluntary (somatic nervous system).	Involuntary (autonomic nervous system).	Involuntary (autonomic nervous system).
Contraction regulation	Acetylcholine released by somatic motor neurons.	Acetylcholine and norepinephrine released by autonomic motor neurons; several hormones.	Acetylcholine and norepinephrine released by autonomic motor neurons; several hormones; local chemical changes; stretching.
Capacity for regeneration	Limited, via satellite cells.	Limited, under certain conditions.	Considerable (compared with other muscle tissues, but limited compared with epithelium), via pericytes.

Thank you