SKELETAL MUSCLE AND MUSCLE FIBERS

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INDEX

INTRODUCTION

Muscular systems.

Muscles are attached by tendons and fasciae to the skeleton. The abundance of blood vessels gives them their red colour; tendons and fasciae appear white because of their sparse vascular supply.

The technique for determining the electrical activity of muscle contraction is called electromyography (EMG).

The force made by a muscle varies according to its shape. Under intense exercise, the muscle fibers enlarge and if the muscles are not used, they atrophy.

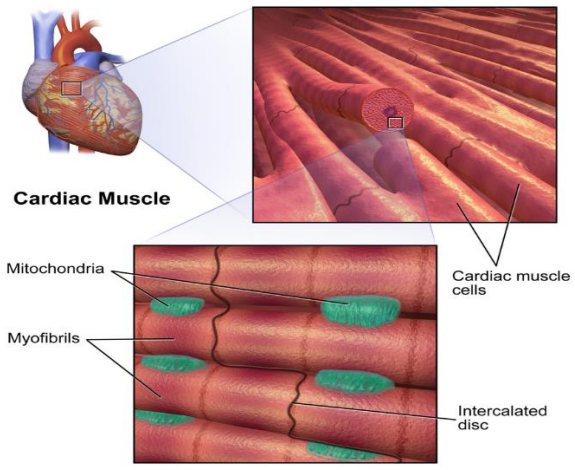
Muscle structure.

The cells that make up muscles are myocytes. They are made up of proteins called actins and myosins, long filamentous proteins that alternate to modify the length of the cell to produce the contraction.

The human body has three types of muscle.

- **Cardiac.**

This type of muscle cell is found only in the heart. Autonomic nerves can adjust the rate of contraction by adapting the output of the heart to the needs of the body.



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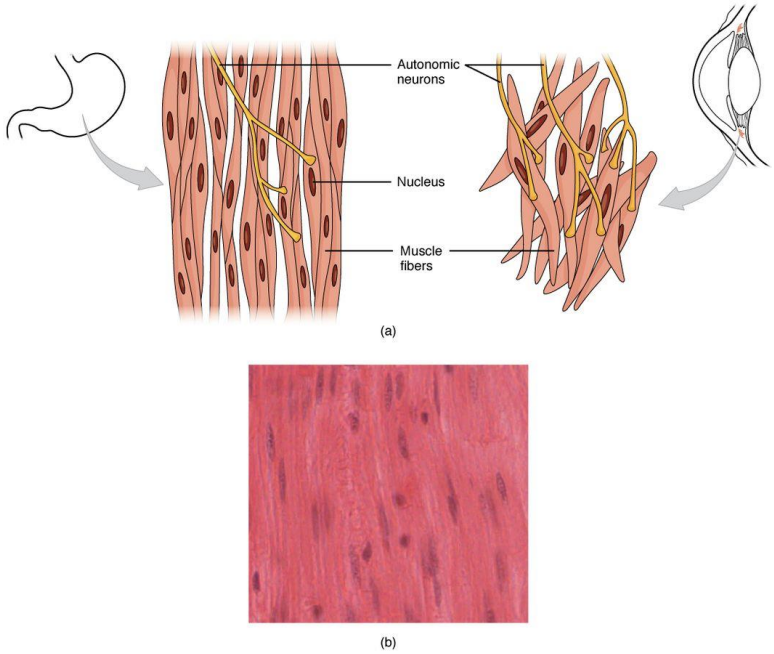
- **Smooth or involuntary.**

Corresponds to the visceral muscles.



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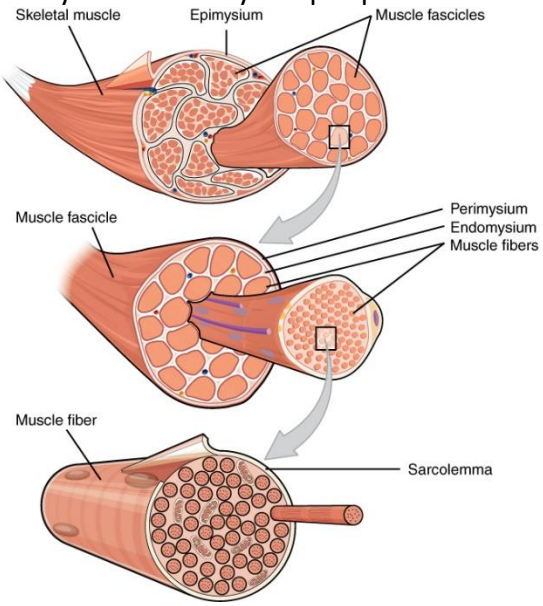
- **Skeletal or voluntary.**

These are muscles, composed of parallel fiber bundles, supplied by somatic motor nerves. They are consciously controlled by the peripheral nervous system.



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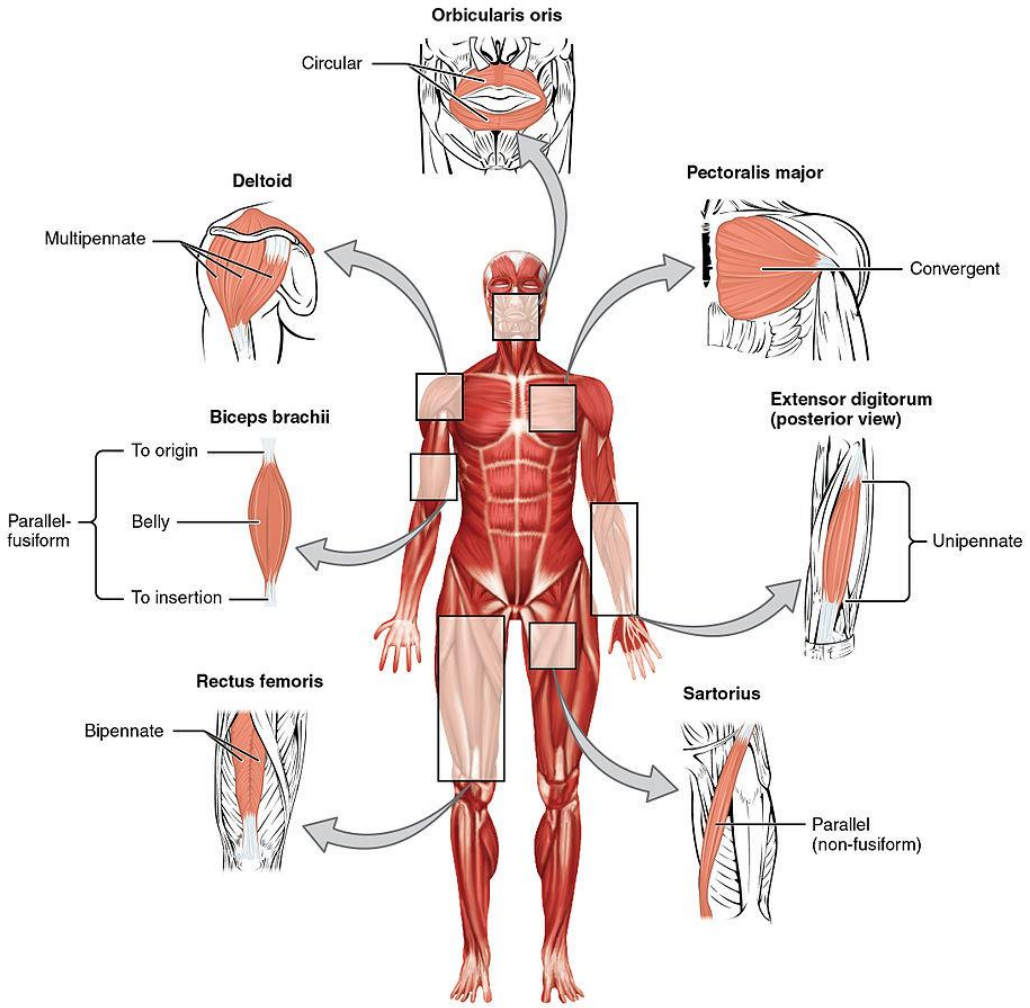
Muscle forms.



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The human body is capable of controlling more than 750 muscles. Functionally, muscles are classified into extensor (antigravity) and flexor (gravity) muscles. Muscles with similar actions act on a joint versus antagonists, which act in opposite ways.

Types of movement: reflex, rhythmic and voluntary.

✦ Reflex movements.

These are short-lived, stereotyped responses to a sensory stimulus that occur unexpectedly and happen automatically.

✦ Rhythmic movements.

These are rhythmic, repetitive movements such as locomotion, breathing or chewing.

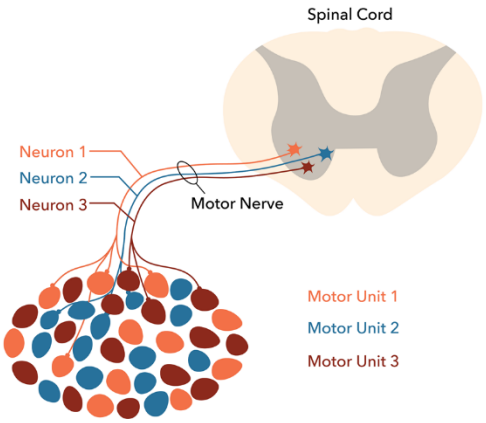
✦ Voluntary movements.

They are performed intentionally.

Motor units.

Skeletal muscles are controlled by alpha motor neurons, cholinergic neurons whose soma are located in the anterior horn of the spinal cord and the motor nuclei of the cranial nerves. The system consisting of an alpha motor neuron and skeletal muscle fibers forms a motor unit.

There are three different types of motor units. All muscles have them but in different proportions.



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✦ Type I, slow and resistant to fatigue.

They are small in size, act at a slower speed and have a lower excitation threshold than the others. Their function is to discharge a low-frequency but constant action in the muscles. They are the so-called slow muscles.

Anti-gravity muscles would be an example. They can generate tension for long periods of time without fatigue.

✦ Type IIa, fast and fatigue resistant.

They possess properties common to both type I and type IIb motor units. They are notable for having sufficient aerobic capacity to resist fatigue for several minutes.

✦ Type IIb fast and fatiguable.

They are large in size and have anaerobic metabolism thanks to this quality they can perform great forces, but for a short period of time this is due to the decrease in their

glycogen deposits and the accumulation of lactic acid which makes them fatiguable. The large motor neurons they possess have high conduction velocities and excitation thresholds. Their activity is of short duration with high frequency action discharges. Denervation of a fast muscle and its reinnervation by stimulation of a slow muscle nerve can change its motor units to slow ones.

The strength of a muscle or muscle group acts in proportion to the number of active motor units and their degree of activation. There are two nervous system mechanisms for the control of muscle force.

Recruitment of the number of active motor units

The activation or binding of motor units takes place selectively according to the so-called "size principle". First, they are activated in increasing order of size. Thus, depending on the need for muscular force, type I, type IIa and type IIb motor units are activated first.

Frequency of discharge of each motor unit.

The nerve impulse produces a weak contractile force, the higher the force requirement, the higher the frequency of release. The force increases cumulatively until it reaches a limit called tetanic contraction. This muscle force control mechanism is used when high levels of force are needed.

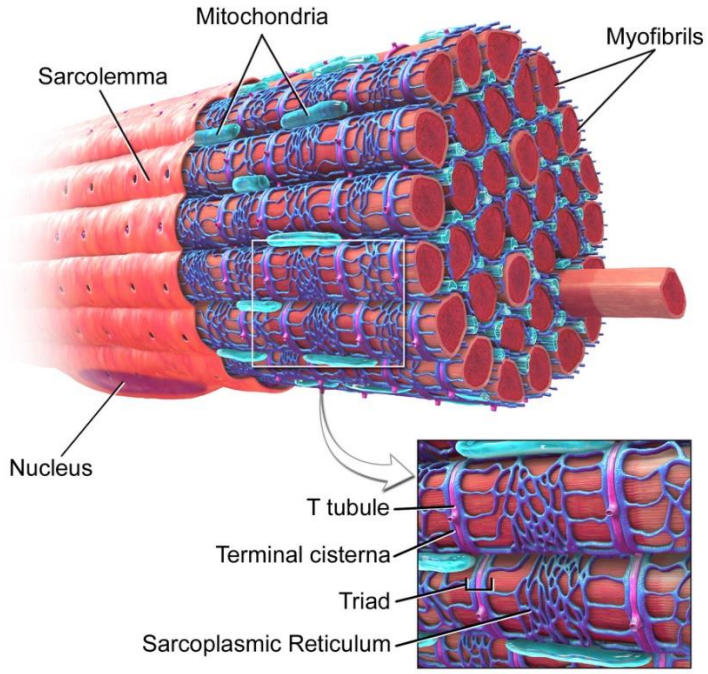
STRUCTURE AND FUNCTION OF SKELETAL MUSCLE

Muscle fibers are cylindrical, elongated, polynucleated cells. They are the longest cells in our body and are formed by the fusion of individual embryonic muscle cells.
Muscle fibers have little cytosol and the vast majority of the cytoplasm is occupied by structures called myofibrils that are responsible for contraction.

The myofibrils are surrounded by an extensive sarcoplasmic reticulum, whose function is to concentrate and trap calcium ions. Attached to the sarcoplasmic reticulum are the T-tubules, a structure of the sarcolemma that extends deep into the fiber. Inside, there is extracellular fluid that allows the propagation of the action potential from the surface of the cell to the interior of the fiber. The other structures found between the myofibrils are the mitochondria.

Mitochondria are responsible for generating ATP, the main source of energy. These

molecules contain the necessary material capable of oxidizing high-energy precursors and transforming them into molecular oxygen and water. During this process, ATP is able to capture a large amount of chemical energy.



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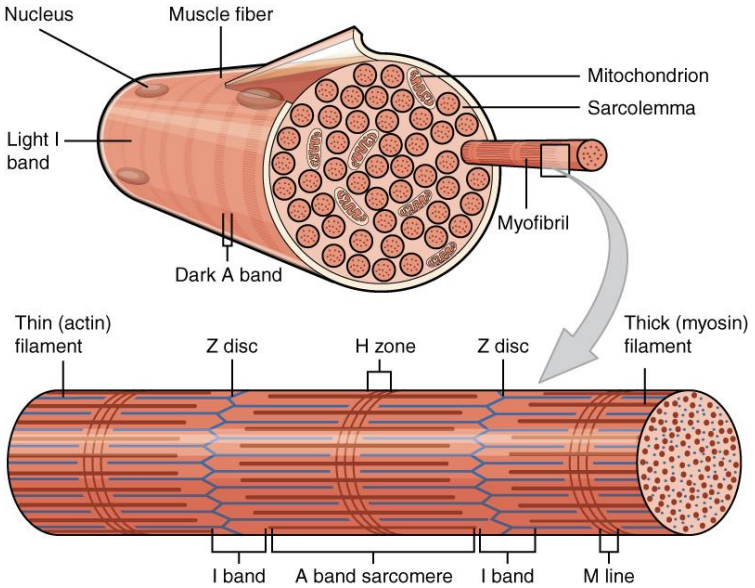
Each muscle fiber is made up of more than a thousand myofibrils (contractile structures). They occupy most of the intracellular volume and have proteins inside them. These proteins can be of different types:

-Contractile proteins (actin and myosin).
-Modulatory proteins (tropomyosin and troponin).
-Proteins that confer electricity to the muscle (titin and nebulin).

Ultrastructure of myofibrils.

If the muscle is cut longitudinally, alternating dark and light bands are observed. Under the microscope, the dark bands are anisotropic (A-bands) and the light bands are isotropic (I-bands). During a contraction the I-bands shorten while the A-bands remain constant.

A thin transverse line called Z is observed in the middle of the I-band. The proportion of myofibrils between two Z lines is called the sarcomere. It describes the changes made in the relaxation and contraction cycle. The I and A bands are made up of thin actin and thick myosin filaments.



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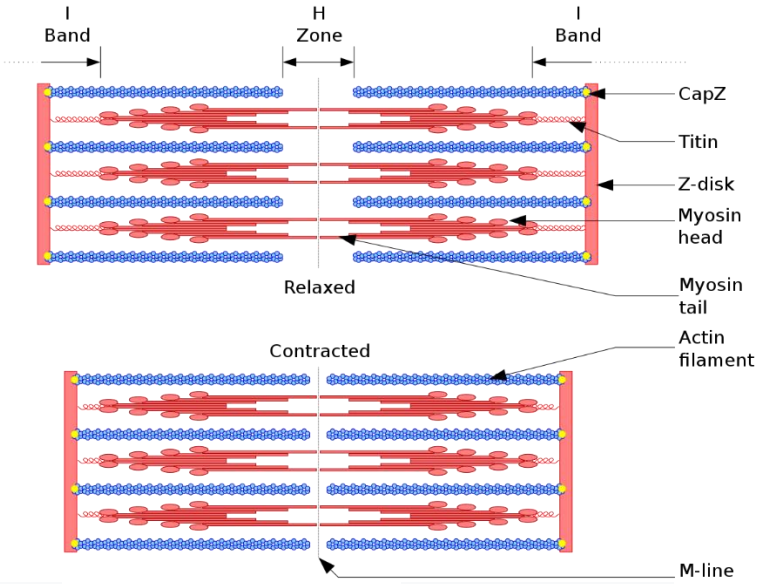
Contractile proteins.

The protein that forms the thick filaments of the myofibril and the bulk of the A-band is myosin. This filament is arranged so that the myosin heads are at the ends and the central portion is formed by a bundle of myosin tails.

The myosin head acts as an ATPase enzyme, allowing the head to hydrolyse ATP and use the energy released for the process of contraction.



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Actin is the protein that forms the thin filaments of the myofibril. It is globular in shape. They normally join together to form long chains or filaments in skeletal muscle. Most of the time, the thin and thick filaments arranged in parallel are connected by junctional bridges. These are formed when the myosin heads weakly bind to the actin filaments.

The junctional bridges can be made in two ways:

1. Actin and hydrolysis products are bound together (initial phase movement stroke).
2. After the initial phase when ADP and phosphates are released.

Modulatory proteins.

They regulate the contraction process, preventing the muscle from continuing to contract continuously in the presence of ATP. Troponin and tropomyosin are proteins found in the thin filaments associated with actin. Their function of regulating the junction between actin and myosin prevents cross-bridging and contraction during relaxation.

Cycle of contraction.

The myofiber is activated by a nerve impulse and causes contraction. The junction of the actin filaments is exposed, allowing the ATP-activated myosin heads to bind, bend and reattach. Pulling the thin filaments towards the center of the sarcomeres contracts the myofiber.

- Coupling phase.

The myosin head is activated and binds to actin forming a cross bridge between filaments.

- Active beating phase.

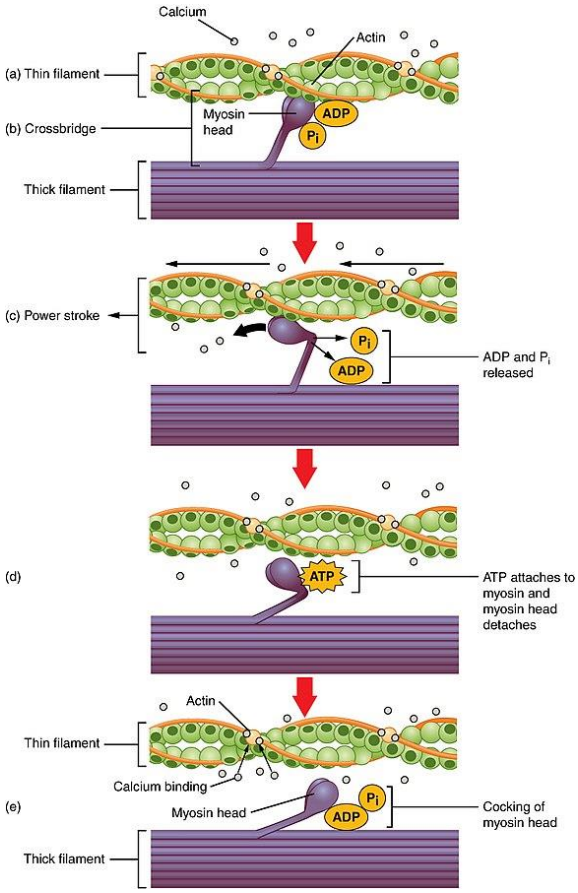
Myosin cross bridges rotate towards the center of the sarcomere, contraction occurs.

- Uncoupling phase.

The myosin head binds to the ATP molecule and unbinds from the actin filament attachment point and releases the cross-bridge.

- Energy release phase.

The ATP releases energy and the myosin head takes up its high-energy position, ready for the next cycle.



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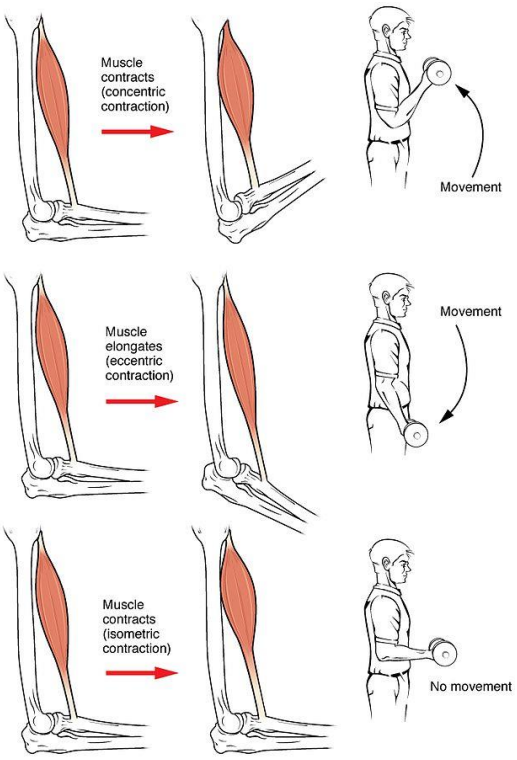
Types of contraction.

To move or hold an object a muscle has to exert a force on it. If the muscle tension is equal to the load, it is an isometric contraction and the muscle does not shorten.

However, if the muscle tension exceeds the load, an isotonic contraction takes place. The muscle shortens to generate and maintain tension.



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TYPES OF MUSCLE FIBERS

In the human body there are three types of fibers, types I, IIA and IIB. All three fibers can be found in every muscle, but in different proportions. Depending on the type of myosin and the speed of fiber shortening, their classification is determined.

Type I fibers (slow, oxidative).

Type I fibers hydrolyse ATP more slowly in order to contract, which determines their maximum speed of fiber contraction, which is the lowest among the different fiber types, which is why they are called slow fibers.

A smaller number of cellular elements are involved in the coupling and contraction cycle, because the action potentials are transmitted less frequently from motor units. Therefore, the fibers have more time to relax after contraction. They do not need a large development of systems to relax, allowing energy savings and greater resistance

to fatigue.

They obtain most of their ATP from aerobic metabolism, metabolic pathways that require the presence of oxygen in the cell. They are adapted to receive an adequate supply of oxygen. Irrigation by tortuous and highly branched capillaries, increased surface area for gas exchanges, energy and waste substrates with the blood, high concentrations of myoglobin... This allows the cells the ability to perform aerobic exercise for prolonged periods of time.

Type II (fast) fibers

They contract faster than type I fibers by 3 to 5 times. They are classified into subgroups.

The IIB fibers are the fastest with a more glycolytic metabolism.
The IIA fibers are the slowest and have an oxidative character.

According to the form expressed, the fast fibers are subdivided into IIa, IIb and IIx fibers. The main difference between the fibers is that they have several myosin heavy chain isoforms (MHC-2A, MHC-2B, MHC-2X).
IIa fibers are the thickest fibers. The calcium2 ATPase isoform present is SERCA (sarco/endoplasmic reticulum) in which it is found in all fast fiber subtypes.
In addition to being a different isoform than in type I fibers, it is 5-7 times more abundant calsecuestrin protein. However, in type II there is also parvalbumin, which allows type II fibers to store more calcium and release it into the sarcoplasm faster than their myofibrils, to contract more quickly and, finally, for the calcium released to be introduced back into the SR (sarcoplasmic reticulum) more quickly, so that fiber relaxation is also faster. The process of contraction and relaxation is faster than type I fibers.

Type II fibers use glycolysis as an energy source. They are characterised by a faster response and greater tension when activated, although due to their metabolism they are quickly fatiguable. They are therefore adapted for short, intense physical exercise.
The recruitment of type II fibers occurs when physical exercise is of high intensity. Type I fibers are recruited first, followed by type II fibers. The amount of force needed is what determines the recruitment of a fiber type, they act simultaneously in submaximal activities and aerobic and anaerobic exercises of high intensity.

Differences between muscle fibers.

	Slow *(Type I)*	*Intermediate* *(Type II A)*	*Fast* *(Type II B)*
Diameter	**Intermediate**	**Big**	**Small**
Thickness line "Z"	**Wide**	**Intermediate**	**Narrow**
Glycogen Content	**Low**	**Intermediate**	**High**
Fatigue resistance	**Loud**	**Intermediate**	**Casualty**
Capillaries	**Many**	**Many**	**Few**
Myoglobin content	**High**	**High**	**Low**
Shrinkage speed	**Slow**	**Speedy**	**Speedy**
ATPase activity	**Casualty**	**Loud**	**Loud**
Predominant energy system	**Aerobic**	**Combined**	**Anaerobic**
Motoneurona	**Small**	**Big**	**Big**
Discharge	**Casualty**	**Loud**	**Loud**

"Exercise Physiology" (Fisiología del ejercicio). Jose Lopez Chicharro. Almudena Fernandez Vaquero.

Distribution of muscle fiber types.

A determining factor in defining the distribution of muscle fibers is genetics. In sedentary people, the proportion of type I fibers is greater. Each muscle will have a different composition and distribution of fiber types.
Anti-gravity muscles are usually made up of high percentages of type I fibers as they are responsible for maintaining posture and need to be low in fatigue. Muscle fibers are highly adaptable and able to change their phenotype although these changes do not affect different cellular systems in the same way.
Physiological factors such as ageing and training can affect fiber type.

Aging is associated with morphological changes in muscle: reduction in fiber number and decrease in fiber size, which together lead to muscle atrophy, loss of strength and lengthening of the contraction time of muscle fibers.
With training, skeletal muscle is able to perform different tasks, which directly affects performance. Skeletal muscle is able to adapt to the functional demands placed on it, the muscles used in training can be modified and this is not the case for those muscles that do not participate.

In elite athletes participating in endurance sports, the percentage of type I fibers exceeds 60-65%, while in strength athletes, the percentage of type II fibers is higher than 65% in the muscles used.

It is not clear whether training is capable of producing changes in muscle fiber, especially with regard to the percentage of type I fibers. Studies indicate that the percentages of type I and II fibers do not alter substantially with training and that the percentage of slow and fast fibers in an individual is genetically defined. The fibrillar transitions that have been demonstrated do occur between the different subtypes of type II fibers.
It appears that there is a decrease in the levels of type IIB fibers and an increase in type IIA fibers and also an increase in the proportions of hybrid fibers, which is considered a sign of transformation from one type to another. Training does not induce changes in the percentages of type I and II fibers, but this does not mean that the muscle is not capable of improving its resistance or strength, modifications in capillarization, fiber diameter, increase in certain enzymatic activities may constitute beneficial adaptations for performance. Training has been shown to produce muscle hypertrophy (increase in the diameter of individual fibers) due to an increase in the number of myofibrils and is more noticeable in strength sports than in endurance sports. On the other hand, it has been shown that both type I and type II fibers are capable of hypertrophy.

One difference between strength and endurance sports is that endurance sports produce an increase in capillarization of the fibers, which means an increase in the exchange surface between muscle tissue and blood. This increases the myoglobin content and therefore improves the oxygen transport system from the membrane to the mitochondria; the number of mitochondria increases as well as their size, which leads to an increase in oxidative capacity. The effects of endurance training on the enzymes of glycolysis and glycogenesis are more limited, although it does appear to significantly improve glucose uptake capacity in response to insulin and also increases intracellular triglyceride and glycogen stores. Thus, the proportion of energy obtained from fat burning increases, resulting in glycogen sparing which allows exercise at submaximal intensities to be performed for longer. However, strength training induces greater improvements in glycolytic and glycogenolytic capacity without producing improvements in oxidative capacity.

BIOENERGETICS OF EXERCISE

Bioenergetics is mainly concerned with the transformation of the food we eat into energy. By breaking the chemical bonds of these molecules, the energy necessary for muscular activity is released.
Catabolism is the process by which larger molecules are reduced to smaller molecules, releasing energy. This energy is used to carry out processes such as anabolism, the process by which smaller molecules are joined together to form a larger molecule.

Exothermic reactions release energy and are carried out in catabolic processes. Endothermic reactions, however, require energy and are typical of anabolic processes. The intermediate energy molecule is ATP, without which muscle activity and growth would be impossible.

ATP is composed of adenine, a nitrogen-containing base, ribose, a sugar with five carbon atoms, and three phosphate groups. Release by hydrolysis of one phosphate group gives rise to adenosine diphosphate (ADP) and hydrolysis of a second phosphate group produces adenosine monophosphate (AMP). ATP provides the energy for muscle action and movement in the human body.

Biological energy system.

There are three energy systems for breaking down ATP: the oxidative system, the phosphagen system and glycolysis.

Of the three main components of food carbohydrates, fats and proteins, only carbohydrates can be metabolised for energy without the direct involvement of oxygen, hence the importance of carbohydrates in anaerobic metabolism. All three energy systems are always active, but it depends on the intensity of the activity and the duration of exercise.

Oxidative system.

The oxidative system is the main source of ATP at rest and during low intensity exercise. It primarily uses carbohydrates and fats as substrates. Protein is not usually a major metabolic substrate except in situations of prolonged fasting and long duration physical activity.

At rest most of the ATP produced is obtained from fat (70%) and the remainder from carbohydrate (30%).

During physical activity, as intensity increases the energy produced is derived from carbohydrate (≈100%). However, during prolonged submaximal exercise of constant intensity there is a gradual shift. The longer the duration of exercise the greater the contribution of fats and proteins and the lower the contribution of carbohydrates.

The phosphagen system.

Provides ATP primarily for short duration, high intensity activities.
It is active from the onset of physical activity regardless of intensity. Obtains energy through the chemical reactions of ATP, phosphocreatine and the enzymes myosin ATPase and creatine kinase.
Myosin ATPase catalyses the hydrolysis of ATP to ADP and inorganic phosphate with energy release. Creatine kinase catalyses the synthesis of ATP from phosphocreatine

and ADP, with phosphocreatine providing the phosphate group that combines with ADP to form ATP. These reactions provide energy at a high rate as ATP and phosphocreatine is stored in small amounts in the muscle in the phosphagen system. It cannot provide the energy needed for continuous, long-lasting activities. Generally, fast twitch type II muscle fibers contain higher concentrations of phosphagen than slow twitch type I fibers.

Glycolysis.

This is the breakdown of carbohydrates to produce ATP which adds to the process of the phosphagen system to sustain high-intensity physical activity. It takes place in the cytoplasm of cells.

Glycolysis can follow two distinct pathways called fast glycolysis and slow glycolysis.
In fast glycolysis, energy is produced at a faster rate than in slow glycolysis. Pyruvate is transported to the mitochondria for utilization in the oxidative system which occurs in reduced oxygen environments in muscle cells and one of its end products is an organic product called lactic acid. Muscle fatigue experienced during physical activity is in many occasions related to high lactic acid concentrations. In muscle, lactic acid accumulation is the result of an imbalance between its production and utilization and directly interferes with excitation-contraction coupling. Possibly through inhibition of calcium binding to troponin or cross-bridge formation.

In addition, the decrease in pH inhibits the enzymatic activity of the cell's energy systems, resulting in a decrease in the amount of energy available and the contractile force of the muscle during exercise.
The blood converts lactic acid to lactate. Lactate is often used as an energy substrate, especially in type I fibers and cardiac muscle fibers.

The higher the intensity of exercise, the higher the production of lactic acid, which is converted to lactate in the blood, indicating a return to homeostasis, thus affecting the individual's ability to recover. Lactate can be transformed by oxidation within the muscle cell in which it has been produced or transported in the blood to other muscle cells, lactate can be transported to the liver where it is converted to glucose.

Slow glycolysis if oxygen is present in sufficient quantities in the mitochondria the end product of glycolysis is pyruvate and is not converted to lactic acid but is transported to the mitochondria when pyruvate enters the mitochondria it is converted to acetylCoA which can enter the Krebs cycle where it will be used to produce ATP.

The total amount of ATP from the phosphagen system provides ATP primarily for high intensity and short duration activities, the glycolytic system for moderate to high intensity activities of short to medium duration and the oxidative system for low intensity and long duration activities.

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