Human Physiology
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Week - 06
Lecture - 03

Hello everyone, welcome to another new class on human physiology. This week we were discussing the skeletal system. So, in the last few classes, we discussed different types of human bones, and we also talked about human joints. In this class, we will discuss human muscles; we will also see what the different types of muscles are, the different components of muscles, and how they work. So, let us stick with it. So, what different concepts will be covered in this class? We will first see what muscle is, then we will discuss the types of muscle, then we will examine the structure of muscles, the structure of muscle fibers, the filaments of muscle fibers, and the different crucial proteins present in the muscle.

I will also briefly discuss smooth muscle and cardiac muscle. So, let us go one by one: first, what is muscle? Muscle is defined as a tissue primarily composed of specialized cell fibers, which can contract to effect movement. So, basically, as we all know, if there are certain environmental responses, for example, sensory responses, those responses are generally accepted by the sensory nerves, and those signals are sent to the spinal cord first and then from the spinal cord to the brain. Now, in response to the sensory responses, many times the brain sends motor signals via the motor nerves.

And these signals reach different types of muscles, including skeletal muscles, smooth muscles, or organ muscles. And then these muscle cells perform actions, and in terms of those initial sensory responses, the body kind of performs certain reactions. So, in the human body, we basically have more than 600 muscles. And as we already said, the primary function of muscle is the transformation of chemical energy into mechanical energy. And why is the mechanical energy needed? Basically, it is necessary to generate force, perform work, and produce movement.

Apart from that, muscle tissues also stabilize our body's position. It also regulates different types of organ volume. It also generates heat and maintains an overall heat balance in our body. Lastly, it also propels fluids and food matter through different body systems. The scientific study of the muscle is also known as myology.

So, what are the different types of muscles? So, as you can see in the images, we have mainly two types of muscle. One is like striated muscle. So, in the striated muscles, you will see this type of striation, right? So, these are called striated muscle, and they can be either skeletal muscle or cardiac muscle. And secondly, there can also be non-striated muscle. For example, you can see that in smooth muscle, it is non-striated because there is no striation present.

Depending on the control, the muscles are also classified into two types. One is voluntary, and the second is involuntary. For example, in the case of voluntary movement, this muscle can be controlled by the will like skeletal muscle. In cases of involuntary muscles, which are mostly present in organs, these muscles cannot be controlled by us, and they can actually function without any specific stimulation as well. Mostly, these types of muscles are innervated by the autonomic nervous system.

Let's see, like the first one, which is the skeletal muscle. So, this is like a gross overall structure of the skeletal muscle, which is basically situated in association with the bone. So, you can see like this is a bone over here and from the bone first there is a tendon. So, muscle fibers are also connected to the bones via the tendon. As we know, a tendon is a strong connective tissue.

Now, as you can see right from the tendon, we have layers and layers of muscle fibers that are basically formed together, and each of these muscle fibers has a specific membrane on top of it. So, from those bones and with the tendon, the first coil of muscle fiber coming out of the top membrane is called epimysium. And from the epimysium, if you can see that there are a lot of round shapes that are basically called fascicles. These are like a bunch of muscle fibers together, which are called fascicles. So, if you basically pull up, if you simply pull out one fascicle outside.

So, the epimysium is the outer layer, and if you pull out one bundle of myofibrils or a bundle of fascicles, the membrane of it is called perimysium. So, it is basically three layers of membrane that are present in the muscle: the outermost layer, which is the epimysium. This is the outermost layer of the muscle fiber, and now if you pull out one group of muscle, then this middle layer, which is called perimysium, and then you can see further there are small fascicles. So, pull out one fascicle. So, if you pull out a single fascicle, you will find something like the unit cell of the muscle or a myofibril.

Inside the myofibril, this layer, or the membrane layer, is called the endomysium. So, basically, we will have like three layers. The outermost layer is called the epimysium, and the middle layer is called the perimysium. And just above this myofibril, which is also a kind of unit of muscle cells, you can find the innermost layer of the muscle, which is called the endomysium. So, this is basically the three layers of muscle membrane.

And now inside that myofibril, or the muscle fiber, if you see, each muscle cell is basically cylindrical in shape. So, you can see that each muscle cell is kind of cylindrical in shape, and the average length of the fiber is about 3 centimeters. Next, you can further see that each muscle fiber is enclosed by a cell membrane called the sarcolemma. And this sarcolemma is just above the endomysium. So, you remember in the last slide we also discussed what endomysium is, which is basically.

So, if it was like the myofibril, if it was a myofibril. So, the upper part of the inner layer of the myofibril was the outer layer of the myofibril. The inner layer of the myofibril is called the endomysium, right, endomysium. And now just beneath the endomysium, there is another cell membrane called the sarcolemma. The cytoplasm of the muscle is also called sarcoplasm, and inside the sarcoplasm, there is a lot of endoplasmic reticulum, which is called sarcoplasmic reticulum.

The role of the sarcoplasmic reticulum is very crucial because it stores calcium, and during the contraction process, it releases calcium, leading to muscle contraction. So, how the sarcoplasmic reticulum releases the calcium that we will discuss in our next class, but just try to remember these are some basic components of the muscle fiber. And, importantly, myofibrils are the fine parallel filaments present in the sarcoplasm of muscle cells. So, myofibrils are very important; they are the fine parallel filaments present in the sarcoplasm of muscle cells. Now, let us see what those filaments of the muscle fiber are.

So, basically, muscle fiber consists of two types of filaments: one is the thin filament or actin filament, and the second is the thick filament or myosin filament. So, in cases of thin filaments or actin filaments, these are mostly anchored to the Z disc. What is a Z disc? We will discuss this very soon, but just consider that these thin filaments are anchored or attached to the Z disc. And in the thin filament, you can see different types of proteins; the most primary or important protein you can see is actin. So, actin is basically one of the main or key components of the thin filament, and individual actin molecules create a helical, twisted filament formation.

So, this individual actin molecule eventually creates a helical twist. There are two more proteins, one is troponin and the other is tropomyosin. So, we will discuss all of their functions in the next slide. In the case of the thick filament, myosin is the main component of the protein. And in skeletal muscle, almost 300 molecules of myosin form a single thick filament.

So, 300 myosin molecules basically form this single thick filament. And as you can see, once like this, the myosin thick filament kind of gets twisted for a thick filament; it also gives a golf bat-like structure. So, after the twist, it kind of gives a golf bat-like structure. And this part, where this looks like a golf bat head or a golf bat-like structure, is called the myosin head.

Let's see its function. So, in the case of myosin, which is present in thick filaments, right? So, this is basically a contractile protein. and the myosin molecules contain both a tail and two myosin heads. So, it basically has what we said; it kind of creates a folding. So, it has a head like it has two heads, and then it also has a tail. So, basically, myosin consists of both a tail and a head.

This binds to the myosin binding site on the actin molecules of the thin filament. So, basically what it does is that these components of myosin bind to the myosin binding site of the actin molecules that are present in the thin filament, and when it happens, it occurs during muscle contraction. We will see in the next slide how it exactly happens. Then, as we said, in cases of thin filaments, there are three proteins. So, myosin, if you see in cases of myosin, this is present in the thick filament, right? And then actin, tropomyosin, and troponin are present in the case of the thin filament.

So, actin is also like a contractile protein; this is the primary protein present in the thin filament. On each actin molecule, there is a myosin binding site. So, basically each actin, if you consider actin as a kind of protein, has a myosin binding site. So, it has a myosin binding site. So, basically, each actin protein has a myosin binding site where the myosin head of the thick filament can bind, right? So, this receptor or this protein binding site is called the myosin binding site, okay.

And in this myosin binding site, what happens is that this head part of the myosin can eventually bind with the actin. The next is tropomyosin, which is a regulatory protein present in the thin filament. When a skeletal muscle fiber is relaxed, tropomyosin basically covers the myosin binding site. So, what we are saying is that in the case of the thin filament, for example, we have this actin molecule. And during relaxation, let us assume this tropomyosin is bound to the myosin binding site which is present on the actin.

And if this tropomyosin is already bound to the actin like with the myosin binding site, what will happen? Myosin will not be able to come and bind correctly. So, basically, myosin will not be able to come and bind to this myosin binding site of the actin. So, this troponin or basically this is tropomyosin, which is a regulatory type of protein that eventually blocks the binding site of the myosin to the actin. And then the last one is troponin, which is also a regulatory type of protein present in the thin filament. And what happens basically during muscle contraction, whenever there is a release of calcium ions from the sarcoplasmic reticulum, is that this calcium ion binds to the troponin.

So, what happens is that basically, the troponin calcium ion binds, and then it undergoes a shape and conformational change and eventually removes this tropomyosin away. So, what are basically all four proteins we discussed? We first discussed myosin, which is a part of the thick filament. And in the case of myosin, we saw that it has both a head and a tail. Head mostly binds to the actin in the myosin binding site. Actin is present in the thin filament, and now it has two regulatory proteins that are present in the thin filament.

One is tropomyosin; the second is troponin. When the muscle is in a relaxed condition, tropomyosin attaches to the myosin binding site. and that prevents any of these head groups of myosin from coming closer and attaching to it. But during muscle contraction, when the sarcoplasmic reticulum releases calcium, this calcium binds with troponin, causing conformational changes in the protein, and eventually what that does is remove the tropomyosin array. So, basically, it removes the tropomyosin array from the myosin binding site, leaving the open ligand binding site inside and outside of the actin, and in that case, myosin can easily come and bind to the actin, causing muscle contraction.

So, if you kind of understood the different types of proteins that are present in the muscle. Now, let us quickly see how this muscle contraction happens and what the different roles of the proteins are; we will go through this in a pictorial way. So, basically, you can see this is the thick filament, right? So, in the thick filament, it basically has two types of heads, the two heads we discussed, right? It has this type of structure where there is a twisting, twisting of a lot of myosin protein, but eventually it creates two golf bat-like heads. So, you can see that in the first step, whenever there is a release of calcium and how it generates, we will discuss in the next class, but just remember that neuromuscular transmission happens during the process of neuromuscular transmission. Calcium is released by the sarcoplasmic reticulum.

So, during neuromuscular transmission, calcium is basically released by the sarcoplasmic reticulum, and you see that this calcium, what it does, already we said, this calcium binds to the troponin. and causing a conformational change in the shape of this myosin here, right. So, basically, when troponin binds, it removes the tropomyosin that are already occupying the myosin binding sites. So, that means myosin can now bind to the actin, right? So, once calcium comes in, let's recall, it binds to the troponin. Troponin removes the tropomyosin away from the myosin binding site, which means myosin can bind to the actin.

And now, once myosin can bind to the actin, you can see the bound myosin rotate its head, so basically a rotation of the head happens, producing a power stroke. In the next stage, ADP is released and an ATP molecule binds with the myosin. So, basically, from this condition, ADP is getting released and one ATP molecule is bound to the myosin head. In the next step, what happens is that you can see both this actin part and the myosin protein part; they get detached.

ATP is hydrolyzed. So, basically two things happen: actin and myosin both get reattached to each other. The next step is that ATP is hydrolyzed, and again the ADP-bound myosin head is cocked and ready to bind to the actin again. So, basically in the next step, again these rotational changes happen to the head, leaving the myosin to be bound again to the actin for the next cycle whenever calcium ions come in during the process of neuromuscular transmission. So, this is the way that both actin and myosin work together, along with two regulatory proteins that are present in the thin filament: troponin and tropomyosin. There are some other important proteins related to muscle as well.

For example, titin, which is like a structural protein that connects a Z disc to the M line of the sarcomere. Then, actinin, which is also a structural protein of the Z disc, attaches to the actin molecule. Then nebulin, which is also a structural protein, wraps around the entire length of each thin filament. Finally, the dystrophin, which is a structural protein that links the thin filaments of the sarcomere to integral membrane proteins in the sarcolemma, is discussed. This is attached, in turn, to proteins in the connective tissue matrix that surrounds the muscle fiber.

So, these are some additional protein components that have an important role in overall muscle. Now, let us see as we are discussing different topics, such as Z Disc and M-line. So, what are these? So, basically, if we check the microscopic structure of muscle or the muscle fiber, the sarcomere is generally called the unit cell or the functional unit of skeletal muscle. So, the functional unit of the skeletal muscle is the sarcomere.

So, this is basically the structure of a sarcomere. Right, each sarcomere basically extends between two Z lines of a myofibril. So, in the myofibril, you remember like we discussed about myofibril, right? We discussed about myofibril. So, in the myofibril, we will see this type of unit cell, which is called a sarcomere. So, this one cell, which is called a sarcomere, is the functional unit of the skeletal muscle cell. And each sarcomere basically extends between two Z lines.

So, if you think like that, each sarcomere is basically extended between two Z lines. So, you can see here that these are the Z line or the Z disk. So, this is, and this part is called a Z line and the Z disk, and exactly in between we have one sarcomere unit. And in the sarcomere, you can see both thick and thin filaments. So, in this part, you can see that all the thick filament components are there, and you can see the thin filaments, which are actin, troponin, and tropomyosin.

This has been mostly here, but there are certain thin filaments which are also infused with the myosin or with the thick filament. So, basically, in this part, we have the thin filament, right? Some amount of thin filament is also present alongside the thick filament. So, basically you can see from this part that it starts from one corner to another corner of the thick filament; this is called the A band. So, what is basically a band? A band is the total zone or region of the thick filament, although in the corners there might also be some thin filament that is infused with the thick filament.

So, this is called the A-band. So, basically, a band is the complete zone of the thick filament. Now, in the corner, you see that this is only a thin filament, right? There is no presence of any thick filaments. So, this component or this part is called the I band. So, you will have two I bands on both sides, the left side and the right side, where there is no presence of any thick filament; that means only actin and troponin, right? So, only actin, troponin, and tropomyosin.

Which is part of the thin filament is present. So, this part is called the I band, and in this area, there is especially no presence of any thick filament. A band is the total zone or area of the thick filament, which is mostly myosin; in the corner area, there is also an infusion of thin filaments, such as actin, troponin, and tropomyosin. In the corner area just beside the Z disc, you can see that only the thin filament is present; this is called the I band. Now, in between this part, where there is no presence of any thin filament and only thick filament is there, it is called the H zone. And this H zone is a very dark, dense area; it is a darker area where you can see there is no presence of any thin filament.

So, only pure myosin components will be present in this middle area, which is called the H zone. Inside the age zone, there is also an M line. Basically, the M line is the center of the A band that contains certain proteins to hold the thick filaments together at the center of the sarcomere. So, the M line is basically the center of the age zone. So, you can also kind of go through all these, like Z-discs, which are basically the narrow plate-shaped regions of the dense material that separate one sarcomere from the next.

Then we already discussed the A-band, which is the total region of the thick filament. In the A-band, they are mostly adjacent to the I band, and you will also see that there is an overlap that happens in the thin filament. However, in the corner near the Z disk, those are purely the thin filaments; there is no overlapping region. In the middle part, there is only thick filament with no overlap with the thin filament. That particular dark grey area where only thick filaments are present is called the H zone, and the middle line of the H zone is called the M line.

So, go through those; hopefully, you have basically understood the basic components and structure of muscle. Then lastly, we will discuss smooth muscle, which is non-striated cells. So, you can see that it can be binucleated, non-striated types of cells, and these can be seen in different areas. For example, like a wall of organs such as the esophagus, stomach, and intestine. Ducts of the digestive gland, trachea, bronchial tubes, urethra, urinary bladder, walls of different blood vessels, mammary glands, and ciliary body of the eye.

You can see so many areas; you can see that these smooth muscle cells are present. Then these fibers are basically very small; the diameter is about 2 to 5 microns, and in length, it is about 50 to 200 microns. The nucleus is single and elongated; mostly, it is present centrally, but generally, two or more nuclei can be seen inside the nucleus. You can see that 2 to 3 nuclei can be present inside the nucleus. And in terms of type, smooth muscle can be either single-unit smooth muscle, in which case you can see the fibers that connect to one another by gap junctions.

So, basically, multiple fibers can get connected to create a single unit of smooth muscle, and they are connected by gap junctions. And this way, they form a network of smooth muscle where it can be seen; it can be found in almost every small artery and vein. Also, in the case of different hollow organs, such as the stomach and intestine, you can see the single unit of smooth muscle. And in the case of multi-unit smooth muscle, you will not see any of this type of gap junctions or network of smooth muscle.

Mostly, this can be found in the large walls of the large artery. Apart from that, it can also be seen in the lung, pupil diameter, in the ciliary body, etc. Finally, one of the most crucial muscles is the heart. So, the heart is also called, as you know, a muscle. But the heart is, as you know, a striated type of muscle.

The principal tissue in the heart wall is cardiac muscle. And the cardiac muscle fibers have the same arrangement of actin and myosin as we discussed already. However, there is the presence of this intercalated disc. So, you can see that the intercalated disc is different from normal skeletal muscle. So, as a presence of this intercalated disc, the heart is unique to the cardiac muscle fiber. These microscopic structures are generally irregular transverse thickenings of the sarcolemma that basically connect the ends of the cardiac muscle fibers to one another.

This disc contains desmosomes that hold the fibers and the gap junctions together. This also allows muscle action potentials to spread from one cardiac muscle fiber to another. Also, it is very important to highlight that in response to a single action potential, cardiac muscles generally remain contracted almost 10 to 15 times longer than skeletal muscles. It is due to the prolonged delivery of calcium ions to the sarcoplasm. So, basically, a larger amount of calcium ions and the prolonged delivery of these ions cause a contraction that is prolonged by more than 10 to 15 times in a single action potential in cardiac muscle, which is also different from normal skeletal muscle.

So, if you like the class of muscles, do you know that cardiac muscle contracts continuously without any stop? Cardiac muscle tissues contract and relax about 75 times a minute during resting conditions. Cardiac muscle fibers can also use lactic acid produced by the skeletal muscle fibers to make ATP. So, ATP is like all the time needed, as you saw how ATP is getting attached during the muscle contraction step.

and how the overall process happened. So, it is also beneficial during exercise. So, during exercise, as you know, a lot of lactic acid is produced, and this skeletal muscle fiber can use this lactic acid to make more ATP. So, can you also answer this question: which type of smooth muscle is more like cardiac muscle than skeletal muscle with respect to both its structure and function? So, hopefully you are enjoying the human physiology classes. In the next class, we will discuss the neuromuscular junction, and we will see how the process of this neuromuscular junction occurs and how muscle contraction initiates. Thank you again for attending another class of human physiology. We will meet with you very soon for another new class. Thank you.