Muscle tissue- part 1

Functions of the muscles:

1) Movement:

The movement that results from muscle contraction and relaxation is not restricted to locomotion (walking, jumping, or moving from point A to point B), movement is also important to keep us alive, for example, the heart muscle, which is basically a pump that squeezes and relaxes in order to pump the blood to all blood vessels of the body, the same concept applies to smooth muscles in the walls of stomach, blood vessels, etc.

2) Maintenance of posture:

While you are sitting for example, the muscles of your back and your neck are contracted even if you're not moving, to maintain a balanced sitting posture. We have what is called "slight contraction of the muscles" and this is called "muscle tone" (minimal contraction to keep the muscles tense)

3) Joint stabilization:

Because muscles are inserted into bones and cross joints, they help in stabilizing joints. The muscle should at least cross one joint in order to produce movement.

4) Heat generation:

Muscles produce movement by contraction (contraction is shortening of the muscle, approximation between origin and insertion) and this will produce body movements.

This process needs energy (this energy is chemical energy in the form of ATP then it is converted to mechanical energy) and the byproduct of this process is Heat.

Why do we shiver when we are cold?

Our CNS subconsciously sends stimuli to the muscles to contract and when the muscle contracts, it produces heat. And this is the reason why infants have brown fat to supply them with heat (they haven’t developed heat production mechanisms yet (they don’t shiver)).

Muscle classification:

Muscle tissue is classified according to a morphological classification or a functional classification.

Morphological classification (based on histological appearance)
There are two types of muscle tissue based on the morphological classification system

1. Striated
2. Non striated or smooth.

Functional classification
There are two types of muscle tissue based on a functional classification system

1. Voluntary: under conscious control
2. Involuntary: under unconscious control

Types of muscles: there are three types of muscles in the human body:

1. Skeletal muscles: striated and voluntary (they move the skeleton; this is why they are called skeletal).
2. Cardiac muscles (only inside the heart): striated and involuntary.
3. Smooth muscles: non -striated and involuntary.

Where can we find smooth muscles?
In the wall of internal organs (hollow organs, viscera, and tubes). (Examples: walls of the blood vessels, esophagus, stomach, urinary bladder.)

Muscle cell = Muscle fiber

- The muscle cell is also called muscle fiber (because they're elongated)
- Has high number of contractile filaments (Actin and Myosin), these filaments are called **myofilaments** (myo: muscle).
- Muscle cells like any other cells in our body are composed of: plasma membrane, nucleus, cytoplasm and organelles, but they are highly specialized and highly differentiated.
- The plasma membrane of the muscle fiber is called **sarcolemma.**
- Muscle cells have prominent smooth ER (called sarcoplasmic reticulum in muscle cells) (remember: SER functions in lipid synthesis, steroid synthesis and it is **a storage site for calcium**).
- Note that the pre-suffix sarco and myo both refer to muscle. Therefore, if you see a word with either of these, you should immediately think of MUSCLES.

Skeletal muscle:

The origin of the skeletal muscle:

- From mesenchymal cells (mesoderm) ----> mesenchymal cells differentiate into myoblasts.
- These myoblasts fuse together (note that each myoblast contains one single nucleus) to form elongated structure called myotube.
- This myotube differentiates until we end up with a long fiber (this long fiber is the muscle cell) and each muscle cell has many nuclei, <u>why?</u> Because the origin was the fusion of many myoblasts together.

❖ Note that the skeletal muscle cell is multinucleated! And the nuclei are exactly under the sarcolemma)

*** Now look at the shape of the cell

➢ It is long, cylindrical in shape and that's why it is called muscle fiber. (Because it looks like a fiber)

➢ Is multinucleated, long, and cylindrical in shape and shows striations.

➢ Next to these cells we can find small, undifferentiated cells called **satellite cells**. These are mesenchymal cells, and in case of an injury to the muscle they differentiate into muscle cells (they are stem cells) (few cells present only)

Because of the low numbers of the satellite cells in the muscle tissue, often it's not enough to replace the damaged muscle tissue by these cells.

For example: if a muscle is severely injured, the satellite cells are going to differentiate into new muscle cells, but due to the low number of satellite cells, they're not enough to repair the muscle.

So, how the muscle is repaired?

- The muscle fiber is highly differentiated, thus it does not undergo mitosis
- The highly differentiated cells are less likely to undergo mitosis.
- Injured muscle tissue is repaired mainly by Collagen fibers produced by fibroblasts from the connective tissue sheaths surrounding the muscle (see below).

The skeletal muscle is composed of two parts:

1- The fleshy part (belly part).

2- The tendon which connects the fleshy part to the bone.

Remember: Histologically, the tendon is a dense regular type of connective tissue (collagen fibers and fibroblasts).

The fleshy part:-

- The fleshy part of the muscle is surrounded by a connective tissue (dense irregular type) called epimysium (epi =above, mysium=muscle).
- This Epimysium sends septa to divide the muscle into groups/bundles, each group is called a fasciculus or fascicle (plural: fasciculi).
- Now each fascicle is surrounded by a connective tissue called perimysium (peri=around, mysium=muscle). The perimysium is a dense type of c.t but it is less dense than epimysium.

The fascicle:-

- Each fascicle is composed of muscle cells/fibers.

The muscle cell (muscle fiber) is a tube like structure and it is multi nucleated

- Each muscle cell is surrounded by a loose type of connective tissue called endomysium (endo =inside, mysium=muscle).

Summary

There are 3 types of connective tissue coverings:

1. The epimysium is the outermost layer that covers the whole muscle
2. The perimysium surrounds each fasciculus.
3. The endomysium surrounds each muscle cell (muscle fiber), its rich in reticular fibers

1- Endomysium is loose type of connective tissue

2- Perimysium is dense irregular type of connective tissue (thinner than the epimysium).

3- Epimysium is dense irregular type of connective tissue

As we go towards the internal part of the muscle the connective tissue becomes more loose (thinner), same thing in the glands.

Remember, the main function of the loose connective tissue is to support, connect, and to carry blood vessels (vascular).

The three coverings (epimysium, perimysium and endomysium) converge to form the tendon that connects the muscle to the bone.

The skeletal muscle cell (muscle fiber):-

- The muscle cell is striated; it has alternating light and dark areas.
- The muscle cell (like any other cell) has cytoplasm (which is called sarcoplasm) and organelles.
- The sarcoplasm is filled with cylindrical shaped structures called myofibrils.
- A myofibril is an organelle within the sarcoplasm.
- So a single muscle cell is composed of myofibrils.
- We can also see the nuclei located at the periphery of the cell directly under the sarcolemma.

Now if we magnify the myofibril, we will see that it is composed of thick and thin filaments (myofilaments) and they are highly organized along the myofibril to form the sarcomeres.

- ✓ The sarcomere is the smallest functional unit of the muscle (in the compact bone, the smallest functional unit is the osteon).
- ✓ The myofibril is composed of repeating units of sarcomeres.
- ✓ The sarcomere is composed of the thick and thin filaments organized in a highly regular manner, and producing striations.

Under the electron microscope, the sarcomere is composed of:

1- The A band (dark band) composed of thick filaments and some overlapping areas that contain thin filaments (the letter A refers to **A**nisotropic). A band corresponds to the length of thick filaments.
Anisotropic means that when the tissue is exposed to a polarizing light these filaments have the ability to alter the direction of the light and appear dark.

2- The I band (light band) composed of thin filaments only (the letter I refers to **i**sotropic).
Isotropic means that when the tissue is under polarizing light, the light passes through and in-between these filaments and they are less birefringent

so they don't alter the polarizing light and that's why this band appears light in color.

3- **Two Z lines** (it is called z line because **z**wischen means in-between *in German)*

4- In the middle we have **the M line**. (**m**itte in German means middle)

5- **The H zone** is an area in the middle of the A band and it looks lighter because it is only composed of thick filaments (myosin) (H stands for **H**ell, Hell means bright in German).

- ✓ The thin filaments (actin mainly) are attached to the Z line and the thick filaments (myosin) are attached to the M line.
- ✓ The skeletal muscle cell looks striated because again it is composed of myofibrils and the myofibrils are composed of myofilaments (creating bands).
- ✓ The Z line bisects the middle of I band, so a sarcomere is composed of an A band and 2 halves of I bands.
- ✓ The Z line is composed of actin binding proteins (attach to actin filaments) ex: -Alpha Actinin.
- ✓ The M line is also composed of proteins that anchor the myosin filaments to the midline (myosin binding proteins).
- ✓ The thick filaments are also attached indirectly to the Z line by a protein called Titin. This protein is yellow and coiled because it's elastic.

Function of the Titin protein:
1- It keeps the sarcomere aligned.
2- Prevents overstretching of the muscle because it's elastic.
3- Anchors the myosin filaments indirectly to the Z line.

Ultra structure of thick and thin filaments:
A thick filament is not only a single myosin molecule; the single thick filament is composed of around 300 molecules of myosin that aggregate and form the thick filament.

Myosin: it has two heads and one tail. The myosin molecule is composed of six subunits, two heavy chains are helical and twisted around each other to form the tail (we have only one tail) and four light chains forming two heads, each head has two light chains.

- Each head has two binding sites, one binds to actin and the other binds to ATP, remember the process of contraction needs energy.
- The thin filament is mainly composed of actin filaments.
- The actin protein is composed of monomers, globular in shape called G actin, when they aggregate and polymerize they form a long and helical strand called filamentous actin (F actin). Two strands are twisted to form actin filament

A single thin filament is composed of:
1) Two twisted strands of filamentous (F) actin
2) Two other proteins: a helical protein called tropomyosin, and a 3-subunit protein called troponin.

G actin has a binding site for the myosin head (myosin head has two binding sites one binds to actin and the other binds to ATP).

When the muscle is relaxed, myosin can't bind to the actin because tropomyosin masks the binding sites on actin.

Troponin is composed of three subunits: one interacts with calcium (subunit C), one for regulation (subunit I) and the largest one interacts with tropomyosin (subunit T).

The contraction of the muscle is approximation between the origin and the insertion (shortening of the muscle).

Myofilaments (actin and myosin) <u>DO NOT SHORTEN,</u> they only overlap and that causes the shortening of the muscle.

<u>So what happens during contraction?</u>
Actin filaments slide over the myosin filaments and they move toward the midline, this leads to shortening of the sarcomeres and thus the whole myofibril shortens, and the whole muscle cell shortens and eventually the whole muscle shortens.

Myofibril is composed of repeating units of sarcomeres, so when every sarcomere shortens the overall muscle cell will shorten.

What happens to the bands upon contraction?

The **A band** will not be shortened because it corresponds to the length of thick filaments (myosin) and these filaments DO NOT shorten.

The **I band** is composed of thin filaments; thin filaments will slide over the myosin upon contraction leading to shortening of the I band.

The **H zone**: it's the central area of the A band where myosin doesn't overlap with actin, when contraction happens, H zone will also shorten.

So again, the plasma membrane of the muscle cell is called sarcolemma, its cytoplasm (sarcoplasm) is filled with myofibrils, each myofibril is composed of thick and thin filaments (myofilaments). Inside the cytoplasm, we find also the sarcoplasmic reticulum (smooth endoplasmic reticulum) and each myofibril is surrounded by this smooth endoplasmic reticulum which acts as a calcium reservoir (is important for the muscle contraction).

This sarcoplasmic reticulum (SR) forms a network, its tubules (called L tubules) run longitudinally with the long axis of the myofibril and they terminate with dilated sacs called the terminal cisternae (remember: the tubules and sacs of the endoplasmic reticulum are called cisternae).

The sarcolemma sends tubular invaginations inwards called T tubules. T tubules surround each myofibril. T tubules run transversely to the long axis of the myofibril and that's why they are called Transverse tubule (T tubules).

What is the function of T tubules?

In order for the muscle to contract it needs nerve supply (without the nerve supply muscles will be paralyzed) and that nerve supply carries electrical signals (action potential), so when these electrical signals reach the sarcolemma, depolarization happens (change of charges across the sarcolemma) and if the T tubules were absent, only the myofibrils on the periphery will be stimulated while in the presence of these T tubules, all the myofibrils within the muscle cell will receive that stimulation and will contract.

Triad: is a feature of skeletal muscle cell, composed of a T tubule in the middle and terminal cisternae of SR on each side, its located at the junction between A and I bands.

Each sarcomere has two triads because we have two junctions (A and I junction).

When action potential reaches the muscle through T tubules, calcium will be released and that will lead to muscle contraction.

When stimulation occurs, nerve endings release certain neurotransmitters and they bind to certain receptors on the sarcolemma leading to depolarization and that depolarization will propagate and reach each myofibril and once it reaches the triad area, it triggers the release of calcium ions from the sarcoplasmic reticulum.

Calcium (from the sarcoplasmic reticulum) will bind to troponin causing conformational changes that stimulate tropomyosin to leave the complex exposing the binding sites on actin and now the myosin head will interact with its binding site on actin.
We call the binding between actin and myosin: cross bridge.