1. Details of Module and its structure

Module Detail	
Subject Name	Biology
Course Name	Biology 02 (Class XI, Semester - 2)
Module Name/Title	Locomotion and Movement: Part – 2
Module Id	Kebo_22002
Pre-requisites	Knowledge about characteristics of living of living organism?
Objectives	After going through this lesson, the learners will be able to understand the following: • What are muscles? • Types of muscles • Properties of muscles • Structure of myofibrils and contractile proteins • Mechanism of muscle contraction • Muscular skeleton and its functions
Keywords	Muscles, Myofibrils, Structure, Contractile, Proteins, Contraction, Skeletal, Visceral, Cardiac, Contractibility, Excitability, Elasticity, Extensibility

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1. Introduction

The muscular system is responsible for the movement of the human body. Attached to the bones of the skeletal system are about 700 named muscles that make up roughly half of a person's body weight. Each of these muscles is a discrete organ constructed of skeletal muscle tissue, blood vessels, tendons, and nerves. Almost every muscle constitutes one part of a pair of identical bilateral muscles, found on both sides, resulting in approximately 320 pairs of muscles.

The muscular system is composed of specialised cells called muscle fibres. Their predominant function is contractibility. Muscles, attached to bones or internal organs and blood vessels, are responsible for movement. Nearly all movement in the body is the result of muscle contraction. Exceptions to this are the action of cilia, flagellum on sperm cells, and amoeboid movement of some white blood cells.

The integrated action of joints, bones, and skeletal muscles produces obvious movements such as walking and running. Skeletal muscles also produce more subtle movements that result in various facial expressions, eye movements, and respiration.

In addition to movement, muscle contraction also fulfils some other important functions in the body, such as posture, joint stability, and heat production. Posture, such as sitting and standing, is maintained as a result of muscle contraction. The skeletal muscles are continually making fine adjustments that hold the body in stationary positions. The tendons of many muscles extend over

joints and in this way contribute to joint stability. This is particularly evident in the knee and shoulder joints, where muscle tendons are a major factor in stabilising the joint. Heat production, to maintain body temperature, is an important by-product of muscle metabolism. Nearly 85 percent of the heat produced in the body is the result of muscle contraction.

2. What are Muscles?

Muscles are a band or bundle of fibrous tissues in a human or animal body that has the ability to contract, producing movement in or maintaining the position of parts of the body. The term muscle is derived from the Latin word ‘musculus’ meaning "little mouse" perhaps because of the shape of certain muscles or because contracting muscles look like mice moving under the skin.

Muscles are an organ, composed of muscle tissue that contracts to produce a particular movement. Muscles are grouped in different ways. Muscles and nerve fibres allow us to move our bodies. They enable our internal organs to function. The human body has over 600 muscles, which make up around 40 percent of our bodyweight.

Muscle is a specialised tissue which constitutes about 40-50% of the body weight of a human adult. They have special properties like excitability, contractibility, extensibility and elasticity (to be discussed in detail later in the module).

All muscles are made of a kind of elastic tissue. Each muscle consists of thousands, or tens of thousands, of small musculus fibres. Each muscle fibre is about 40 millimetres long. It consists of tiny strands of fibrils. Each muscle fibre is commanded by a nerve, which makes it contract. A muscle's strength depends mainly on how many fibres are present.
Muscle tissues are derived from the mesodermal layer of embryonic germ cells in a process known as myogenesis. There are three types of muscle, skeletal or striated, cardiac, and smooth. Muscle action can be classified as being either voluntary or involuntary. Cardiac and smooth muscles contract without conscious thought and are termed involuntary, whereas the skeletal muscles contract upon command. Skeletal muscles in turn can be divided into fast and slow twitch fibres.

As a whole, they make up about 36% of the body. The muscles that you move by thinking are also called skeletal muscles since they use bones as levers. The involuntary muscles are found in all hollow organs except for the heart. They move very slowing in a way called peristalsis. These muscles are also called smooth muscles. Cardiac (heart) muscles pump the heart.

To fuel a muscle, the body metabolises food to make adenosine triphosphate (ATP), and muscle cells turn ATP into mechanical energy. Muscle cells contain protein filaments of actin and myosin that slide past one another, producing a contraction that changes both the length and the shape of the cell. Muscles function to produce force and motion. They are primarily responsible for maintaining and changing posture, locomotion, as well as movement of internal organs, such as the contraction of the heart and the movement of food through the digestive system via peristalsis.

Muscles are predominantly powered by the oxidation of fats and carbohydrates, but anaerobic chemical reactions are also used, particularly by fast twitch fibres. These chemical reactions produce Adenosine TriPhosphate (ATP) molecules that are used to power the movement of the myosin heads.

1. Types of Muscles

Each human body possess in between 600 and 700 different muscles throughout the body. Muscle is the tissue of the body which primarily functions as a source of power. There are three types of muscle in the body.

- Muscle which is responsible for moving extremities and external areas of the body is called "skeletal muscle."
- Muscle that is in the walls of arteries and bowel is called "smooth or visceral muscle."
- Heart muscle is called "cardiac muscle."

2. Skeletal Muscles

Skeletal muscle derives its name from the fact that these muscles always connect to the skeleton in at least one place. Skeletal muscle is the only voluntary muscle tissue in the human body. Every physical action that a person consciously performs, like speaking, walking, or writing, requires skeletal muscles.

- Skeletal muscles or striated muscles:
    - Closely associated with skeleton.
    - They are striped appearance under the microscope and called Striated muscles.
    - They are under voluntary control of nervous system, hence called voluntary muscles.
    - These involved in locomotion and change of body postures.
    - Unbranched and multi nucleated

Structure of skeletal muscle:

- Each organised skeletal muscle in our body is made of a number of muscle bundles called fascicles held together by common fibrous covering called fascia.
- Each fascicle consists of a number of muscle fibres (cell) covered by a common fibrous perimysium.
- Each muscle fibre is lined by the plasma membrane called sarcolemma, enclosing cyto-plasm called sarcoplasm.
- The sarcoplasm contain endoplasmic reticulum, called sarcoplasmic reticulum is the store house of calcium ion.
- Muscle fibre is a syncitium as the sarcoplasm contain many nuclei.
- Muscle fibres contain a large number of parallelly arranged filaments in the sarcoplasm called myofilaments or myofibrils.
- There are two types of myofibrils are present in the sarcoplasm –
    - Thin filament – Actin
    - Thick filament – Myosin
- The arrangement of thick and thin filament gives the characteristic striated appearance.
- The light bands contain only actin filaments and are called I-band or isotropic band.
- The dark band called ‘A’ or anisotropic band contains both actin and myosin.
- In the centre of each ‘I’ band is an elastic fibre called ‘Z’ line which bisects it.
- The thin filaments or actin are firmly attached with the ‘Z’ line.
- The thick filaments or myosin in the ‘A’ band are also held together in the middle by a thin fibrous membrane called ‘M’ line.
- The portion between two successive ‘Z’ lines is considered as the functional unit of the muscle called sarcomere.
- Each ‘A’ band contains two overlap zone of thick and thin filament called ‘O’ band.
- The central part of thick filament, not overlapped by thin filament is called ‘H’ band.
- ‘A’ band = 2(O) + H.

The function of skeletal muscle is to contract to move parts of the body closer to the bone that the muscle is attached to.

3. Visceral Muscles

Visceral muscle is found inside of organs like the stomach, intestines, and blood vessels. The weakest of all muscle tissues, visceral muscle makes organs contract to move substances through the organ. Because visceral muscle is controlled by the unconscious part of the brain, it is known

as involuntary muscle. It cannot be directly controlled by the conscious mind. The term “smooth muscle” is often used to describe visceral muscle because it has a very smooth, uniform appearance when viewed under a microscope. This smooth appearance starkly contrasts with the banded appearance of cardiac and skeletal muscles.

- Visceral muscles or smooth muscles
    - are located in inner wall of hollow visceral organ.
    - are Spindle shaped and uni-nucleated.
    - They do not exhibit any striation and are smooth in appearance.
    - are called smooth muscles or non-striated muscles.
    - activities are not under voluntary control of nervous system hence called as involuntary muscles.
    - They assist in transport of food through digestive tract and gametes through the genital tract.

4. Cardiac Muscles

Found only in the heart, cardiac muscle is responsible for pumping blood throughout the body. Cardiac muscle tissue cannot be controlled consciously, so it is an involuntary muscle. While hormones and signals from the brain adjust the rate of contraction, cardiac muscle stimulates itself to contract. The natural pacemaker of the heart is made of cardiac muscle tissue that stimulates other cardiac muscle cells to contract. Because of its self-stimulation, cardiac muscle is considered to be auto rhythmic or intrinsically controlled.

- Cardiac Muscles:
    - are the muscles of heart, involuntary in nature.
    - cells assemble in a branching pattern to form a cardiac muscle.
    - are uni-nucleated with characteristic intercalated disc.

The cells of cardiac muscle tissue are striated—that is, they appear to have light and dark stripes when viewed under a light microscope. The arrangement of protein fibres inside of the cells causes these light and dark bands. Striations indicate that a muscle cell is very strong, unlike visceral muscles.

The muscle that makes up the heart is called cardiac muscle. It is also known as the myocardium. The thick muscles of the heart contract to pump blood out and then relax to let blood back in af-

ter it has circulated through the body. The cells of cardiac muscle are branched X or Y shaped cells tightly connected together by special junctions called intercalated disks. Intercalated disks are made up of finger-like projections from two neighbouring cells that interlock and provide a strong bond between the cells. The branched structure and intercalated disks allow the muscle cells to resist high blood pressures and the strain of pumping blood throughout a lifetime. These features also help to spread electrochemical signals quickly from cell to cell so that the heart can beat as a unit.

Just like smooth muscle, cardiac muscle works all by itself with no help from you. A special group of cells within the heart are known as the pacemaker of the heart because it controls the heartbeat.

5. Properties of Muscles

Muscle Tissue possesses some unique characteristics that help to differentiate it from other bodily tissue such as the following :

- **Contractility**- A notable characteristic of muscles are that they can contracts forcefully. Muscle cells shorten and generate a strong pulling force as they contract.
- **Excitability**- Nerve signals or other factors excite muscle cells, causing electrical impulses to travel along the cells' plasma membrane. These impulses then stimulate the cells to contract.
- **Extensibility**- Muscle tissue can be stretched by the contraction of an opposing muscle.
- **Elasticity**- After being stretched, muscle tissue can recoil passively and resume its usual resting length.

6. Structure of Myofibril

A myofibril, also known as a muscle fibril, is a basic rod-like unit of a muscle cell. Muscles are composed of tubular cells called myocytes, known as muscle fibres in striated muscle, and these cells in turn contain many chains of myofibrils. They are created during embryonic development in a process known as myogenesis.

Myofibrils are composed of long proteins including actin, myosin, and titin, and other proteins that hold them together. These proteins are organised into thick and thin filaments called myofilaments, which repeat along the length of the myofibril in sections called sarcomeres. Muscles contract by sliding the thick and thin filaments along each other.

There are hundreds of myofibrils in each muscle fibre. Myofibrils line up with each other such that the Z-lines (formed from adjacent Z discs) of each sarcomere in one myofibril line up with the Z-lines of the sarcomeres in adjacent myofibrils.

The filaments of myofibrils, myofilaments, consist of two types, thick and thin. Thin filaments consist primarily of the protein actin, coiled with nebulin filaments. Actin, when polymerised into filaments, forms the "ladder" along which the myosin filaments "climb" to generate motion. Thick filaments consist primarily of the protein myosin, held in place by titin filaments. Myosin is responsible for force generation. It is composed of a globular head with both ATP and actin binding sites, and a long tail involved in its polymerisation into myosin filaments. The protein complex composed of actin and myosin is sometimes referred to as “actinomyosin".

In striated muscle, such as skeletal and cardiac muscle, the actin and myosin filaments each have a specific and constant length on the order of a few micrometers, far less than the length of the elongated muscle cell. The filaments are organised into repeated subunits along the length of the myofibril. These subunits are called sarcomeres. The muscle cell is nearly filled with myofibrils running parallel to each other on the long axis of the cell. The sarcomeric subunits of one myofibril are in nearly perfect alignment with those of the myofibrils next to it. This alignment gives rise to certain optical properties which cause the cell to appear striped or striated. In smooth muscle cells, this alignment is absent, hence there are no apparent striations and the cells are called smooth.

7. Structure of Contractile Proteins

Three types of proteins form myofibrils: contractile, regulatory, and structural.

- Contractile proteins generate force for muscle contraction. The two contractile proteins in myofibrils are actin and myosin. Each actin filament is made up of two “F” (filamentous) actins helically wound up to each other. Each ‘F’ actin is a polymer of monomeric ‘G’ (Globular) actins. Two filaments of another protein, tropomyosin also run close to the ‘F’ actins throughout its length. A complex protein Troponin is distributed at regular intervals on the tropomyosin. In the resting state a subunit of troponin masks the active binding sites for myosin on the actin filaments.

Each myosin (thick) filament is also a polymerised protein. Many monomeric proteins called Meromyosins constitute one thick filament. Each meromyosin has two important parts, a globular parts, a globular head with a short arm and a tail, the former being called the heavy meromyosin (HMM) and the latter, the light meromyosin (LMM). The HMM component, i.e. the head and short arm projects outwards at regular distance and angle from each other from the surface of a polymerised myosin filament and is known as cross arm.

8. Mechanism of Muscle Contraction

Mechanism of muscle contraction is best explained by the sliding filament theory, which states that contraction of a muscle fibre takes place by the sliding of the thin filaments over the thick filaments. Muscle contraction is initiated by a signal sent by the central nervous system (CNS) via a motor neuron.

A motor neuron along with the muscle fibres connected to it constitute a motor unit. The junction between a motor neuron and the sarcolemma of the muscle fibre is called the neuromuscular junction or motor-end plate. A neural signal reaching this junction releases a neurotransmitter (Acetyl choline) which generates an action potential in the sarcolemma. This spreads through the muscle fibre and causes the release of calcium ions into the sarcoplasm. Increase in Ca++ level leads to the binding of calcium with a subunit of troponin on actin filaments and thereby remove the masking of active sites for myosin.

Utilising the energy from ATP hydrolysis, the myosin head now binds to the exposed active sites on actin to form a cross bridge. This pulls the attached actin filaments towards the centre of ‘A’ band. The ‘Z’ line attached to these actins are also pulled inwards thereby causing a shortening of the sarcomere, i.e., contraction. It is clear from the above steps, that during shortening of the muscle, i.e., contraction, the ‘I’ bands get reduced, whereas the ‘A’ bands retain the length. The myosin, releasing the ADP and P1 goes back to its relaxed state. A new ATP binds and the cross-bridge is broken. The ATP is again hydrolysed by the myosin head and the cycle of cross bridge formation and breakage is repeated causing further sliding.

The process continues till the Ca++ ions are pumped back to the sarcoplasmic cisternae resulting in the masking of actin filaments. This causes the return of ‘Z’ lines back to their original position, i.e., relaxation. The reaction time of the fibres can vary in different muscles. Repeated activation of the muscles can lead to the accumulation of lactic acid due to anaerobic breakdown of glycogen in them, causing fatigue.

Muscle contains a red coloured oxygen storing pigment called myoglobin. Myoglobin content is high in some of the muscles which gives a reddish appearance. Such muscles are called the Red fibres. These muscles also contain plenty of mitochondria which can utilise the large amount of oxygen stored in them for ATP production. These muscles, therefore, can also be called aerobic muscles. On the other hand, some of the muscles possess very less quantity of myoglobin and therefore, appear pale or whitish. These are the White fibres. Number of mitochondria are also few in them, but the amount of sarcoplasmic reticulum is high. They depend on anaerobic process for energy.

9. Muscular system and its functions

The main functions of the muscular system are as follows:

i) Mobility

The muscular system's main function is to allow movement. Like walking, running, swimming. The smaller skeletal muscles are usually responsible for writing, speaking, facial expressions etc. Most muscle movement of the body is under conscious control. Some movements are reflexive, such as withdrawing a hand from a source of heat.

ii) Stability

Muscle tendons stretch over joints and contribute to joint stability. They also stabilize the body and assist in tasks, such as lifting weights.

iii) Posture

Skeletal muscles help keep the body in the correct position when someone is sitting or standing. This is known as posture. Good posture relies on strong, flexible muscles. Long-term, bad posture leads to joint and muscle pain in the shoulders, back, neck, and elsewhere.

iv) Circulation

The heart is a muscle that pumps blood throughout the body. It’s movement is involuntary. These muscles maintain blood pressure and circulation.

v) Respiration

Breathing involves the use of the diaphragm muscle. When the diaphragm contracts, it pushes downward, causing the chest cavity to get bigger. The lungs then fill with air. When the diaphragm muscle relaxes, it pushes air out of the lungs.

vi) Digestion

During digestion, the muscular system allows for movement within the body. Smooth muscles in the gastrointestinal tract control digestion. Food moves through the digestive system with a wave-like motion called peristalsis. Muscles in the walls of the hollow organs contract and relax to cause this movement, which pushes food through the oesophagus into the stomach. The upper muscle in the stomach relaxes to allow food to enter, while the lower muscles mix food particles with stomach acid and enzymes.

The digested food moves from the stomach to the intestines by peristalsis. From here, more muscles contract to pass the food out of the body as stool.

vii) Urination

The urinary system comprises both smooth and skeletal muscles, including those in the:

- bladder
- kidneys
- penis or vagina
- prostate
- ureters
- urethra

The muscles and nerves must work together to hold and release urine from the bladder.

viii) Childbirth

Smooth muscles in the uterus expand and contract during childbirth. These movements push the baby through the vagina. Also, the pelvic floor muscles help to guide the baby's head down the birth canal.

ix) Vision

Six skeletal muscles around the eye control the movements. These muscles work quickly and precisely, and allow the eye to:

- maintain a stable image
- scan the surrounding area
- track moving objects

x) Organ protection

Muscles in the torso protect the internal organs at the front, sides, and back of the body. The bones of the spine and the ribs provide further protection. Muscles also protect the bones and organs by absorbing shock and reducing friction in the joints.

xi) Temperature regulation

Maintaining normal body temperature is an important function of the muscular system. Almost 85 percent of the heat a person generates in their body comes from contracting muscles.

10. Summary

The skeletal and muscular system work together very closely to help make the body move. Without one, the other would not be able to function. The *musculoskeletal system* has many functions to it because it is actually two *systems* that are put together; muscular and skeletal. If the skeletal system did not supply structure to the body there would be nothing for the muscles to cling on to and move the part of the body. And if the muscles weren't there the bone would not be able to lift up the limb and make a movement. The muscles and bones also help to provide protection to the other systems in the body. Bones are connected to each other at the joints by ligaments or cartilage and skeletal muscle is attached to bones, usually by tendons.