Physical Education (HKDSE)

Part II: Human Body

Physical Education Section
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Acronyms

ADP	Adenosine diphosphate
ATP	Adenosine triphosphate
ATP-PC system	Adenosine triphosphate phosphocreatine system
AV node	Atrioventricular node
BMI	Body Mass Index
CNS	Central nervous system
CVS	Cardiovascular system
HDL	High-density lipoproteins
LDL	Low-density lipoproteins
MET	Metabolic Equivalent of Task
Pi	Phosphate group
PNS	Peripheral nervous system
SA node	Sinoatrial node
$VO_{2\ max}$	Maximal oxygen uptake

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Learning Objectives

This part helps students build a foundation in PE through familiarising themselves with the human body and its systems. It is complementary to and strongly linked with movement analysis (Part III), fitness and health (Part IV), training methods (Part V), sports injuries (Part VI) and psychological skills (Part VII).

Expected learning outcomes: Students will be able to

1. illustrate the structure and functions of the skeletal, nervous, muscular, cardiovascular and respiratory systems of the human body;
2. explain the mechanism of the aerobic and anaerobic systems and analyse the energy supply for different types of physical activities; and
3. compare the physiological characteristics of different stages of development.

Glossary

	Term	Description
1.	Adenosine triphosphate (ATP) 三磷酸腺苷	ATP is a complex organic compound formed from the addition of a phosphate group (Pi) onto adenosine diphosphate (ADP). The process is endergonic, with the energy for the process being obtained from the respiration of food. It is the only form of energy which can be used directly by the cell for its activities.
2.	Axon 軸突	A single, long, relatively unbranched process projecting from a cell body of a neurone which transmits nerve impulses away from the body cells.
3.	Cartilage 軟骨	A tough and flexible connective tissue which has no nerves or blood vessels. It heals slowly after damage.
4.	Cholesterol 膽固醇	It is a lipid-related compound. There are two main types of cholesterol, low-density lipoproteins (LDL) and high-density lipoproteins (HDL). LDL is the form in which cholesterol is transported in the blood and is associated with atherosclerosis. Hence, it is known as bad or harmful cholesterol. HDL can reduce the likelihood of cholesterol becoming deposited in the arterial wall. Therefore, it is considered good or beneficial cholesterol.
5.	Concentric contraction 向心收縮	During its contraction, the muscle shortens and produces body movement.
6.	Connective tissue 結締組織	A tissue found in all parts of the body. Its functions include support, storage, and protection. Bones, cartilages, tendons and ligaments are examples of connective tissues, whereas special connective tissues include blood and lymph.

Glossary

	Term	Description
7.	Cytoplasm 細胞質	The jelly-like part outside the nucleus of a cell. It comprises 90% of water and different organelles. The type and number of organelles vary according to the functions of the cells.
8.	Dendrite 樹突	A short branching process of a neurone which serves as a receiver of information from the neighbouring neurones, transmitting nerve impulses towards the cell body.
9.	Eccentric contraction 離心收縮	During its contraction, the muscle is lengthened by the resisted load.
10.	Extracellular fluid 細胞外液	A body fluid located outside the cells. It contains blood plasma and interstitial fluid.
11.	Ganglion 神經節	A collection of neurone cell bodies located outside the central nervous system.
12.	Glycogen 糖原 / 肝醣	A highly branched polysaccharide stored in the muscle or liver. It is a vital metabolic fuel during heavy and prolonged exercise. Fatigue is associated with the depletion of muscle glycogen.
13.	Glycolysis 糖酵解	The first stage of cellular respiration, occurring with or without oxygen in the cytoplasm, in which glucose is broken down into pyruvic acid. Energy is also generated, which is used to produce ATP from ADP.
14.	Hormone 激素 / 荷爾蒙	They act as chemical messengers to regulate specific body functions. They are produced in the endocrine glands and are carried by the bloodstream to the target organs.
15.	Isometric contraction	During its contraction, the muscle does not produce any body movement and its length remains the same.

Glossary

Term	Description
等長收縮	
16. Lactate 乳酸鹽	It usually dissolves in the blood and its concentration is used as a biochemical measurement of the exercise intensity. Its value varies from 1-2 mmol/L (near to resting level) of low intensity exercise to 6-7 mmol/L of maximal intensity exercise.
17. Lactic acid 乳酸	It is a metabolite of the lactic acid system resulting from the breakdown of glucose. An excessive production of lactic acid as a result of high intensity exercise is associated with muscle fatigue and acute muscle soreness.
18. Ligament 韌帶	A band of tough, non-elastic, fibrous connective tissue. Its main functions are to bind bones together, to strengthen and stabilise joints, and to limit their movements.
19. Lymphatic system 淋巴系統	A system of blind-ending vessels which drains excess tissue fluid from the extracellular space. The system contains lymph nodes, which removes foreign bodies and produces antibodies.
20. Maximal oxygen consumption (VO_{2max}) 最大攝氧量	The maximum amount of oxygen that a person can extract from the atmosphere and then transport and use it in the muscle fibres. It reaches the peak by the individual when the individual pursues continuous large muscle group activities of progressively increasing intensity until exhaustion.
21. Mitochondrion 線粒體 / 粒線體	The inner membrane is heavily folded (i.e., cristae). It is referred to as the powerhouse of the cell where aerobic respiration takes place and a large amount of ATP is produced.

Glossary

Term	Description
22. Muscle fibre 肌纖維 / 肌肉纖維	A single multinucleated muscle cell which contains a large amount of myofibrils. It is a basic unit for muscle contraction. A muscle fibre's length can be up to 35 cm.
23. Nutrient 營養素	A substance present in food that is used by the body to promote normal growth, health maintenance and repair. The major nutrients are carbohydrates, lipids, proteins, minerals, vitamins and water.
24. Ossification (Osteogenesis) 骨化過程	The development of fibrous tissues or cartilage into bones.
25. Phosphocreatine (PC) 磷酸肌酸	An energy-rich compound used in the production of ATP from ADP in the muscle. The breakdown of phosphocreatine to creatine and inorganic phosphate is an exergonic reaction coupled to the synthesis of ATP.
26. Red bone marrow 紅骨髓	The blood-forming tissue found within the internal cavities of bones.
27. Spirometry 肺活量測量法 / 肺功能測量法	A measurement of the volume of air inspired into and expired from the lungs during ventilation by using a spirometer.
28. Stroke volume 每搏輸出量 / 心搏量	The volume of blood pumped from the left ventricle of the heart per beat. A typical value for an untrained person at rest is 50-70 ml per beat, and for a trained person is 90-110 ml per beat.
29. Synovial cavity 滑液腔	A fluid-containing joint cavity which separates the articulating bones. It is covered by a synovial membrane. The synovial fluid can reduce the friction

Glossary

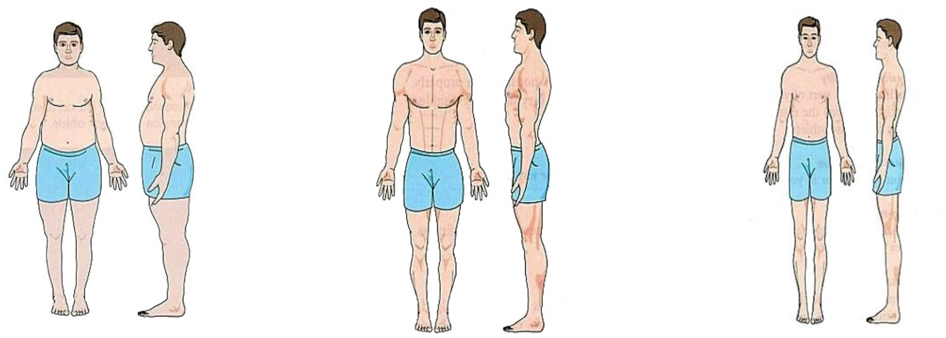
Term	Description
	during joint movements.
30. Tendon 腱 / 肌腱	A band of connective tissues connecting a muscle to a bone. A tendon consists mainly of numerous bundles of parallel collagen fibres, which provides some elasticity.
31. Tidal volume 潮氣量	The volume of air inspired into or expired out of the lungs during each breath. The typical value is about 500ml but it increases dramatically during exercise.
32. Vital capacity 肺活量	The maximum volume of air forcefully expired after maximal inspiration. Values vary from 3.5 – 6 litres at rest.
33. Voluntary muscle 隨意肌	The skeletal muscle is under conscious control. When stimulated, it moves a part of a skeleton, such as an arm.

Essential Concepts and Theories

A. Body Types and basic structures of human body

Somatotypes - Somatotyping is a system of classifying body types into three categories through an overall visual evaluation of body shapes (*See Fig 2.1 and 2.2*):

- **Endomorphs** are people with a rounded body shape and a tendency to store fat.
- **Mesomorphs** are more muscular and are generally taller.
- **Ectomorphs** tend to be tall and thin.



Endomorph **Mesomorph** **Ectomorph**

Fig 2.1 Somatotypes

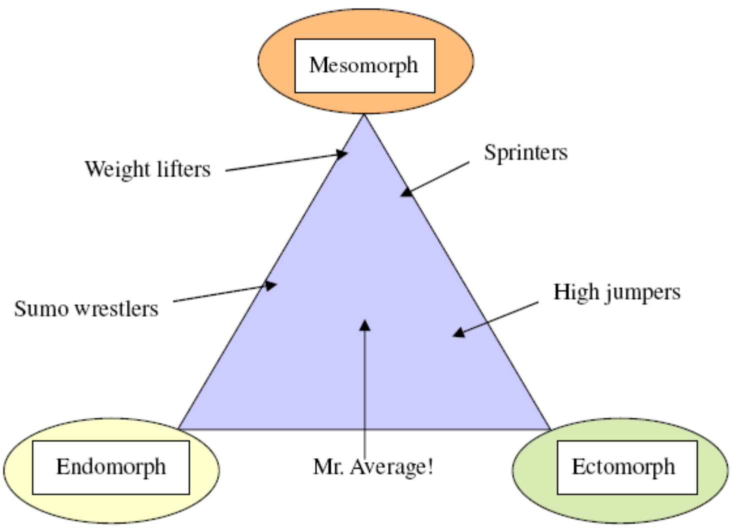


Fig 2.2 Somatotypes and sports events

Body Mass Index (BMI) – One of the common indicators which describes body fatness. According to the Department of Health, a BMI between 18.5 and 22.9 is a normal range for Asian adults. BMI can be calculated in the following way:

$$\text{BMI} = \frac{\text{Weight (in kilogram)}}{\text{Height (in meters)} \times \text{Height (in meters)}}$$

BMI can be considered an alternative for direct measure of body fat and is an inexpensive and easy-to-perform method. However, only one's weight and height are used to calculate the BMI, so the percentage of body fat in one's body composition cannot be shown.

Weight for height – The Department of Health defines "overweight" as having a body weight exceeding 20% of the median (50^{th} percentile) weight for height and "underweight" as having a body weight lower than 20 % of the median weight for height. Weight for height is only suitable for children and adolescents who are 18 years old or below and the height between 91-165cm (female) or 91-175 cm (male).
You may visit the following websites for more examples and the "Weight- for-height" charts: https://www.chp.gov.hk/en/resources/e_health_topics/pdfwav_11015.html

and https://www.chp.gov.hk/en/resources/e_health_topics/pdfwav_11016.html

Body composition – It refers to the relative composition of fatty tissues, bones, muscles and water. The School Physical Fitness Award Scheme adopts 10.3% - 20.1% for boys and 15% - 26.8% for girls, as the optimal range of body fat.

	Very Low	Low	Optimal Range	Moderately High	High	Very High
Boys	< 5.8%	5.9-10.2%	10.3-20.1%	20.2-25.3%	25.4-30%	>30%
Girls	< 12.1%	12.2-14.9%	15-26.8%	26.9-31.9%	32-35%	>35%

(Source:《School Fitness Award Scheme Teacher Handbook (2013/14)》)
http://cd1.edb.hkedcity.net/cd/pe/tc/spfas/1314/SPFAS_T_HB_C.pdf (in Chinese only)

Table 2.1 The Percentage of body fat

The Basic structures of the human body

- **Cell -** A cell is a living organism in its simplest form. Each individual cell has the ability to maintain bodily functions by taking in nutrients and converting them to energy (See Fig 2.3).
- **Tissue -** A tissue is a collection of interconnected cells that perform a similar function within an organism.
- **Organ -** An organ is a group of tissues that perform one or more specific physiological functions.
- **System** –The complex functions of the human body are carried out by groups of organs working together as a system.

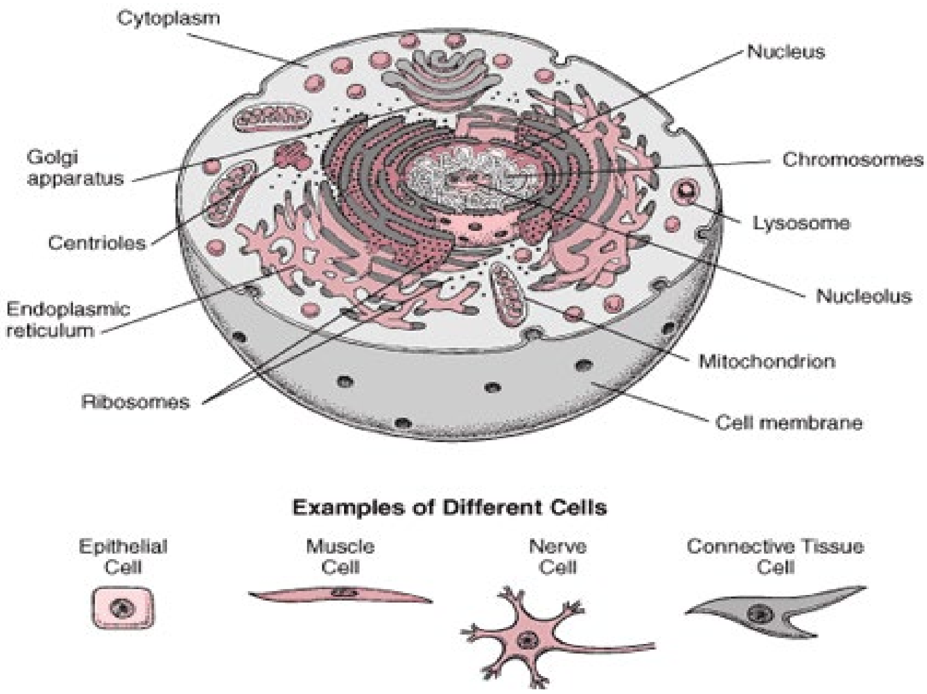


Fig 2.3 The human cell

B. The skeletal system

The skeletal system of the human body consists of bones, cartilage, ligaments and muscle tendons. It accounts for about 20 % of the body weight.

Structure: The skeletal system comprises the **axial skeleton**, which is comprised of the skull, vertebral column and thoracic cage, and **the appendicular skeleton**, which is comprised of the bones of the limbs and the girdles of attachment. (*See Fig 2.4 and 2.5*)

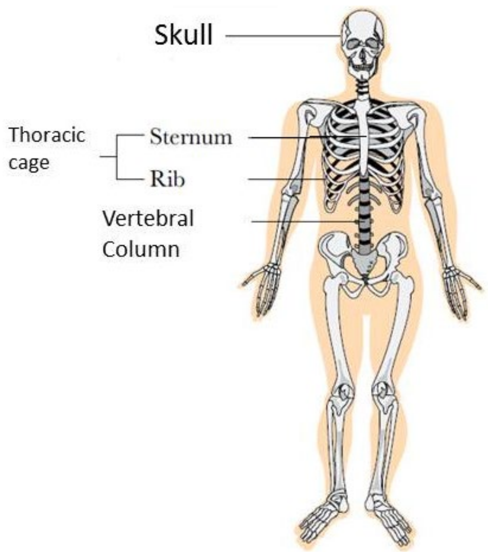


Fig. 2.4 The axial skeleton

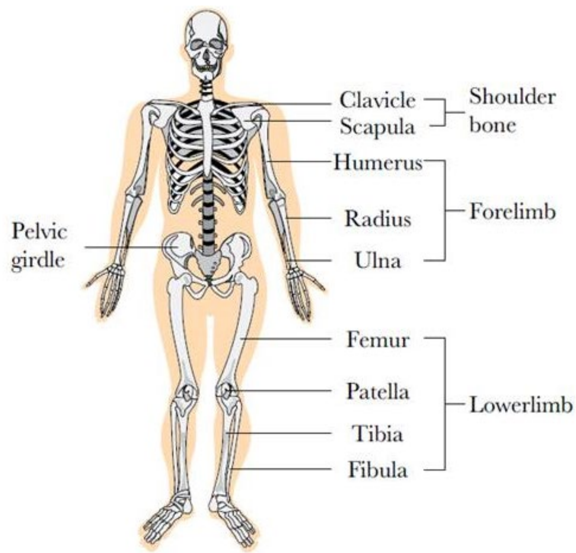


Fig. 2.5 The appendicular skeleton

The vertebral column is divided into five major regions (*See Fig 2.6*):

1. Cervical (7 vertebrae)
2. Thoracic (12 vertebrae)
3. Lumbar (5 vertebrae)
4. Sacral (5 vertebrae)
5. Coccyx (4 vertebrae)

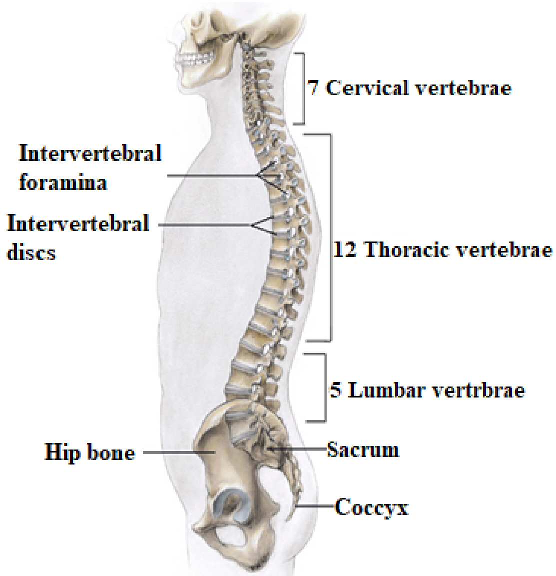


Fig. 2.6 The vertebral column

i) Functions

Support - The key function of the skeletal system is to provide a solid and rigid support to help the body remain upright and withstand the force of gravity pulling it downwards.

Movement - Provide attachment surface for muscles, bear the forces exerted by the muscle contractions and generate movements using the leverage principles.

Protection - Protect the internal organs, including the brain, spinal cord, lungs and heart.

Mineral storage - The main storage site for calcium and phosphorus.

Production - The red bone marrow in the internal cavities of bones produces red blood cells, white blood cells and blood platelets.

ii) Bones

A bone is a rigid and non-elastic tissue composed of 65% minerals and 35% organic tissues. Its surface and inner layers are made of compact bone and cancellous bone respectively. Compact bone is a hard bone that forms the surface layer, and cancellous bone is a spongy element that lies beneath with a "criss-cross" matrix appearance. Bones are extremely well vascularised and are formed through the process of ossification. There are 206 pieces of bones of various shapes and sizes in an adult's skeletal system.

iii) Joints

A joint is the area where two or more bones are attached. Joints are classified into three main types[1] (according to its structure):

- **Fibrous joints -** No movement is allowed by these types of joints, for example, the human skull.
- **Cartilaginous joints -** Slight movement is allowed by these joints, for example, the intervertebral discs in the lumbar spine (*Refer to Fig. 2.6*).
- **Synovial joints** – In a synovial joint, a synovial cavity, which is a fluid-containing joint cavity, separates the articulating bones. It is covered by a synovial membrane. The synovial fluid inside the synovial cavity is a thick, colourless fluid and acting

[1] According to the degree of movement, joint can be classified into: fixed (immovable) joint, slightly-movable joint and movable joint.

as a lubricant to reduce friction as well as cushioning the joint at the point of impact or during joint movements. There are many types of synovial joints in our body, and most of them are movable joints,for example:

- **Ball-and-Socket Joints** (for example, the hips and shoulders; refer to *Fig. 2.7*).
- **Hinge Joints** (for example, the knees and elbows; refer to Fig. 2.7).
- **Pivot Joints** (for example, the joint between the first and second cervical vertebrae which allows the head to rotate)
- **Gliding Joints** (for example, the joints between the small bones of the wrist; refer to Fig. 2.8).

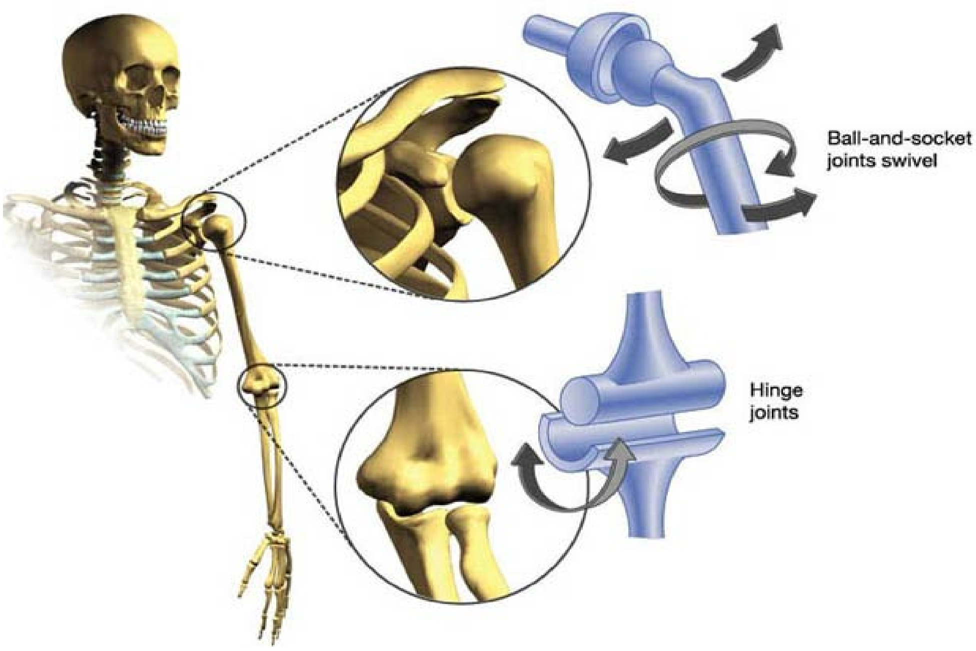


Fig. 2.7 Examples of hinge joints (elbow) and ball-and-socket joints (shoulder)

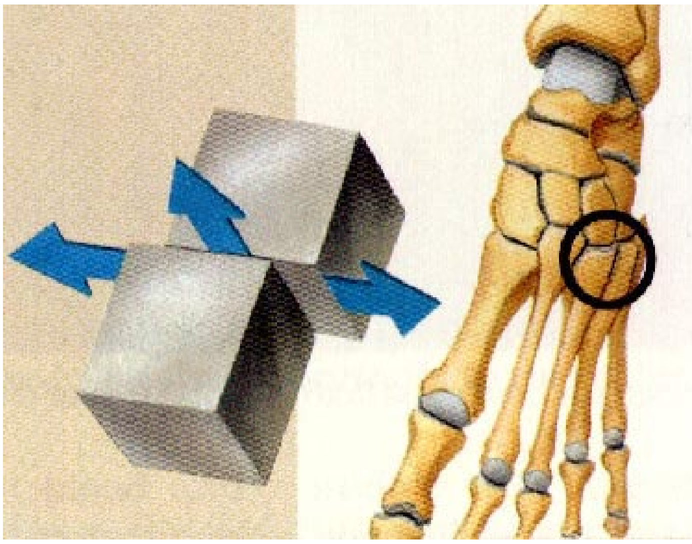


Fig. 2.8 An example of a gliding joint (wrist)

iv) Cartilage

Cartilage is a material which is softer than bones and acts as a shock absorber. It has no blood supply but can receive nutrients from the diffusion of fluids from the nearby capillaries. Hyaline cartilage, fibrocartilage and elastic cartilage are the three different types of cartilage found in the human body.

v) Ligament

A ligament is a tough fibrous connective tissue connecting bone to bone and is formed mostly of collagen. Ligaments play a role in the stabilisation of joints.

vi) Tendon

A tendon is a band of connective tissue connecting a muscle to a bone. A tendon consists mainly of numerous bundles of parallel collagen fibres, which provides some elasticity. The function of tendon is transmitting forces from muscle to bone during the muscle contraction.

C. The nervous system:

i) Functions

The human nervous system consists of the brain, spinal cord and nerves. It is the human body's central hub of all human movements. The nervous system controls every muscle action that the body carries out. The nervous system is divided into the **central nervous system** (CNS) and **the peripheral nervous system** (PNS). The complex neural fibres connect to these two systems, the nervous system controls all functions of the body, and gives us the ability to think, memorise and change our emotions to cope with the changes in the environment.

Nerve Cell – it is also known as a neuron which is the basic structure and functional unit of the nervous system. Based on the directions of the transmission, there are three types of neurons:

- **Sensory (afferent) Neurons -** Send signals to the CNS
- **Motor (efferent) Neurons -** Send signals from the CNS to the working muscles
- **Associative (interneurons) Neurons -** Communicate between the sensory neurons and motor neurons

These messages travel as impulses along the dendrites (towards the cell body) and axons (away from the cell body), which are the extensions of cytoplasm from the cell body. All nerve cells have many dendrites but only one axon. Most axons are coated by a fatty material called a myelin sheath which is laid down by connective tissues and permits nerve impulses to travel at great speed away from the cell body (*See Fig 2.9*). After the maturation of the nerve cells, they lose their ability to divide and multiply. In general, damaged nerve cells cannot regenerate.

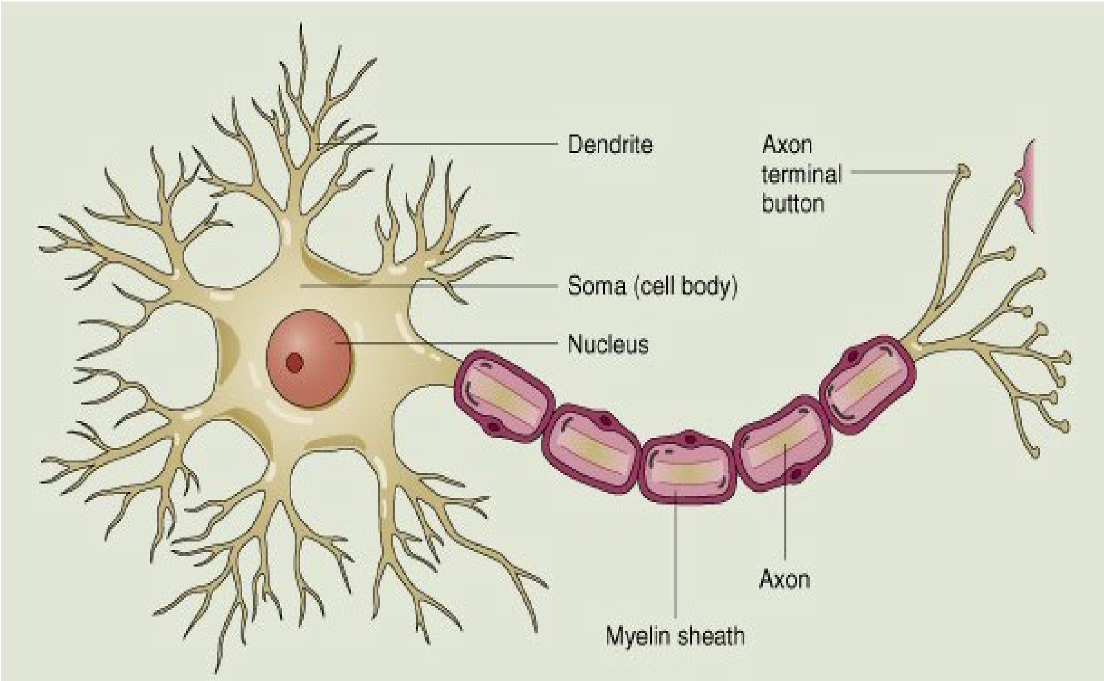


Fig. 2.9 The structure of a Neuron

ii) The central nervous system

It is made up of the brain and spinal cord. It is to receive, assemble various peripheral information and to initiate reaction and action orders.

The Brain - The human brain is a highly developed, complex mass of soft organ, and is made up of about one thousand billion neurons. It is protected by the meninges, the cerebrospinal fluid and the bones of the skull. The brain has many parts which all communicate and function together:

- **The cerebrum** - The cerebrum is the largest part of the brain. It is divided into the left hemisphere and the right hemisphere. The left hemisphere controls the activities of the right half of the body, and the right hemisphere controls the activities of the left half of the body. Both of the hemispheres are covered by a thin outer layer of grey matter containing many neurons. This layer is called the **cerebral cortex**. It is responsible for thinking, memorising, reasoning and performing abstract mental functions. The cerebrum is divided into four different lobes, namely **the frontal lobe**, **the parietal lobe**, **the occipital lobe** and **the temporal lobe** *(See Fig 2.10)*.
- **The cerebellum -** It regulates all bodily movements of the voluntary muscles and is responsible for maintaining the balance and controlling the posture and muscle tone.

- **The brainstem -** It maintains life and is responsible for important functions such as regulating breathing, heart rate and blood pressure.

The spinal cord - It is a long rope-like structure with the diameter of a little finger. Its upper part is connected to the brain and it runs downwards through a canal formed by the bones of the spine. Similar to the brain, it is surrounded by the cerebrospinal fluid and three layers of meninges. The spinal cord has various nerves spreading to the skin, muscles, bones and organs of the body. The spinal cord acts as a conduit for the two-way flow of information between these nerves and the brain.

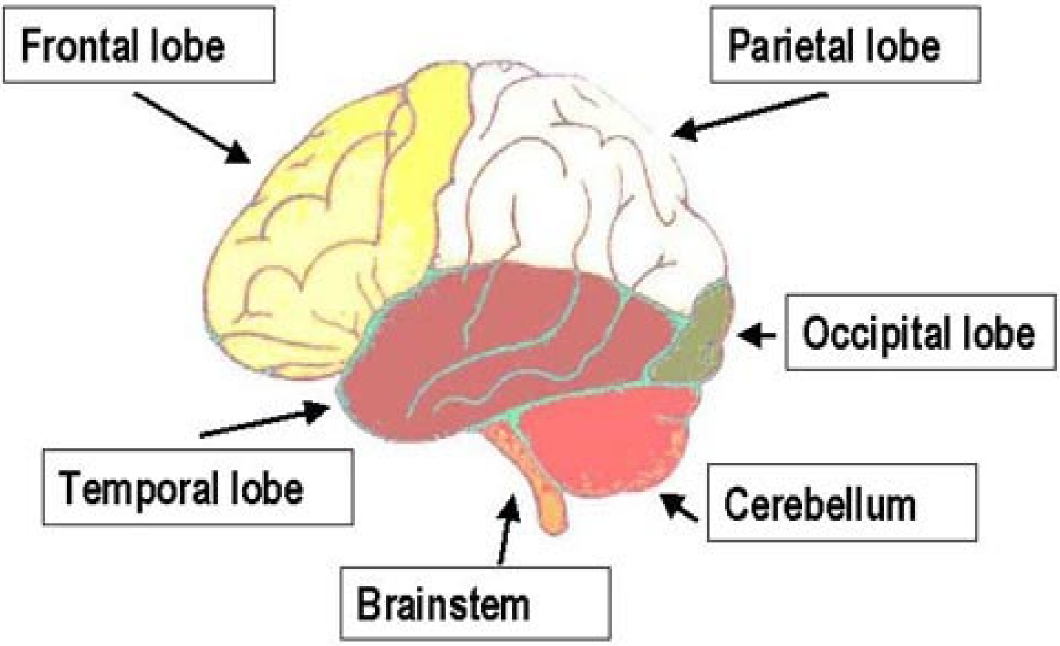


Fig 2.10 The human brain

D. Muscular system

i) Functions

Movement – Skeletal muscles are attached to the skeleton. When the skeletal muscles contract, they exert a pull upon the bones and so move them to produce a movement or maintain a posture.

Heat and Energy - On top of assisting with the human movement, the muscles are also the sources of considerable amount of energy and heat. Muscle contraction needs energy which is produced by a series of chemical reactions among oxygen, glucose and other materials in the muscle cells. As the energy is released, the heat which is given off by the reaction is then used by the body as a means for thermo-regulation.

ii) Types of muscle and muscle fibre

The more muscle fibres that are recruited, the stronger the force is generated. Muscles have the following characteristics:

- **Contractibility:** the ability of muscle to contract or shorten in length.
- **Excitability**: the ability of muscles to respond to the stimuli
- **Extensibility**: the ability of muscles to stretch or extend in length
- **Elasticity**: the ability of muscles to return to the normal resting length after stretching. It allows the muscles to prepare for a series of repeated contractions.

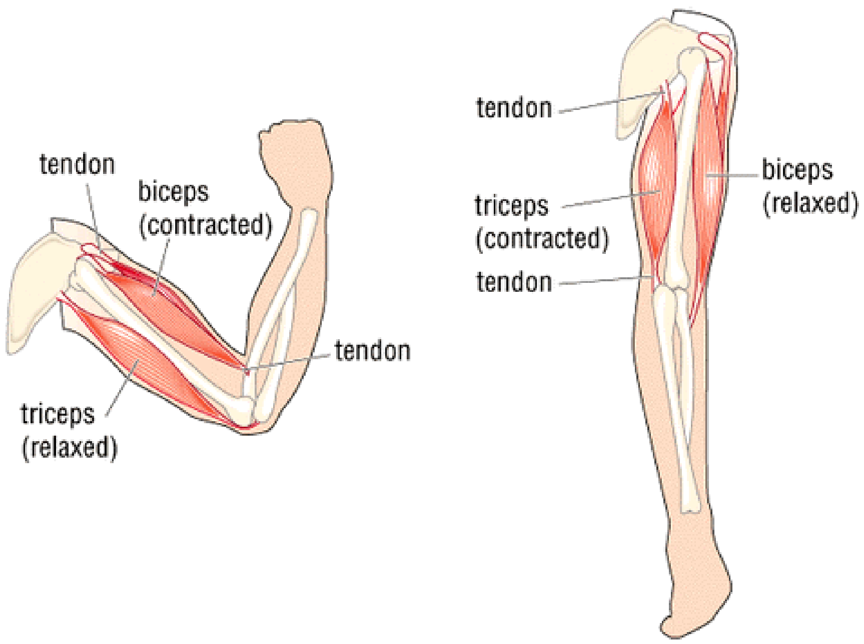


Fig. 2.11 An example of the biceps and triceps working as antagonistic pairs

Types of muscles

- **Skeletal muscles** – Most of them are attached to the bones of the skeleton and appear to be cross-banded (striated) when viewed under a microscope. They are composed of muscle cells known as muscle fibres. These are voluntary muscles under one's conscious control (*See Fig 2.12 and 2.13*). Many of the muscles of the body are arranged in pairs. One will be the agonist (prime mover), and the other moving in the opposite direction will be the antagonist. An example of this is the flexion and extension of the elbow joint. (*See Fig 2.11*)

- **Smooth muscles -** They are not attached to the bones. They do not tire easily and can remain contracted for a long period of time. Smooth muscles are so called as they do not appear to be striated. These muscles are not under one's conscious control and are therefore called involuntary muscles.

- **Cardiac muscles -** They are found only in the heart and are not under one's conscious control. They comprise muscle cells that are striated and branched. Cardiac muscles never tire, but they do need a continuous supply of oxygen to function**.**

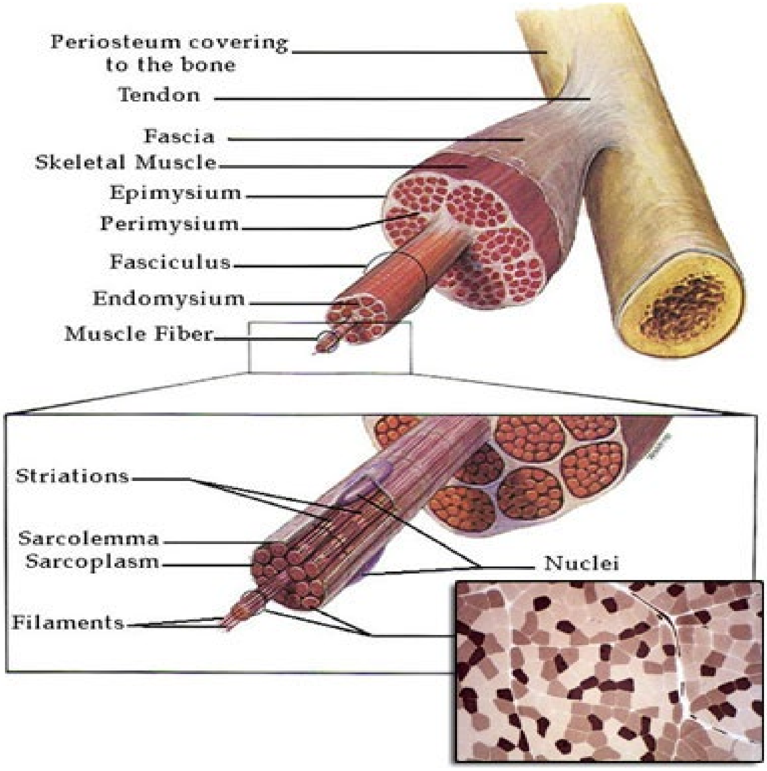


Fig 2.12 The structure of a muscle

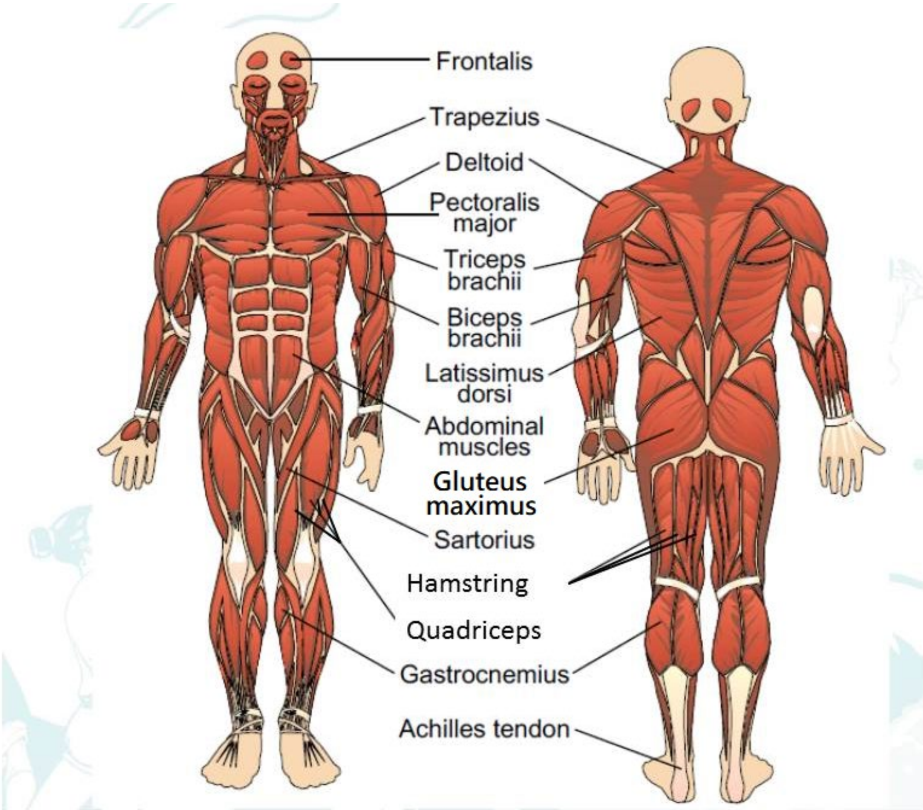


Fig. 2.13 The main muscles of human body

Types of Muscle Fibres

- **Slow-twitch muscle fibres (Type I)** - This type of muscle fibres is characterised by a high oxidative (aerobic) and low glycolytic (anaerobic) metabolic capacity. They are mainly recruited for low intensity endurance type activities. A marathon runner may have about 80% slow-twitch muscle fibres.

- **Fast-twitch muscle fibres (Type II)** - This type of muscle fibres can generate extremely high force but fatigue quite easily. They can be further categorised into Type IIa: fast oxidative glycolytic (aerobic); and Type IIb: fast-twitch glycolytic (anaerobic).

iii) Types of muscle contractions

Isotonic - During an isotonic contraction, this will cause the movement of the body parts and the changes in the muscle's length. It can be further divided into two categories:

- **Concentric -** During a concentric contraction, the muscle shortens. For example, raising the dumbbells in the biceps curl causes a concentric contraction of the biceps.
- **Eccentric** - During an eccentric contraction, the muscle is lengthened. For example, lowering the dumbbell in the biceps curl causes an eccentric contraction of the biceps.

Isometric - During an isometric contraction, the muscle does not produce any body movement and its length remains the same. For example, performing a plank causes an isometric contraction of the transversus abdominis muscle.

Isokinetic - During an isokinetic contraction, the muscles maintain a movement at a constant speed. An isokinetic dynamometer is needed to induce isokinetic contractions.

iv) Neuromuscular control:

Sensory nerve – Sensory receptors (such as eyes, ears, skin and etc) receive information and nerve impulses are produced. The sense of (afferent) neurons is spread to the central nervous system (the brain and spinal cord) and then the feeling is caused.

Motor nerve – consists of the somatic nervous system and the autonomic nervous system.

- **Somatic nervous system –** It is associated with the voluntary control of body movements. It dominates the activities of the skeletal muscles.
- **Autonomic nervous system –** It controls the involuntary actions. It consists of the sympathetic nervous system (exciting) and the parasympathetic system (inhibiting). Its main function is to regulate the smooth muscle organs and the endocrine glands to produce hormones.

Reflex Arc: Reflex actions occur relatively quickly by activating the spinal motor neurons without the delay of routing signals through the brain and showing responses systematically from the stimuli. For example, when an individual accidentally touches something hot such as a boiling pot, he or she will remove his/her hand from it. This reaction takes place as a result of the sensation of the heat of the pot being taken in by the sensory neurons in his/her hand. This information then travels along the dendrites and axons of the neuron and signals a message via the associative neurons to the motor neurons to activate the effector muscles which results in removing his/her hand from the boiling pot. The rapid muscular response causes the removal of his/her hand from the object before the actual perception of the pain occurs. (*See Fig 2.14*)

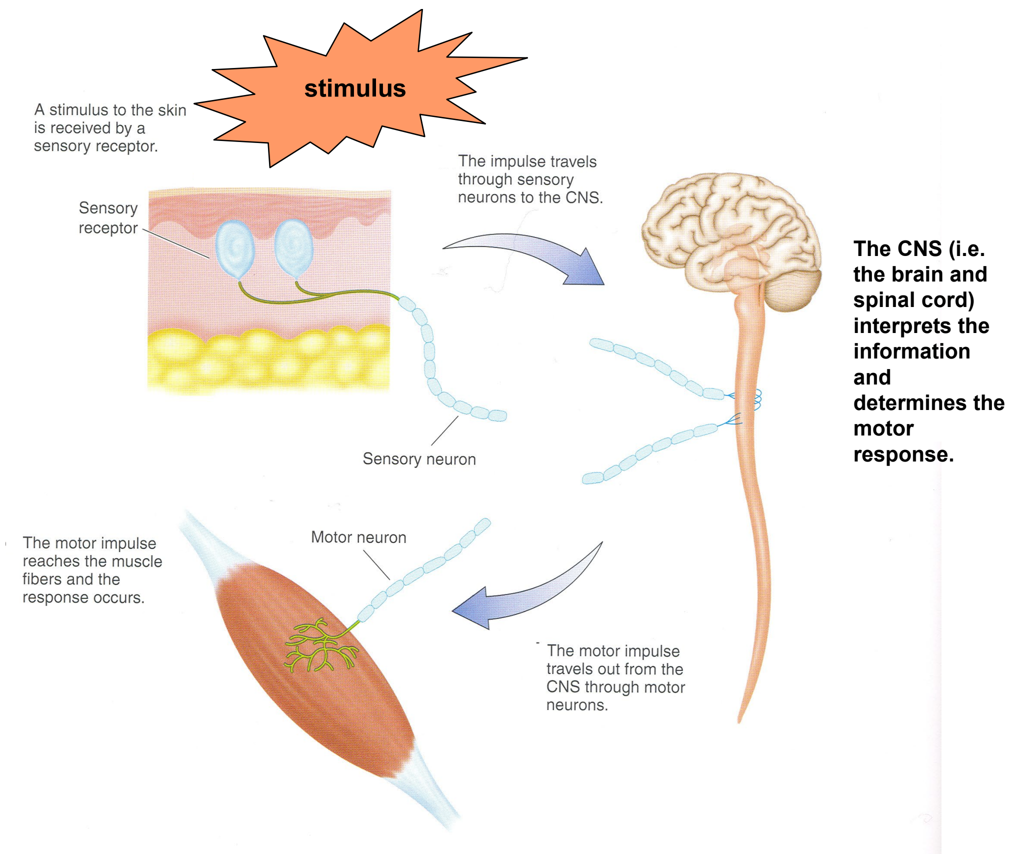


Fig. 2.14 Neuromuscular control

E. The cardiovascular system

i) Functions

- It pumps blood all over the body.
- It carries oxygen and nutrients to the cells and takes away waste products.

ii) Blood vessels *(See Fig 2.15)*

Arteries - They carry oxygenated blood away from the heart to the capillaries. They are elastic, muscular and thick-walled.

Capillaries - They are the smallest type of blood vessels and function by connecting the arterioles with the venules. The capillary walls are extremely thin to allow for selective permeability of various cells and substances (oxygen and nutrients).

Veins - They carry deoxygenated blood away from the capillaries to the heart. Veins are less elastic and less muscular than arteries due to the fact that they do not have to operate under high internal pressure. Valves are located along the inside of the vein wall to prevent the backflow of blood.

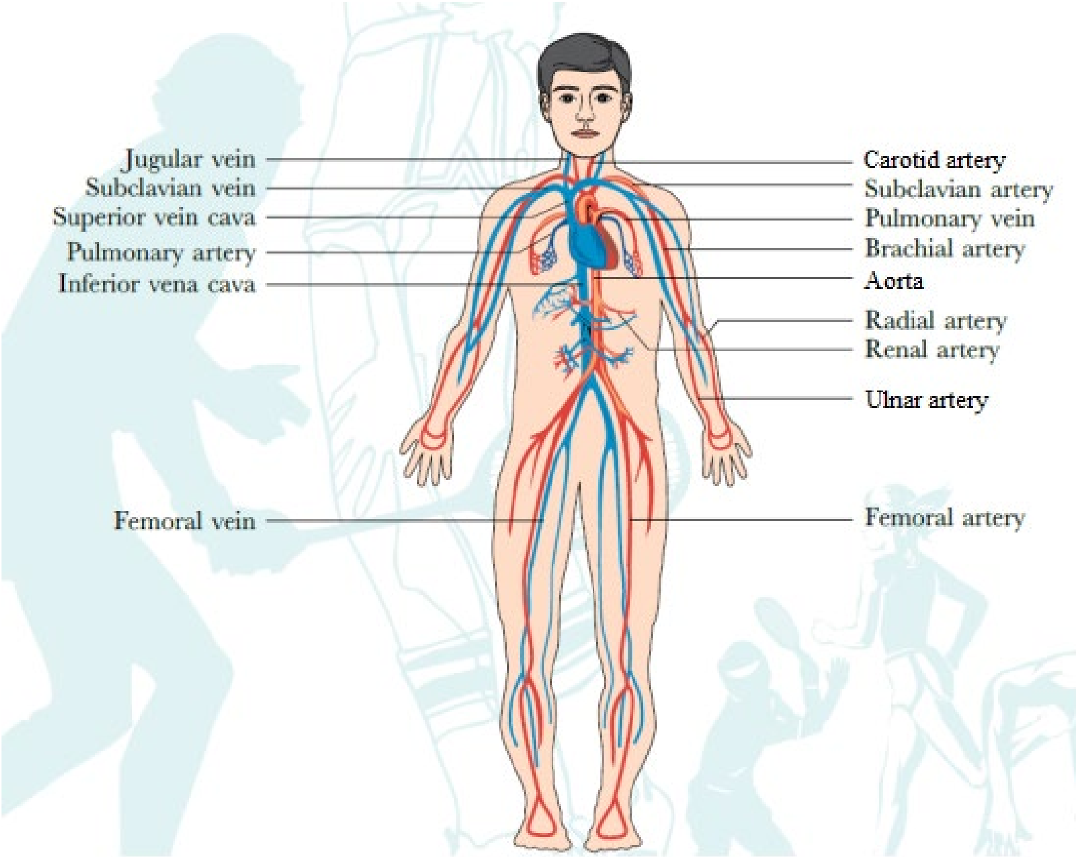


Fig 2.15 Major blood vessels

iii) The heart

The heart is located between the lungs and slightly to the left of the midline of the body. It is a hollow organ. The heart is divided into four chambers. The two upper chambers (atria) are the blood receiving chambers, and the two lower chambers (ventricles) act as the forceful pumps.

Cardiac Output - It refers to the amount of blood pumped out of the left ventricles per minute (ml/min).

Stroke Volume - It is the volume of blood pumped from the left ventricles per beat.

Cardiac Cycle - The four chambers of the heart work together as one unit. Blood is squeezed through the chambers by a muscle contraction of the thin-walled atria, followed by a larger contraction by the thick-walled ventricles. This contraction phase is known as systole. It is followed by a relaxation period known as diastole. One complete sequence of contraction and relaxation is called a cardiac cycle. At rest, this cycle takes less than one second.

Conduction System - Electrical energy stimulates the contraction of the cardiac muscle. Some specialised tissues in the heart called nodes generate this electrical energy or impulses.

Sinoatrial Node (SA) - It sits in the upper wall of the right atrium and determines the rhythm of the heart contractions, and therefore it is commonly referred to as the pacemaker.

Atrioventricular Node (AV) - It is located at the top of the septum and allows a rapid flow of impulses down various smaller fibres and then throughout the heart. It is an electrical relay station for the transmission of nerve impulses from the atria to the ventricles. It is a part of the system that regulates the heart beat.

iv) Circulation

Blood flows in the human body through a double circulation as shown in *Table 2.2* and *Fig 2.16*. While we are doing exercise, the blood flow to different organs or body systems is regulated as shown in *Table 2.3*.

Heart → Aorta → Arteries → Arterioles → Capillaries → Venules → Veins → Vena cava → Heart → Pulmonary arteries → Lungs → Pulmonary vein→ Heart

Table 2.2 The flow chart showing blood circulation in the body

Organ / Body Structure	Rest		Exercise	
	Percent	L/min	Percent	L/min
Bone	5	0.5	0.5	0.15
Brain	15	0.9	4	1.2
Heart	5	0.3	4	1.2
Kidney	25	1.5	2	0.6
Liver	25	1.5	3	0.9
Muscle	15	0.9	85	25.5
Skin	5	0.3	0.5	0.15
Other	5	0.3	1	0.3
Total	100	6.0	100	30

Table 2.3 Distribution of blood to various organs and tissues of the body at rest and during strenuous exercise

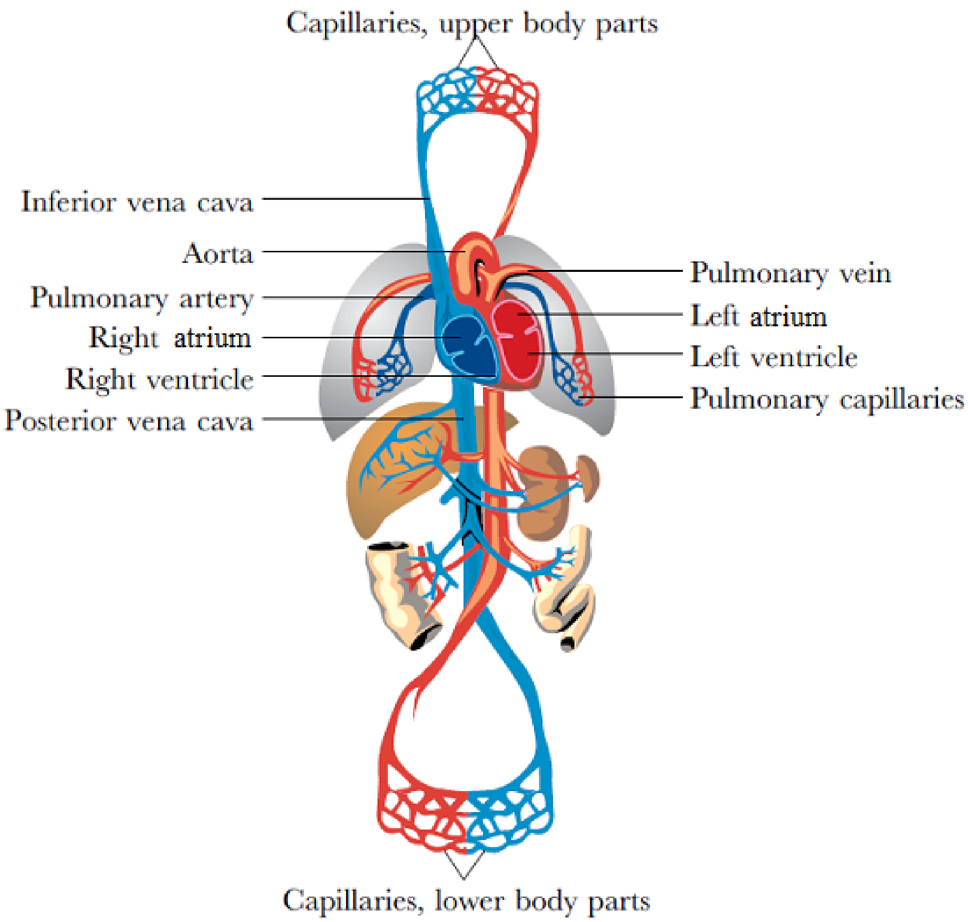


Fig. 2.16 The cardiovascular system

F. The respiratory system

i) Functions

Respiration – Respiration is the process by which oxygen is inhaled and delivered to bodily cells. Carbon Dioxide is then exhaled in the opposite direction.

Sound Production - The respiratory system is also responsible for sound production which is created by the vibration of the vocal cords as air is expelled from the lungs. Individual differences in voices are determined by the length and thickness of the vocal cords. Sounds can be modified by changing the position of the tongue and the shape of the oral cavity.

ii) The lungs

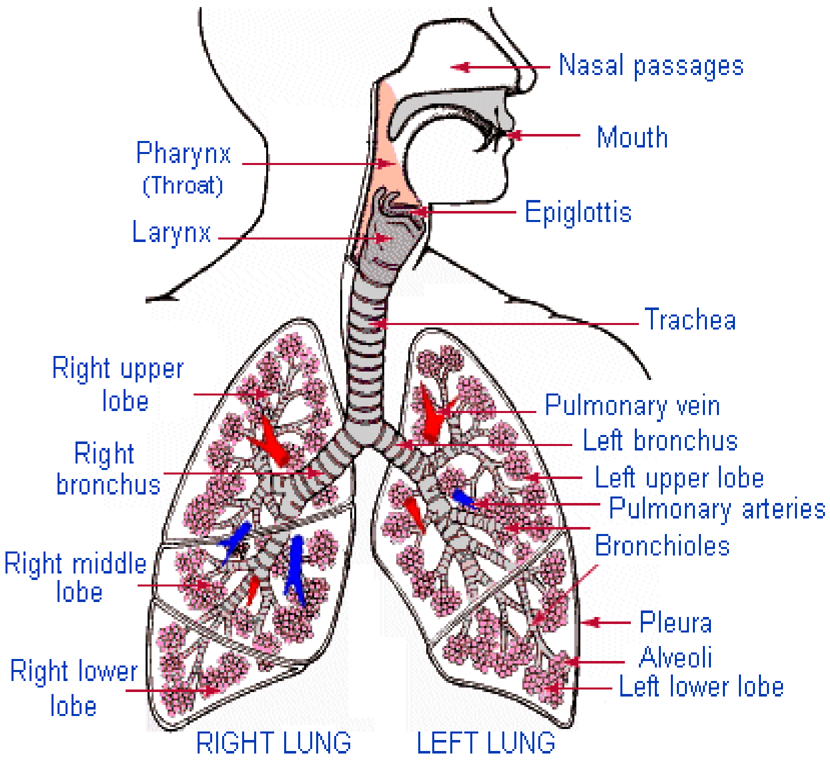
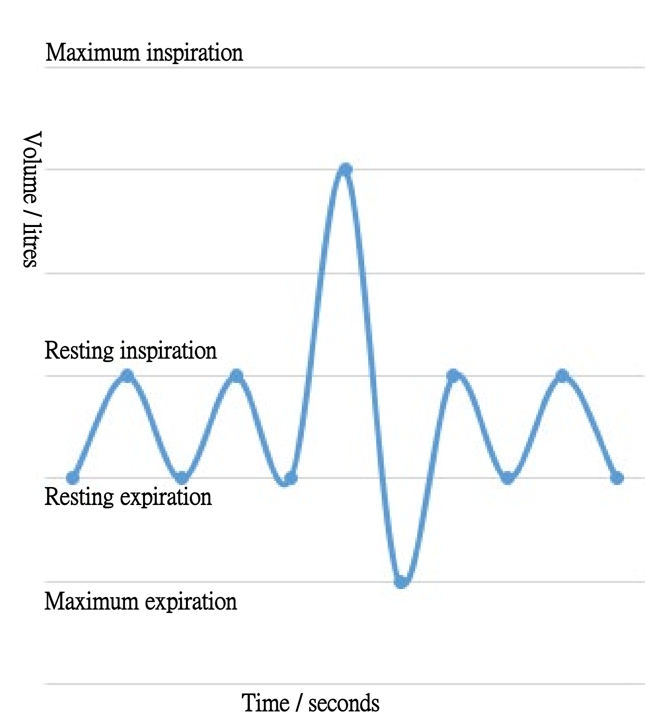


Fig. 2.17 The structure of the respiratory system

Two passageways facilitate the movement of air into the lungs. *(See Fig 2.17)* Air enters into the nose through the nostrils into the nasal cavity where dust and dirt particles are filtered out by the nasal mucosa. Air is warmed and moistened as it passes through the air cavities of the skull called the sinuses. Next, air travels down the pharynx (throat) into the triangular voice-box chamber known as the larynx. Extending downwards from the larynx is the trachea (wind pipe). During swallowing, food and drink are prevented from entering the larynx and trachea by a flap of cartilage known as the epiglottis covering the entrance. The trachea continues to extend downwards and is divided into left and right bronchi for each lung. As the bronchi enter each lung, they are each divided up into smaller tubes known as the bronchioles. At the end of each bronchiole is an alveolar duct that ends in the alveoli. The wall of the alveoli is thin and moist, its surface is full of capillaries. It can facilitate the gaseous exchange. The respiratory system plays a key role in regulating bodily functions in response to an increase in the exercise levels. It can be assessed by a spirometry, which can measure the volume of air inspired into and expired from the lungs during ventilation. During exercise, the tidal volume (the volume of air inspired into or expired out of the lungs during each breath) increases dramatically *(See Fig 2.18)*.



<table>
<tr><td>Inspiratory Reserve Volume(IRV)</td><td rowspan="2">Inspiratory Capacity(IC)</td><td rowspan="3">Vital Capacity(VC)</td><td rowspan="4">Total Lung Capacity (TLC)</td></tr>
<tr><td>Tidal Volume(TV)</td></tr>
<tr><td>Expiratory Reserve Volume(ERV)</td><td rowspan="2">Functional Residual Capacity(FRC)</td></tr>
<tr><td>Residual Volume(RV)</td><td>Residual Volume(RV)</td></tr>
</table>

Fig. 2.18 The lung volume and capacity

iii) The pulmonary ventilation and gaseous exchange

Respiration is divided up into three parts:

- **Pulmonary ventilation –** This is the term used to describe the exchange of gases between the atmosphere and the air sacs (or the alveoli) of the lungs. This process consists of inspiration and expiration.

- **Gaseous exchange – external and internal respiration**
  - **External respiration –** It occurs in the lungs, as oxygen diffuses from the air sacs into the blood, and carbon dioxide diffuses out of the blood to be eliminated.
  - **Internal respiration** – It occurs in the tissues and involves the diffusion of oxygen from the blood to the cells and the diffusion of carbon dioxide in the opposite direction. Diffusion is facilitated by the moistness of the respiratory membrane.

- **Cellular respiration -** At this stage, oxygen is used to release energy which is stored in the nutrient molecules such as glycogen (glucose) in mitochondria. This energy cannot be directly used by the body until it is converted to the energy-rich chemical molecules, like ATP. All body cells including those in the skeletal muscles can extract energy from ATP to maintain their normal functions. Carbon dioxide is the waste product of this process and will be removed by the circulatory system.

iv) The importance of the cardio-respiratory system during exercise

During any physical activity, training programme, sports event, etc, the work of the cardiovascular (CVS) and respiratory systems is crucial to our performance. The two systems are so closely linked that they are often termed as the “cardiorespiratory system”. When an athlete is riding an exercise bike, these two systems are constantly working in tandem to ensure that the athlete can complete the sustained workout. During the workout, the main role of the CVS is to ensure that sufficient oxygenated blood and nutrients are transported to those working lower limb muscles through the manipulation of the blood flow involving the vasodilatation and dilation of the blood vessels. The CVS increases the heart rate and stroke volume so that an increased blood volume is transported faster to the working muscles. The respiratory system also plays a key role in this process. By increasing the breathing rate and the tidal volume, it ensures that more oxygen is brought into the body and carbon dioxide is removed. However, there is a limit for the cardiorespiratory system. The limit of the oxygen uptake is called the “Maximal oxygen uptake” ($VO_{2\,max}$). The focus of many endurance training programmes aims to improve the athletes’ $VO_{2\,max}$.

G. The energy System

i) The anaerobic system

The ATP-PC system - The ultimate energy source for the cells in any body movement is supplied by ATP *(See Fig. 2.19a)*. Taking muscular activities as an example, the storage of ATP is limited and can provide energy for less than ten seconds. After decomposition, ATP is converted to ADP and Pi and this provides energy for the body cells involved in the body movement. When there is energy supplied, all these substances re-synthesise into ATP again *(See Fig.2.19b&c)*. This system is characterised by low energy supply, short provision time, high output of power, with no lactate formed and in the absence of oxygen. It is the initial energy source for the maximal exercise.

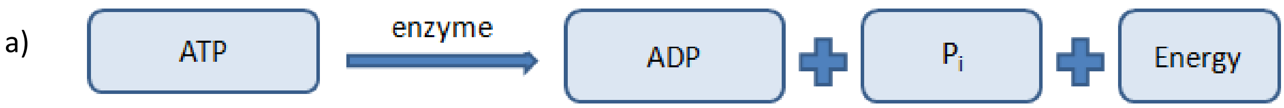


Figure 2.19a ATP-PC system

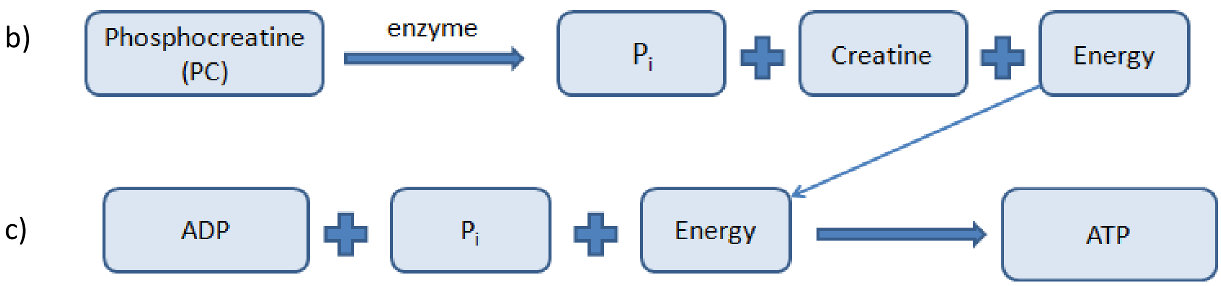


Figure 2.19b&c The ATP-PC system

The lactic acid system - It refers to the glycolysis, the resynthesis of ATP from glucose in the absence of oxygen. In glycolysis, glucose is broken down to glucose-6-phosphate and then to pyruvic acid through a series of reactions. In the absence of oxygen, pyruvic acid is then converted to lactic acid (*See Fig 2.20)*. Although this system cannot provide a lot of energy for the body movement, it ensures the provision of energy for the body cells for a short period of time when ATP-PC system cannot provide sufficient ATP. In maximal exercise, the contribution of this system to the energy supply in the initial stage is limited. The supply of energy reaches the peak after 30 seconds and it is the main energy supply for athletes during high-intensity exercise for one to two minutes, (for example, 800m run and 200m swimming.)

Lactic acid can be translocated by blood circulation to the liver for resynthesis into glycogen by oxidation in the presence of oxygen. It can also be broken down in the kidneys.

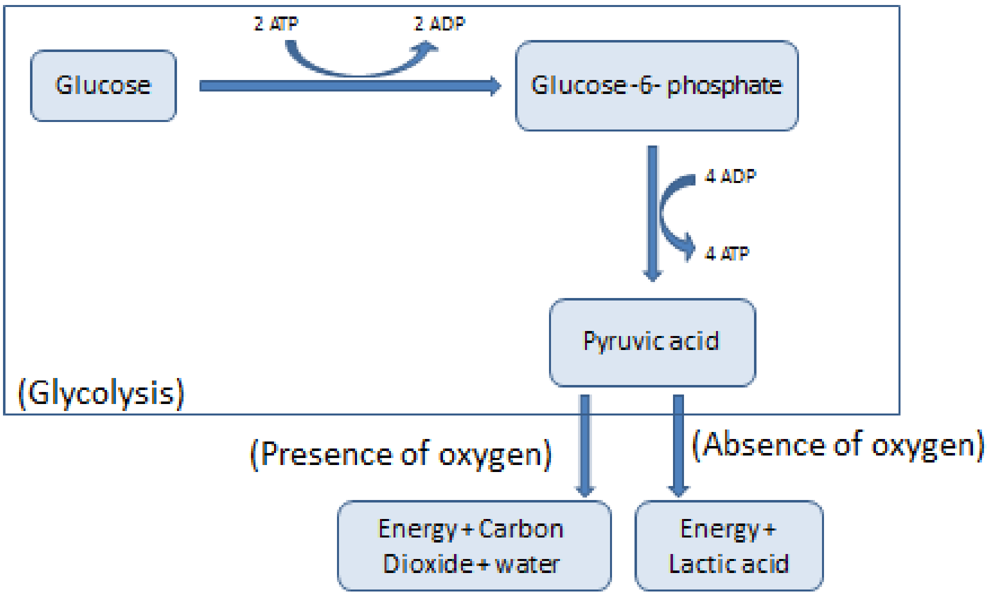


Figure 2.20 The decomposition process of glucose in the lactic acid system and aerobic system

ii) The aerobic system

It involves the disassembling of fuel with the aid of oxygen to generate energy for exercise lasting for several minutes or longer. A large amount of energy is produced by oxidising glucose and fat in the mitochondria of the cells while releasing carbon dioxide and water. In glycolysis, glucose is broken down to glucose-6-phosphate and then to pyruvic acid through a series of reactions. With the presence of oxygen, the pyruvic acid is decomposed to give out energy, carbon dioxide and water through various processes. After decomposition of lipids into glycerol and fatty acids in different pathways, the fatty acids will enter the aerobic system to give out energy, carbon dioxide and water.

With a huge storage of glycogen and fat in the body, the supply of the substrates seems unlimited to the aerobic system to produce energy (glycogen will be depleted in one to two hours; fat depletion usually takes a longer time, the actual time depends on the amount of storage in one's body). The aerobic system produces energy at a lower rate but for a long period of time and without the accumulation of the lactic acid. It is the basic system to supply energy for endurance sport.

Energy systems	**Main sources of energy* for ATP regeneration**	**Metabolites**	**Exercise duration**
ATP-PC system	Phosphocreatine	Nil	Less than 10 seconds
Lactic acid system	Glucose	Lactic acid	1 – 2 minutes
Aerobic system	Glucose or Fat	Carbon dioxide and water	Unlimited, until all energy substrates are used up

Table 2.4 The energy systems and their sources of energy

* In general, protein is not a main but can be one of the sources of energy

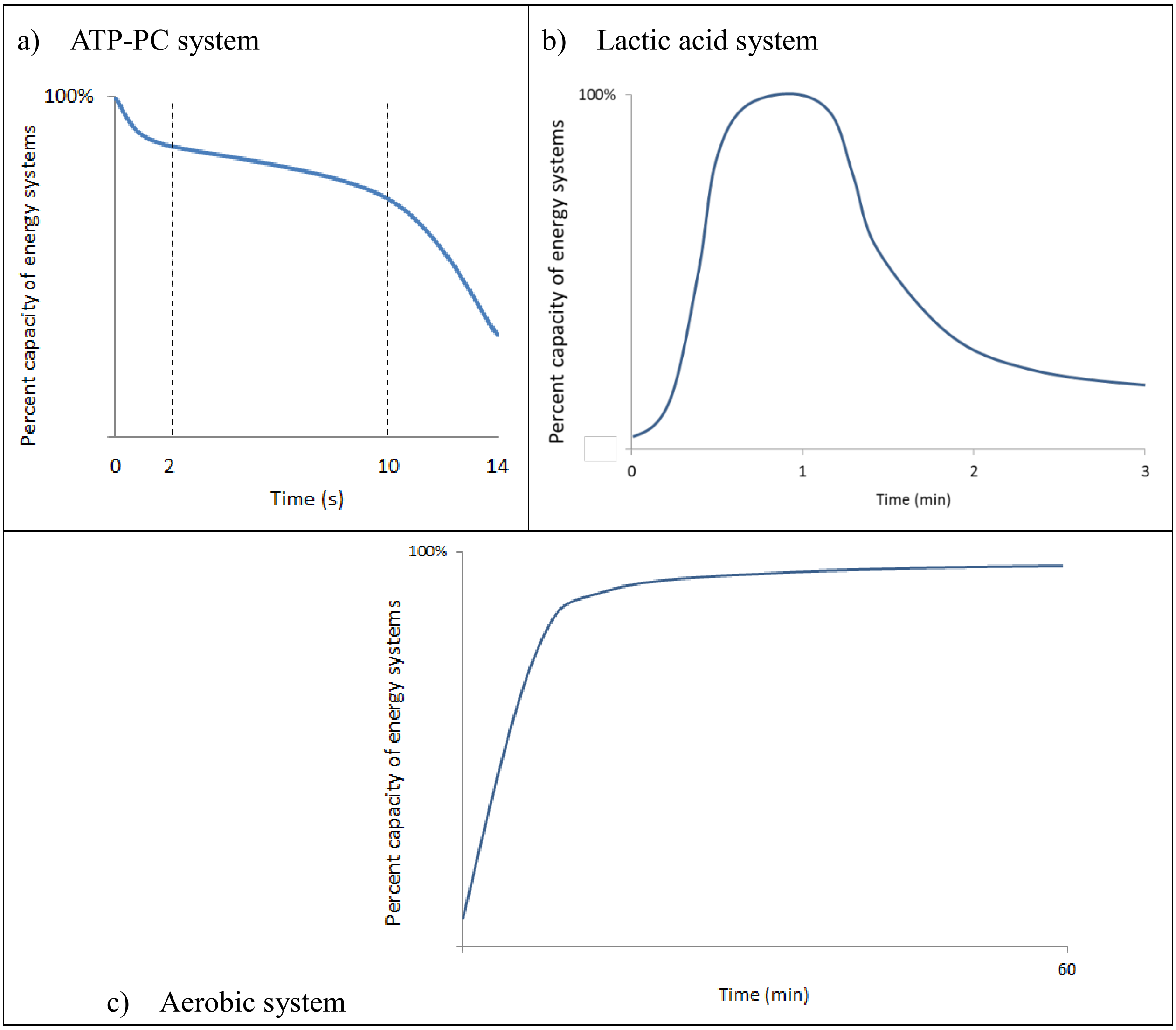


Figure 2.21a,b&c A sample graph to illustrate the relationship between different energy systems and exercise duration for an athlete in running

iii) Energy metabolism at rest and during physical activities *(See Table 2.5)*

Energy metabolism at rest

The basal or resting metabolism accounts for 60 % to 75 % of our total daily energy expenditure.

- **Basal metabolic rate -** It is the minimum level of energy required to sustain the body's vital functions (for example, breathing, heart beating, maintaining normal body temperature, etc) in the waking state. The basal metabolic rate is measured under strictly standardised conditions, for example, "the measure is taken immediately after waking up from a good sleep", "12-hour fasting before the measurement" and "thermoneutral environment".
- **Resting metabolic rate -** Its definition is the same as the basal metabolic rate. However, it is measured under less demanding conditions, for example, "the

measure is taken after a ‘30 to 60 minute rest’” or a “four-hour fasting”.

The basal or resting metabolic rate is affected by sex and age. In general, females have slightly lower basal or resting metabolic rate than males. From the age of 20 onwards, the basal or resting metabolic rate gradually decreases.

- **Thermic effect of food -** It refers the energy consumption for the intake, digestion and metabolic activities associated with food. This will contribute to about 10 % of our daily energy consumption.
- **Metabolic Equivalent of Task (MET) –** It is a physiological indicator to express the energy cost of physical activities. One MET refers to the metabolic rate for a healthy adult while seated and resting. The energy expenditure of one MET is about 1 kilocalorie or 4.184 kilojoules per hour for each kilogram of body weight.

Activity	Metabolic Equivalent of Task（MET）
Sleeping	0.9
Sitting (taking a rest, attending a lecture, reading, chatting, etc)	1.0
Standing	1.2
Cooking	2.5
Walking (downstairs)	3.0
Dancing (Waltz, slow)	3.0
Strolling for 45 minutes	3.0 – 3.5
Practising Tai Chi for 40 minutes	3.5 – 4.0
Walking (upstairs)	4.5
Basketball (shooting practice)	4.5
Latin dance for 30 minutes	4.5 – 5.5
Cycling for 25 minutes (finish 8 km)	4.5 – 5.5
Swimming for 25 minutes	5.5 – 6.5
Playing in a basketball match for 20 minutes	7.0 – 8.0
Playing in a badminton match for 20 minutes	7.0 – 8.0
Step aerobics (step height: 15-20cm）	8.5
Skipping for 15 minutes	9.5 – 10.5
Jogging for 15 minutes (finish 2.4 km)	9.5 – 10.5

Table 2.5 The energy expenditure of different physical activities

(Source: LCSD “Know Your Physical Activity Level Booklet”: https://www.lcsd.gov.hk/en/sportforall/common/pdf/leaflet_e.pdf)

The energy metabolism during physical activities

- Physical activities account for 15% to 30% of our total daily energy expenditure. Table 2.8 shows the energy expenditure of different types of physical activities.
- At the beginning of exercise or each time when the exercise intensity is increased (for example, increasing the running speed, resistance, etc), the oxygen consumption rises rapidly and then becomes steady in one to four minutes. Before reaching the steady state, the body relies on the anaerobic system for energy supply and accumulates lactic acid. When the body adapts to the new exercise intensity, the aerobic system dominates the energy supply and the oxygen consumption rate becomes stable. People who have better cardiorespiratory fitness reach the steady state of oxygen consumption earlier, therefore, they accumulate less lactic acid in the muscles.
- Although active muscle activities slow down after exercise, oxygen consumption (i.e. energy consumption) needs a period of time to restore to a resting value. The oxygen is used to maintain a higher breathing rate, heart rate and body temperature compared to the resting state. In addition, the oxygen is also used to remove lactic acid and carbon dioxide from the body. People who have better cardiorespiratory fitness will recover in a shorter time.

H. Growth and development

i) Growth curves

Based on large sets of data of children, the growth curves of height, weight, head circumference, etc. can be plotted against their age. We may use this information to monitor and predict the growth and development of children. For a simulated height-for-age graph shown in *Fig. 2.22,* the heights of boys at the 10th, 25th, 50th, 75th and 90th percentiles are plotted against their age (in years). According to the chart, the heights of 15-year-old boys at 50th and 90th percentiles are approximately 170 cm and 178 cm respectively. This means that 50% of them are below 170 cm and 90% of them are below 178 cm in height.

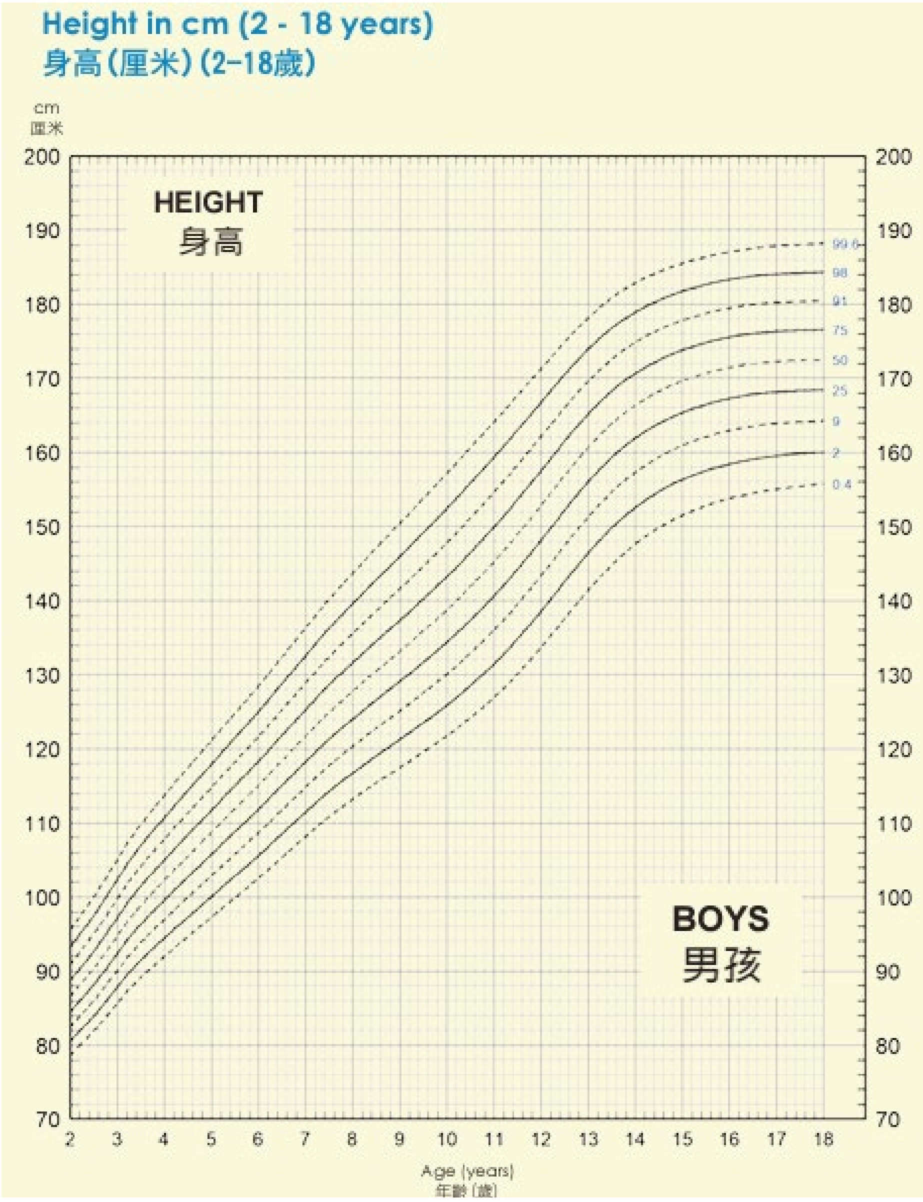


Fig 2.22 The growth curves (height for age - boys)
Hong Kong 2020 Growth References (HK2020)
https://www.dh.gov.hk/english/useful/useful_PP_Growth_Chart/files/growth_charts.pdf

ii) Stages of development

Infancy - It refers to the first two years of the human life. During this stage, walking, talking, balance and coordination are learnt. The body also begins to grow in proportion.

Childhood – It refers to the period from the age of two to adolescence. During this stage, the bones and teeth grow rapidly and intellectual skills begin to develop quickly. The physiological characteristics of this stage of development are shown in *Table 2.6*.

Adolescence - In general, girls aged 10 and boys aged 12 will enter adolescence and the functions of the body becomes mature. It is sometimes an emotionally distressing time for teenagers. The physiological characteristics of this stage of development are shown in *Table 2.7*.

Adulthood - At this stage, the growth of the body gradually slows down. Certain changes occur such as hair loss and decreases in the bone density and muscle mass. The physiological characteristics of this stage of development are shown in *Table 2.8.*

Physiological Characteristics of Childhood	
Bones and joints	- Not very hard but elastic; not easily broken but easily deformed. - Shallow glenoid fossa and articular capsule. Ligaments around the joints are thin and loose. - Great range of motion at the joints. Low stability of joints, dislocation can be easily caused by an external force.
Muscles	- Comprise a lot of water content but not so much protein, fat and inorganic salts. - Delicate and elastic, but weak in contractility and endurance. - Imbalance development of muscles in different parts, large muscles develop faster than small muscles and upper limb muscles develop faster than lower limb muscles. - Uneven growth of muscle strength.
Heart and blood vessels	- Heart weight and volume (per kg body weight) are similar to those of adults. - High metabolism and heart rates are caused by the not well-developed neural regulation. - A small stroke volume is caused by less myocardial fibre contractility and weak heart pumping power, but the cardiac output (per kg body weight) is relatively large. - Compared with adults, the relative blood volume (per kg body weight) is higher. The unit volume of blood haemoglobin content is lower. - Compared with adults, blood vessels are more elastic and thicker, blood pressure is lower.
Respiration	- High in oxygen consumption and respiratory rate as a result of high metabolism. - As the respiratory muscles are weak, the lung capacity is small.
Nervous system	- Easily excited as the inhibition process of the nervous system is not well developed. - The nerve cells are weak and easily fatigued, but they are easy to restore.

Table 2.6 The physiological characteristics of childhood

Physiological Characteristics of Adolescence	
Bones and joints	- As adolescents are in the process of growth and development, they gain height and weight at a quick rate. - The joint structure is basically the same as that of adults, but the articular surface of cartilage is thicker, the joint capsule is thinner; ligaments are more flexible, and the muscles around the joints are slender. Compared with adults, adolescents have a wider range of motion, and more flexible but less stable joints. - At the end of adolescence (17-23 years), physical development becomes well-developed and gradually slows down. - The rate of growing tall gradually slows down. Although the growth stops due to the completion of ossification after the age of about 25, the body begins to put on muscle rapidly and gains weight.
Muscles	- Comprise a lot of water content but not so much protein, fat and inorganic salts. - Compared with adults, adolescents' muscles are relatively small and delicate with weak contractility but they have a faster recovery rate. - At this growth acceleration period, muscles develop faster in vertical dimension. After this period, muscles develop faster in horizontal dimension and significantly enlarged. The gain in muscle strength is the most significant in women of 15 to 17 years old and men of 18 to 19 years old.
Heart and blood vessels	- The weight and volume of the heart have reached the adult level but the cardiac contractility is weak. - Compared with adults, adolescents' secondary arteries and capillaries are relatively greater in diameter, but with relatively small peripheral resistance. Blood pressure is lower. - As age increases, the heart rate goes down. The stroke volume, blood pressures and peripheral resistance of blood vessels also increase.
Respiration	- The lungs and respiratory muscles are fast-growing and gradually increase in vital capacity.
Nervous system	- Increasingly balanced in the development of nervous excitation and inhibition. - The abstract thinking ability, the capacity of analysis and synthesis improve gradually.

Table 2.7 The physiological characteristics of adolescence

Physiological Characteristics of Adulthood (The decline in the functions of the human organs at the rate of 1% each year starts approximately at the age of 30)	
Bones and joints	- The process of bone decalcification begins, resulting in lower bone density.
Muscles	- The muscles begin to shrink which causes reduced elasticity and reduced contractile force.
Heart and blood vessels	- For every 10 years starting from the age of 30, the cardiac output falls 6% to 8% and the blood pressure increases 5% to 6%. - The flexibility in the blood vessel wall, the vasomotor function and blood pressure regulation reduce. - The blood cholesterol concentration increases with age. The heart and cerebral arteries are more prone to atherosclerosis.
Respiration	- The flexibility of the lung tissues reduces which leads to a reduced lung capacity due to smaller lung expansion and contraction.
Nervous system	- The neural activity reduces and memory declines. - Gradual weakening of nervous inhibition, which causes difficulties in falling asleep and waking up easily.

Table 2.8 The physiological characteristics of adulthood

Examples of Enquiry Activities

<table>
<tr><th colspan="2">Themes</th><th>Activities</th></tr>
<tr><td>1</td><td>Growth and development</td><td>Information collection and analysis:
● Study the curves of different parameters from books or the Internet to understand the physiological characteristics of secondary school students.
● Collect the following student information in the school:
- Height, weight and body mass index (BMI)
- Percentage of body fat
- Resting heart rate
- Muscular strength of upper limbs (for example, results in chin-ups)
- Muscular strength of lower limbs (for example, results in standing high jump)
● In group of five to six, compare the differences between
- boys and girls
- athletes and non-athletes
- athletes of different sports events</td></tr>
<tr><td>2</td><td>Different systems in human body</td><td>Information collection:
● Quoting the sources of evidence to show that participation in physical activities enhances the following systems:
- The skeletal system
- The nervous system
- The muscular system
- The cardiovascular system
- The respiratory system
- The energy system</td></tr>
</table>

Examples of Enquiry Activities

Themes		Activities
3	Physiological responses to physical activities	Data collection and analysis: ● Learn how to use the following apparatus: - Heart rate monitor - Electronic sphygmomanometer - Infrared thermometer ● Record one's heart rate, blood pressure and body temperature when taking exercise: - Before the exercise - Right after the warm-up activities - Every 5 minutes after the warm-up activities - Right after the cool-down activities - In every 5 minutes within the first 30 minutes after the cool-down activities ● Use graphs, tables, etc to show one's changes in heart rate, blood pressure and body temperature. Try to explain the underpinning mechanism. ● In groups of five to eight, compile the data of individual members and prepare a report to explain the physiological responses to physical activities.

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