بسم الله الرحمن الرحيم

ECOLOGY AND ANIMAL PHYSIOLOGY

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ECOLOGY

Lecture 1

Ecology, according to the usual definition, is the scientific study of the relationship between organisms and their environment.

That definition is good so long as we consider relationship and environment in their fullest meaning.
Environment includes not only the physical but also the biological conditions under which an organism lives.
relationship includes interactions with the physical world and with members of other and the same species.
The term ecology was originally coined by the German Zoologist Ernst Hackle in 1866. The term ecology comes from the Greek word "oikos" meaning "home".

A more informative definition has been suggested by Krebs (1974), who defined ecology as " the scientific study of the interactions that determine the distribution and abundance of organisms " This definition has the merit of pinpointing the ultimate subject matter of ecology:
the distribution and abundance of organisms, where they occur, how many there are and what they do.

Organisms interact with their environment within the context of the ecosystem.
The eco part of the word relates to the Environment.
the system part implies that the ecosystem is a system.
A system is a collection of related parts that function as a unit.
Thus the ecosystem has interacting parts that support a whole.
Broadly, the ecosystem consists of two basic interacting

components : the living or biotic, and the physical or abiotic. For example, in a natural ecosystem; a forest, the physical component consists of the atmosphere, climate, soil, and water.

<u>Ecosystem components</u>

The various kinds of organisms that inhabit the forest make up populations.
The term population has many uses and meanings in other fields of study.
In ecology, " a population is a group of (potentially) interbreeding individuals occurring together in space and time ".
this definition implies that the individuals comprising the population are of the same species.

Population of plants and animals in the ecosystem do not function indepently of each other.
Some populations compete with populations for limited resource, such as food, water, or space.
In other cases, one population is the food resource for another.

Two populations may mutually benefit each other.
<u>All populations within an ecosystem are referred to as a community and have some connection to one another</u>

The community and the physical environment make up the ecosystem.
So, the ecosystem has many levels. <u>One level individual</u> organisms. Including humans, both respond to and influence the physical environment.
<u>At the next level, individuals of the same species from the populations.</u> Further, these populations interact with each other forming the community.
<u>Combined, the ecosystem of Earth from the planetary ecosystem, or biosphere.</u>

Mini-Glossary of Ecology Terms

Population : A group of organisms of the same species that live together.
Community : All the living organisms found in a particular

environment. Includes all Populations of different species that are living together.

Ecosystem : A Community and environment. Includes all the interactions between living things and their physical environment.

Biosphere : All of the Earth's living organisms. Includes all the communities on Earth.

Ecosphere : The largest, worldwide ecosystem. It encompasses all the living things on Earth and their interactions with each other, the land, the water, and the atmosphere.

Organism and its Environment

All living organism are constantly interacting with their environment.
Animals consume plants and other animals. They diest food, absorb, nutrients, and discharge waste products.
For an organism to succeed, it needs to find essential resources and supporting conditions.
If the organism can survive, grow, and reproduce under a given set of environment conditions, we say it is adapted to that environment.
If the environment does not offer the resources and conditions for its survival, the organism dies.

Variations in environment conditions

All organism live in a varying physical environment of temperature moisture, light, and nutrient.
These factors differ from location to location – in latitude, region and locality.
In addition, at any location, the physical environment varies with time - yearly seasonally and daily.

Solar radiation directly influences air temperature atmospheric moisture, and light. To a large extent, it defines the general physical environment in which organisms live.
The amount of solar radiation reaching any point of Earth's surface and the resulting patterns of surface air temperature vary both spatially and temporally.

Organisms at any location face both seasonal and daily variations in temperature.
The variations are greatest in the temperate regions, where differences between average daily temperature in the winter and summer can be extreme.

In an ever changing physical environment, organisms must maintain a fairly constant internal environment, within narrow limits required by their cells, organs, and enzyme. For example, the human body must maintain internal temperature within a narrow range around 37

An increase or decrease of only a few degrees from this value could prove fatal.
Likewise, organisms must maintain certain levels of water, acidity, and salinity to mention a few factors.

Maintaining these constant conditions requires continuous exchange of energy and materials between organisms and the external environment.
The organisms must consume and digest food to adjust its metabolism.
Then it must excrete by-products and wastes from these chemical processes.
The maintenance of conditions within the range that the organisms can tolerate is called *homeostasis*.

Limiting factors:-

Limiting factor definition

In biology, the term *limiting factor* is defined as an environmental factor or variable that has the capacity to restrict growth, abundance, or distribution of a population in an ecosystem. These factors are present in limited supply. Thus, organisms tend to compete for their limited availability in the ecosystem

Principles and laws

The principle of limiting factors is defined as the principle whereby a factor that is in shortest supply will limit the growth and development of an organism or a community.[1] Liebig's *law of the minimum*, Blackman's *law of limiting factor*, and Shelford's *law of tolerance* are the laws that explain the principles of limiting factors.

Liebig's Law of Minimum

In the 19th century, the German scientist Justus von Liebig formulated the "Law of the Minimum," which states that if one of the essential plant nutrients is deficient, plant growth will be poor even when all other essential nutrients are abundant.
In another definition:-
Growth is dependent on the amount of food stuff that is present in minimum quantity.

Blackman's *law of limiting factor*

The law of limiting factor was proposed in 1905 by the British plant physiologist, Frederick Frost Blackman. According to this law, a process that depends on multiple factors will have a rate limited by the pace of the slowest factor. Photosynthesis, for example, is a biological process that depends on multiple factors. The general chemical reaction of photosynthesis is $6CO_2+12H_2O+energy=C_6H_{12}O_6+6O_2+6H_2O$. Based on this equation, CO_2, H_2O, and light energy (sunlight) are the limiting factors of this reaction. If any of them become accessible at a pace slower or lower than the usual, the rate of photosynthesis is expected to become slow based on the pace of the slowest factor. For example, if CO_2 concentration becomes scarce (e.g. due to closure of stomatal openings in response to elevated temperatures in the environment), the rate of photosynthesis becomes slow even if H_2O and light energy levels are amply available. The same result will occur if light energy becomes less available or less intense, the rate of photosynthesis will be slower despite the abundance of CO_2 and H_2O. Light becomes a limiting factor in photosynthesis when the plant is unable to collect light, for instance, due to shade resulting from the dense population of plants.

<u>Limiting factors by Shelford, 1932</u>

Organisms may be limited in their growth and their occurrence not only by too little of an element or too low an intensity of factor but also by too much of an element

<u>Range of tolerance</u>

As the example of body temperature shows, there are limits to the range of the environment conditions over which homeostasis work.

A graph illustrates this range.

The X axis represents some feature of the physical environment, e.g., temperature.

Axis represents the response of the organism.

The response of an organism to physical environment falls along a bell-shaped curve describing performance (in this case the probability of survival).

The point along the X axis where the response of the organisms is the highest is called the optimum, the probability of survival decreases.

The two point (minimum and maximum) at which the survival intercepts the X axis represent the environment conditions beyond which these two points an organism can survive, but not necessarily grow or produce.

The minimum and maximum values of the environment are referred to as the *<u>environment tolerance</u>* of the organisms.

The figure represents the response of an organisms to a range of values for a single factor: temperature.

However, organisms depend upon a wide range of environment factors each having an optimum of tolerance. To complicate things further the factors interact.

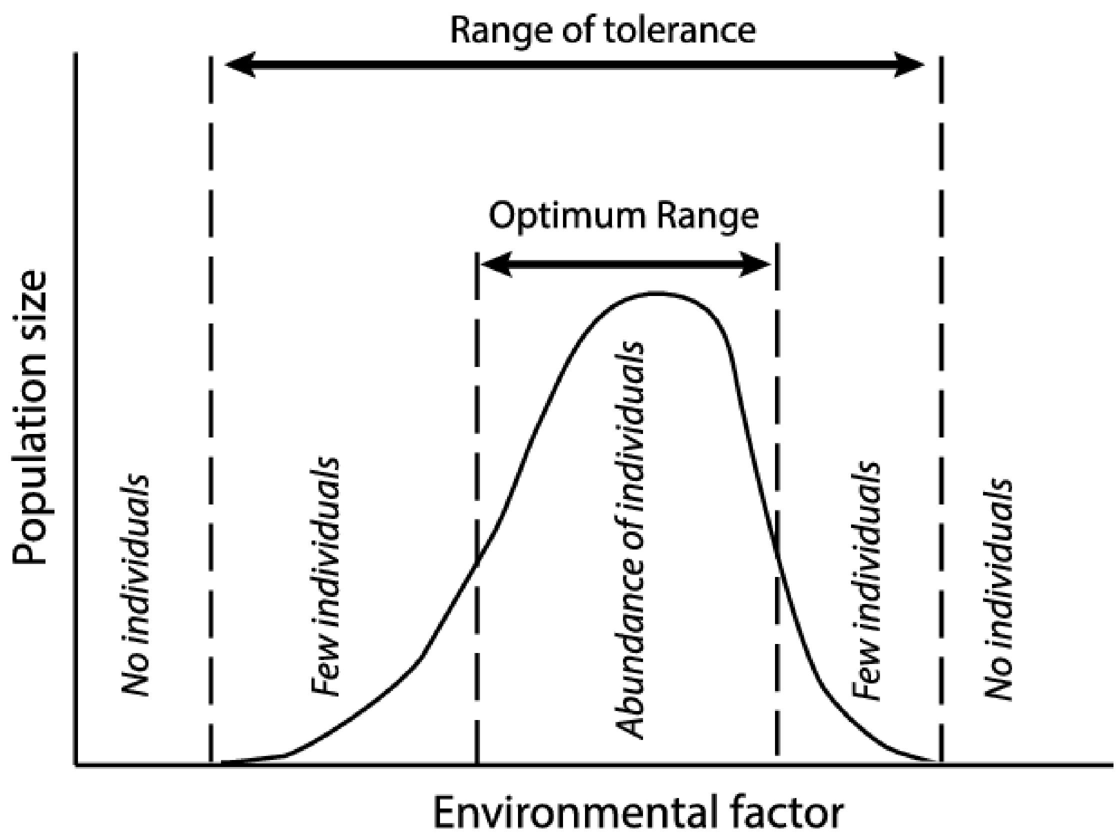
In the example of body temperature in humans, an important homeostatic response to rising body temperature is evaporative cooling or sweating.

This response requires water. Therefore, water needed to survive is related to temperature.

Hot conditions demand increase in water intake.

Organisms, than, are limited by a number of conditions, and often by an interaction among them.
Organisms live within ranges from too much to too little the limits of tolerance.
This concept, that minimum and maximum conditions limit the presence and success of an organism is called the *laws of tolerance*.

Minimum and maximum temperature tolerance define the limits of species, distribution.
Although conditions close to the tolerance may be sufficient to maintain survival, growth, and reproduction, their values will be much below those that occur closer to the optimum.
The nearer conditions approach the minimum and maximum tolerances of the organism, the fewer the individuals.
We would expect the abundance of a decrease to increase as we move toward optimal environment conditions.



Lecture 2

ABIOTIC FACTORS

Abiotic (Physical) Factors

Climate is the combination of temperature, humidity, precipitation wind, cloudiness and other atmospheric conditions. Climate determines the availability of heat and water. It influences the amount of solar energy that plants can capture.
Thus it controls the distribution and abundance of plants and animals.

Earth, immersed in sunlight, intercept solar radiation on the outher edge of its atmosphere.
The intercepted energy causes thermal patterns.
Coupled with Earth's rotation and movement around the sun, it generates the prevailing winds and ocean currents. These movements of air and water in turn influence the distribution of rainfall.
Nevertheless, environmental conditions will be quite different underground or on the surface, beneath vegetation or on exposed soil or on mountain slopes.
Heat moisture, air movement, and light all vary greatly from one part of the landscape to another to create a whole range of localized climates. These microclimate define the conditions under which organisms live.

Light

Light is a driving force of life. Plants use visible light as an energy source to convert carbon dioxide and water to organic carbon compounds.

The hours of light and dark influences the daily and seasonal activities of terrestrial and shallow water organisms.
Of the total range of solar radiation reaches Earth's atmosphere, the wave lengths making up the visible light are known as *photosynthetic active radiation*, because they include the wavelengths plants use in photosynthetic.
Wavelengths shorter than the visible range are ultraviolet.
Radiation with wavelengths longer than the visible range is infrared.
The ozone layer in the upper atmosphere (stratosphere) absorbe nearly all wavelengths, especially the violets and blues of the visible light.
Molecules of atmosphere gases scatter long wavelengths.

Periodicity

Daily and seasonal patterns govern life's activities. Bird song signals the arrival of dawn.
Butterflies, dragonflies and bees warm their wings, hawks being to circulate, and tree squirrels become active.
At dusk daytime animals retire, water-lilies fold, moonflowers open, and animals of the night appear.
Foxes, flying squirrels, owls, and luna moths take over niches others occupy during the day.

As seasons progress, day length changes, and activities shift.
Spring brings migrant birds and initiates the reproductive cycles of many plants and animals.
In fall the deciduous trees of temperate regions become dormant, insects and herbaceous plants disappear, summer birds return south, and winter birds arrive.

These rhythms are driven by the daily rotation of Earth on its axis and its 365- day revolution about the sun.
through time, life has become attuned to the daily and seasonal changes in the environment. At one time biologists thought that organisms were responding only to external stimuli such as light intensity, humidity, temperature and tides.
Laboratory investigations, however, have shown there is more.

Living organisms possess innate rhythms of activity

At dusk in the forests of North America, the flying squirrel emerges from a tree hole. With a leap, the squirrel sails downward in along sloping glide, maintaining itself in flight.
Using its tail as a rudder and brake it makes a short upward swoop that lands it on the trunk of another tree.
It emerges into the forest world with the arrival of darkness, it retires to its nest before the first light of dawn.
The flying squirrel's day to day activity conform to a 24 – hour cycle.

The correlation of the onset of activity with the time of sunset suggests that light has a direct or indirect regulatory effect.
If the flying squirrel is brought in doors and confined under artificial conditions of night and day, it will restrict its periods of activity to darkness and its periods of inactivity to light.
Whether the conditions under which the squirrel lives are 12 hours of darkness and 12 hours of light or 8 hours of darkness and 15 hours of light, the onset of activity always begins shortly after dark.

If we keep the same squirrel in a constant darkness, it still maintains its pattern of activity and inactivity from day without any external cue.
Under these conditions the squirrel's activity rhythm deviates from the 24 hour periodicity defined by the diurnal cycle.
Its cycle of activity and inactivity in constant darkness varies from 22 hours 58 minutes to 24 hours, 21 minutes, the average is less than 24 hours. Because the cycle length deviates from 24 hours, the squirrel gradually drifts out of phase with the external world.

Circadian rhythm

This innate rhythm of activity and inactivity covering approximately 24 hours is characteristic of all living organisms, except bacteria. Because these rhythms approximate, but seldom match, the period of Earth's rotation, they are called *circadian rhythms* (from the Latin circa. "about" and dies, "day").

Circadian rhythms have a strong genetic component, transmitted from one generation to another.
Temperature changes have little effect on them and they are not learned from or imprinted upon the organisms by the environment.

They do not adapt to specific local or regional environmental conditions.
Circadian rhythms influence not only the times of physical activity and inactivity, but also physiological processes and metabolic rates.
They provide a mechanism by which organisms maintain synchrony with their environment.

Thus two daily periodicities – the external rhythm of 24 hours and the internal circadian rhythm of approximately 24 hours – influence the activities of plants and animals.
If the two rhythms are to be in phase, some external cue or time cue or time –setter must adjust he internal rhythm to the environment rhythm. The most obvious time setters are temperature, light, and moisture.
Of the three master time – setter in the temperate zone is light. It brings the circadian rhythm of organisms into phase with the 24 hour photoperiod of their external environment.

Biological Clock

The circadian rhythm and its sensivity to light and dark are the major mechanisms that operate the biological clock that timekeeper of physical and physiological activity in living things.
In multicellular animals the clock is within the brain.
To keep time, the clock has to have an internal mechanism with a natural rhythm of approximately 24 hours.

Recurring environmental signals such as changes in the time of dawn and dusk, should reset it.
The clock has to be able to run continuously in the absence of any environmental time-setter and the same at all temperatures
Circadian

Rhythm fit all these criteria

Adaptive value of circadian rhythms

One adaptive value is that the biological clock provides the organism with a time-dependent mechanism.
It enables the organism to prepare for periodic changes in the environment ahead of time.

For example, trees of the African savanna begin leaf growth just prior to the onset of rainy season.

circadian rhythms help organisms with physical aspects of the environment other than light or dark. For example, the transition to night is accompanied by a rise in humidity and a drop in temperature.
Woodlice, centipedes, and millipedes, which lose water rapidly in dry air, spend the day in the darkness and damp under stones, logs and leaves. At dusk they emerge when humidity of the air is more favorable.
The circadian rhythms of many organisms relate to biotic aspects of their environment.
Predators such as insectivorous bats must match their feeding activity rhythm of their prey.
Moths and bees must seek nectar when flowers are open.
Flowers must open when insects that pollinate them are flying. The circadian clock lets insect, reptiles and birds orient themselves by the position of the sun. Organisms make the most economical use of energy when they adapt to the periodicity of their environment.

and reproduction, too.

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Lecture 3

PHOTOPERIODISM

- Photoperiod refers to the length of the light and dark portions of the 24- hours day. Because of the way in which the earth's axis is tilted, the length of day and night changes seasonally every where except at the equator. In the northern hemisphere, the longest day occurs about June 21 and is called the summer solstice, the shortest day is December 21 , the winter solstice, the spring and autumn when day and night are each 21 hours occur on March and September, the word photoperiodism mean the response of organisms to photoperiods.photoperiodism should not be confused with the effect of light alone. Photosynthesis, phototaxis, and photoreceptor all have to do with the biological effects of light energy, but are not necessarily involved in photoperiodism. Photoperiodism has to do with the biological effect of regulatory occurring periods of both light and dark.

Critical day lengths trigger seasonal responses

In the middle and upper latitudes of the Northern and Southern hemispheres, the daily periods of light and dark lengthen and shorten with the seasons.
The activities of plants and animals are geared to the changing seasonal rhythms of night and day.
Most animals and plants of temperate regions have reproductive periods that closely follow the changing day lengths of the seasons.
For most birds the height of the breeding season is the lengthening days of spring for deer, the mating season is the shortening days of fall.

The signal for these responses is _critical day length_. When the duration of light (or dark) reaches a certain portion of the 24 hour day, it inhibits or promotes a photoperiodic response. critical day length varies among organisms, but it usually falls somewhere between 10 and 14 hour.

Increasing day length induces spring migratory behavior, stimulate gonadal development, and brings on reproductive cycle in birds.
In mammals, photoperiod influences activity such as food storage and reproduction, too. Seasonality in temperate and arctic regions depends on changes in light and temperature. In a broad way, Seasonal changes in temperature and light cause alternate warm and cold periods.
The progression is gradual, however, and in temperate zones, seasons can be identified as early or late spring, early or late fall, and so on. Seasonality in tropical regions is keyed to rainfall.
In other parts of the earth, such as the tropics and some deserts, photoperiod may change little, or a change from dry to wet season may be the important seasonal change, The seasonal tropics have alternate wet and dry seasons.
The beginning of rainy season is a dependable environment cue by which plants and animals become synchronized to seasonal changes.

Photoperiodism in Mammals

A number of internal physiological rhythms have been found in Mammals are related to photoperiodism

One of the simplest daily rhythms is that of hunger.

It is possible that the activity rhythm of an animal is determined by whether or not it is hungry. Perhaps the white, footed mouse became active when it got hungry. Since its feeding behavior follows a day-to-day rhythm, hunger would account for the periodicity of its physical exercise.

Another well- known physiological rhythm is that of body temperature.
Mammals are worm-blooded, that is they maintain their body temperature at a rather constant level. But even so, there is a shallow daily cycle of temperature changes. Such a rhythm is more pronounced in a small mammal, such as a mouse, than in a larger one, such as a horse.

As the body temperature of the mouse reaches maximum in the middle of night. The lowest temperature of the day occurs around noon. During the middle of the daylight hours, the mouse will be rather quiet, and it is at this time that its body temperature is lowest. Mice are active at night and it is at night that the animals temperature is highest.

Lecture 4

Temperature

Temperature has a pervasive influence on life. It affects rates of photosynthesis and energy storage in plants. It influences the need for moisture and the rates of chemical reactions in all living organisms.
It is a key to climate, microclimate, and distribution of organisms.

All organisms live and live and exchange energy with a thermodynamic environment – a world of heat and cold. They absorb solar radiation, which may be direct, diffused from the sky or reflected from the ground, as well as thermal radiation from rocks. Soil, vegetation and the atmosphere.
In addition, organisms produce heat during metabolic processes such as respiration and lose heat as infrared radiation.
To maintain a constant body temperature, organisms must both lose heat to and gain heat from the environment.

Green plants convert a considerable amount of incoming solar radiation
To chemical energy through photosynthesis. They store this energy and pass it on to animals when consumed as food. Other radiation is converted directly to heat.

Whether produced by metabolism or absorbed, excess heat must be dissipated to the environment. When the surrounding or ambient temperature is lower than the temperature of the organisms. The problem, then is for the organism to balance heat gains with heat losses to maintain a constant internal temperature.

The heat balance of an organism may be summarized by the following expression :
Heat gain (solar radiation + thermal radiation + food energy storage + conduction + convection) =
Heat loss (thermal radiation + conduction + convection + evaporation).

Physiological group of animals

Physiological animals can be divided into three group, according to the way they maintain temperature :

- One group notably birds and mammals, relies primarily on stored energy to keep constant internal temperature independent of external temperature. This internal heat production is endothermy. These animals are *homeotherms*. They are popularly called " *warm-blooded*".
- A second group controls body temperature by external means. They gain heat through exposure to environmental sources and dissipate heat through conduction, convection and evaporation. This means of maintaining body temperature is *ectothermy*. They body temperature is variable. These animals are *poikilotherms* and are often called *cold-blooded*. These animals include invertebrates amphibians fish and reptiles.
- A third group regulates body temperature by endothermy at some time and by *ectothermy* at other times. These animals are *hetertherms*.

Poikilotherms

Poikilotherms gain heat easily from the environment and lose it just as fast.
Environment temperature control the rates of metabolism and activity among most Poikilotherms.

Rising temperature increase the rate of enzymatic activity, which controls metabolism and respiration.

For every 10
rise in temperature , the rate of metabolism in Poikilotherms doubles. They become activity only when the temperature is sufficiently warm. Conversely, when ambient temperatures fall, metabolic activity declines, and they become sluggish.

Poikilotherms have an upper and lower thermal limit that they can tolerate. Most terrestrial Poikilotherms can maintain a relatively constant daytime body temperature by behavioral means, such as seeking sunlight or shade.
Lizards and snakes, for example may vary their body temperature by no more than 4-5, and amphibians by 10 when active.
Aquatic Poikilotherms, completely immersed, do not maintain any appreciable difference between their body temperature and the surrounding water. They are poorly insulated.
Any heat produced in the muscles moves to the blood and on to the gills and skin, where heat transfers to the surrounding water by convection. Because seasonal water temperatures are relatively stable fish and aquatic invertebrates maintain a fairly constant seasonal temperature. They exhibit a low range of temperature variation in any given season.

Fish and aquatic invertebrates adjust seasonally to changing temperature by *acclimatization*. They undergo physiological changes over a period of time. Poikilotherms have an upper and lower limit of tolerance to temperature that varies with the species. If they live at the upper end of their tolerable thermal range, Poikilotherms will adjust their physiology at the expense of being able to tolerate the lower range. Similarly, during periods of cold, the animals shift to a lower temperature range that would have been lethal before. Because water temperature changes slowly through the year, aquatic Poikilotherms can make the adjustment slowly. Fish are highly sensitive to rapid change in environmental temperatures. If they are subjected to a sudderl temperature change, they will die of thermal shock.

Homeotherms

Homeothermic birds and mammals meet the thermal constraints of the environment by being endothermic. They

maintain body temperature by oxidizing glucose and other energy – rich molecules.
They regulate the gradient between body and air or water temperatures by seasonal changes in insulation (the type and thickness of fur, structure of feathers, and layer of fat), which Poikilotherms do not possess.
They rely on evaporative cooling and on increasing or decreasing metabolic heat production.
Homeothermy allows these animals to remain active regardless, of environmental temperatures, although at high energy costs.

Insects are ectothermic and Poikilotherms, yet in the adult stage most species of flying insects are heterothermic.
When flying they high rates of metabolism, with heat production as great as or greater than heterotherms. Temperature is critical to flight of insects.
Most cannot fly if the temperature of the thoracic muscles is below 30, nor can they fly if the muscle temperature is over 44. This constraint means that an insect has to warm up before it can take off, and it has to get rid of excess heat in flight.
With wings beating up to 200 time per second insects can produce a prodigious amount of heat.

Some insects, such as butterflies and dragonflies, warm up by orienting their bodies and spreading their wings to sun. most warm up by shivering their flight muscles in the thorax. Moth and butterflies vibrate their wings to raise thoracic temperature above ambient.

Regulating body temperature

To maintain a tolerable and fairly constant temperature during active periods, terrestrial and amphibian Poikilotherms resort to behavioral means. They seek out appropriate microclimates. Insects such as butterflies, moth bees, and dragonflies bask in the sun to raise their body temperature to the levels necessary to become highly active. When become too warm, these animals seek the shade.

Most reptiles are terrestrial and exposed to widely fluctuating temperatures. They bask in the sun to raise their body temperature. Snakes for example, heat up rapidly in the morning sun.

Endotherms also use microclimates to keep warm or cool. In the heat of a summer day, birds and mammals seek shady places. Desert mammals go underground by day and emerge at night. In winter, some mammals, such as rabbits go underground during periods of inactivity. Large mammals such as deer seek the thermal cover of conifer thickets. Mammals such as flying squirrels and birds such as penguins and quail huddle together during periods of cold, reducing individual surface area and conserving body heat.

Insulation

To regulate the exchange of heat between the body and the environment heterotherms and certain poikilotherms use some forms of insulation – a covering of fur, feathers, or body fat. For mammals, fur is a major barrier to heat flow, but its insulation value varies with thickness, which is greater on large mammals than on small ones. Small mammals are limited in the amount of fur they can carry, because thick coat could reduce their ability to move. Mammals change the thickness of their fur with season.

Evaporative cooling

Many birds and mammals, and even wasps employ evaporative cooling to reduce the body heat load. Birds and mammals lose some heat by evaporative of moisture from the skin. They accelerate evaporative cooling by sweating and panting. Only certain mammals have sweat glands, particularly horses and humans.

Lecture 5

Moisture

An organism's water balance is closely related to its thermal balance. It is difficult to discuss one without the other, sweating, which allows the evaporation of water is one way animals reduce body heat generated metabolically during strong physical exertion. Terrestrial animals and plants could never maintain their thermal and moisture balance without the unique features of water that make life on earth possible. Water is the medium by which elements and other materials make their never-ending odyssey through the ecosystem. Without the cycling of water decomposition and nutrient cycling could not proceed, ecosystems could not function and life could not persist.

Water balance in animals

For animals the usual sources of gaining water are drinking water, water in food and metabolic water. Loss is through urine, feaces and water evaporated problem in maintaining water balance. All animals however possess a more or less universal mechanism, the excretory system, which is simple in some animals and complex in others.

Osmotic pressure moves water through cell membranes from the side of greater water concentration to the side of lesser water concentration, aquatic organisms living in fresh water have a higher salt concentration in their bodies than in the surrounding water. Their problem is to prevent uptake or to rid themselves of excess water. Protozoans accomplish that task by means of contractile vacuoles, which collect and expel wastes. Freshwater fish maintain osmotic balance by absorbing and retaining salts in special cells and producing plentiful amount of watery urine. Amphibians balance the loss of salts through the skin by aborbing ions directly from water and transporting them across the skin and gill membranes.

Terrestrial animals, such as birds and reptiles, have a salt gland and a cloaca, a common receptacle for the digestive, urinary and reproductive tracts. They absorb water from the cloaca back into the body. Mammals possess kidneys capable of producing urine with high osmotic pressure and ion concentrations.

In arid environment, animals face a severe problem of water balance. They can solve the problem in one of two ways either by evading the drought or by avoiding its effects. Animals of semiarid and desert regions may evade drought by leaving the area during dry season. That is the strategy employed by many of the large African ungulates. The spade foot toad of the southern desert of the U.S.A aestivates below the ground and emerges when the rains return. Some invertebrates, such as flatworms which occupy ponds that dry up in summer, develop hardened cysts in which they remain for the dry period. Other aquatic or semi aquatic animals retreat deep into the soil until reach the level of groundwater. Many insects undergo diapauses.

Other animals remain active during the dry season but reduce respiratory water loss. Some small desert rodents lower the temperature of the air they breathe out. Moist air from the lungs passes over cooled nasal membranes, leaving condensed water on the walls. As the rodents inhales the warm, dry air is humidified and cooled by this water.

Some small desert mammals reduce water loss by remaining in burrows by day and emerging by night. Many desert mammals, such as camels, produce highly concentrated urine and dry feces and extract water metabolically from the food they eat.
In addition, some desert mammals can tolerate a certain degree of dehydration. Desert rabbits may withstand water losses of up to 50% and camels up to 27% of their body weight.

Animals in salts environment faces problems opposite to these in fresh water. These organism have to retain their body fluids. When the concentration of salts is greater outside the body than within, organisms tend to dehydrates. Osmosis draws water out of the body into the surrounding environment. In marine and brackish environment, organisms have to inhibit the loss of water by osmosis through the body wall and prevent an accumulation of salts in the body.
There are many solutions to this problem. Invertebrates get around it by possessing body fluids that have the same osmosis pressure as seawater. Marine bony fish absorb salt water into the gut. They secrete magnesium and calcium through the kidneys and pass these ions off as a partially crystalline paste. Fish excrete sodium and chloride, major, ions in seawater, by pumping the ions across special membranes in the gills.
This pumping process is one type of active transport. Salts move across a concentration gradient at a cost of metabolic energy. Sharks retain a sufficient amount of urea to maintain a slightly higher concentration of salt in the body than in surrounding seawater. Birds of the open sea can consume seawater because they possess special salt-secreting glands located on the surface of the cranium. Gulls and other seabirds excrete from these glands fluids in excess of 5% salt.

In marine mammals the kidney is the main route for the elimination of salt. Porpoises have highly developed kidneys to eliminate salt loads rapidly. In marine mammals the urine has a greater osmotic pressure (ion concentration) than blood and seawater, their physiology is poorly understood.

Lecture 6

Pollution

Definition

Types of Pollution

Definition of pollution

- **Pollution** is an unfavorable alteration in the physical, chemical or biological characteristics of air, water and land that may or will adversely affect human life, industrial life, industrial progress, living conditions and cultural assets.

Water pollution:

- From the name itself, we can understand that water pollution is a type of pollution which involves contamination of many water bodies. Many creatures which live in these water bodies are totally dependent on these water bodies.

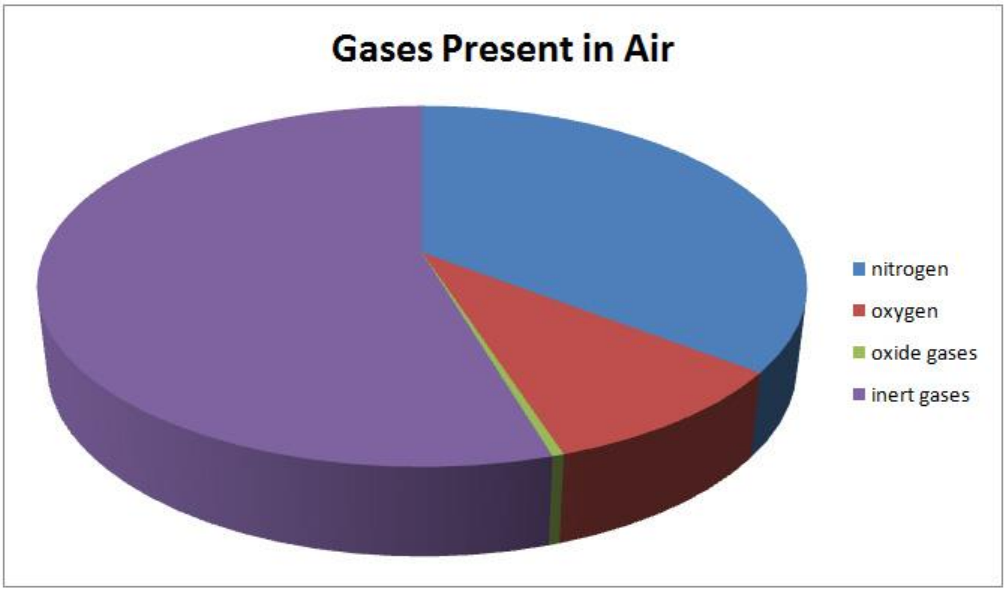
- **Causes of water pollution:** causes of water pollution are mentioned below:
- Industrial waste which is dumped into water bodies and this dumped waste cause a chemical imbalance. This chemical imbalance results in the death of aquatic animals.
- The nearby streams and groundwater systems get the insecticides, pesticides, and ripening chemicals which are used on plants.

- Eutrophication is also a cause of water pollution and eutrophication is nothing but entering of detergent in lakes and rivers. This happens because of washing clothes near rivers and lakes. Eutrophication prevents sunlight to enter inside the rivers and lakes; this prevention of sunlight decreases the value of oxygen in the water. Thus, results in an inhabitable environment.
- Damage to huge oil rigs and oil tankers which are present in oceans causes oil spills. This damage may be by either natural disaster or by human mistakes. Longtime damage is caused by oil spills because they also don't allow sunlight to enter into water as oil is lighter than water and it floats on water.
- Few natural disasters like hurricanes and flash floods result in intermixing of harmful substances and water on land.

Air pollution

- Pollutants of air present in atmosphere are called as air pollution. Respiration is a vital life process which needs air. If we breathe the air which has pollutants then it will have bad effects on our health. Air is comprised of below gases:

Content of Gases Present in Air



- **Causes of air pollution:** causes of air pollution are mentioned below:
- Burning of rubber, wood, and discarded plastic release gases called carcinogenic gases into atmosphere.
- Few industries release gases like sulfur dioxide, carbon monoxide and these gases mix with clouds and air and cause acid rains.
- Gases which are released from internal combustion of engines include gases into atmosphere which are poisonous.

Greenhouse Effect

- Generally, a physical property of the atmosphere of earth is referred by an expression called greenhouse effect; if there is an absence of atmosphere then the temperature of the earth will be -18 degrees Celsius. Greenhouse gases absorbs infrared radiation balance of energy of planet gets damage and along with this, there will be a dissimilarity in temperature. During present state, atmosphere system of our planet maintains a balance in taking of solar radiation by emitting radiations of infrared in the balance.

Soil pollution

- Soil pollution is nothing but stripping soil from its natural fertility by availing artificial chemicals like ripening agents, insecticides, and pesticides. Normally, plants are dependent on nitrogenous compound for the purpose of their nutrition which is present in soil. Use of artificial chemicals like ripening agents, insecticides, pesticides absorbs the nitrogen which is present in soil and makes that soil unfit for plant's growth. Plants hold soil very firmly and when there is no growth of plants then it results in splitting of soil and at last causes to soil erosion.

Thermal pollution:

- Thermal pollution is the increase in temperature because of high amount of release of heat energy by unnatural methods or techniques and natural disasters. The heat energy released by manufacturing industries is transferred to water bodies and air. Outcome of thermal pollution is rise in temperature and this is an important cause for melting of polar ice caps.

Radioactive pollution:

- Radioactive pollution happens when radioactive metals release harmful beta rays. These beta rays have the ability to cause mutative diseases and cancer. This type of pollution happens because of following reasons:
- Damage to nuclear reactors which results in radioactive contamination
- Dumping of radioactive waste into water bodies which are produced from nuclear plants
-

Noise pollution

- We have distinct qualities of sound and the sounds which are unpleasant to hear are known as noises. Thus, more noise in outdoors results to **noise pollution**. This kind of pollution has more physiological effects than physical effects. Noise pollution is caused because of the reasons mentioned below:
- Many vehicles honking at roads
- Trains
- Clubs
- Overpopulated crowds
- If a heavy machinery is operated in an open area

Light pollution

- Very bright lighting in big cities, functions and much more causes pollution called as light pollution. Bright lighting on retina not only causes discomfort to eyes but also results in straining of eyes and migraine.

Lecture 7

Mid -Term Exam

Lecture 8

Populations

After studying the relationship of individual organisms to their physical environment, this part will turn to the biotic environment. How the individual interacts with others of its own species, and with competitors, predators, parasites, diseases, and mutualisms are the subjects of this part.

Properties of Populations

A population is group of potentially interbreeding and interacting individuals of the same species living in the same place at the same time.
It is reproductively isolated from other such groups.

Population have unique features.

1 - They have an age structure,
2 - Density,
3 - and distribution in time and space.
4 -They exhibit a birthrate, a death rate and a growth rate.
5 - They respond in their own ways to competition, to predation, and to other pressures.
6 - Individuals that make up a population affect one another in various ways.
7 - The relationship of one population with another influence the structure and function of whole ecosystems.

Density

Two outstanding attributes of a population are density and dispersion. Individuals in natural populations are affected by density. Trees in crowded stands may grow more slowly, and some may succumb to a lack of water, nutrients, and light, unequally shared. Scarce food may be denied to smaller or less aggressive mammals in a populations.

Some birds may deny others access to nest sites when not enough sites exist to meet the demand. Having too few individuals in a population may reduce the chances of finding a mate or inhibit behavior essential to the welfare of the population. <u>Low population density may raise an individual's risk of succumbing to predation.</u> Affecting the welfare of individuals in all these ways, density in part controls a population's birth rates, death rates, and growth.

<u>density is difficult to define and to determine</u>. <u>*Density*</u> can be characterized as the number of individuals per unit of spaces, as so many per square kilometer, per hectare, or per square meter. That measure is <u>*crude density*</u>. The trouble with this measure is that individuals do not occupy all the space within a unit, because not all of it is suitable habitat. A biologists might estimate the number of deer living in a square kilometer. The deer, however, might avoid half the area, because human habitation, land use, and lack of cover and food.

<u>Dispersion</u>

How organism are dispersed over space has an important bearing on density. Individuals of population may be distributed <u>*randomly*</u>, <u>*uniformly*</u> or in <u>*clumps*</u>. Individuals are distributed <u>*randomly*</u> if the position of each is independent of the other's. some invertebrates of the forest floor, particularly spiders may be spaced at random.
By contrast, individuals distributed <u>*uniformly*</u> are more or less evenly spaced. In the animals world, uniform dispersion usually results from some form of competition, such <u>*territoriality*</u>.
The most common dispersion type is <u>*clumped*</u> dispersion, in scattered groups. Clumping results from responses to habitat differences, daily and seasonal weather changes, reproductive patterns, and social behavior. There are various degrees and types of clumping.

Group may be randomly or nonrandomly distributed over an area. Aggregation may range from small groups to a single centralized group. If environmental conditions encourage it, populations may be concentrated in long bands or strips along some features of the landscape, such as a river, leaving the rest of the area unoccupied.

Age **structure**

Population has age structure. Because reproduction is restricted to certain age classes and mortality is most prominent in others, the ratio of the age groups bears on how quickly or slowly populations grow.

Population divide into three ecological period : prereprouductive reprouductive, and postreprouductive.

The length of each period depends largely on the life history of organisms.

Among annual species the length of the prereprouductive period has little influence on the rate of population growth. In longer lived animals, the length of the prereprouductive period has a pronounced effect on the population's rate of growth. Organisms with a short prereprouductive period often increase rapidly, with a short span between generations. Organisms with a long prereprouductive periods, such as elephant and whales, increase slowly and have a long span between generations.

The age structure of a population is the ratio of the various age classes to each other at a given time. Age pyramids compare the sizes of age groups to help us visualize age structure. As the population changes with time, the number of individuals in each age class changes, and so do the ratios, a large number of young, which expands the base of the pyramid, characterizes a growing population.

This large class of young eventually moves up into the reproductive age classes. A high proportion of individuals moving into the older age classes characterize a declining population. With fewer young, fewer individuals will enter the reproductive age classes, further depressing the population. In this way age structure changes over time.

Life history Patterns

Reproductive is the major drive of all living organisms. The role of the reproductive drive is to transmit genetic characteristics from one generation to another. The ability of an organisms to accomplish that successfully is termed its *fitness*. Fitness is equated with the ability of an organisms to leave behind reproducing offspring. Individuals that leave behind the most reproducing offspring are supposedly the fitness. Achieving fitness involves, among other things, fecundity and survivorship, physiological adaptations, modes of reproduction age at reproduction, number of eggs or young produced, parental care, size, and time to maturity. How organisms achieve fitness becomes the organism's Life history Pattern.

Reproduction

Reproduction falls into two categories : *asexual* and *sexual*. *Asexual* reproduction creates new individuals genetically the same as the parent. The one – called *Paramecium* reproduces by dividing in two. Hydra reproduce by budding. Aphids produce eggs by normal cell division or mitosis that develop into female adults without fertilization. A process called *parthenogenesis*. However, organisms that rely heavily on asexual reproduction revert on occasion to sexual reproduction. Hydras at some time in their life cycle produce eggs and sperms. At the end of summer aphid resort to sexual reproduction to make males.

sexual reproduction : is common in multicellular organisms. Two individuals produce haploid gometes: egg and sperm, that combine to form a diploid cell or zygote. This halving and recombination of genes allow the gene pool to mix, producing genetic variability among offspring.
Some individuals possess male and female organs. They are *hermaphroditic*

Mating strategies

The behavioral mechanisms and social organization involved in obtaining a mate make up a mating system.

Monogamy is the formation of a pair bond between one male and one female. It is most prevalent among birds and rare among mammals, except several carnivores, such as foxes and few herbivores, such as beavers and muskrat.

Monogamy occurs mostly among species in which cooperation by both parents is needed to rear young successfully.

Polygamy is the acquisition by an individual of two or more mates, non of which is mated to other individuals. It can involve one male and several females or one female and several males. A pair bond exists between the individuals and each mate.

A special form of polygamy is promiscuity, in which males and females copulate with one or many of the opposite sex and form no pair bonds.

Reproductive effort

Organisms spend their energy to meet many needs. Some energy must go to growth, to maintenance to acquiring food, to defend territory, and to escape predators. Some must go to reproduction. To achieve optimal fitness, and organism has to budget its energy and time in reproduction. Allocation of time and energy make up an organism's "reproductive effort".

Energy investment and parental care

The same energy can produce many small young or one or two large ones. The number of offspring affects the investment each receives. If the parent produce a large number of young, it can afford only minimal investment in each one. In such case, animals provide no parental care. Such organisms usually inhabit disturbed sites, unpredictable environments, or places such as the open ocean, where opportunities for parental care are difficult. By diving energy for reproduction among as many young as possible, these parents increase the chances that some young will successfully settle somewhere.

Environmental conditions and number of young

Organisms living in variable environment or facing heavy predation produce numerous offspring, ensuring that some will survive. A large number of young is characteristic of short-lived mammals, insects, and species which reproduce only once in their live.

Having few young is a characteristic of long-lived species. Species reproducing many times in their life may adjust the number of young in response to environmental conditions and the availability of resources. Production of young often reflects the availability of food. In times of food scarcity, parents may fail to feed some offspring. In other situations, vigorous young kill their weaker sibs.

Lecture 9

Populations growth

The study of Populations reviews the ways Populations change in size. Birth (natality) and deaths (mortality) account for most changes in the Populations. The differences between the two rates determines its growth or decline.

The number of births in a given time period is called " *natality rate*". Also the number of individual dying in a given time period is called " *mortality rate*". Mortality and natality are two major forces influencing Populations growth. Birth minus deaths (b-d) equals the rate of increase. When births exceed deaths, the Populations remains the same. When deaths exceed births, the Populations declines.

Two additional influences of Populations growth are immigration (i), and influx of new individuals into a Population and emigration (e), the dispersal of individuals from a Population. To account for those gains and losses a general formula for the rate of increase (or decrease) is (b + i) – (d + e).

Maximum Populations growth

The maximum rate at which a Population could increase under ideal conditions is known as its "*biotic potential*". Different species have different biotic potential. A particular species biotic potential is influenced by several factors, including the age at which reproduction begins, the percentage of the life span during which the organism is capable of reproducing, and the number of offspring produced during each period of reproduction.

If one were to plot this increase versus time, the graph would have the "j" shape that is characteristic of "*exponential growth* " the constant reproducing rate that occurs under optimum conditions.

Limitation of Population growth

Certain Populations may exhibit exponential growth for a short period of time. However, organism cannot reproduce indefinitely at their biotic potentials, because the environment sets limits, which are collectively called "environmental resistance". Using the earlier example. Bacteria would never be able to reproduce unchecked for an extended period of time, because they would run out of food and living space, and poisonous body wastes would accumulate in their vicinity.

Lecture 10

Interaspecific Population Regulation

No population continues to grow indefinitely. Even those with exponential growth confront the limits of the environment. Most populations, however, do not behave in an exponential fashion. As the density of a population changes, interactions set in among members of the population that tend to regulate its size.

Population regulation and density dependence

Involved in the concept of population regulation is density dependence. *Density-dependent* effects influence population in proportion to its size. At low density, there is no influence. Above that point, the larger the population becomes the greater is the population of individuals affected. Density – dependent mechanisms act largely through competition for abundant or scanty resources. If the effects of a particular influence do not change with population density, or if the proportion of individuals affected is the same at any density, then the influence is density-independent.

One aspect of population regulation is competition among individuals of the same species for environmental resources (intraspecific competition). Individuals compete only when a resources is in short supply relative to the number seeking it. As long as resources enable each individual to survive and reproduce, no competition exists. When resources are limited, a population may exhibit one of two responses : scramble competition and contest competition. *Scramble competition* occurs when no individual receives enough of the resource for growth and reproduction, as long as the population remains dense. *Contest competition* takes place when some individuals claim enough resources while denying others a share.

Intraspecific competition retards growth and reproduction

Because the intensity of intraspecific competition is density-dependent, it increases gradually at first affecting just the equality of life. Later it affects individual survival and reproduction.

As population density increases toward a point at which resources are insufficient, individuals in scramble competition reduce intake of food. That diet slows the rate of growth and inhibits reproduction. Tadpoles reared experimentally at high densities experienced slower growth, required a longer time to change from tadpoles to frog, and had a lower probability of completing this transformation. These that did reach threshold size were smaller than those living in less dense population. Fish living in overstocked ponds exhibit a similar response to density.

As population reaches a high density, individual living space become restricted. Often aggressive contacts among individuals increase. One hypothesis of population regulation is that increased crowding and social contact cause *stress*. Such stress triggers hyper activation of the system that controls the endocrine glands.

Profound hormonal changes suppress growth, curtail reproductive functions and delay sexual activity. They may also suppress the immune system and break down white blood cells, increasing vulnerability to disease. Social stress among pregnant females may increase intrauterine mortality and cause inadequate lactation. Thus stress results in decrease birth and increased infant mortality.

Social behavior

Intraspecific competition express itself in social behavior, the degree to which individuals of the same species tolerate one another. Social behavior appears to be a mechanism that limits the number of animals living in a particular habitat, having access to a common food supply and engaging in reproductive activities. It excludes the others. Social behavior limits populations in a density dependent fashion. A population has a substantial portion of population consists of surplus animals that do not breed because they either die or attempt to breed and fail. Such individuals are prevented from breeding by dominant individuals.

Lecture 11

Populations interactions

Although the most intense relationships exist between them, individuals of the same species do not live apart from individuals of other species. Living in close association different species interact. They may compete for a shared resource. Such as food, light, space, or moisture. One may depend upon the other as a source of food. They may provide mutual aid, or they may have no direct effect on each other at all.
Interactions between species include : competition predation, parasitism, mutualism and commensalisms.

Interspecific Competition

Interspecific Competition, as in Interspecific Competition, individual seek a resource in short supply, but they are of two or more species. Both kinds of Competition may take place simultaneously. Grey squirrels for example. Compete among themselves for acorns during a poor crop year. At the same time they compete with the white-footed mice, white-tailed deer and wild turkey for the same crop. Because of competition, individuals within a species may be forced to broaden the base of their foraging efforts. Population of various species may be forced to turn away from acorns to food less in demand. Thus Interspecific Competition selects for a broadening of the use of the resource, whereas Interspecific Competition favors a reduction of the use of the resource base.
Like Intraspecific Competition, Interspecific Competition takes two forms. Interspecific Competition. Like contest Competition, is direct or aggressive. One Competitor interferes with another's access to resource. Exploitative Competition. Similar to scramble Competition, reduces the abundance of shared resources. Each species indirectly reduces the abundance of the other species. The

outcome depends on how attentively each of the Competitors use the resource.

Outcomes of interspecific Competition

Early in the twentieth century,two mathematicians. The American Alfred Lotka and the Italian Vittora Volterra, independently arrived at mathematical expressions to describe the relationship between two species using the same resource. Lotka – Volterra equations predict four different outcomes of interspecific completion:

., B.) In two situations, one species uins out over the other. In one case species 1 inhibits further increase in species 2 while continuing to increase itself. In this case species 2 is driven to extinction. In the other case species 2 inhibits further increase in species 1 continuing to increase itself, and species 1 disappears. The Russian biologist A.F. Gause (1934), grew in the laboratory, two of *Paramecium . P. Aurelia and P. Caudatum.* When the two species were grown in separate test tubes. Each species quickly increased its population to a high level. Which is maintained for some time thereafter. When the two were grown together. However, only *P. Aurelia* thrived; *P. Caudatum dwindled* and eventually died out. Under different sets of culture conditions. *P. Caudatum* prevailed over *P. Aurelia* which died out. Gause interpreted this to mean that one set of conditions favored one species, and a different set favored the other. Because the two were similar, given time one or the other would eventually triumph at the other's complete cost.

C) In third situation each species, when abundant, inhibits the growth of the other species more than it inhibits its own growth. Both species hang on in an unstable equilibrium. In the long run one wins. The outcome depends upon which species is the most abundant and upon which species adapts better to environmental change.

D) In the fourth situation neither population can achieve a density capable of eliminating the other. Each species inhibits its own population growth more than that of the other species.

Competitive exclusion principle

In three of the four situations predicted by the lotka-Voltera equations one species drives the other to extinction. The results of the laboratory studies tends to support the mathematical models. These observations have led to the concept called the" Competitive exclusion principle" it states that complete competitors cannot coexist. Basically. If two non interbreeding populations possess exactly the same ecological requirement and live in exactly the same place. And if population A increases the least bit faster than population B. than A eventually will occupy the area completely. B will become extinct

The results of many field experimental studies do suggest that interspecific completion has a large overall effect that varies widely among organisms. For example. The studies show strong competition among toads. Frogs, and arthropods of flowing water. Among herbivores interspecific competition is less significant than intraspecific completion in controlling populations. Among most organisms the effects of intraspecific and intraspecific completion are equally strong.

coexcistence

two or more competing species can coexist, although such competition reduces the fitness of all parties. Among some animals, notably dirds, competing species exhibit territorial behavior. This interspecific territoriality reduces the number of breeding individuals of each species that occupy a given area of shared habitat.

Predation

Predation is the eating of one living organism (prey) by another (predator). One organism benefits at the other's expense. Predation includes not only carnivory, but parasitism, cannibalism and herbivore. A fly or a wasp laying its eggs on a caterpillar of another species to develop there at the expense of its victim is exhibiting a form of predation called *parasitism.* The parasitoid attacks the host (the prey) indirectly by laying its eggs on the host's body. When the eggs hatch, the larvae feed on the host. Slowly killing it. A deer feeding on shrubs and grass and a mouse eating a seed are practicing a form of predation called *herbivore*. Seed consumption is outright predation because the embryonic plant is killed. A special form of predation is *cannibalism*, in which the predator and the prey are of the same species.

However, there is a close interaction between the predator and the prey. Each influences the fitness of the other. Predation is more than a transfer of energy. It is a direct and often complex interaction of two or more eater and the eaten. The numbers of some predators may depend upon the abundance of their prey. Each can influences the population growth of the other and favor new adaptations.

Cannibalism

Cannibalism is a special form of Predation. Called Intraspecific Predation. Cannibalism is killing and eating an individual of the same species. It is common to a wide range of animals, aquatic and terrestrial, from protozoans and rotifers through centipedes, mites, and insects to frogs, toads, fish, birds, and mammals, including humans

Cannibalism has been associated with stressed population, particularly those facing starvation. Although some animals do not become cannibalistic until other foods run out, others do so when alternative foods decline and individuals are malnourished. Other conditions that may promote cannibalism are :

1) crowded conditions or dense populations. Even when food is adequate:
2) stress, especially when individuals of low social rank are attacked by dominant individuals:
3) the presence of vulnerable individuals – such as nestlings, eggs, or weak individuals that provide easy prey even in the presence of food.

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Parasitism and Mutualism

Coevolution

Sometimes two different species develop an intimate association so that, over time, the course of each species evolution is affected. We call a relation in which two interacting populations appear to strongly influence the evolution of traits in each other "coevolution". Any evolutionary change in one member changes the selective forces acting on the other. They play a game of adaptation and counteradaption. Coevolution is found between parasites and hosts. And between mutualalism.

Most coevolutionary responses appear to be general. For example, plants have evolved chemical defense against a diverse array of herbivorous insects. In turn, many insects have evolved the ability to detoxify a wide range of plant chemicals. Similarly animals have evolved a generalized immune system in response to a wide range of parasites. Flowering plants and their animal pollinators provide an excellent example of coevolution. During millions of years over which these associations developed, Flowering plants evolved a number of ways to attract animal pollinators, such as attractive colors and scents. Also, the animal pollinators, such as insects, hummingbirds, and bats, coevolved specialized body parts and behaviors that enabled them to both aid pollination and obtain nectar and pollen as a reward.

However, period interactions between certain parasites and their hosts or between certain mutualists suggest closer, more specific convolution.

Parasitism

Parasitism is a condition in which two organisms live together, one deriving is nourishment at the expense of the other. Parasites draw nourishment from the tissues of the larger host, a case of the weak attacking the strong (in perdation, the strong predator attacks the weak prey). Mostly the Parasites do not kill their hosts as predators do, although the host may die from secondary infection or suffer stunted growth weakness or sterility.

Parasitic organisms belong to awide range of taxonomic groups, including viruses, bacteria, protists, fungi, and an array of invertebrates among them arthropods

Mutualism

Mutualism is the name given to associations between two species that bring mutual benefits. The individuals in a population of each mutualist species grow and/or survive and/or reproduce at a higher rate when in the presence of individuals of the other. Each mutualist gains one of a variety of kinds of advantage. Most often this involves food resources for at least one of the parties and frequently, for the other, protection from enemies or provision of a favovrable environment in which to grow and reproduce. In other cases, the species that gets the food provide a service by ridding its partner of parasites (e.g. cleaner fish) or by bringing about pollination or seed dispersal

Commensalism

A " Commensal" organism lives on or around the individuals of some other species (which may be called host) and drives benefit from the association. The host suffers no negative effects.
Van Beneden (1876) wrote. " *The Commensal is simply a companion at the table*". Good examples of Commensals in this sense are the scavengers such as vultures that live on the scraps from the kills of large carnivores such as lions. The remora fish uses its suction cup on the top of its head to attach itself to a shark. It thus travels with the shark and eats the leftovers from the big fish's meal.

The term " Commensalism" is now used in a broaden sense to refer to coactions in which the gain is something other than direct access to food provided by the host. Usually the gain is some combination of *transportation, support or shelter*. The use of prairie dog burrows as nest sites for burrowing owls and the use of old bird's nests by deer mice as sites for their own nests are examples of Commensalism.

Lecture 12

Community and Ecosystem

Populations of organisms do not live apart from one another as separate entitles. Sharing environment and habitat they interact in various ways. These interactions came together in the concept of Community : as assemblage of species in a given place interacting directly and in directly with each other. The Community involves the biota only. The interaction of the biotic Community with the a biotic environment forms the ecosystem.

Community Structure

Although ecologists classify communities in different ways, all communities have certain characteristics that define their biological and physical structure. These characteristics vary in both space and time.

biological structure

the mix of species, including their number and relative abundance defines the biological structure of a community. A community can be composed of a few common species: or it can have a wide variety of species, some common with high population density, but most rare with low population density. When a single or few species predominate within a community, these organisms are *dominants*.

Dominancy : It is not easy to determine the dominant species. The dominants in a community may be the most numerous, possess the highest biomass, occupy the most space, make the largest contribution to energy flow or nutrient cycling or by some other means control or influence the rest of the community. Some ecologists ascribe to dominant role to those organisms that are greatest in number, but abundance alone is not sufficient.

physical structure

communities are characterized not only by the mix of species, the biological structure, but also by physical features. The physical structure of the community reflects Abiotic factors, such as the depth and flow of water in aquatic environment. It also reflect biotic factors, such as the spatial configuration of organisms.
In a forest, for example, the size and height of the trees and the density and dispersion of their populations define the physical attributes of the community

The form and structure of terrestrial communities reflect the vegetation. The plants may be tall or short evergreen or deciduous herbaceous or woody. Such characterstics can describe growth form. Thus we might speak of shrubs, trees, and herbs.

Vertical structure

Each community has a distinctive vertical structure. On land, vertical structure is determined largely by the life form of the plants – their size branching and leaves – which in turn, influence and is influenced by the vertical gradient of light. The vertical structure of the plant community provides the physical framework in which many forms of animal life are adapted to live.
A well-developed forest ecosystem, for example, has several layers of vegetation. From top to bottom, they are the canopy, the understory, the shrub layer, the herb or ground layer, and the forest floor. We could continue down into the root layer and soil strata.

The *canopy*, which is the primary site of energy fixation through photosynthesis, has a major influence on the rest of the forest. If it is fairly open, considerable sunlight will reach the lower layers, will have ample water and nutrients resulting in well developed understory and shrub strata. If the canopy is dense and closed, light levels are low and the understory and shrub layers will be poorly developed

<u>The understory</u> consists of tall shrubs. Understory trees and younger trees, some of which are the same species as those in the canopy. Species which are unable to tolerate shade will die. Survivors eventually reach the canopy after older tress die or harvested.

The nature of the *<u>herb layer</u>* will depend on the soil moisture and nutrients conditions, the slope position, the density of the canopy and understory, and the exposure of the slope, all of which vary from place to place throughout the forest.

The final *<u>forest floor</u>* is the site where the important process of decomposition takes place and where decaying organic matter release nutrients for reuse by the forest plants

Aquatic ecosystems such as lakes and oceans have strata a determined by light penetration. They have distinctive profiles of temperature and oxygen. Layers are defined according to light penetration an upper zone, *the trophogenic zone* dominated by phytoplankton, which is the site of photosynthesis, and a lower zone, the *<u>tropholytic zone</u>* in which decomposition is most active. All communities, both terrestrial and Aquatic, have a similar biological structure, related to these patterns of vertical layering. They possess an autotrophic layer concentrated where light is most available, which fixes the energy of the sun through photosynthesis, producing organic carbon compounds from CO_2 .

In forests this layer concentrates in the canopy, in grasslands in the herbaceous layer: in lakes and seas, in the upper layer of water. Communities also possess a heterotrophic layer that utilizes the carbon, stored by autotrophs as food source, transfers energy, and circulates matters by means of herbivory, predation in the broadest sense, and decomposition.

<u>Horizontal structure</u>

In a forest, for example, often there are patches of open grass and tall shrubs. Sometimes there are gaps, openings in the canopy caused by the death of a canopy tree, where dense thickets of new growth have claimed the sunlit openings.

The *<u>horizontal patchiness</u>* adds to the physical complexity of the Community. This patchy distribution of plants shows influences of both the physical and bidogical environment. In terrestrial Communities, soil structure, soil fertility, moisture sonditions and aspect influence the microdistribution of plants. Patterns of light and shade shape the development of the understory vegetation.

Grazing animals have subtle but important effects on the patterning of vegetation, as do Abiotic distribances such as wind and fire. Like vertical structure, horizontal patchiness of plant life influences the distribution and diversity of animals life within the Community. Generally, Communities that are most highly stratified (vertically and horizontally) offer the richest variety of animal life because they contain the greatest assortment of habitats.

Niche

Every organism has its own role within the structure and functions of an ecosystem, this role is its ecological niche. An organism's ecological niche takes into account all aspects of the organisms existence – all the physical, chemical, and biological factors that the organism needs to survive, to remain healthy, and to reproduce.

Among other things, the niche includes the physical surrounding in which an organism lives (its habitat) and how it interacts with and is influenced by the nonliving components of its environment (light, temperature, and moisture). An organism's niche also encompasses the organisms it eats, the organisms that eat it, and the living organisms with which it competes. The niche, then, represents the totality of an organism's adaptations, its use of resources, and the life style to which it is fitted.

There are two aspects to an organism's ecological niche : the role the organism could play in the Community, the potential or *fundamental niche*, and the role it actually fulfills : the *realized niche*. The niche may be far broader potentially than it is in actuality. An organism is usually capable of utilizing much more of its environment's resources or living in a wider assortment of habitats than it actually does, but various factors such as competition with other species may exclude it from part of its fundamental niche.

Lecture 13

PRODUCTION IN ECOSYSTEM

In the concept of the ecosystem, the biological and physical components of the environment are a single interaction system. Like the community, the ecosystem is a spatial concept : it has defined boundaries. The primary focus of ecosystem ecology is the exchange of energy and matter. Exchange from the surrounding environment into the ecosystem are *inputs*. Exchanges from inside the ecosystem to the surrounding environment are *outputs*.

Basic components of ecosystems

In the simplest terms, all ecosystems, both aquatic and terrestrial, consist of three basic components – the autotrophs, the consumers, and Abiotic matter. The *producers*, or *autotrophs*, are largely green plants. These organisms use the energy of the sun in photosynthesis to transform inorganic compounds into simple organic compounds

The *consumers*, or *heterotrophs* use the organic compounds produced by the autotrophs as a source of food. The heterotrophic components of the ecosystem is often subdivided into two subsystems, consumers and decomposers. The consumers feed largely on living tissues, and the decomposers break down dead matter into simple inorganic compounds that are once again used by the producers.

The third, or *abiotic*, components consists of the soil sediments, particulate matter, dissolved organic matter in aquatic ecosystem, and litter in terrestrial ecosystems. All of the dead organic matter is derived from plant and consumer remains and is acted upon by decomposers. Such dead organic matter is critical to the internal cycling in the ecosystem.

The driving force of the system is the energy of the sun. the energy harnessed by the producers flows from producers to consumers to decomposers and eventually dissipates as heat.

Laws of thermodynamics govern energy flow

Production in ecosystems involves the fixation and transfer of energy from the sun. green plants fix solar energy in the process of photosynthesis. The products of Photosynthesis accumulate as plant *biomass*. Nonphotosynthetic organisms convert this stored energy into *heterotrophic* *biomass*. This fixation and transfer of energy through the ecosystem is governed by the laws of thermodynamics, which apply to all things in the universe

Energy exists in two forms, potential and kinetic. *Potential energy* is stored energy. *Kinetic energy* is energy in motion, which performs work at the expense of Potential energy. The expenditure and storage of energy are governed by the laws of thermodynamics. The first laws of thermodynamics states that energy is neither created nor destroyed. It may change form, pass from one place to another, or act upon matter in various ways. Regardless of what transfer and transformations take place, however, no gain or loss in total energy occurs. When wood burns, the potential energy lost from the molecular bonds of the wood equals Kinetic energy released as heat.

The transfere of energy involves the second law of thermodynamics. It states that when energy is transferred or transformed part of the energy assumes a form that cannot pass on any further. When coal is burned in a boiler to produce steam, some of the energy creates steam, and part is dispersed as heat to the surrounding air. The same thing happens to energy in the ecosystem. As energy is transferred from one organism to another in the form of food, a large part of that energy is degraded as heat –no longer transferable. The remainder is stored as living tissue.

The flow of energy through Ecosystem

The passage of energy in one direction through an ecosystem is known as energy flow. Energy enters an ecosystem in the form of the radiant energy of sunlight. Some of it is trapped by plants during the process of photosynthesis. Now in chemical form it is stored in the bonds of organic molecules such as glucose. When these molecules are broken apart by cell respiration, the energy becomes available to do work such as repairing tissues, producing body heat, or reproducing. As the work is accomplished the energy escapes the living organism and dissipates into the environment as heat. Ultimately, this heat energy radiates into space. Thus, once energy has been used by living organism, it becomes unavailable for reuse.

The path of Energy Flow : Food Chains

Energy in ecosystem occurs in food chains, in which energy from food passes from one organism to the next in a sequence. Producers start the food chain by capturing the sun's energy through photosynthesis. Herbivores (and omnivores), who reap the energy stored in the herbivore's molecules. At the end of a food chain are decomposers, which use organic molecules in the remains (the carcasses and body wastes detritus) of all other members of the food chain.

Each level in a food chain is called a *trophic level*. The first trophic level is formed by the producers (green plants), the second trophic by primary consumers (herbivores), the third trophic level by secondary consumers (carnivores) and so on.

Ecological Pyramids :

An important feature of energy flow is that most of the energy goining from one trophic level to another in a food chain or food web dissipates into the environment. The relative energy values of trophic levels are often graphically represented by ecological pyramids. There are three main types of pyramids : a Pyramids of numbers, a Pyramid of biomass, and a pyramid of energy.

A Pyramid of numbers shows the numbers of organisms at each trophic level in a given ecosystem, with greater numbers illustrated by wider section of the pyramid. In most pyramids of numbers, each successive trophic level is occupied by fewer organisms. Thus in a typical grassland the number of zebras and wildebeests (herbivores) is greater than the numbers of lions (carnivores).

Ecological Pyramids :

A pyramid of biomass: illustrates the total biomass of each trophic level. It also illustrate a progressive reduction of biomass in successive trophic levels.

A pyramid of energy: illustrates the energy relationships of an ecosystem by indicating the energy content of the biomass of each trophic level.

Lecture 14

General Discussion Of All The Above Lectures

Answer the following questions:

Question 1: Choose the correct answer from (A, B, C, D)

1-The natural world that surrounds an organism is called the organism's:

A- Energy B- Environment C- Population D- Nutrients

2- The Earth is tilted relative to the sun

A-Water B-Axis C- Poles D- Heat

3- Ecology is the study of how:

A- The physical environment changes over time.

B- Biotic factors change over time.

C- Matter interacts with energy in our environment.

D- Living things interact with each other and their environment.

4- An unusually cold winter causes the squirrel population to decrease. This is an example of temperature as a

A- Abiotic factor B-limiting factor

C- Climax community D- Pattern in space

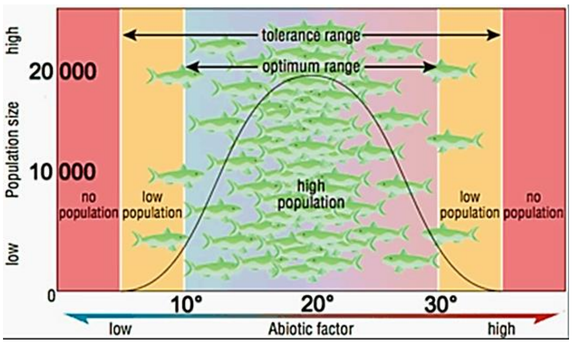
5- Concentrates on factors that affect how many individuals of a species live in an area

A-Population ecology B-Operant conditioning

C-Reproductive table D-Coniferous forest

6- At which temperature would this fish population be in the zone of physiological stress because the temperature was too hot?

A-32 degrees B-8 degrees C-20 degrees D-40 degrees



7- Shelford’s law of tolerance suggests that organisms with a wide tolerance limit for environmental factors show: -
A- Narrow distribution with low population
B- Wide distribution with high population
C-Wide distribution with low population
D- Narrow distribution with high population

<u>Question 2: Read the following sentences and then determine if its True (T) or False (F)</u>

1- One male competes for, and breeds with, many females, they do not usually assist with rearing the offspring
→ Polygyny
(T) or (F)

2 -A population in which the proportion of individuals in each age class is constant

→Generalists
(T) or (F)

3- Innate biological rhythms which approximate the daily rotation of the earth

→ Circadian rhythms
(T) or (F)

4-The point where the energy being produced through photosynthesis equals the amount of energy used in metabolism
→ homeostasis (T) or (F)

5 -Can tolerate a large range of temperatures → Eurytherm (T) or (F)

6 -Aquatic animals usually face more of a diurnal change in water temps than animals in terrestrial locations
(T) or (F)

7 -The body temp of amphibians and reptiles, fish and invertebrates conform to outside temp of the environment called ectotherms (T) or (F)

8 -Approximately one year" → Circannual
(T) or (F)

9 -Limiting factors are sometimes helpful because they can keep the population from getting too large.
(T) or (F)

10 -A population pyramid with a very wide base is a sign that the population is decreasing.
(T) or (F)

1-Write on each of the following:-
- a- Poikilotherms and regulation their body temperature.
- b- Photoperiod.
- c- Food chains and food webs.

2- Write as essay about the energy flow within ecosystem.

3- Explain 3 points from the following:-
- a- Range of tolerance.
- b- Water problem in aquatic habitat.
- c- pond as an ecosystem.
- d- Competition between animals.
- e- Energy pyramids.

Zoology Department

(Part : Physiology)

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Second Semester 2022-2023

Content

Introduction

Physiology: biological science dealing with how the body functions at the various levels of organization/study of the function of all living organisms. Physiology derived from two Greek words Physis= nature, logos= study

Physiology is the study of function

Levels of organization

The atom – e.g. hydrogen, carbon

The molecule –e.g. water, glucose

The macromolecule (large molecule) – e.g. protein, DNA

The organelle – e.g. nucleus, mitochondria

The tissues – e.g. liver – muscle

The organs – e.g. heart- kidney

The organ system – e.g. skeletal, cardiovascular

The organism – e.g. human, cat

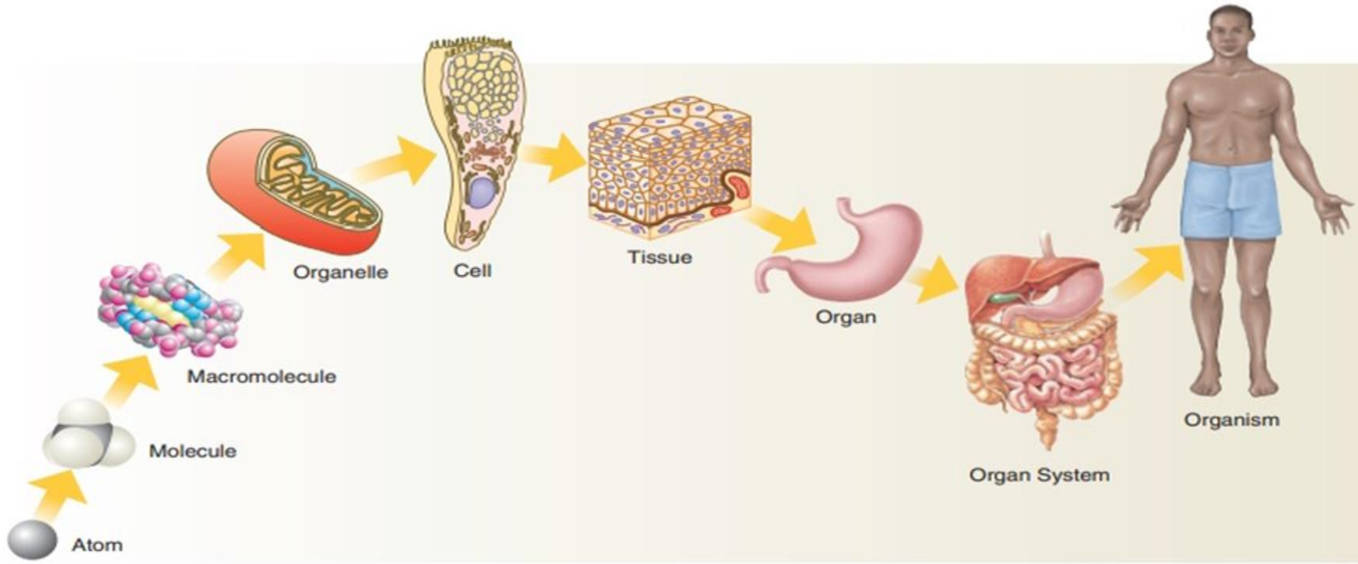


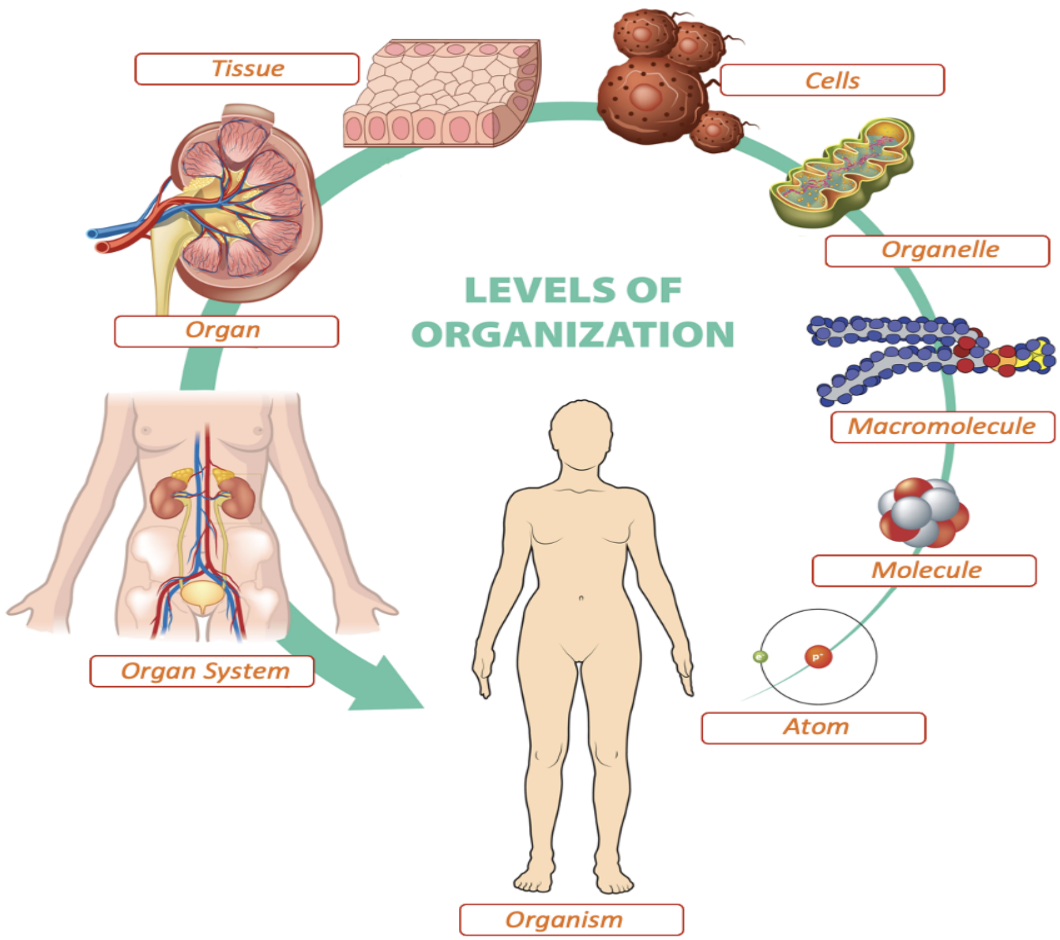
FIGURE 1-1 Organization levels of the body.

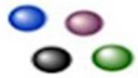
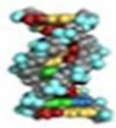
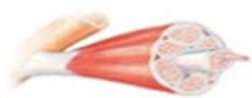
Adapted from Shier, D.N., Butler, J.L., and Lewis, R. Hole's Essentials of Human Anatomy & Physiology, Tenth edition. McGraw Hill Higher Education, 2009.

Levels of Organization (From Molecules to Organisms) - Worksheet - Answer Key

Q.1. Use the words in the box below to label the levels of the organization.

• Cells	• Organ	• Atom
• Organelle	• Macromolecule	• Organ System
• Tissue	• Molecule	• Organism



Level of Organization	Explanation	Example
 Atomic Level	Atoms are defined as the smallest unit of an element that still maintains the property of that element.	Carbon, Hydrogen, Oxygen
 Molecular Level	Atoms combine to form molecules which can have entirely different properties than the atoms they contain.	Water, DNA, Carbohydrates
 Cellular Level	Cells are the smallest unit of life. Cells are enclosed by a membrane or cell wall and in multicellular organisms often perform specific functions.	Muscle cell, Skin cell, Neuron
 Tissue Level	Tissues are groups of cells with similar functions	Muscle, Epithelial, Connective
 Organ Level	Organs are two or more types of tissues that work together to complete a specific task.	Heart, Liver, Stomach
 Organ System Level	An organ system is group of organs that carries out more generalized set of functions.	Digestive System, Circulatory System
 Organismal Level	An organism has several organ systems that function together.	Human

Characteristics of life:

Reproduction

Growth

Movement

Respiration

Responsiveness: this allows the organism to respond to changes

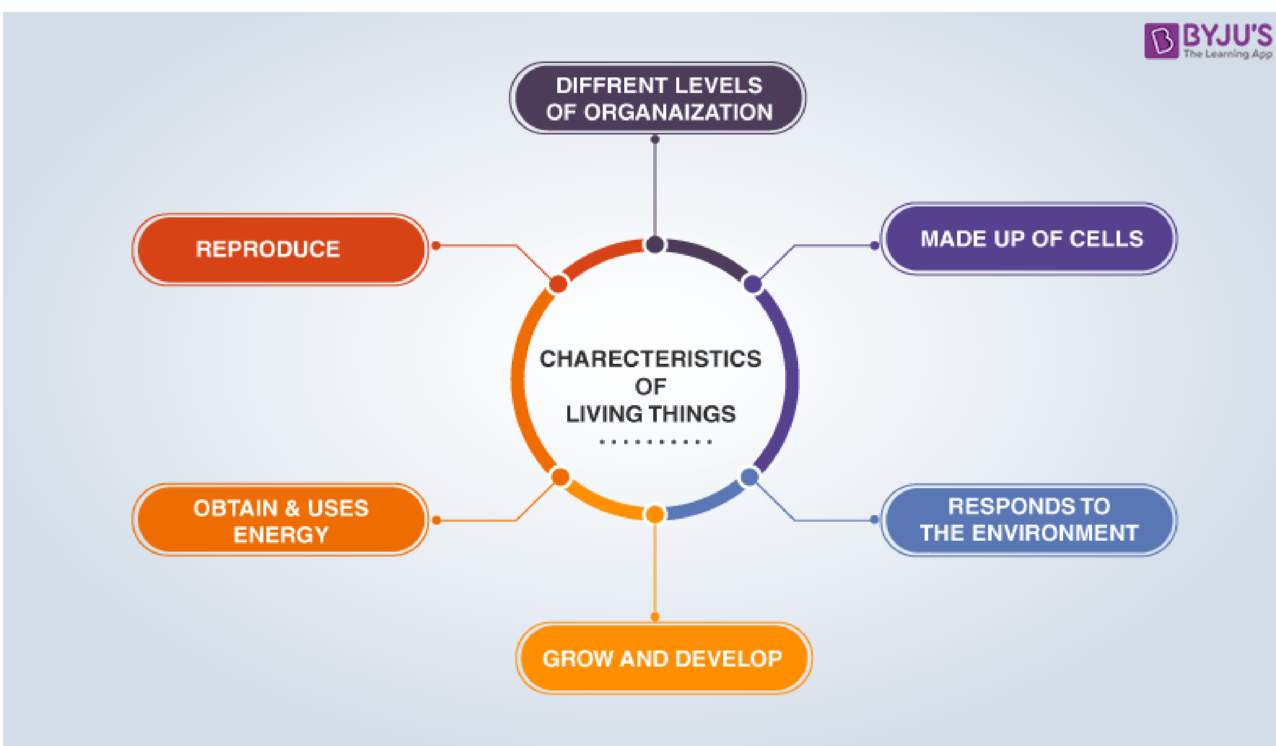
Digestion: produce the energy necessary for life

Absorption: blood and lymph, which then carry the substances to the parts of the organism requiring them

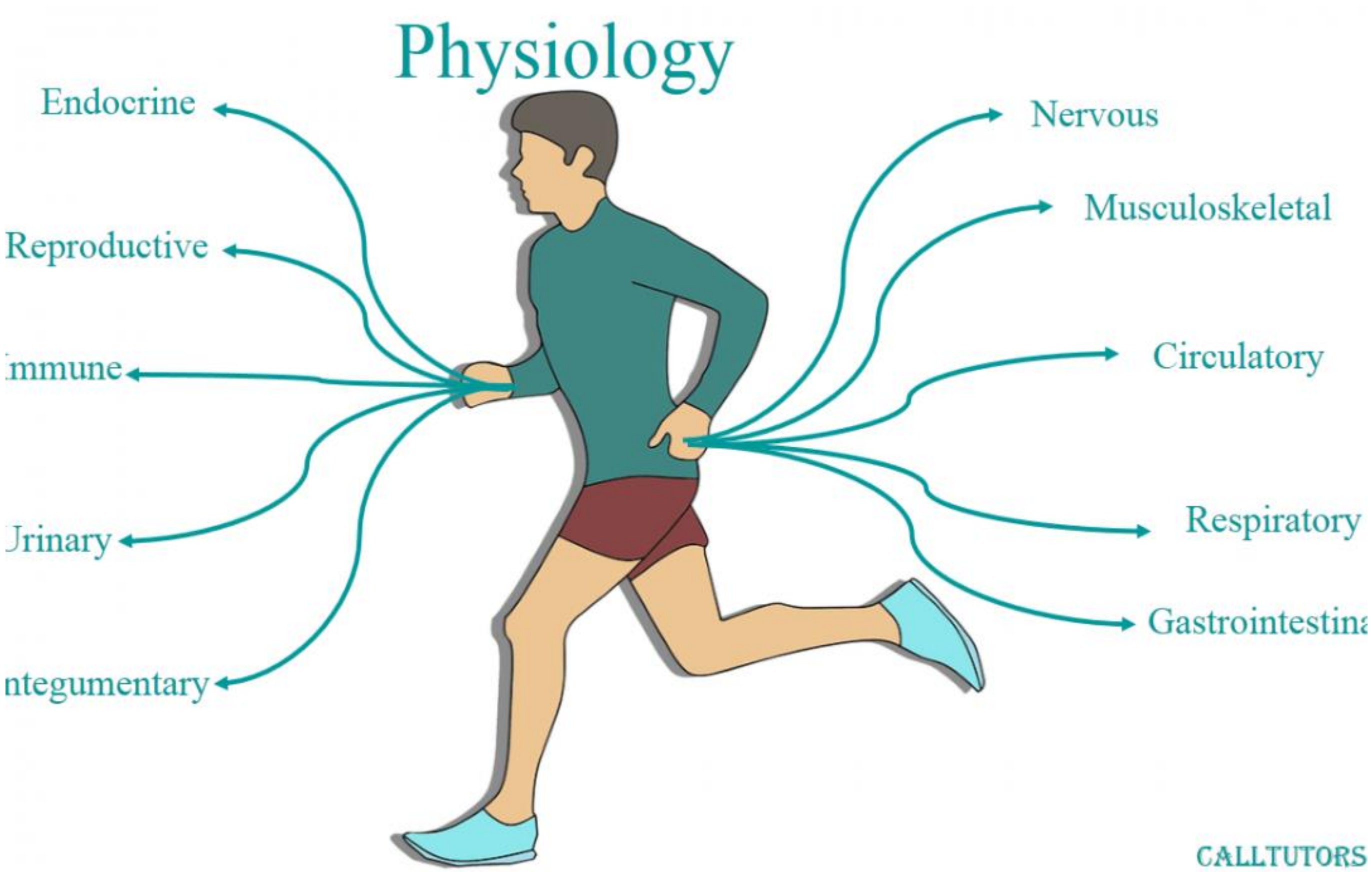
Circulation

Assimilation: the changing of absorbed substances into different substances, which can then be utilized by the tissue of the body.

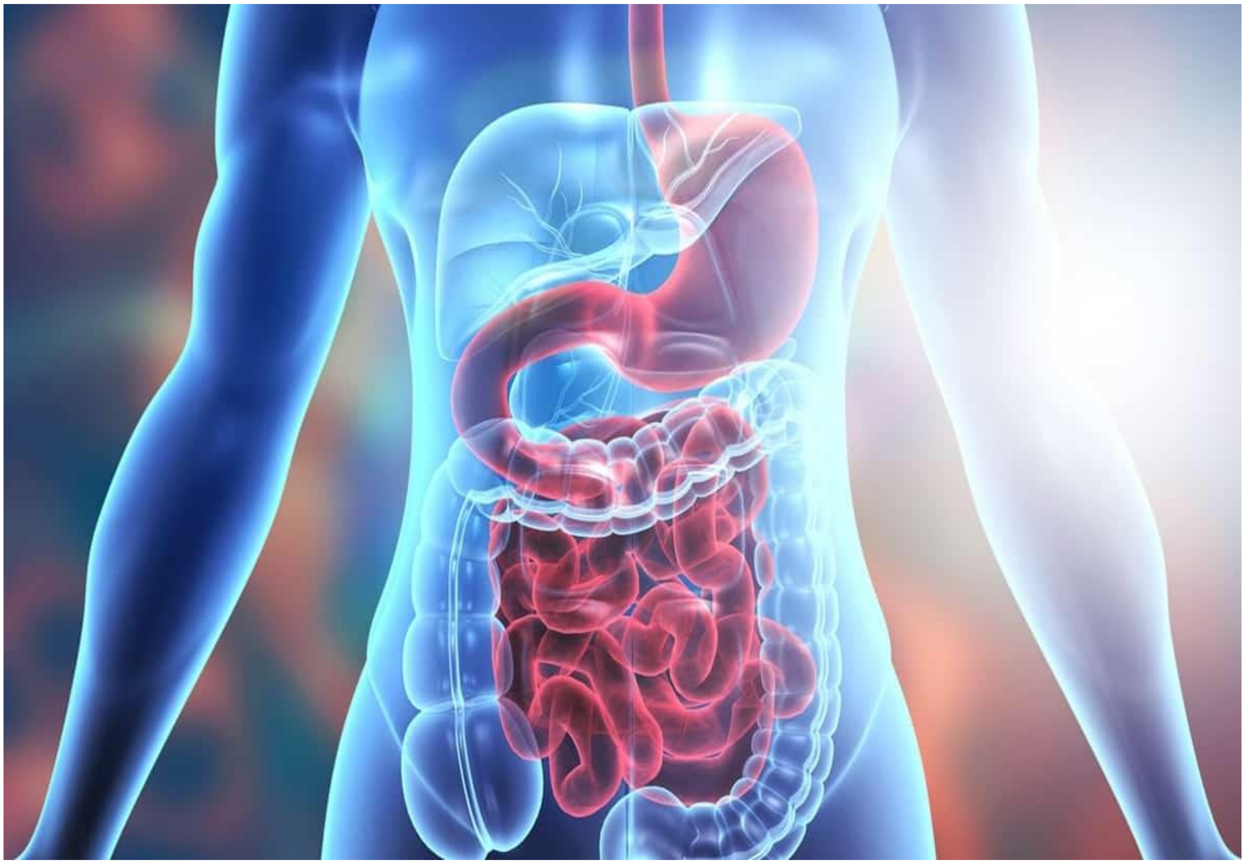
Excretion: the removal of waste substances from the body.



Physiology is the study of the function of each of these structures associated with the body. The body is often thought of as a complicated machine. For the machine to work, it must have all of its parts but each of these parts must function optimally. If organs or organ systems are not functioning properly, then the body is described as having the disease. Let's discuss a specific example. Some patients have a thinning (weakening) in the wall of an artery. This is referred to as an aneurysm. The blood in arteries is under very high pressure. This pressure becomes even greater when we are undergoing activities such as exercise. If the artery wall is weak and the pressure on the blood increases too much, the vessel may rupture (burst aneurysm) and the patient may bleed to death. The structure (vessel wall) has changed so that the artery can no longer carry out its function (containing the blood).



The Digestive System



People are probably more aware of their digestive system than of any other system, not least because of its frequent messages. Hunger, thirst, appetite, gas ☺, and the frequency and nature of bowel movements are all issues affecting daily life.

We need food for cellular utilization:

1- nutrients as building blocks for the synthesis

2- sugars, etc to break down for energy

most food that we eat cannot be directly used by the body

1- too large and complex to be absorbed

2- chemical composition must be modified to be useable by cells

Digestion is important for breaking down food into nutrients, which the body uses for energy, growth, and cell repair. Food and drink must be changed into smaller molecules of nutrients before the blood absorbs them and carries them to cells throughout the body. The body breaks down nutrients from food and drinks into carbohydrates, protein, fats, and vitamins.

The digestive system is formed of

1-Alimentary canal: the mouth, pharynx, esophagus, stomach, small intestine, and large intestine.

2-Digestive glands: the salivary gland, gastric gland, intestinal glands, liver, and pancreas.

The digestive system is made up of the gastrointestinal (GI) tract—also called the digestive tract or Alimentary canal and the liver, pancreas, and gallbladder. The GI tract is a series of hollow organs joined in a long, twisting tube from the mouth to the anus. The hollow organs that make up the GI tract are the mouth, esophagus, stomach, small intestine, large intestine—which includes the rectum—and anus. Food enters the mouth and passes to the anus through the hollow organs of the GI tract. The liver, pancreas, and gallbladder are the solid organs of the digestive system. The digestive system helps the body digest food.

→ organs of the digestive system form essentially:

a long continuous tube open at both ends

→the alimentary canal (gastrointestinal tract)

mouth→ pharynx → esophagus → stomach → small intestine → large intestine

→ attached to this tube are assorted accessory organs

and structures that aid in the digestive processes

salivary glands

teeth

liver

gall bladder

pancreas

mesenteries

→ The GI tract (digestive system) is located mainly in abdominopelvic cavity

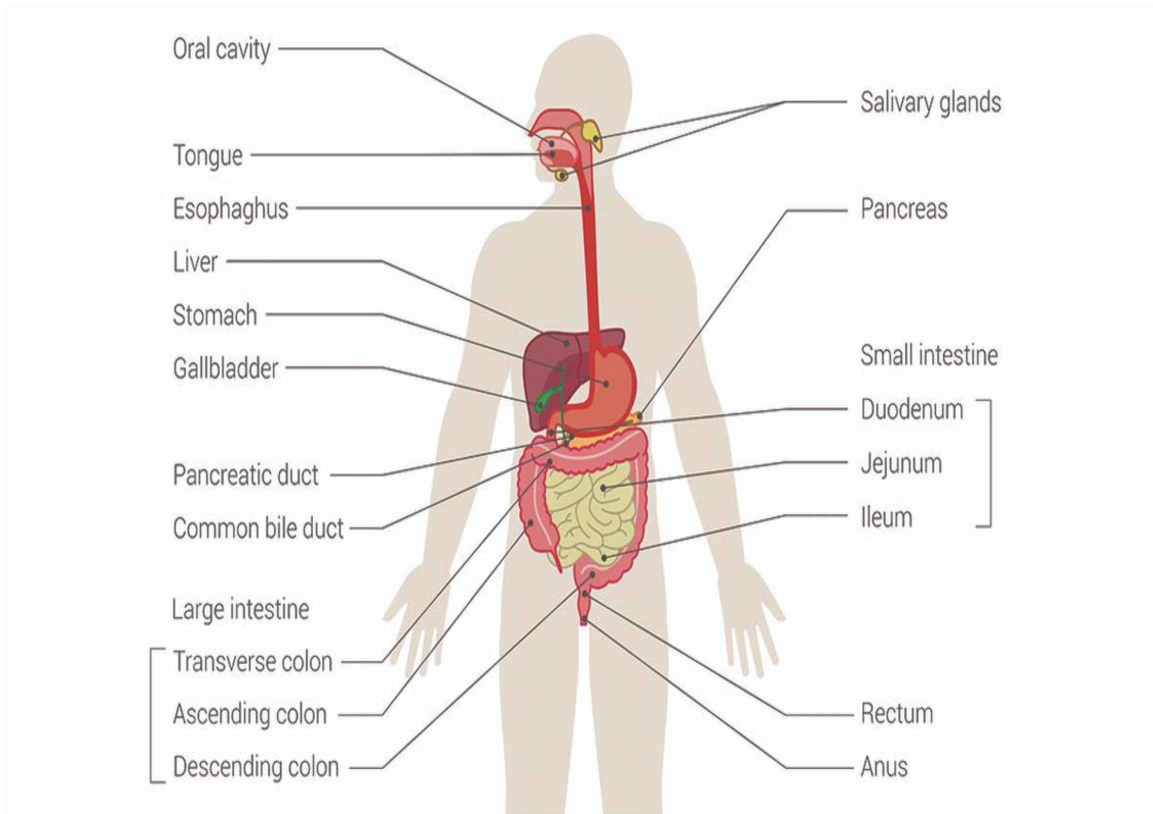
surrounded by serous membrane = visceral peritoneum

this serous membrane is continuous with the parietal peritoneum and extends

between digestive organs as mesenteries

→ hold organs in place, prevent tangling

Bacteria in the GI tract, also called gut flora or microbiome, help with digestion. Parts of the nervous and circulatory systems also play roles in the digestive process. Together, a combination of nerves, hormones, bacteria, blood, and the organs of the digestive system completes the complex task of digesting the foods and liquids a person consumes each day.



→ Six Functions of the Digestive System:

1. Ingestion
2. Mechanical processing
3. Digestion
4. Secretion
5. Absorption
6. Excretion

Characteristics of the GIT wall:

★ The cross-section of the wall of the GIT is formed of (5) layers:

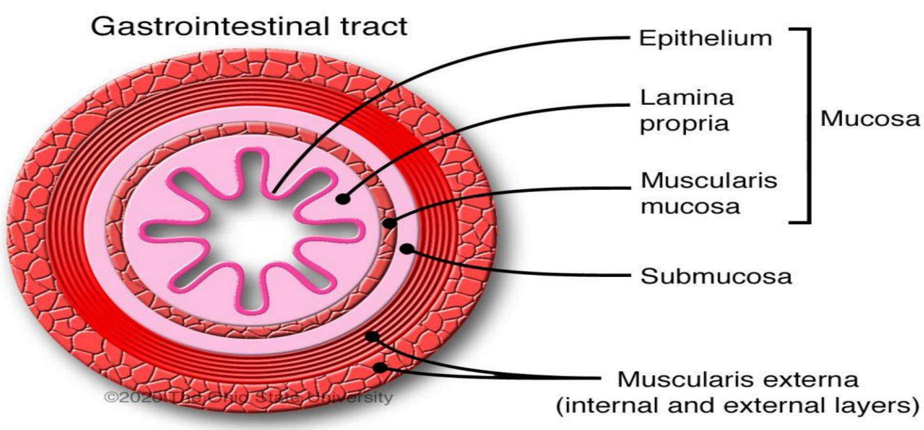
1- Mucosa: epithelial layer contains many mucus-secreting cells. The type of epithelium.

is simple columnar.

2- Submucosa: The layer of connective tissue contains blood vessels and some of the nerves that help regulate digestive activity.

3- Circular muscle layer and longitudinal muscle layer: The alternate contractions of these muscles create the wavelike movement that propels food through the digestive tract and mixes it with digestive juices. This movement is called peristalsis.

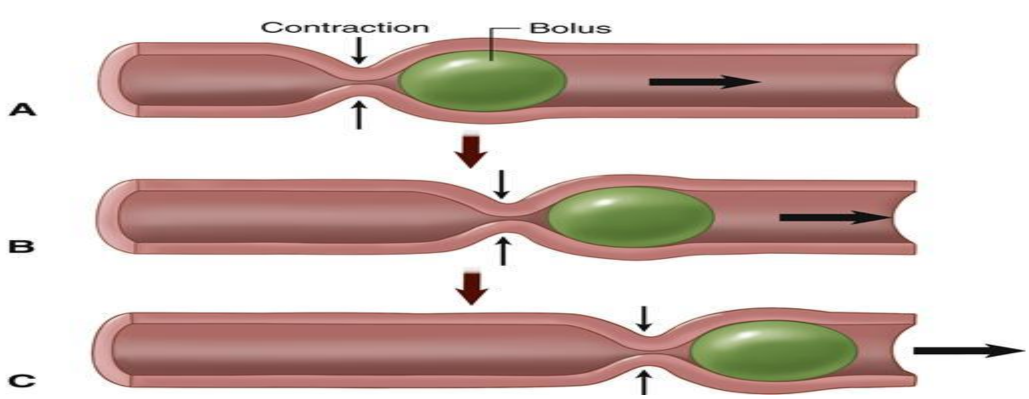
5- Serosa: fibrous connective tissue part of the peritoneum.



(1)- Propulsive movement (peristalsis):

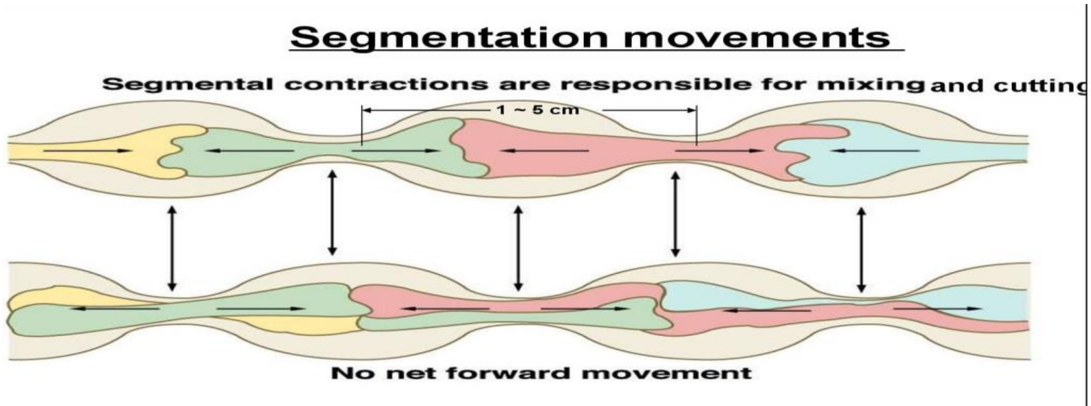
Aim: propelling the food forward along the GIT at a rate suitable for digestion and absorption.

Mechanism: A reflex initiated by a stretch of the gut wall → circular contraction behind the stimulus and relaxation in front of it → the wave of contraction moves in an oral to a caudal direction at rates (2- 25 cm/sec)



(2)- The mixing movements

The mixing movements are different in different parts of the alimentary canal sometimes, peristalsis causes most of the mixing when the forward progression of the intestinal contents is blocked by a sphincter. At other times, local constrictive contractions occur every few cms in the gut wall (only a few seconds), then new constrictions occur at other points of the gut → chopping off the contents.



Organ	**Movement**	**Digestive Juices Used**	**Food Particles Broken Down**
Mouth	Chewing	Saliva	Starches
Esophagus	Swallowing	None	None
Stomach	The upper muscle in the stomach relaxes to let food enter and lower muscle mixes food with digestive juice	Stomach acid	Protein
Small intestine	Peristalsis	Small intestine digestive juice	Starches, protein, and carbohydrates
Pancreas	None	Pancreatic juice	Starches, fats, and protein
Liver	None	Bile acids	Fats

★ Mastication (Chewing): Definition: It is the mechanical breakdown of large food particles into smaller ones in the mouth. Mastication helps digestion by increasing the exposed surface area to enzymes and helps to swallow.

Deglutition (swallowing): the propelling of food from the mouth to the stomach through the pharynx and esophagus.

Digestive Processes

The processes of digestion include six activities: ingestion, propulsion, mechanical or physical digestion, chemical digestion, absorption, and defecation.

The first of these processes, ingestion, refers to the entry of food into the alimentary canal through the mouth. There, the food is chewed and mixed with saliva, which contains enzymes that begin breaking down the carbohydrates in the food plus some lipid digestion via lingual lipase. Chewing increases the surface area of the food and allows an appropriately sized bolus to be produced.

Food leaves the mouth when the tongue and pharyngeal muscles propel it into the esophagus. This act of swallowing, the last voluntary act until defecation, is an example of propulsion, which refers to the movement of food through the digestive tract. It includes both the voluntary process of swallowing and the involuntary process of peristalsis. Peristalsis consists of sequential, alternating waves of contraction and relaxation of alimentary wall smooth muscles, which act to propel food along (Figure 1). These waves also play a role in mixing food with digestive juices. Peristalsis is so powerful that foods and liquids you swallow enter your stomach even if you are standing on your head.

Digestion includes both mechanical and chemical processes. Mechanical digestion is a purely physical process that does not change the chemical nature of the food. Instead, it makes the food smaller to increase both surface area and mobility. It includes mastication, or chewing, as well as tongue movements that help break food into smaller bits and mix food with saliva. Although there may be a tendency to think that mechanical digestion is limited to the first steps of the digestive process, it occurs after the food leaves the mouth, as well. The mechanical churning of food in the stomach serves to further break it apart and expose more of its surface area to digestive juices, creating an acidic "soup" called chyme. Segmentation, which occurs mainly in the small intestine, consists of localized contractions of circular muscle of the muscular layer of the alimentary canal. These contractions isolate small sections of the intestine, moving their contents back and forth while continuously subdividing, breaking up, and mixing the contents. By moving food back and forth in the intestinal lumen, segmentation mixes food with digestive juices and facilitates absorption.

chemical digestion, starting in the mouth, digestive secretions break down complex food molecules into their chemical building blocks (for example, proteins into separate amino acids). These secretions vary in composition but typically contain water, various enzymes, acids, and salts. The process is completed in the small intestine.

Food that has been broken down is of no value to the body unless it enters the bloodstream and its nutrients are put to work. This occurs through the process of absorption, which takes place primarily within the small intestine. There, most nutrients are absorbed from the lumen of the alimentary canal into the bloodstream through the epithelial cells that make up the mucosa. Lipids are absorbed into lacteals and are transported via the lymphatic vessels to the bloodstream (the subclavian veins near the heart). The details of these processes will be discussed later.

In defecation, the final step in digestion, undigested materials are removed from the body as feces.

Regulatory Mechanisms:

Neural and endocrine regulatory mechanisms work to maintain the optimal conditions in the lumen needed for digestion and absorption. These regulatory mechanisms, which stimulate digestive activity through mechanical and chemical activity, are controlled both extrinsically and intrinsically.

Hormone Regulators:

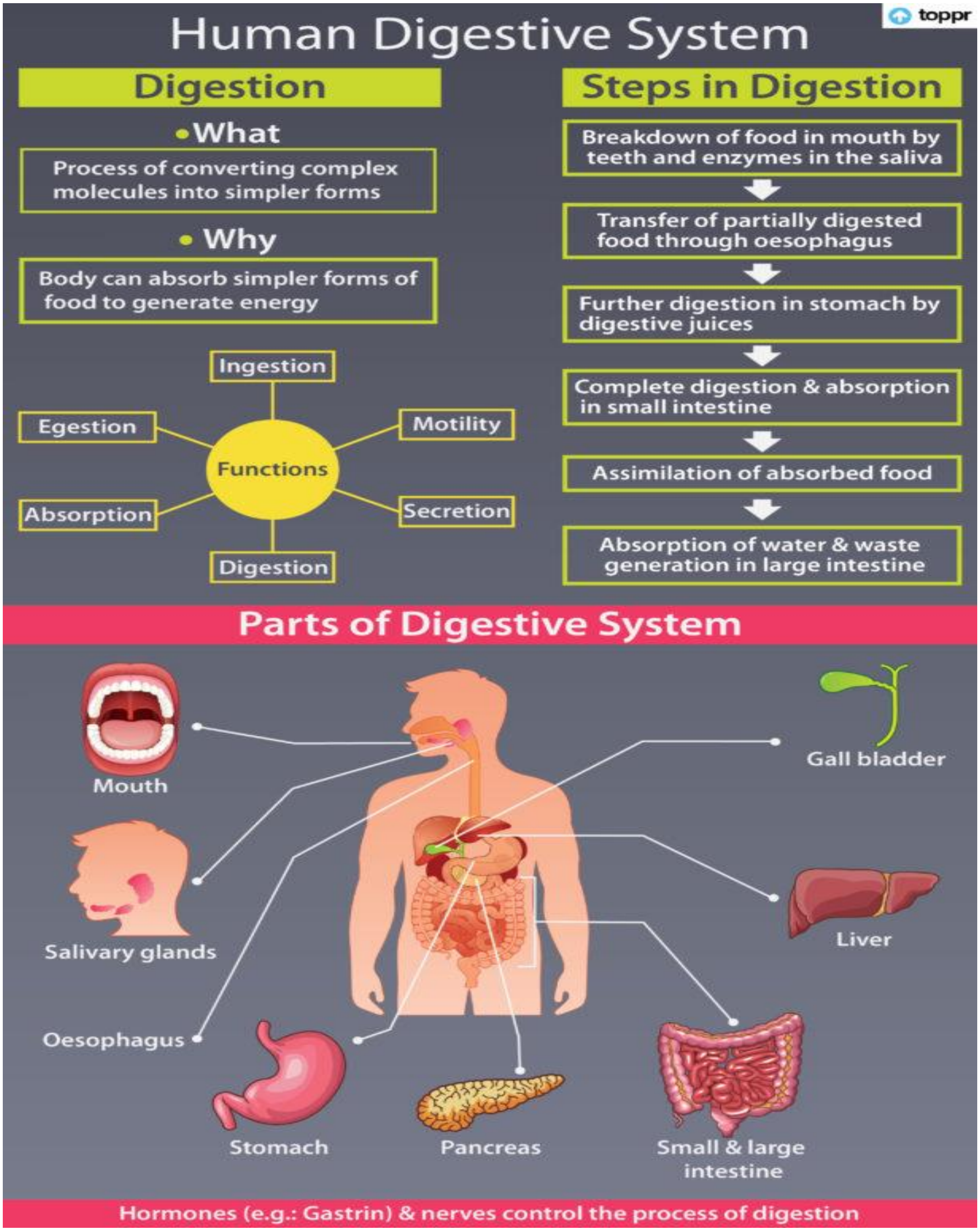
The cells in the lining of the stomach and small intestine produce and release hormones that control the functions of the digestive system. These hormones stimulate the production of digestive juices and regulate

appetite. The main digestive hormone of the stomach is gastrin, which is secreted in response to the presence of food. Gastrin stimulates the secretion of gastric acid by the parietal cells of the stomach mucosa. Other GI hormones are produced and act upon the gut and its accessory organs. Hormones produced by the duodenum include secretin, which stimulates a watery secretion of bicarbonate by the pancreas; cholecystokinin (CCK), which stimulates the secretion of pancreatic enzymes and bile from the liver and release of bile from the gallbladder; and gastric inhibitory peptide, which inhibits gastric secretion and slows gastric emptying and motility. These GI hormones are secreted by specialized epithelial cells, called endocrinocytes, located in the mucosal epithelium of the stomach and small intestine. These hormones then enter the bloodstream, through which they can reach their target organs.

Nerve Regulators

Two types of nerves help control the action of the digestive system: extrinsic and intrinsic nerves. Extrinsic, or outside, nerves connect the digestive organs to the brain and spinal cord. These nerves release chemicals that cause the muscle layer of the GI tract to either contract or relax, depending on whether food needs digesting. The intrinsic, or inside, nerves within the GI tract are triggered when food stretches the walls of the hollow organs. The nerves release many different substances that speed up or delay the movement of food and the production of digestive juices.

Also, the walls of the alimentary canal contain a variety of sensors that help regulate digestive functions. These include mechanoreceptors, chemoreceptors, and osmoreceptors, which are capable of detecting mechanical, chemical, and osmotic stimuli, respectively. For example, these receptors can sense when the presence of food has caused the stomach to expand, whether food particles have been sufficiently broken down, how much liquid is present, and the type of nutrients in the food (lipids, carbohydrates, and/or proteins). Stimulation of these receptors provokes an appropriate reflex that furthers the process of digestion. This may entail sending a message that activates the glands that secrete digestive juices into the lumen, or it may mean the stimulation of muscles within the alimentary canal, thereby activating peristalsis and segmentation that move food along the intestinal tract.

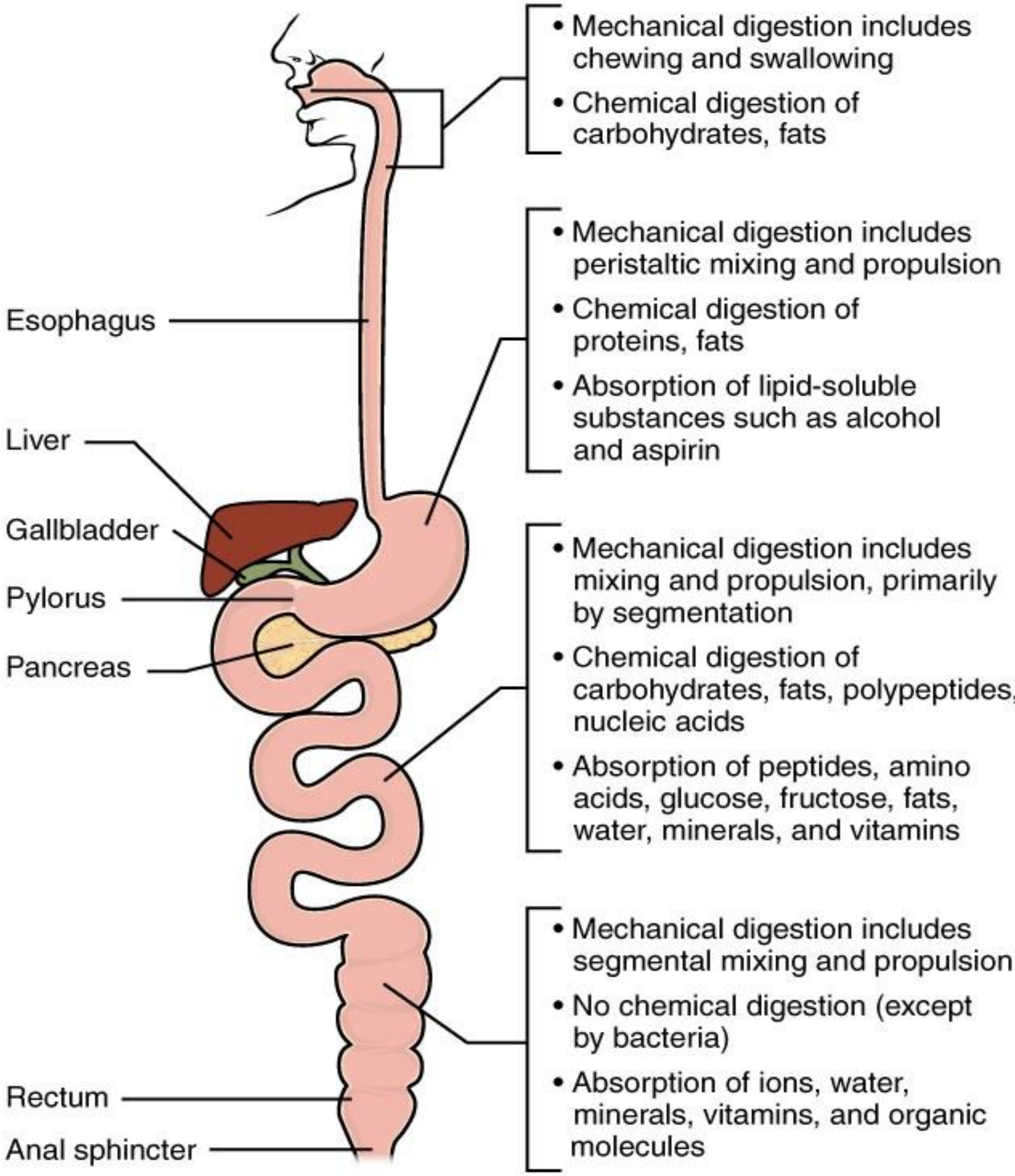


toppr
Human Digestive System
Digestion
What
Process of converting complex molecules into simpler forms
Why
Body can absorb simpler forms of food to generate energy
Ingestion
Egestion
Motility
Functions
Absorption
Secretion
Digestion
Steps in Digestion
Breakdown of food in mouth by teeth and enzymes in the saliva
Transfer of partially digested food through oesophagus
Further digestion in stomach by digestive juices
Complete digestion & absorption in small intestine
Assimilation of absorbed food
Absorption of water & waste generation in large intestine
Parts of Digestive System
Mouth
Salivary glands
Oesophagus
Stomach
Pancreas
Small & large intestine
Gall bladder
Liver
Hormones (e.g.: Gastrin) & nerves control the process of digestion

Region	Function	Enzymes structures and/or characteristic processes
Alimentary Canal		
Mouth	Mechanical maceration	Teeth
	Wetting action, beginning of carbohydrate digestion	Saliva containing enzymes (salivary amylase)
	Appetite stimulation	Taste buds
Pharynx and esophagus	Swallow	Esophageal peristalsis
	Transport of food to the stomach	
Stomach	Eliminate exogenous bacteria	Hydrochloric acid secreted by gastric glands and also pepsin
	Protein digestion	Muscle contractions
	Conversion of chewed food into semiliquid form	Stimulation and secretion of gastric juice
	Production of gastrointestinal hormone	
Small intestine	Completion of protein and carbohydrate digestion	Several enzymes released by the intestinal wall and pancreas
	Beginning and completion of lipid digestion	Pancreatic enzymes and hepatic bile
	Nutrient absorbed into the blood stream	Intestinal villi
	Production of secretin	Stimulation of bile secretion and pancreatic juice
Large intestine	Absorption of water and minerals	Microvilli on surface of cells lining the intestinal wall
Glands and accessory organs		
Pancreas	Two types of cells:	Pancreatic amylase, lipase
	Acinar cells produce many enzymes	Insulin, glucagon,
	Islet cells produce hormones	
	somatostatin that regulate blood sugar levels	
Liver	Storage and release of carbohydrates; conversion of amino acids into carbohydrates	All processes happen in all cells
	Fat packaging for transport	
	Regulation of cholesterol levels	
	HDL and LDL synthesis	
	Bile secretion	
	Fat-soluble vitamins storage	
	Synthesis of proteins present in blood plasma	
	Inactivation of hormones	
	Inactivation of foreign substances, e.g., alcohol, drugs	

Source: Adapted from Arking (2008).

Chemical Digestion and Absorption:



Chemical Digestion

Large food molecules (for example, proteins, lipids, nucleic acids, and starches) must be broken down into subunits that are small enough to be absorbed by the lining of the alimentary canal. This is accomplished by enzymes through hydrolysis. The many enzymes involved in chemical digestion are summarized in Table 1.

Table 1. The Digestive Enzymes

Enzyme Category	Enzyme Name	Source	Substrate	Product
Salivary Enzymes	Lingual lipase	Lingual glands	Triglycerides	Free fatty acids, and mono- and diglycerides
Salivary Enzymes	Salivary amylase	Salivary glands	Polysaccharides	Disaccharides and trisaccharides
Gastric enzymes	Gastric lipase	Chief cells	Triglycerides	Fatty acids and monoacylglyceride

Table 1. The Digestive Enzymes

Enzyme Category	Enzyme Name	Source	Substrate	Product
Gastric enzymes	Pepsin*	Chief cells	Proteins	Peptides
Brush border enzymes	α-Dextrinase	Small intestine	α-Dextrins	Glucose
Brush border enzymes	Enteropeptidase	Small intestine	Trypsinogen	Trypsin
Brush border enzymes	Lactase	Small intestine	Lactose	Glucose and galactose

Table 1. The Digestive Enzymes				
Enzyme Category	**Enzyme Name**	**Source**	**Substrate**	**Product**
Brush border enzymes	Maltase	Small intestine	Maltose	Glucose
Brush border enzymes	Nucleosidases and phosphatases	Small intestine	Nucleotides	Phosphates, nitrogenous bases, ar pentoses
Brush border enzymes	Peptidases	Small intestine	• Aminopeptidase: amino acids at the amino end of peptides • Dipeptidase: dipeptides	• Aminopeptidase: amino acids and peptides • Dipeptidase: amino acids
Brush border enzymes	Sucrase	Small intestine	Sucrose	Glucose and fructose
Pancreatic enzymes	Carboxy-peptidase*	Pancreatic acinar cells	Amino acids at the carboxyl end of peptides	Amino acids and peptides

Table 1. The Digestive Enzymes

Enzyme Category	Enzyme Name	Source	Substrate	Product
Pancreatic enzymes	Chymotrypsin*	Pancreatic acinar cells	Proteins	Peptides
Pancreatic enzymes	Elastase*	Pancreatic acinar cells	Proteins	Peptides
Pancreatic enzymes	Nucleases	Pancreatic acinar cells	• Ribonuclease: ribonucleic acids • Deoxyribonuclease: deoxyribonucleic acids	Nucleotides
Pancreatic enzymes	Pancreatic amylase	Pancreatic acinar cells	Polysaccharides (starches)	α-Dextrins, disaccharides (maltose trisaccharides (maltotriose)
Pancreatic enzymes	Pancreatic lipase	Pancreatic acinar cells	Triglycerides that have been emulsified by bile salts	Fatty acids and monoacylglyceride
Pancreatic enzymes	Trypsin*	Pancreatic acinar cells	Proteins	Peptides

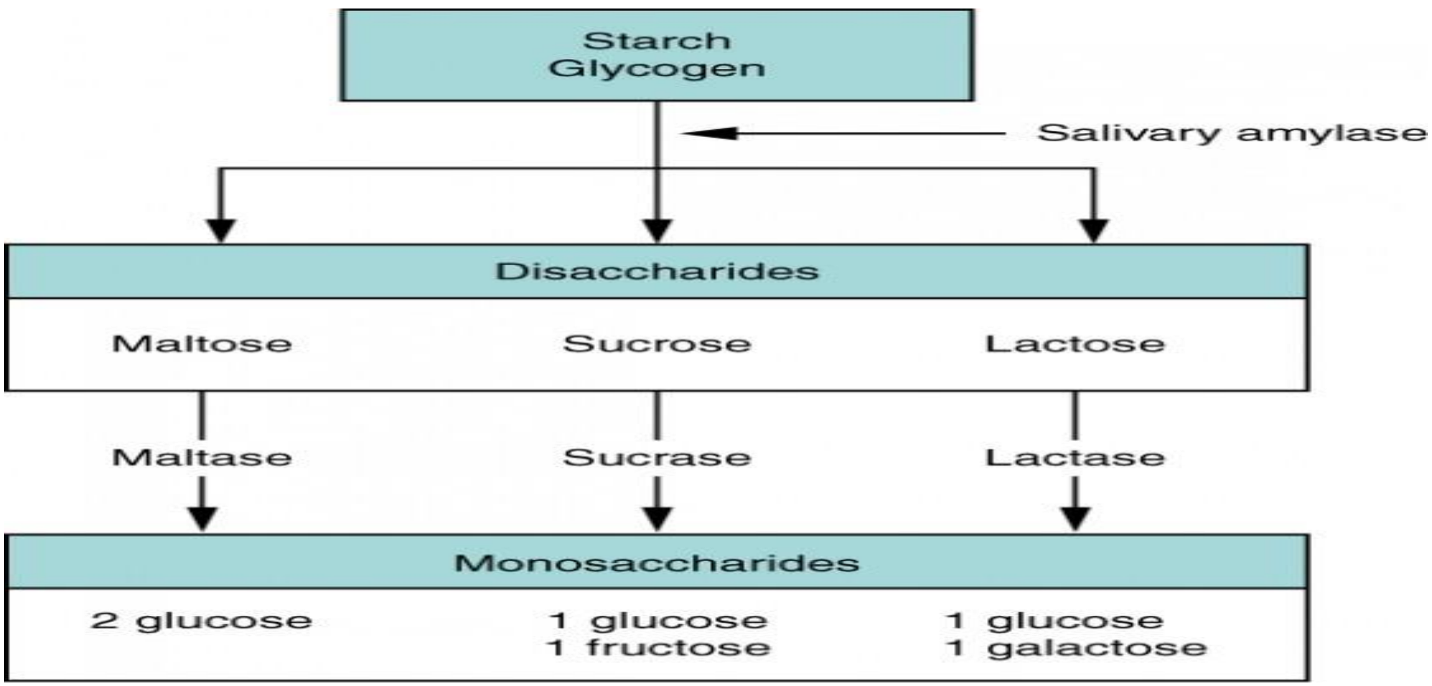
Table 1. The Digestive Enzymes				
Enzyme Category	**Enzyme Name**	**Source**	**Substrate**	**Product**
*These enzymes have been activated by other substances.				

Carbohydrate Digestion

The average American diet is about 50 percent carbohydrates, which may be classified according to the number of monomers they contain of simple sugars (monosaccharides and disaccharides) and/or complex sugars (polysaccharides). Glucose, galactose, and fructose are the three monosaccharides that are commonly consumed and are readily absorbed. Your digestive system is also able to break down the disaccharide sucrose (regular table sugar: glucose + fructose), lactose (milk sugar: glucose + galactose), and maltose (grain sugar: glucose + glucose), and the polysaccharides glycogen and starch (chains of monosaccharides). Your bodies do not produce enzymes that can break down most fibrous polysaccharides, such as cellulose. While indigestible polysaccharides do not provide any nutritional value, they do provide dietary fiber, which helps propel food through the alimentary canal.

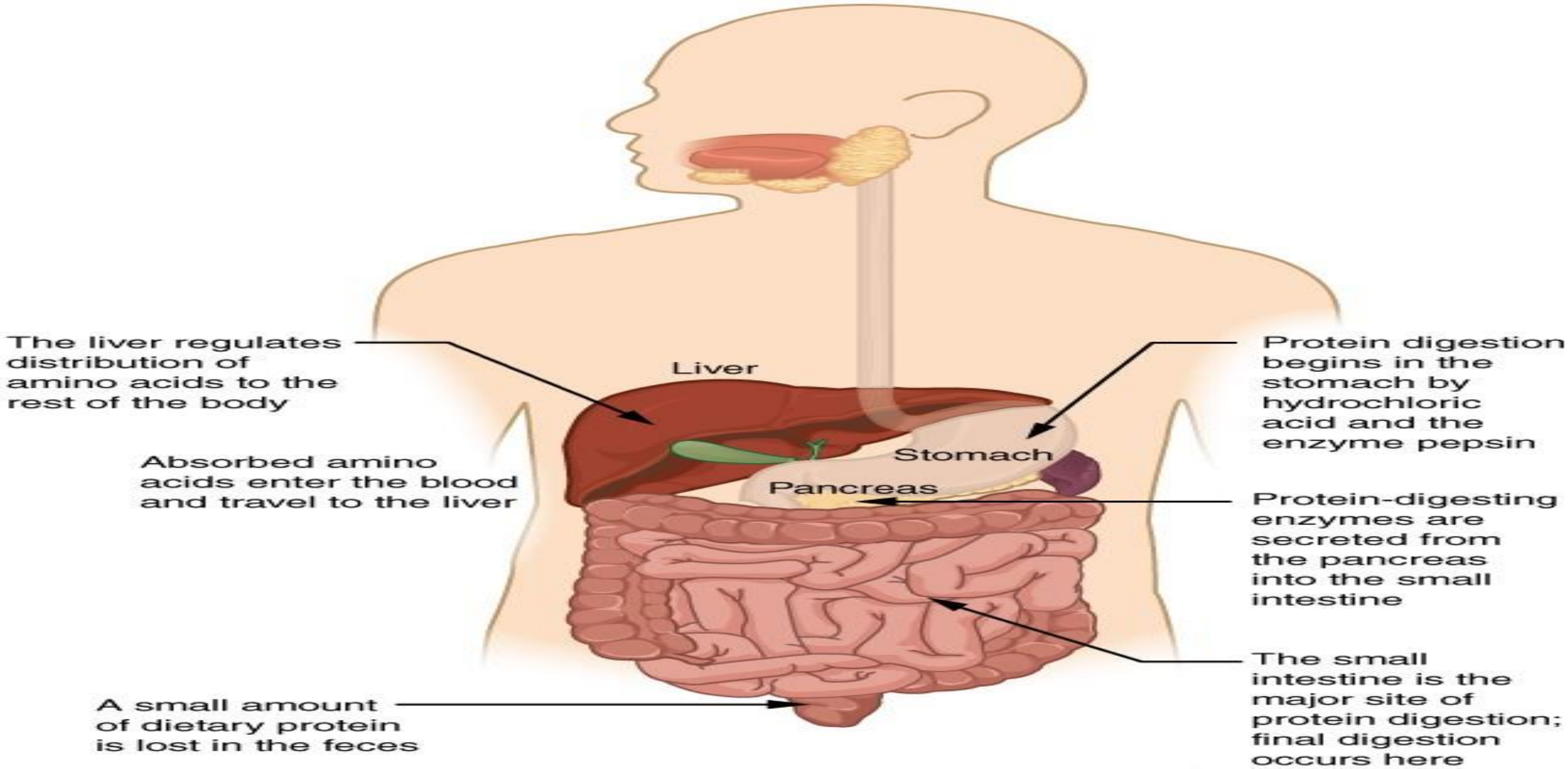
The chemical digestion of starches begins in the mouth and has been reviewed above.

In the small intestine, pancreatic amylase does the ‘heavy lifting’ for starch and carbohydrate digestion (Figure 2). After amylases break down starch into smaller fragments, the brush border enzyme α-dextrinase starts working on α-dextrin, breaking off one glucose unit at a time. Three brush border enzymes hydrolyze sucrose, lactose, and maltose into monosaccharides. Sucrase splits sucrose into one molecule of fructose and one molecule of glucose; maltase breaks down maltose and maltotriose into two and three glucose molecules, respectively; and lactase breaks down lactose into one molecule of glucose and one molecule of galactose. Insufficient lactase can lead to lactose intolerance.

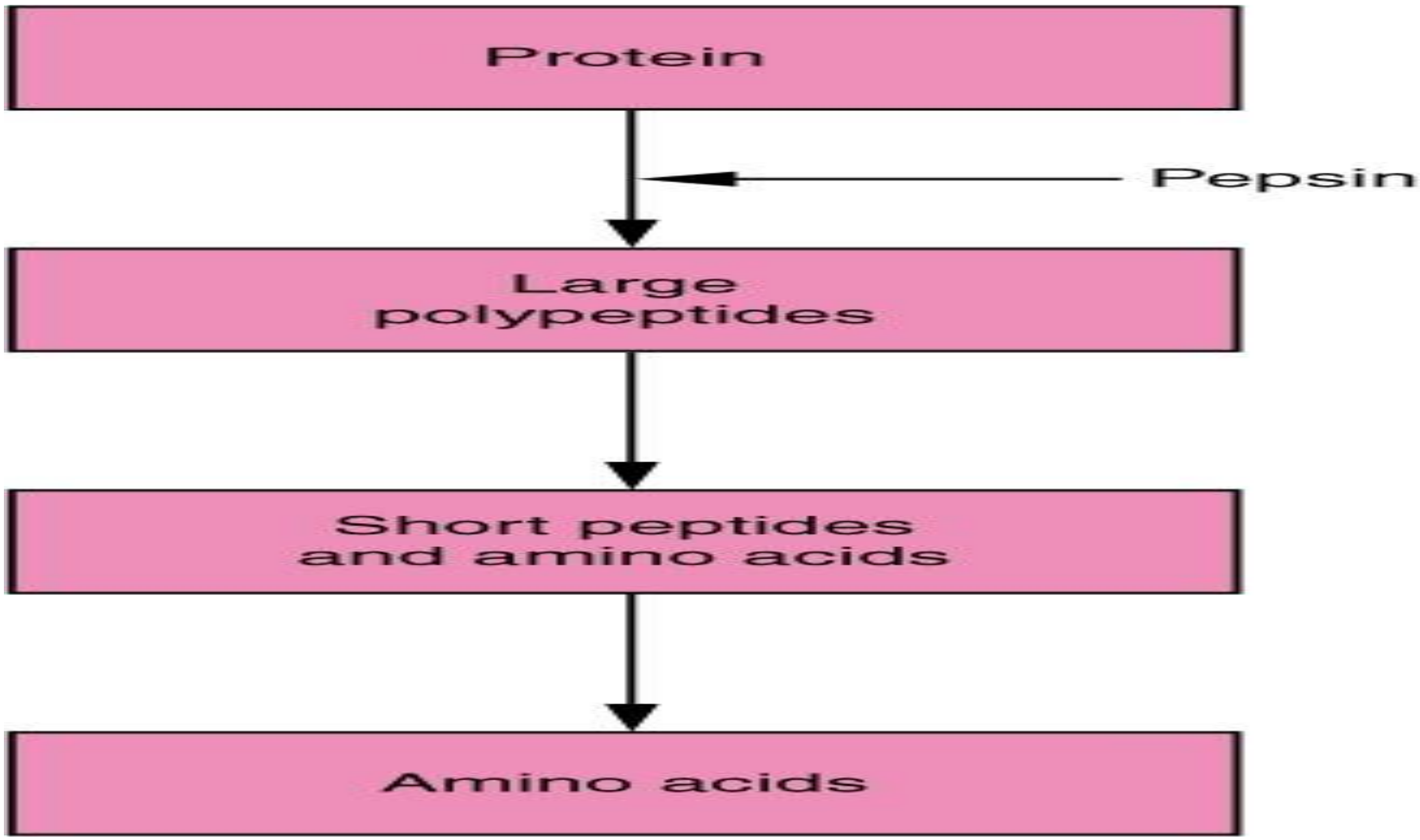


Protein Digestion

Proteins are polymers composed of amino acids linked by peptide bonds to form long chains. Digestion reduces them to their constituent amino acids. You usually consume about 15 to 20 percent of your total calorie intake as protein. The digestion of protein starts in the stomach, where HCl and pepsin break proteins into smaller polypeptides, which then travel to the small intestine. Chemical digestion in the small intestine is continued by pancreatic enzymes, including chymotrypsin and trypsin, each of which act on specific bonds in amino acid sequences. At the same time, the cells of the brush border secrete enzymes such as **aminopeptidase** and **dipeptidase**, which further break down peptide chains. This results in molecules small enough to enter the bloodstream.



The digestion of protein begins in the stomach and is completed in the small intestine.



Proteins are successively broken down into their amino acid components.

Lipid Digestion

A healthy diet limits lipid intake to 35 percent of total calorie intake. The most common dietary lipids are triglycerides, which are made up of a glycerol molecule bound to three fatty acid chains. Small amounts of dietary cholesterol and phospholipids are also consumed.

The three lipases responsible for lipid digestion are lingual lipase, gastric lipase, and pancreatic lipase. However, because the pancreas is the only consequential source of lipase, virtually all lipid digestion occurs in the small intestine. Pancreatic lipase breaks down each triglyceride into two free fatty acids and a monoglyceride. The fatty acids include both short-chain (less than 10 to 12 carbons) and long-chain fatty acids.

Nucleic Acid Digestion

The nucleic acids DNA and RNA are found in most of the foods you eat. Two types of pancreatic nuclease are responsible for their digestion: deoxyribonuclease, which digests DNA, and ribonuclease, which digests RNA. The nucleotides produced by this digestion are further broken down by two intestinal brush border enzymes (nucleosidase and phosphatase) into pentoses, phosphates, and nitrogenous bases, which can be absorbed through the alimentary canal wall. The large food molecules that must be broken down into subunits are summarized in Table 2.

Table 2. Absorbable Food Substances	
Source	**Substance**
Carbohydrates	Monosaccharides: glucose, galactose, and fructose
Proteins	Single amino acids, dipeptides, and tripeptides
Triglycerides	Monoacylglycerides, glycerol, and free fatty acids
Nucleic acids	Pentose sugars, phosphates, and nitrogenous bases

Absorption

The mechanical and digestive processes have one goal: to convert food into molecules small enough to be absorbed by the epithelial cells of the intestinal villi. The absorptive capacity of the alimentary canal is almost endless. Each day, the alimentary canal processes up to 10 liters of food, liquids, and GI secretions, yet less than one liter enters the large intestine. Almost all ingested food, 80 percent of electrolytes, and 90 percent of water are absorbed in the small intestine. Although the entire small intestine is involved in the absorption of water and lipids, most absorption of carbohydrates and proteins occurs in the jejunum. Notably, bile salts and vitamin B_{12} are absorbed in the terminal ileum. By the time chyme passes from the ileum into the large intestine, it is essentially indigestible food residue (mainly plant fibers like cellulose), some water, and millions of bacteria.

Absorption can occur through five mechanisms: (1) active transport, (2) passive diffusion, (3) facilitated diffusion, (4) co-transport (or secondary active transport), and (5) endocytosis. As you will recall from Chapter 3, active transport refers to the movement of a substance across a cell membrane going from an area of lower concentration to an area of higher concentration (up the concentration gradient). In this type of transport, proteins within the cell membrane act as "pumps," using cellular energy (ATP) to move the substance. Passive diffusion refers to the movement of substances from an area of higher concentration to an area of lower concentration, while facilitated diffusion refers to the movement of substances from an area of higher to an area of lower concentration using a carrier protein in the cell membrane. Co-transport uses the movement of one molecule through the membrane from higher to lower concentration to power the movement of another from lower to higher. Finally, endocytosis is a transportation process in which the cell membrane engulfs material. It requires energy, generally in the form of ATP.

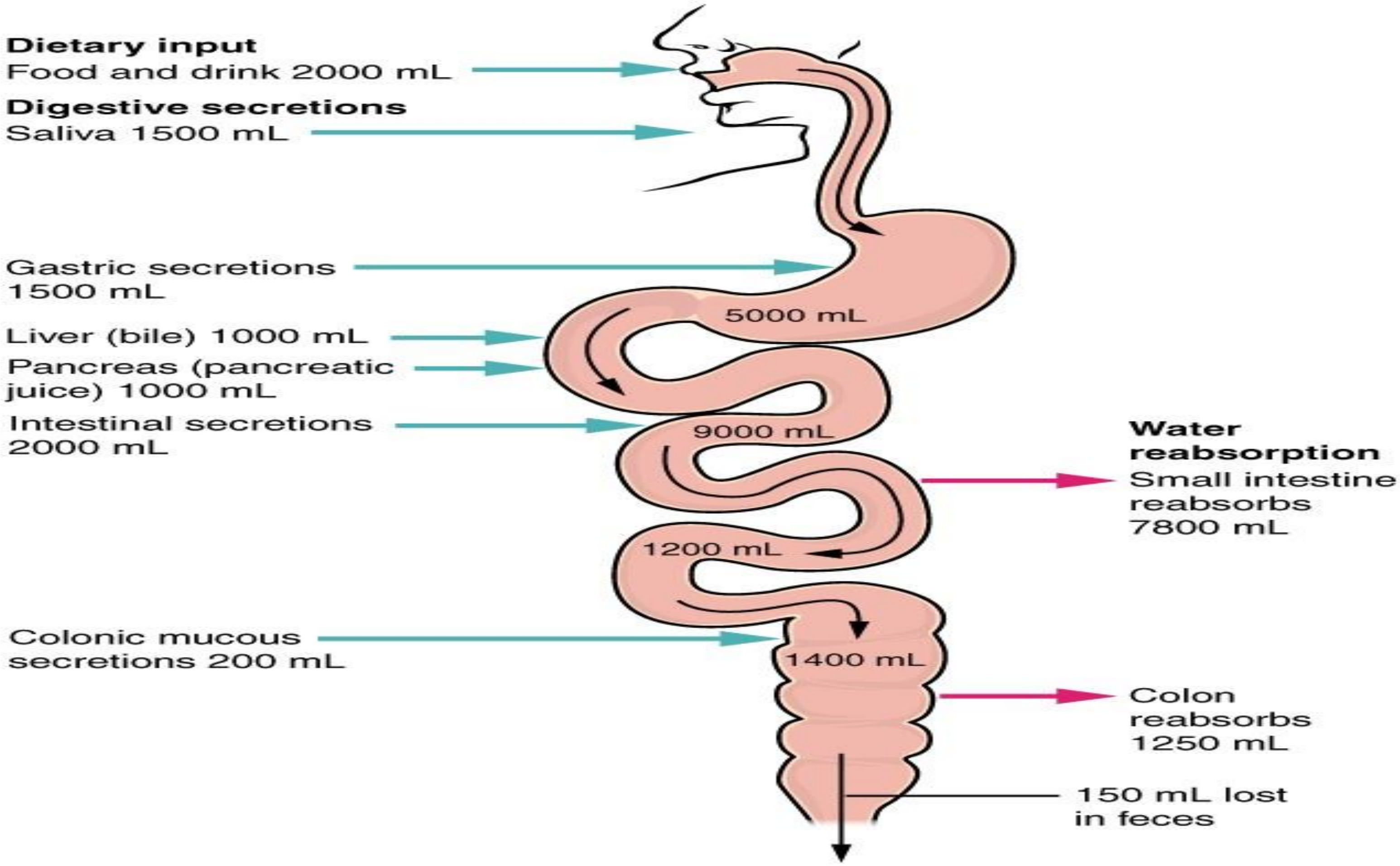
Because the cell's plasma membrane is made up of hydrophobic phospholipids, water-soluble nutrients must use transport molecules embedded in the membrane to enter cells. Moreover, substances cannot pass between the epithelial cells of the intestinal mucosa because these cells are bound together by tight junctions. Thus, substances can only enter blood capillaries by passing through the apical surfaces of epithelial cells and into the interstitial fluid. Water-soluble nutrients enter the capillary blood in the villi and travel to the liver via the hepatic portal vein.

In contrast to the water-soluble nutrients, lipid-soluble nutrients can diffuse through the plasma membrane. Once inside the cell, they are packaged for transport via the base of the cell and then enter the lacteals of the villi to be transported by lymphatic vessels to the systemic circulation via the thoracic duct. The absorption of most nutrients through the mucosa of the intestinal villi requires active transport fueled by ATP. The routes of absorption for each food category are summarized in Table 3.

Table 3. Absorption in the Alimentary Canal				
Food	**Breakdown products**	**Absorption mechanism**	**Entry to bloodstream**	**Destination**
Carbohydrates	Glucose	Co-transport with sodium ions	Capillary blood in villi	Liver via hepatic portal vein
Carbohydrates	Galactose	Co-transport with sodium ions	Capillary blood in villi	Liver via hepatic portal vein
Carbohydrates	Fructose	Facilitated diffusion	Capillary blood in villi	Liver via hepatic portal vein
Protein	Amino acids	Co-transport with sodium ions	Capillary blood in villi	Liver via hepatic portal vein

Table 3. Absorption in the Alimentary Canal				
Food	**Breakdown products**	**Absorption mechanism**	**Entry to bloodstream**	**Destination**
Lipids	Long-chain fatty acids	Diffusion into intestinal cells, where they are combined with proteins to create chylomicrons	Lacteals of villi	Systemic circulation via lymph entering thoracic duct
Lipids	Monoacylglycerides	Diffusion into intestinal cells, where they are combined with proteins to create chylomicrons	Lacteals of villi	Systemic circulation via lymph entering thoracic duct
Lipids	Short-chain fatty acids	Simple diffusion	Capillary blood in villi	Liver via hepatic portal vein
Lipids	Glycerol	Simple diffusion	Capillary blood in villi	Liver via hepatic portal vein

Table 3. Absorption in the Alimentary Canal				
Food	**Breakdown products**	**Absorption mechanism**	**Entry to bloodstream**	**Destination**
Lipids	Nucleic acid digestion products	Active transport via membrane carriers	Capillary blood in villi	Liver via hepatic portal vein



Absorption is a complex process, in which nutrients from digested food are harvested.

Carbohydrate Absorption

All carbohydrates are absorbed in the form of monosaccharides. The small intestine is highly efficient at this, absorbing monosaccharides at an estimated rate of 120 grams per hour. All normally digested dietary carbohydrates are absorbed; indigestible fibers are eliminated in the feces. The monosaccharides glucose and galactose are transported into the epithelial cells by common protein carriers via secondary active transport (that is, co-transport with sodium ions). The monosaccharides leave these cells via facilitated diffusion and enter the capillaries through intercellular clefts. The monosaccharide fructose (which is in fruit) is absorbed and transported by facilitated diffusion alone. The monosaccharides combine with the transport proteins immediately after the disaccharides are broken down.

Protein Absorption

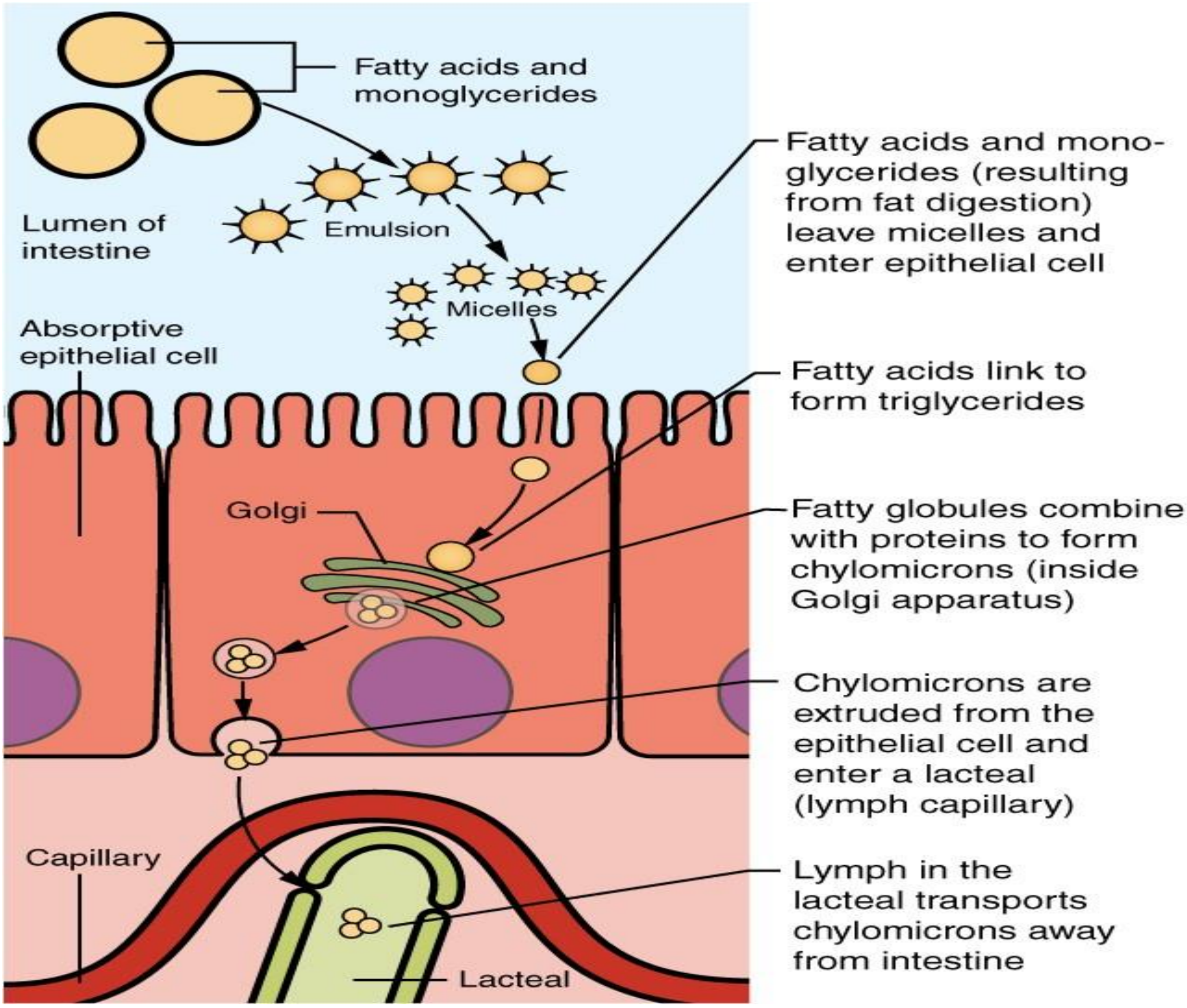
Active transport mechanisms, primarily in the duodenum and jejunum, absorb most proteins as their breakdown products, amino acids. Almost all (95 to 98 percent) protein is digested and absorbed in the small intestine. The type of carrier that transports an amino acid varies. Most carriers are linked to the active transport of sodium. Short chains of two amino acids (dipeptides) or three amino acids (tripeptides) are also transported actively. However, after they enter the absorptive epithelial cells, they are broken down into their amino acids before leaving the cell and entering the capillary blood via diffusion.

Lipid Absorption

About 95 percent of lipids are absorbed in the small intestine. Bile salts not only speed up lipid digestion, they are also essential to the absorption of the end products of lipid digestion. Short-chain fatty acids are relatively water soluble and can enter the absorptive cells (enterocytes) directly. Despite being hydrophobic, the small size of short-chain fatty acids enables them to be absorbed by enterocytes via simple diffusion, and then take the same path as monosaccharides and amino acids into the blood capillary of a villus.

The large and hydrophobic long-chain fatty acids and monoacylglycerides are not so easily suspended in the watery intestinal chyme. However, bile salts and lecithin resolve this issue by enclosing them in a micelle, which is a tiny sphere with polar (hydrophilic) ends facing the watery environment and hydrophobic tails turned to the interior, creating a receptive environment for the long-chain fatty acids. The core also includes cholesterol and fat-soluble vitamins. Without micelles, lipids would sit on the surface of chyme and never come in contact with the absorptive surfaces of the epithelial cells. Micelles can easily squeeze between microvilli and get very near the luminal cell surface. At this point, lipid substances exit the micelle and are absorbed via simple diffusion.

The free fatty acids and monoacylglycerides that enter the epithelial cells are reincorporated into triglycerides. The triglycerides are mixed with phospholipids and cholesterol, and surrounded with a protein coat. This new complex, called a chylomicron, is a water-soluble lipoprotein. After being processed by the Golgi apparatus, chylomicrons are released from the cell. Too big to pass through the basement membranes of blood capillaries, chylomicrons instead enter the large pores of lacteals. The lacteals come together to form the lymphatic vessels. The chylomicrons are transported in the lymphatic vessels and empty through the thoracic duct into the subclavian vein of the circulatory system. Once in the bloodstream, the enzyme lipoprotein lipase breaks down the triglycerides of the chylomicrons into free fatty acids and glycerol. These breakdown products then pass through capillary walls to be used for energy by cells or stored in adipose tissue as fat. Liver cells combine the remaining chylomicron remnants with proteins, forming lipoproteins that transport cholesterol in the blood.



Unlike amino acids and simple sugars, lipids are transformed as they are absorbed through epithelial cells.

Nucleic Acid Absorption

The products of nucleic acid digestion—pentose sugars, nitrogenous bases, and phosphate ions—are transported by carriers across the villus epithelium via active transport. These products then enter the bloodstream.

Mineral Absorption

The electrolytes absorbed by the small intestine are from both GI secretions and ingested foods. Since electrolytes dissociate into ions in water, most are absorbed via active transport throughout the entire small intestine. During absorption, co-transport mechanisms result in the accumulation of sodium ions inside the cells, whereas anti-port mechanisms reduce the potassium ion concentration inside the cells. To restore the sodium-potassium gradient across the cell membrane, a sodium-potassium pump requiring ATP pumps sodium out and potassium in.

In general, all minerals that enter the intestine are absorbed, whether you need them or not. Iron and calcium are exceptions; they are absorbed in the duodenum in amounts that meet the body's current requirements, as follows:

Iron—The ionic iron needed for the production of hemoglobin is absorbed into mucosal cells via active transport. Once inside mucosal cells, ionic iron binds to the protein ferritin, creating iron-ferritin complexes that store iron until needed. When the body has enough iron, most of the stored iron is lost when worn-out epithelial cells slough off. When the body needs iron because, for example, it is lost during acute or chronic bleeding, there is increased uptake of iron from the intestine and accelerated release of iron into the bloodstream. Since women experience significant iron loss during menstruation, they have around four times as many iron transport proteins in their intestinal epithelial cells as men.

Calcium—Blood levels of ionic calcium determine the absorption of dietary calcium. When blood levels of ionic calcium drop, parathyroid hormone (PTH) secreted by the parathyroid glands stimulates the release of calcium ions from bone matrices and increases the reabsorption of calcium by the kidneys. PTH also upregulates the activation of vitamin D in the kidney, which then facilitates intestinal calcium ion absorption.

Vitamin Absorption

The small intestine absorbs the vitamins that occur naturally in food and supplements. Fat-soluble vitamins (A, D, E, and K) are absorbed along with dietary lipids in micelles via simple diffusion. This is why you are advised to eat some fatty foods when you take fat-soluble vitamin supplements. Most water-soluble vitamins (including most B vitamins and vitamin C) also are absorbed by simple diffusion. An exception is vitamin B12, which is a very large molecule. Intrinsic factor secreted in the stomach binds to vitamin B12, preventing its digestion and creating a complex that binds to mucosal receptors in the terminal ileum, where it is taken up by endocytosis.

Water Absorption

Each day, about nine liters of fluid enter the small intestine. About 2.3 liters are ingested in foods and beverages, and the rest is from GI secretions. About 90 percent of this water is absorbed in the small intestine. Water absorption is driven by the concentration gradient of the water: The concentration of water is higher in chyme than it is in epithelial cells. Thus, water moves down its concentration gradient from the chyme into cells. As noted earlier, much of the remaining water is then absorbed in the colon.

Metabolism :

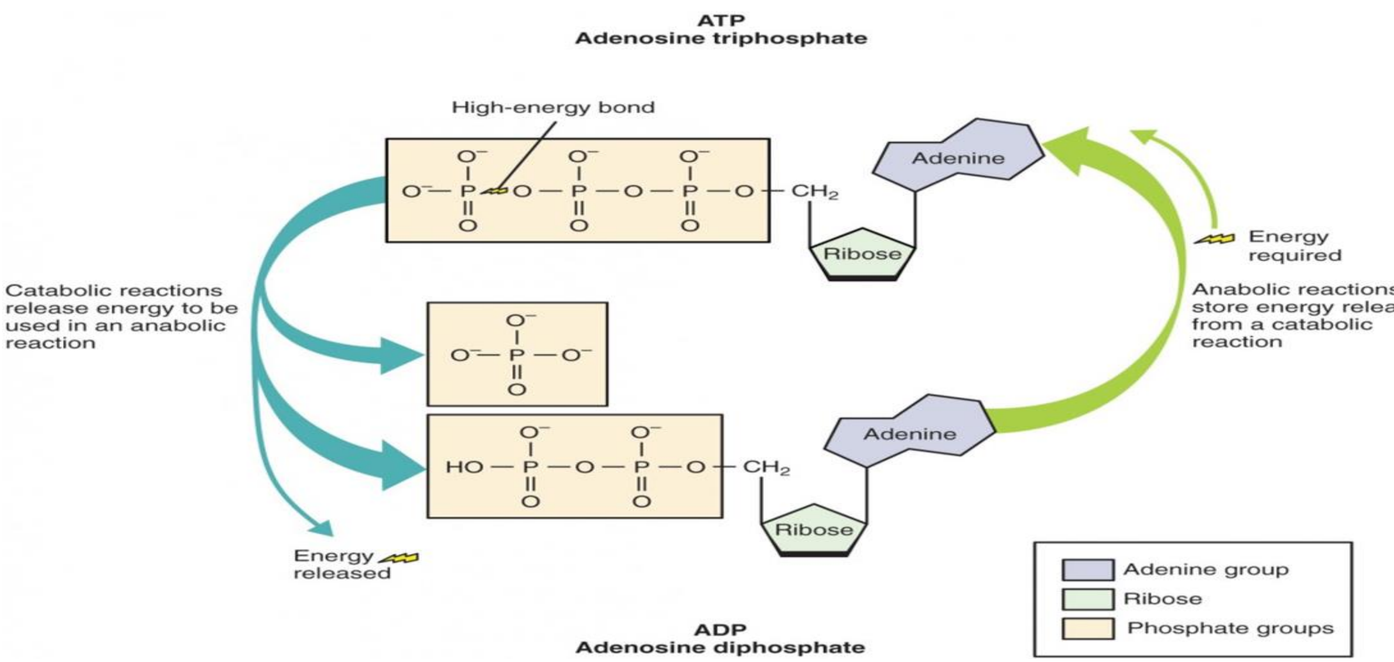
Metabolic processes are constantly taking place in the body. Metabolism is the sum of all of the chemical reactions that are involved in catabolism and anabolism. The reactions governing the breakdown of food to obtain energy are called catabolic reactions. Conversely, anabolic reactions use the energy produced by catabolic reactions to synthesize larger molecules from smaller ones, such as when the body forms proteins by stringing together amino acids. Both sets of reactions are critical to maintaining life.

Metabolism is the sum of all energy-requiring and energy-consuming processes of the body. Many factors contribute to overall metabolism, including lean muscle mass, the amount and quality of food consumed, and the physical demands placed on the human body.

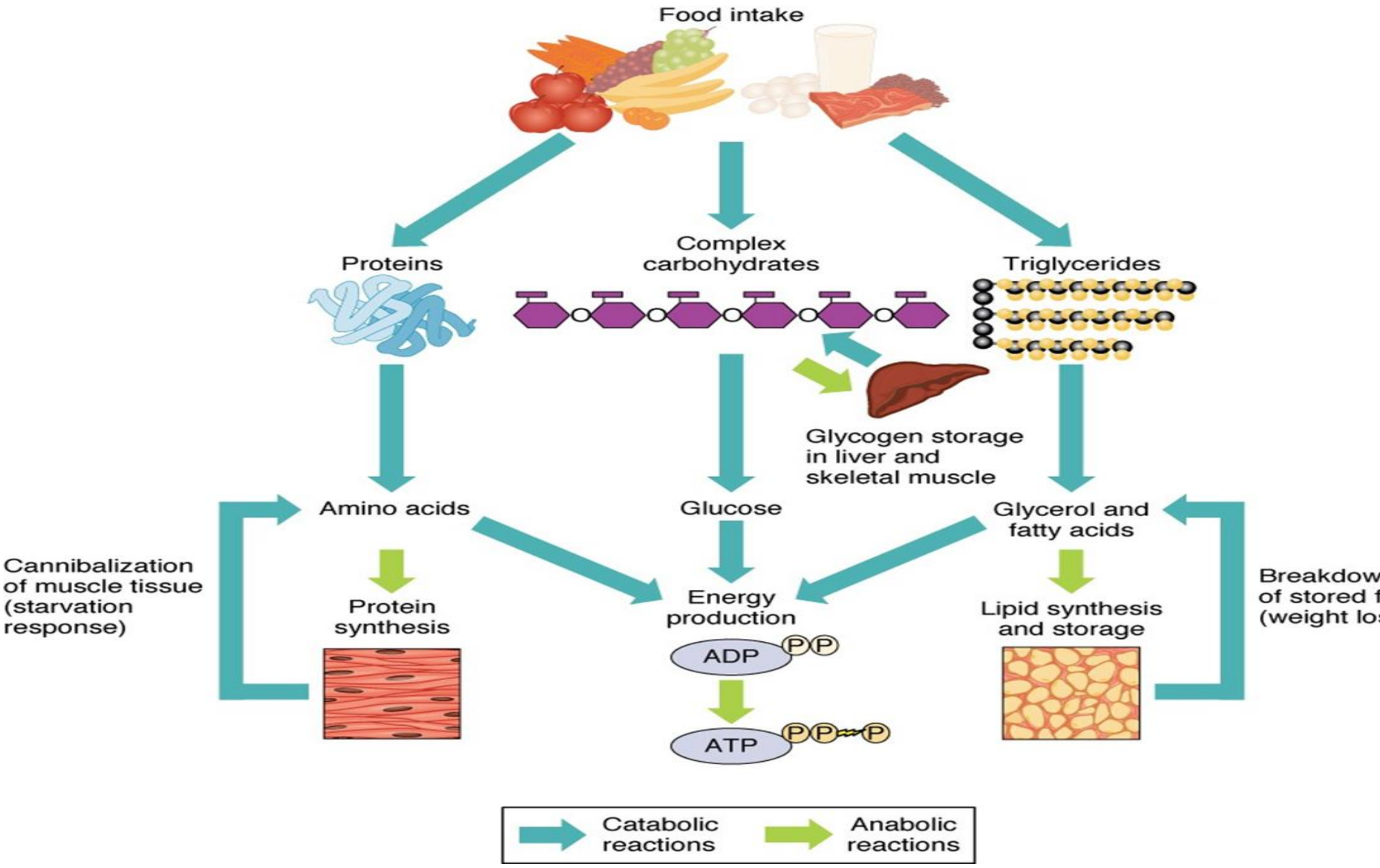
Catabolic Reactions:

- **Catabolic reactions** break down large organic molecules into smaller molecules, releasing the energy contained in the chemical bonds. These energy releases (conversions) are not 100 percent efficient. The amount of energy released is less than the total amount contained in the molecule. Approximately 40 percent of energy yielded from catabolic reactions is directly transferred to the high-energy molecule adenosine triphosphate (ATP). ATP, the energy currency of cells, can be used immediately to power molecular machines that support cell, tissue, and organ function. This includes building new tissue and repairing damaged tissue. ATP can also be stored to fulfill future energy demands. The remaining 60 percent of the energy released from catabolic reactions is given off as heat, which tissues and body fluids absorb.

Structurally, ATP molecules consist of an adenine, a ribose, and three phosphate groups. The chemical bond between the second and third phosphate groups, termed a high-energy bond, represents the greatest source of energy in a cell. It is the first bond that catabolic enzymes break when cells require energy to do work. The products of this reaction are a molecule of adenosine diphosphate (ADP) and a lone phosphate group (Pi). ATP, ADP, and Pi are constantly being cycled through reactions that build ATP and store energy, and reactions that break down ATP and release energy.



The energy from ATP drives all bodily functions, such as contracting muscles, maintaining the electrical potential of nerve cells, and absorbing food in the gastrointestinal tract. The metabolic reactions that produce ATP come from various sources.



During catabolic reactions, proteins are broken down into amino acids, lipids are broken down into fatty acids, and polysaccharides are broken down into monosaccharides. These building blocks are then used for the synthesis of molecules in anabolic reactions.

Of the four major macromolecular groups (carbohydrates, lipids, proteins, and nucleic acids) that are processed by digestion, carbohydrates are considered the most common source of energy to fuel the body. They take the form of either complex carbohydrates, polysaccharides like starch and glycogen, or simple sugars (monosaccharides) like glucose and fructose. Sugar catabolism breaks polysaccharides down into their individual monosaccharides. Among the monosaccharides, glucose is the most common fuel for ATP production in cells, and as such, there are a number of endocrine control mechanisms to regulate glucose concentration in the bloodstream. Excess glucose is either stored as an energy reserve in the liver and skeletal muscles as the complex polymer glycogen, or it is converted into fat (triglyceride) in adipose cells (adipocytes).

Among the lipids (fats), triglycerides are most often used for energy via a metabolic process called β-oxidation. About one-half of excess fat is stored in adipocytes that accumulate in the subcutaneous tissue under the skin, whereas the rest is stored in adipocytes in other tissues and organs.

Proteins, which are polymers, can be broken down into their monomers, individual amino acids. Amino acids can be used as building blocks of new proteins or broken down further for the production of ATP. When one is chronically starving, this use of amino acids for energy production can lead to a wasting away of the body, as more and more proteins are broken down.

Nucleic acids are present in most of the foods you eat. During digestion, nucleic acids including DNA and various RNAs are broken down into their constituent nucleotides. These nucleotides are readily absorbed and transported throughout the body to be used by individual cells during nucleic acid metabolism.

Anabolic Reactions

In contrast to catabolic reactions, anabolic reactions involve the joining of smaller molecules into larger ones. Anabolic reactions combine monosaccharides to form polysaccharides, fatty acids to form triglycerides, amino acids to form proteins, and nucleotides to form nucleic acids. These processes require energy in the form of ATP molecules generated by catabolic reactions. Anabolic reactions, also called biosynthesis reactions, create new molecules that form new cells and tissues, and revitalize organs.

Hormonal Regulation of Metabolism

Catabolic and anabolic hormones in the body help regulate metabolic processes. Catabolic hormones stimulate the breakdown of molecules and the production of energy. These include cortisol, glucagon, adrenaline/epinephrine, and cytokines. All of these hormones are mobilized at specific times to meet the needs of the body. Anabolic hormones are required for the synthesis of molecules and include growth hormone, insulin-like growth factor, insulin, testosterone, and estrogen. The following table summarizes the function of each of the catabolic hormones and the subsequent table summarizes the functions of the anabolic hormones.

Table 3. Catabolic Hormones	
Hormone	**Function**
Cortisol	Released from the adrenal gland in response to stress; its main role is to increase blood glucose levels by gluconeogenesis (breaking down fats and proteins)
Glucagon	Released from alpha cells in the pancreas either when starving or when the body needs to generate additional energy; it stimulates the breakdown of glycogen in the liver to increase blood glucose levels; its effect is the opposite of insulin; glucagon and insulin are a part of a negative-feedback system that stabilizes blood glucose levels
Adrenaline/epinephrine	Released in response to the activation of the sympathetic nervous system; increases heart rate and heart contractility, constricts blood vessels, is a bronchodilator that opens (dilates) the bronchi of the lungs to increase air volume in the lungs, and stimulates gluconeogenesis

Table 2. Anabolic Hormones	
Hormone	**Function**
Growth hormone (GH)	Synthesized and released from the pituitary gland; stimulates the growth of cells, tissues, and bones
Insulin-like growth factor (IGF)	Stimulates the growth of muscle and bone while also inhibiting cell death (apoptosis)
Insulin	Produced by the beta cells of the pancreas; plays an essential role in carbohydrate and fat metabolism, controls blood glucose levels, and promotes the uptake of glucose into body cells; causes cells in muscle, adipose tissue, and liver to take up glucose from the blood and store it in the liver and muscle as glucagon; its effect is the opposite of glycogen; glucagon and insulin are a part of a negative-feedback system that stabilizes blood glucose levels
Testosterone	Produced by the testes in males and the ovaries in females; stimulates an increase in muscle mass and strength as well as the growth and strengthening of bone

Table 2. Anabolic Hormones	
Hormone	**Function**
Estrogen	Produced primarily by the ovaries, it is also produced by the liver and adrenal glands; its anabolic functions include increasing metabolism and fat deposition

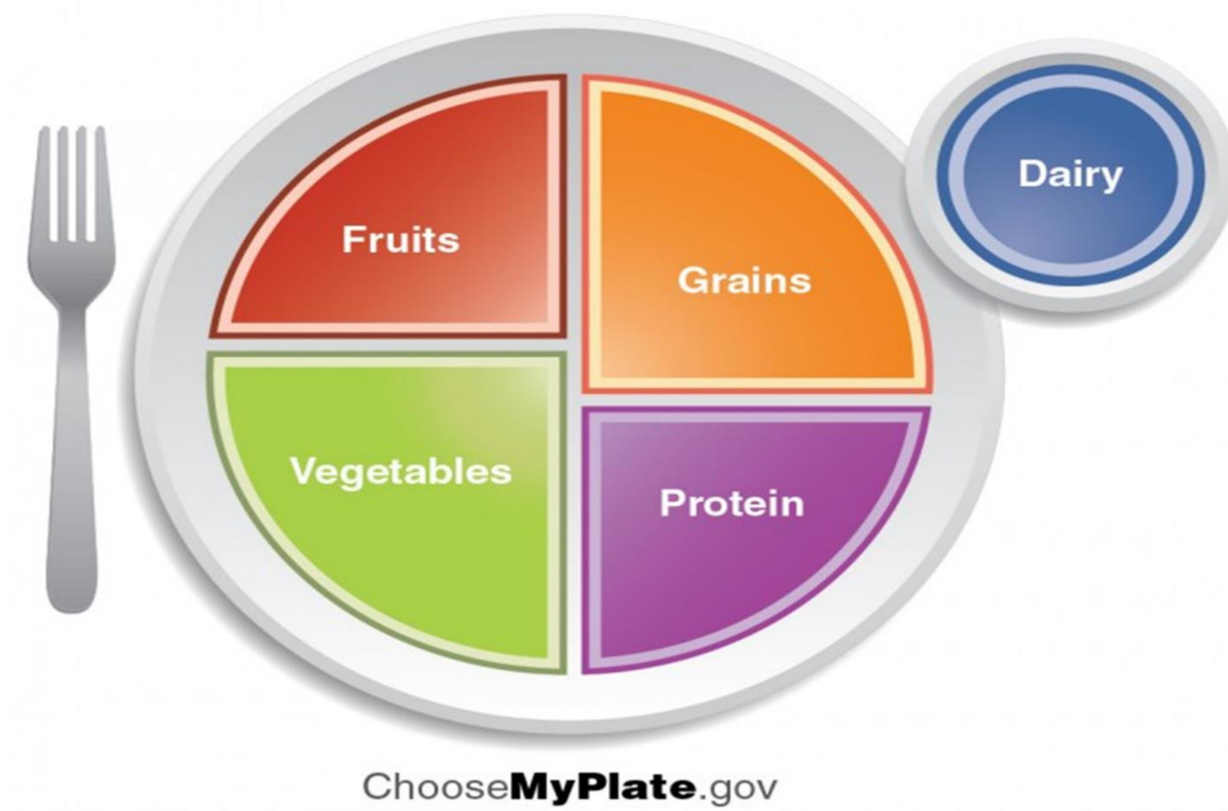
Oxidation-Reduction Reactions

The chemical reactions underlying metabolism involve the transfer of electrons from one compound to another by processes catalyzed by enzymes. The electrons in these reactions commonly come from hydrogen atoms, which consist of an electron and a proton. A molecule gives up a hydrogen atom, in the form of a hydrogen ion ($H+$) and an electron, breaking the molecule into smaller parts. The loss of an electron, or oxidation, releases a small amount of energy; both the electron and the energy are then passed to another molecule in the process of reduction, or the gaining of an electron. These two reactions always happen together in an oxidation-reduction reaction (also called a redox reaction)—when an electron is passed between molecules, the donor is oxidized and the recipient is reduced.

Oxidation-reduction reactions often happen in a series, so that a molecule that is reduced is subsequently oxidized, passing on not only the electron it just received but also the energy it received. As the series of reactions progresses, energy accumulates that is used to combine Pi and ADP to form ATP, the high-energy molecule that the body uses for fuel.

Metabolic Rate

- The **metabolic rate** is the amount of energy consumed minus the amount of energy expended by the body. The **basal metabolic rate (BMR)** describes the amount of daily energy expended by humans at rest, in a neutrally temperate environment, while in the postabsorptive state. It measures how much energy the body needs for normal, basic, daily activity. About 70 percent of all daily energy expenditure comes from the basic functions of the organs in the body. Another 20 percent comes from physical activity, and the remaining 10 percent is necessary for body thermoregulation or temperature control. This rate will be higher if a person is more active or has more lean body mass. As you age, the BMR generally decreases as the percentage of less lean muscle mass decreases.

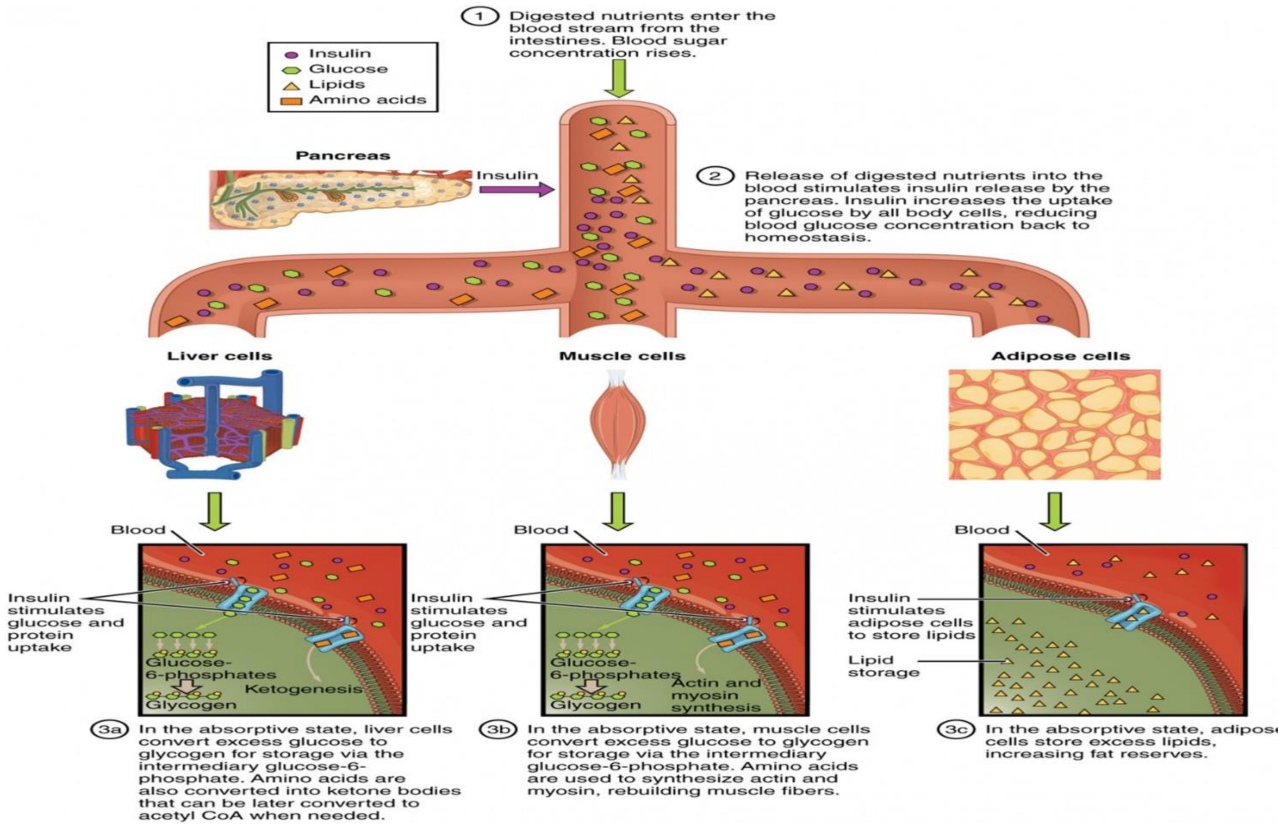


Metabolic States of the Body:

The Absorptive State:

The absorptive state, or the fed state, occurs after a meal when your body is digesting the food and absorbing the nutrients (catabolism exceeds anabolism). Digestion begins the moment you put food into your mouth, as the food is broken down into its constituent parts to be absorbed through the intestine. The digestion of carbohydrates begins in the mouth, whereas the digestion of proteins and fats begins in the stomach and small intestine. The constituent parts of these carbohydrates, fats, and proteins are transported across the intestinal wall and enter the bloodstream (sugars and amino acids) or the lymphatic system (fats). From the intestines, these systems transport them to the liver, adipose tissue, or muscle cells that will process and use, or store, the energy.

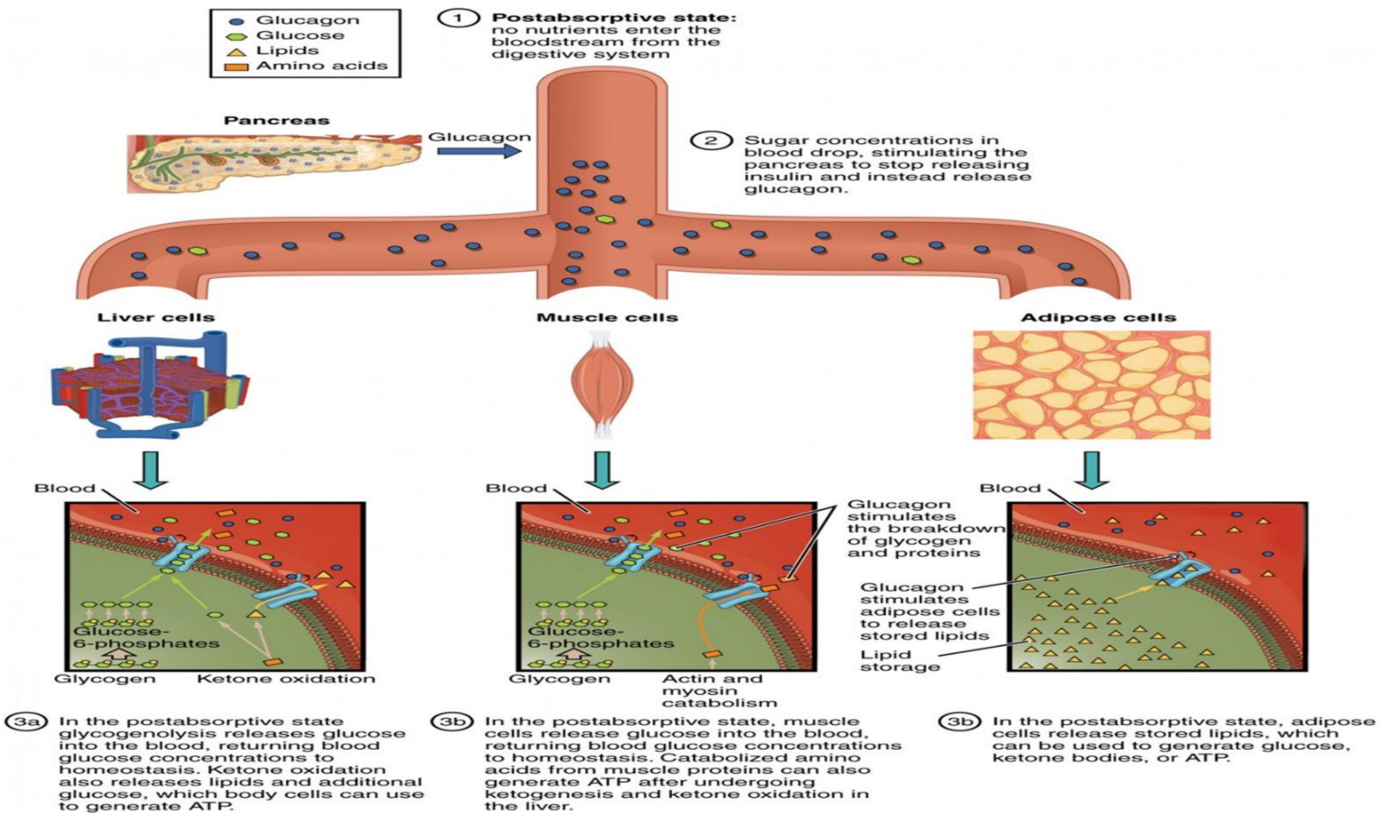
Depending on the amounts and types of nutrients ingested, the absorptive state can linger for up to 4 hours. The ingestion of food and the rise of glucose concentrations in the bloodstream stimulate pancreatic beta cells to release insulin into the bloodstream, where it initiates the absorption of blood glucose by liver hepatocytes, and by adipose and muscle cells. Once inside these cells, glucose is immediately converted into glucose-6-phosphate. By doing this, a concentration gradient is established where glucose levels are higher in the blood than in the cells. This allows for glucose to continue moving from the blood to the cells where it is needed. Insulin also stimulates the storage of glucose as glycogen in the liver and muscle cells where it can be used for later energy needs of the body. Insulin also promotes the synthesis of protein in muscle. As you will see, muscle protein can be catabolized and used as fuel in times of starvation.



The Postabsorptive State

The postabsorptive state, or the fasting state, occurs when the food has been digested, absorbed, and stored. You commonly fast overnight, but skipping meals during the day puts your body in the postabsorptive state as well. During this state, the body must rely initially on stored glycogen. Glucose levels in the blood begin to drop as it is absorbed and used by the cells. In response to the decrease in glucose, insulin levels also drop. Glycogen and triglyceride storage slows. However, due to the demands of the tissues and organs, blood glucose levels must be maintained in the normal range of 80–120 mg/dL. In response to a drop in blood glucose concentration, the hormone glucagon is released from the alpha cells of the pancreas. Glucagon acts upon the liver cells, where it inhibits the synthesis of glycogen and stimulates the breakdown of stored glycogen back into glucose. This glucose is released from the liver to be used by the peripheral tissues and the brain. As a result, blood glucose levels begin to rise. Gluconeogenesis will also begin in the liver to replace the glucose that has been used by the peripheral tissues.

After ingestion of food, fats and proteins are processed as described previously; however, the glucose processing changes a bit. The peripheral tissues preferentially absorb glucose. The liver, which normally absorbs and processes glucose, will not do so after a prolonged fast. The gluconeogenesis that has been ongoing in the liver will continue after fasting to replace the glycogen stores that were depleted in the liver. After these stores have been replenished, excess glucose that is absorbed by the liver will be converted into triglycerides and fatty acids for long-term storage.

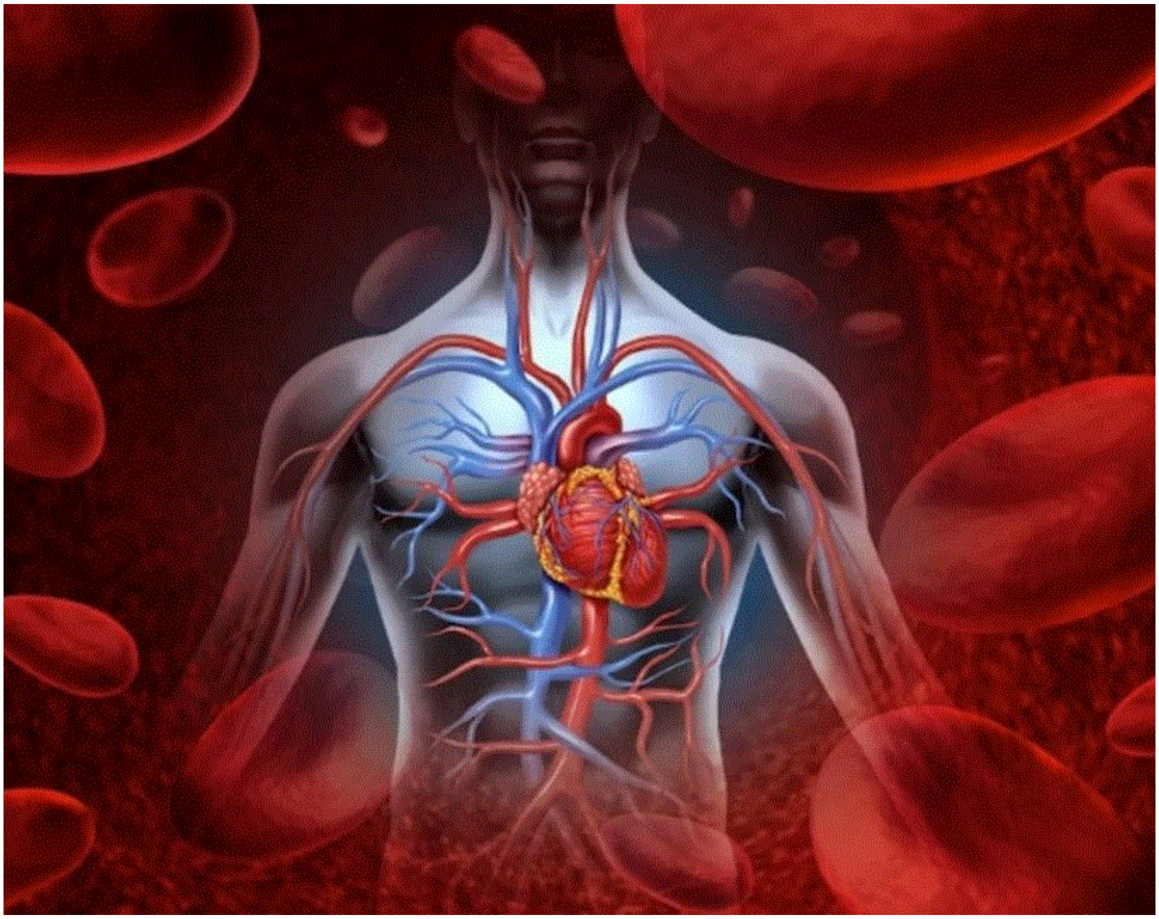


Starvation:

When the body is deprived of nourishment for an extended period of time, it goes into "survival mode." The first priority for survival is to provide enough glucose or fuel for the brain. The second priority is the conservation of amino acids for proteins. Therefore, the body uses ketones to satisfy the energy needs of the brain and other glucose-dependent organs, and to maintain proteins in the cells. Because glucose levels are very low during starvation, glycolysis will shut off in cells that can use alternative fuels. For example, muscles will switch from using glucose to fatty acids as fuel. As previously explained, fatty acids can be converted into acetyl CoA and processed through the Krebs cycle to make ATP. Pyruvate, lactate, and alanine from muscle cells are not converted into acetyl CoA and used in the Krebs cycle, but are exported to the liver to be used in the synthesis of glucose. As starvation continues, and more glucose is needed, glycerol from fatty acids can be liberated and used as a source for gluconeogenesis.

After several days of starvation, ketone bodies become the major source of fuel for the heart and other organs. As starvation continues, fatty acids and triglyceride stores are used to create ketones for the body. This prevents the continued breakdown of proteins that serve as carbon sources for gluconeogenesis. Once these stores are fully depleted, proteins from muscles are released and broken down for glucose synthesis. Overall survival is dependent on the amount of fat and protein stored in the body.

Circulatory system



The cardiovascular system is composed of the heart and a closed system of blood vessels.

The heart:

- ★ Consists of 4 chambers (the Rt. atrium and ventricle- the Lt. atrium and ventricle).
- ★ Has 3 layers; endocardium, myocardium and epicardium (fibrous cover).

★ Is surrounded by a pericardial sac that contains 5 - 30 ml of clear fluid that lubricates the heart and allows it to contract with minimal friction.

The 2 main pumps are:

(1) The left ventricle: (pressure pump)

Pumps blood at a high resistance into the greater (systemic) circulation.

(2) The right ventricle: (volume pump)

Pumps the same volume of blood (at a lower resistance) to the pulmonary circulation.

The valves: (allow the passage of blood one direction only & not the reverse)

(1) Atrioventricular (A- V) valves: (2 valves)

Mitral valve (2 cusps): prevents backflow of blood from the left ventricle to the left atrium

Tricuspid valve (3 cusps): prevents backflow of blood from the right ventricle to the right atrium.

(2) Semilunar valves: (2 valves)

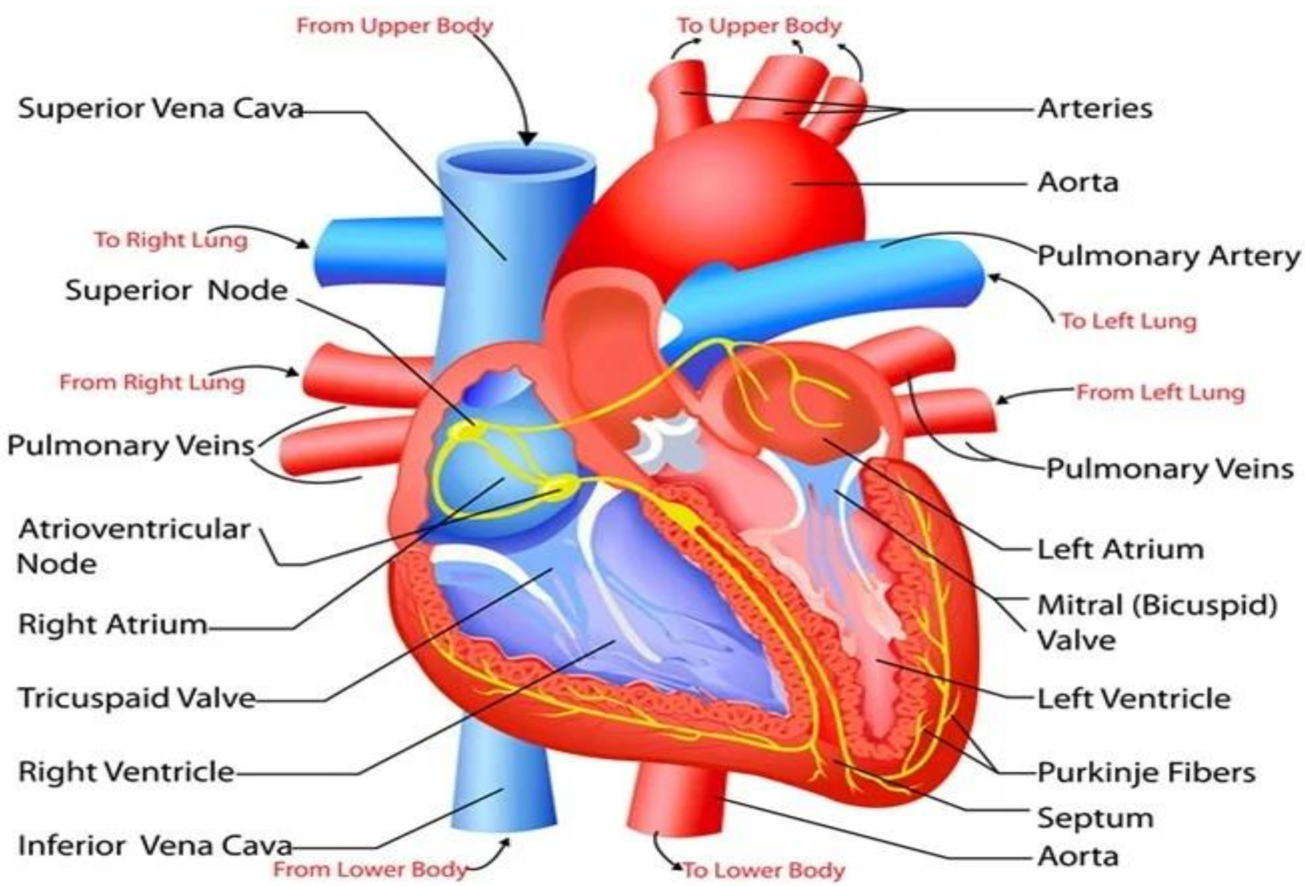
Aortic valve: prevents backflow of blood from the aorta to the left ventricle.

Pulmonary valve: prevents backflow of blood from the pulmonary artery to the right ventricle.

The papillary muscles:

These are ventricular muscles flaps attached to the cusps of the A- V valves by the cordae tendineae.

They contract with ventricular walls & pull the cusps of the valves toward the ventricles.



The heart is composed of:

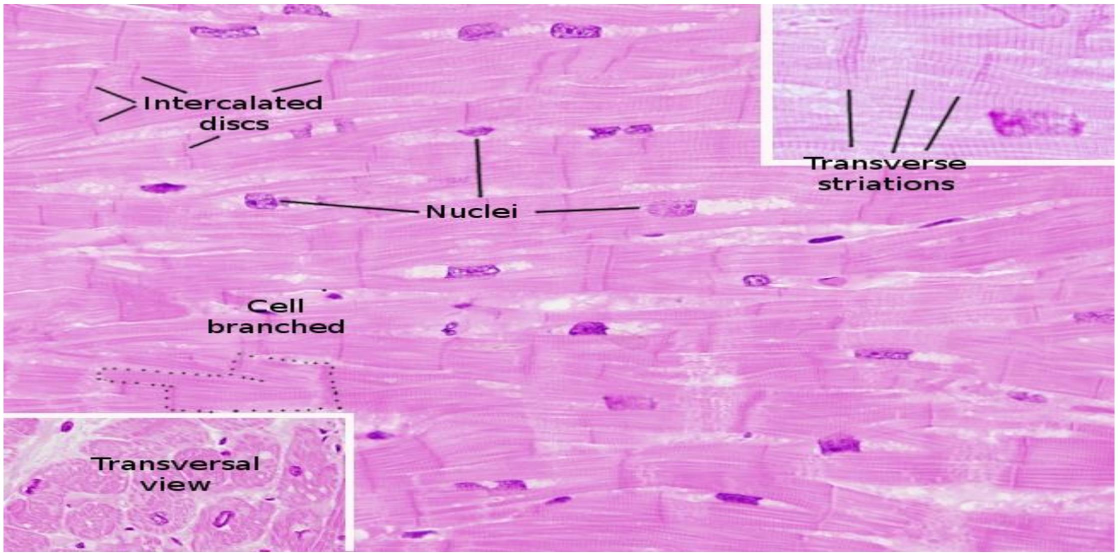
1- Cells full of contractile muscle proteins (e.g. ventricular muscle)

2- Cells with few contractile elements: (e.g. sinoatrial nodal "SAN")

The cardiac muscle fibers:

• Similar to skeletal muscle in striated structure

• Similar to smooth muscle in being involuntary & act as a syncytium



Types of cardiac muscle proteins:

As skeletal muscle (myosin, actin, troponin & tropomyosin) in addition to titin & dystrophin

Titin : A very large elongated protein Binds myosin to the Z line & keeps myosin filaments centered in the sarcomere Congenital anomalies in titin → abnormal dilated heart.

Dystrophin : A large protein, that connects actin to extracellular matrix → structural support to the muscle fiber and congenital defects in dystrophin → muscle weakness.

Properties of heart muscle :

1-Excitability

2-Contractility

3-Rhythmicity (automaticity)

4-Conductivity

Excitability: the ability to respond to an adequate stimulus by generating a propagating AP.

Rhythmicity (automaticity): is the ability of the heart to beat regularly & initiate its own regular repetitive beats independent on nerve supply.

★Due to the presence of automatic cells in the heart: SAN Sinoatrial node initiates cardiac impulses (pacemaker).

Conductivity the conduction of the cardiac impulse through the cardiac tissue.

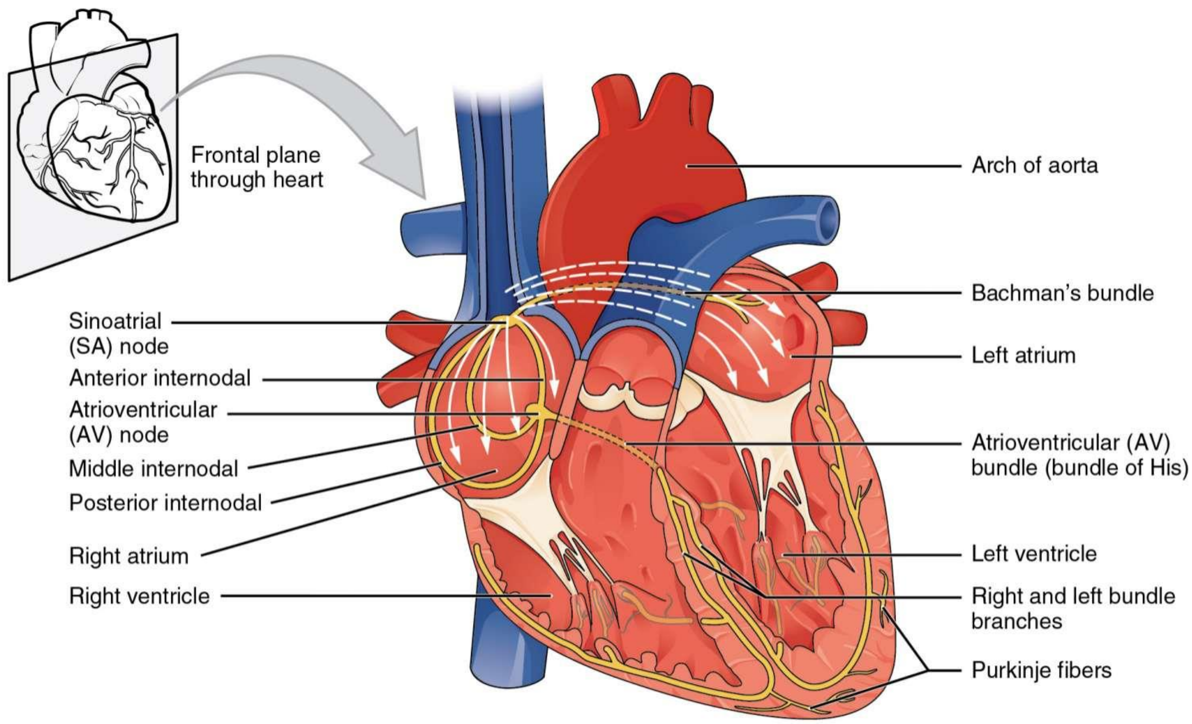
Cardiac cycle

Definition: (the changes from the beginning of one heart beat to the beginning of the next beat). It consists of diastole followed by systole.

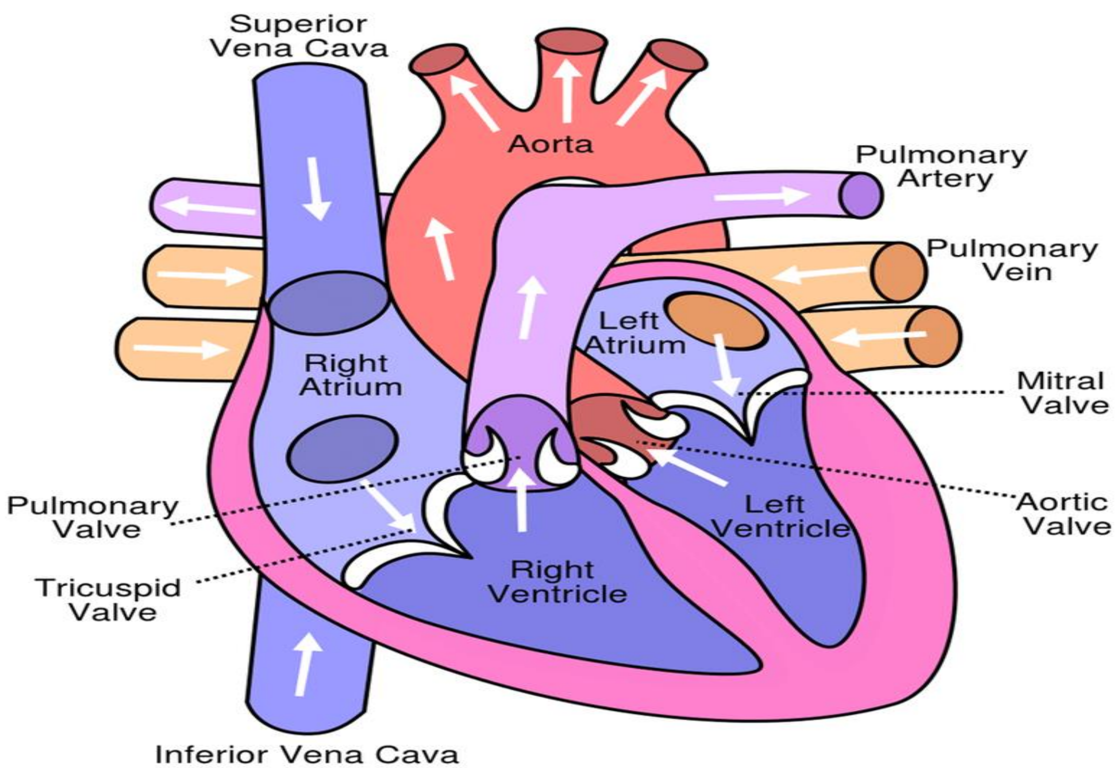
Pacemaker and Conducting System :

The heart beat is initiated by the pacemaker (SA Node) lying between the superior vena cava and the right atrium. The rhythmic depolarizations generated by the SA node are conducted through the atria to less rapidly firing AV node lying in the right atrium, close to the interventricular septum. After a short delay in the AV node, the cardiac impulses are conducted through the main conducting system of the heart, for the rapid conduction of electrical impulses. This is interventricular area conduction cells that radiate into the muscle wall of the ventricles.

Myocardium: The atrial myocardium is comprised of two thin muscular sheaths at right angles to each other, permitting the atria to act as receiving and pumping chambers. The ventricular myocardium is divided into spiral muscles and deep constrictor muscles, that looks like a sandglass; the result of complex twisting contraction is the direction of main stream of blood towards the openings of great vessels. The myocardium has specialized areas of sarcolemma called ‘intercalated disk’, that are cell-to cell junctions close enough to form a gap junction; these gap junctions offer very low electrical resistance, causing the myocardium to respond as ‘functional syncytium’ and not anatomical. There is no impediment to the passage of an action potential; therefore the excitation spreads to all fibers of a chamber.



Anterior view of frontal section



Circulation

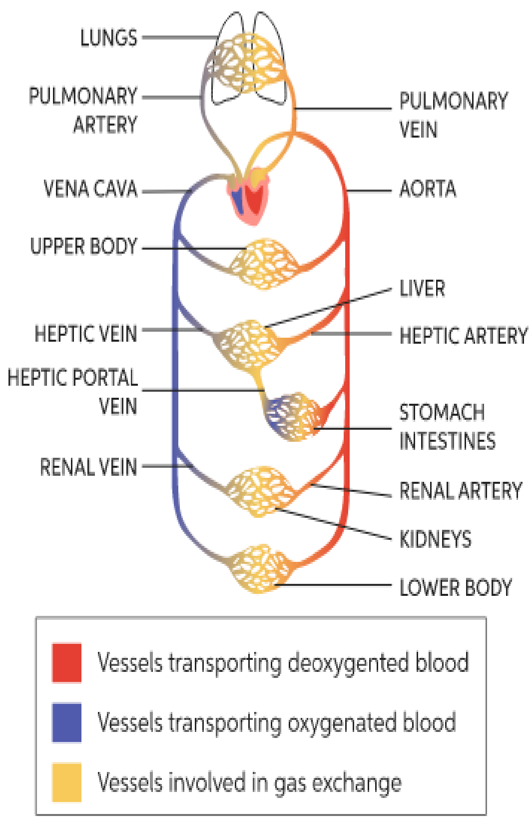
1-Systemic (general) circulation:

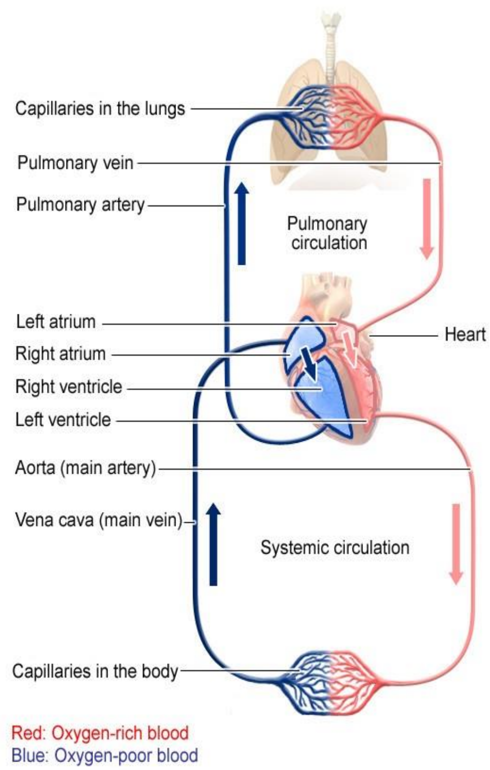
Carries oxygenated blood to all parts of the body

From Lt. ventricle→aorta → arteries → arterioles → capillaries(for exchange with ISF) → venules → veins → SVC & IVC → Rt. atrium.

2- Pulmonary circulation:

Carries deoxygenated blood to the lungs From Rt. ventricle → pulmonary artery → arterioles → pulmonary capillaries (gas exchange with alveoli) → 4 pulmonary veins → Lt. atrium.





Functional parts of the circulation:

	Wall properties	functions
Aorta and large arteries	Elastic (rich in elastic fibers) & contain smooth muscles	1-Transport blood under high pr. to tissues 2- Distend during systole & recoil during diastole 3- Maintain blood flow&prevent marked drop of pr.
Small arteries & arterioles	Strong muscular wall	1- Act as control vessels to bl. flow into capillaries 2- Responsible for the peripheral resistance
Capillaries	Flat endothelium with precapillary sphincter	Exchange fluids, nutrients & electrolytes between blood & ISF
Venules and veins	Thin venous wall	Major reservoir of blood (collect blood from capillaries to larger veins then to the heart)
Lymphatic system	Flat endothelium with pores	Accessory route for the fluid flow from the ISF spaces to blood.

Blood

Blood is the vital fluid tissue, that circulates with CVS. Total blood volume= 5600 ml (8% of body Wt.).

Functions of blood:

1-Transport function: for O^{-}_2 , CO_2, glucose, hormones and waste products

2-Defensive function: by WBCs & antibodies against pathogenic microorganisms

3-Hemostatic function: stoppage of bleeding after injury by clotting mechanism

4-Homeostatic function: keeping the composition of internal environment constant

Composition of blood:

Plasma: 55% total blood volume. Plasma is a yellow clear fluid

that clots on standing leaving the serum (plasma without clotting factors).

Cells: 45% total blood volume. RBCs (erythrocytes), WBCs (leucocytes), and Platelets (thrombocytes).

Composition of plasma:

1-Water:90% total plasma volume.

2-Inorganic substances: 0.9% total plasma volume. e.g. cation and anion

3-Organic substances: 9.1% total plasma volume. e.g plasma proteins and plasma lipid

4-Gases: O^-_2 , CO_2

Plasma proteins (conc. 1.2-7.4 gm /1dl)

1- Albumin

2- Globulins (α_1, α_2, β_1, β_2. y)

3- Fibrinogen

4- Prothrombin

Erythrocytes (RBCs):

Count: males: 5.5 million/mm^3 females. 4.8 million/mm^3. RBCs count is higher in newly born infants, athletes, people living at high altitudes,

less in growing children & old age.

Shape: circular, biconcave, nonnucleated discs

1-lt provides a large surface area for gas exchange

2-lt enhances cell flexibility (squeezing of RBCs in small capillaries)

3-lt results in minimal ↑ in tension on the membrane (if RBCs volume↑)

Life span120 days

Fate: old RBCs are destroyed in the tissue macrophage system (R.E.S) mainly in the spleen.

Structure:

(1) Erythrocyte membrane: semipermeable, plastic

(2) Cytoplasm:

• Hb: is the main content (34% of RBCs wt.)

• K+: is the main cation.

• Carbonic anhydrase: for C02 transport as $HC0_3^-$

• NO nucleus, NO ribosomes, NO mitochondria

It is function : RBCs are responsible for transporting oxygen from your lungs to your body's tissues.

Platelets

300,000 / mm^3 blood (normal range: 250,000 - 400,000 / mm^3 blood)

Life span: 4 days

Origin: in B.M. from megakaryocytes (giant cells derived from the myeloid stem cell line).

Function: hemostasis, thrombosis, and wound healing

White blood cells (leucocytes)

White blood cells (WBCs) are the mobile units of the body defensive system, acting in 2 ways:

(1) Phagocytosis (2) Formation of antibodies & sensitized lymphocytes Count: 4000-11000 /mm 3.

Formation: in bone marrow

Types:

(1) Granulocytes
a- Neutrophils: (60 -70%) of WBCs
(their granules stain with acidic & basic dyes)
b- Eosinophils: (2- 6%) of WBCs
(their granules stain with acidic dyes)
c- Basophils: (0 -1%) ofWBCs
(their granules stain with basic dyes)

(2) Agranulocytes

a-Lymphocytes: (20- 30%) of WBCs

b- Monocytes: (2- 8%) of WBCs

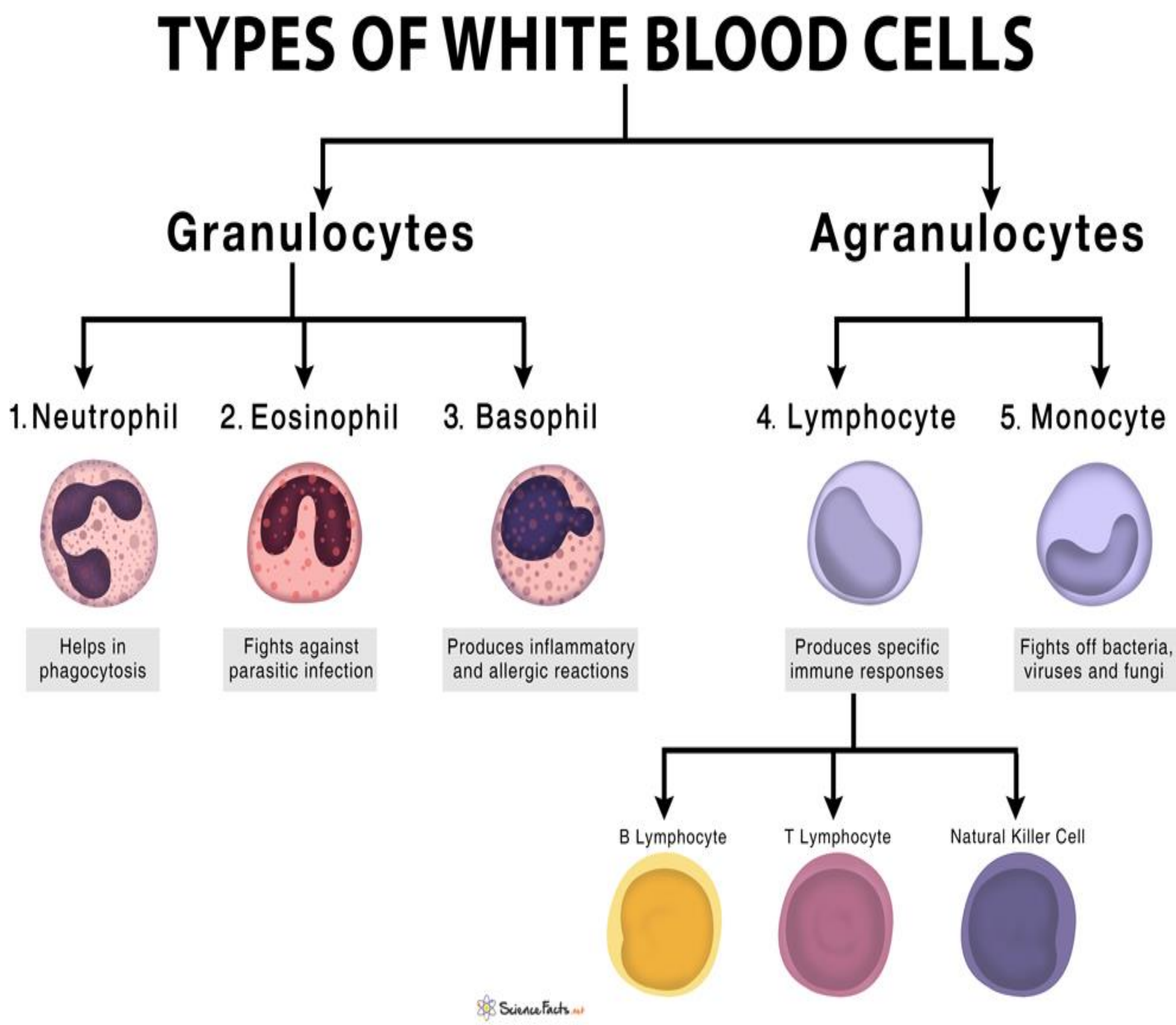
Function of leucocytes:

(1) Neutrophils
They are the first defensive line against invading organisms
→ingest & kill bacteria (phagocytosis)
(2) Eosinophils
a. Attack & kill parasites (by releasing certain substances)
b. Produce chemical mediators & prevent the toxic effects in allergic conditions.
c. They are weak phagocytes & show chemotaxis.
(3) Basophils
a. Contain histamine, heparin & leukotrienes.
b. Responsible for immediate type hypersensitivity reactions (as urticaria)
c. Have receptors that bind lgE-coated antigens~ degranulation of basophils.
(4) Lymphocytes
Formed in bone marrow, lymph node, thymus and spleen
The key cells of specific immunity (it is play important role in defending of the body)

(5) Monocytes

(a) Monocytes pass to areas of inflammation soon after neutrophils phagocytose & digest bacteria, dead neutrophils & remnants of tissue destruction

b. They are the precursors of tissue macrophages & together form the monocyte-macrophage system (have high defense & phagocytic function)



Respiratory system

The major functions of the respiratory system can be divided in two categories: respiratory and non-respiratory. The first function is to carry out the gas exchange. Metabolizing tissues utilize oxygen and produce carbondioxide. The respiratory system must obtain oxygen from the environment and must eliminate carbondioxide produced by cellular metabolism.

These processes must be coordinated so that the demand for oxygen is met and so that the carbondioxide that is produced is eliminated. The respiratory system is well-designed carryout gas exchange in an expeditious manner. The respiratory system is also involved in non-respiratory functions. It participates in maintaining acid-base balance since the increase in Co_2 in the body lead to increased H^+ the lungs also metabolize naturally occurring compounds such as angiotensin I, prostaglandins and epinephrine. The lungs are also responsible for protecting the body

from inhaled particles.

The function of the respiratory system:

The function of the respiratory system is the exchange of O2 and CO2 between the external environment and cells of the body.

Functional anatomy of the respiratory system

Functionally, the respiratory air passages are divided into two zones: a conductive zone and a respiratory zone. The airway tree consists of a series of highly branched hollow tubes that decrease in diameter and become more numerous at each branching. Trachea, the main airway in turn branches into two bronchi, one of which enters each lung. Within each lung, these bronchi branch many times into progressively smaller bronchi, which in turn branch into terminal bronchioles analogous to twigs of a tree. The terminal bronchioles redivide to form respiratory bronchioles, which end as alveoli,

analogous to leaves on a tree.

Conducting zone:

The conducting zone includes all of the anatomical structures through which air passes before reaching the respiratory zone. The conducting zone includes all of the anatomical structures through which air passes before reaching the respiratory zone. The conducting zone carries gas to and from the alveoli, i.e., it exchanges air between the alveoli and the atmosphere. The conducting zone of the respiratory system, in summary

consists of the following parts:

Mouth→ nose→ pharynx→ larynx→ trachea→ primary bronchi→ all successive branches of bronchioles including terminal bronchioles.

Functions

1- Warming and humidification of the inspired air:

Regardless of the temperature and humidity of the atmosphere, when the inspired air reaches the respiratory zone it is at a body temperature of 37o C (body temperature) and it is saturated with water vapor. This ensures that a constant internal body temperature will be maintained and that delicate lung tissue will be protected from desiccation.

2. Filtration and cleaning: Mucous secreted by the cells of the conducting zone serves to trap small particles in the inspired air and thereby performs a filtration function. This mucus is moved along at a rate of 1-2cm/min by cilia projecting from the tops of the epithelial cells that line the Conducting zone. There are about 300 cilia per cell that bend in a coordinated fashion to move the mucus toward the pharynx, where it can either be swallowed or expectorated. As a result of this filtration function, particles larger than about 6µm do not enter the respiratory zone of the lungs. The importance of this disease is evidenced by the disease called black lung, which occurs in miners who inhale too much carbon dust and therefore develop pulmonary fibrosis. The cleansing action of cilia and macrophages in the lungs is diminished by cigarette smoke.

3. Distribute air to the gas exchange surface of the lung.

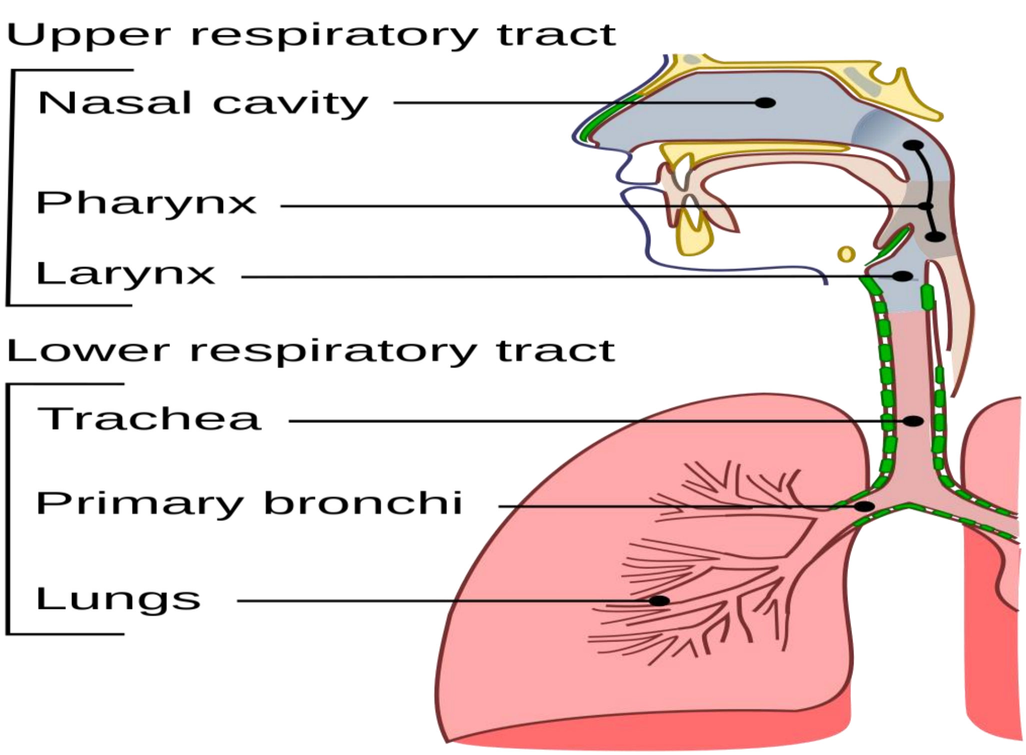
Respiratory zone the respiratory zone includes the respiratory bronchioles (because they contain separate out pouching of alveoli) and the alveoli. Alveoli are tiny air sacs, having a diameter of 0.25-0.50mm. There are about

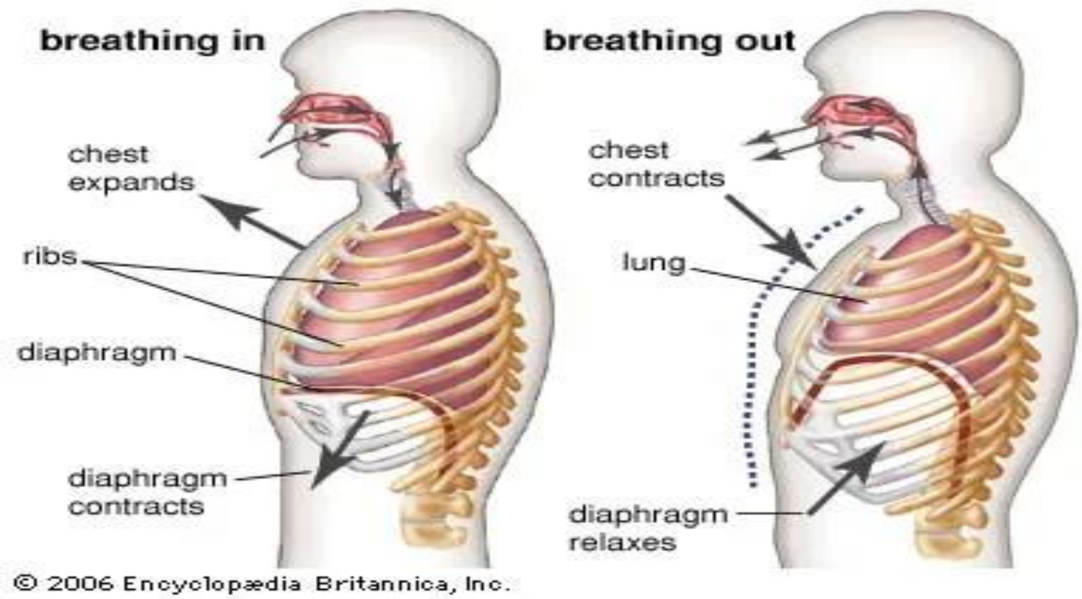
300-500 million alveoli in a lung. The numerous numbers of these structures provide a large surface area (60-80m^2 or 760ft^2) for the diffusion of gases.

Mechanics of breathing:

<u>Muscles used for breathing</u>:

Muscles of inspiration: The diaphragm is the most important inspiratory muscle. When the diaphragm contracts, abdominal contents are pushed downward and the ribs are lifted upward and outward. These changes increase intrathoracic volume and lower intrathoracic pressure. This initiates fthe low of air into the lungs. During exercise, when breathing frequency and TV increase, external intercostals muscles and accessory muscles are used for more vigorous inspiration. Muscles of expiration: Expiration is normally passive. During exercise or in diseases, in which airway resistance is increased (e.g. asthma) expiratory muscles are used such as abdominal muscles which compress abdominal cavity and push diaphragm up. Internal intercostals muscles pull ribs downward and inward.





Mechanics of breathing

The urinogenital system

⋆ Combination of the excretory and reproductive system

Kidney: is the main excretory organ of vertebrates. Concerned with the elimination of metabolic waste products.

Ovary: is the female reproductive organ or gonads.

Testis: is the male reproductive organ. These are concerned with the production of reproductive cells (egg and sperm).

Ducts: are passageways for the excretory waste products and reproductive outside.

Excretory System:

The paired kidneys which are metanephric are flat, elongated and lobulated. The ureters lead directly backward to open into the urodaeum or middle compartment of the cloaca; there is no urinary bladder. The nitrogenenous waste is excreted in the form of uric acid and discharged as a semi-solid mass. Adrenal bodies lie attached to the ventral surface of the kidneys as small yellowish elongated streaks.

Reproductive system:

The female reproductive organs: a pair of ovoid testes are attached to anterior end of the kidneys by peritoneum . From each testis leads the vas deferens which runs backwards along the outer side of the ureter of that side, and opens on a small papilla into the urodaeum. The vas deferens is dilated into a seminal vesicle at its hind end. There is no copulatory organ.

The female reproductive organs consist of a single ovary on the left side which is an adaptation to aerial life and an oviduct which opens into the body-cavity by a funnel-like aperture at the anterior end and posteriorly opens into the urodaeum.

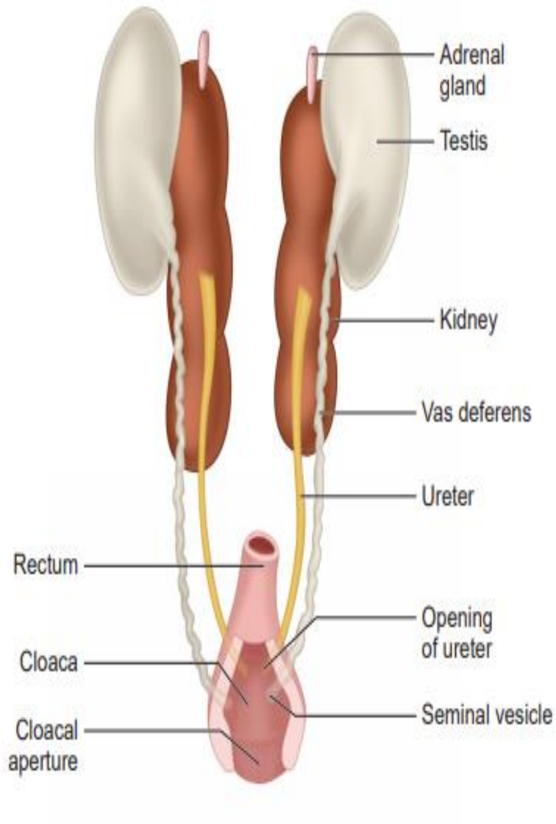


Figure 4.36 Pigeon –Male Urinogenital System

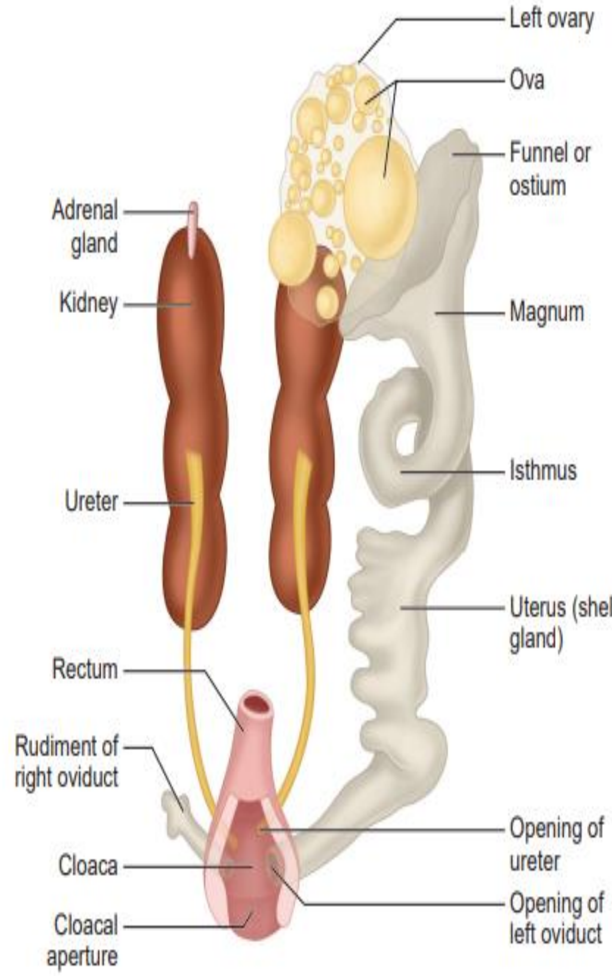


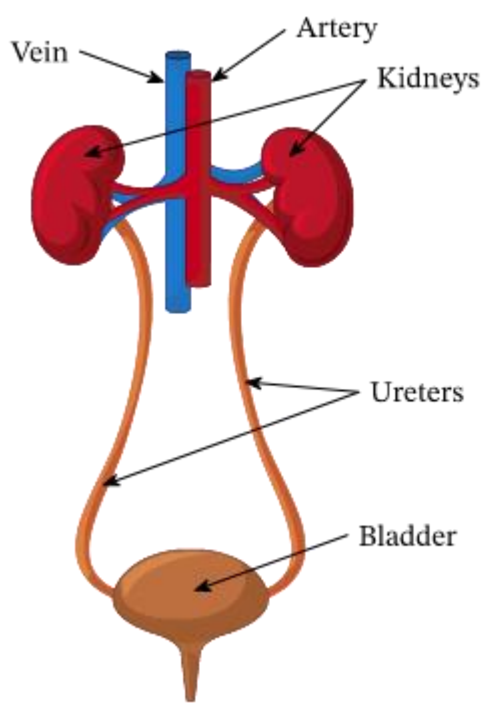
Figure 4.37 Pigeon –Female Urinogenital System

The urinary system

It is customary to link the organs of urinary excretion and reproduction as a urinogenital system. The suitability of this concept is questionable.

The urinary and reproductive organs differ in their embryological origin and development. In postnatal human beings, the association between the components of the urinary and the reproductive systems is very much limited. Hence the urinary and reproductive systems are considered separately.

The urinary organs comprise, two kidneys (renes), ureters, the urinary bladder (vesica urinaria) and the urethra.



human urinary system

The urinary system

The urinary system is one of the excretory systems of the body. It consists of the following structures:

• 2 kidneys, which secrete urine

• 2 ureters, which convey the urine from the kidneys to the urinary bladder

• urinary bladder where urine collects and is temporarily stored

• 1urethra through which the urine is discharged from the urinary bladder to the exterior.

The urinary system plays a vital part in maintaining homeostasis of water and electrolyte concentrations within the body. The kidneys produce urine that contains metabolic waste products, including the nitrogenous compounds urea and uric acid, excess ions and some drugs.

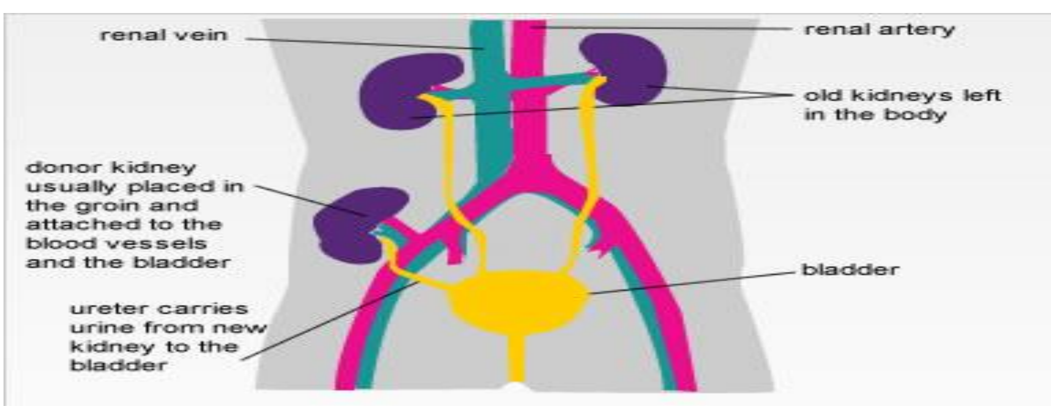
The main functions of the kidneys are:

• formation and secretion of urine

• production and secretion of erythropoietin, the hormone responsible for controlling the rate of formation of red blood cells.

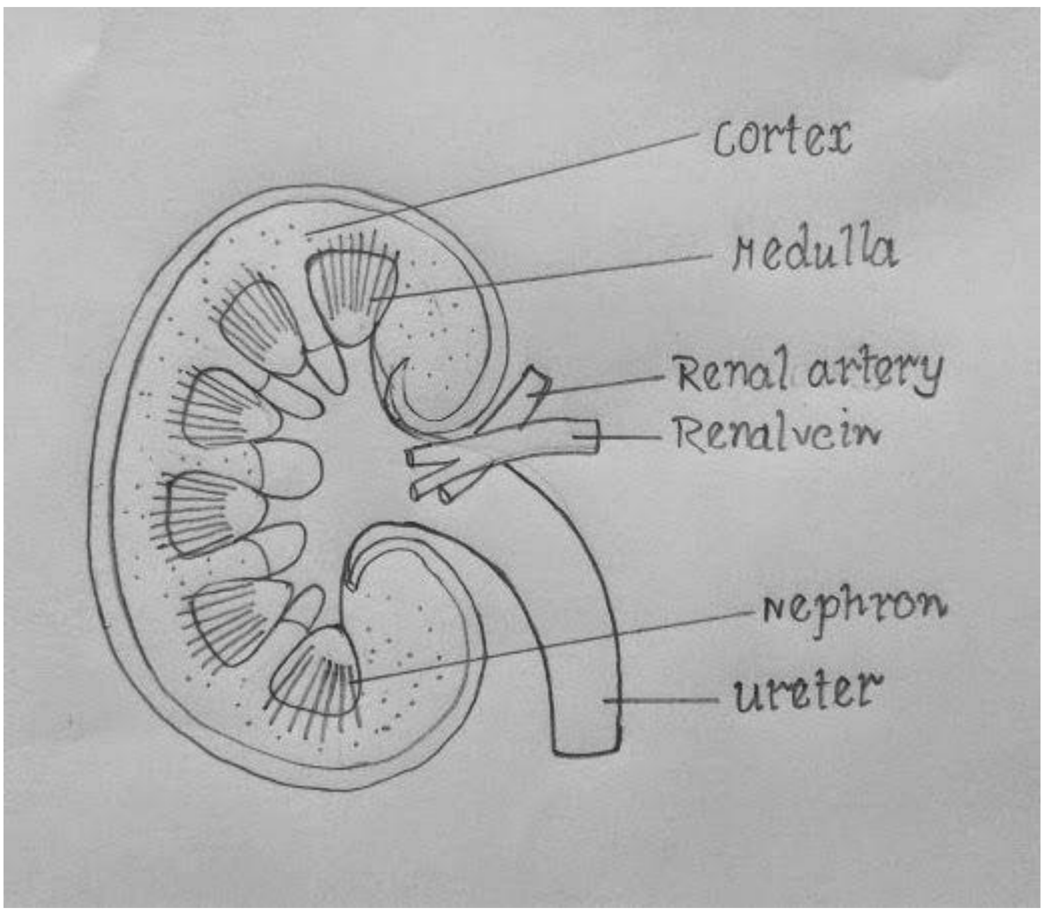
• production and secretion of renin, an important enzyme in the control of blood pressure.

Urine is stored in the bladder and excreted by the process of micturition.



The kidneys:

The kidneys lie on the posterior abdominal wall, one on each side of the vertebral column, behind the peritoneum and below the diaphragm. They extend from the level of the 12th thoracic vertebra to the 3rd lumbar vertebra, receiving some protection from the lower rib cage. The right kidney is usually slightly lower than the left, probably because of the considerable space occupied by the liver. Kidneys are bean-shaped organs, about 11cm long, 6 cm wide, 3 cm thick and weigh 150g. They are embedded in and held in position by, a mass of fat. A sheath of fibroelastic renal fascia encloses the kidney and the renal fat.



kidney

Right kidney

Superiorly —the right adrenal gland

Anteriorly —the right lobe of the liver, the duodenum and the hepatic flexure of the colon

Posteriorly —the diaphragm, and muscles of the posterior abdominal wall

Left kidney

Superiorly —the left adrenal gland

Anteriorly —the spleen, stomach, pancreas, jejunum and splenic flexure of the colon

Posteriorly —the diaphragm and muscles of the posterior abdominal wall

The microscopic structure of the kidney

The kidney is composed of about 1 million functional units, the nephrons, and a smaller number of collecting tubules. The collecting tubules transport urine through the pyramids to the renal pelvis giving them their striped appearance. The tubules are supported by a small amount of connective tissue, containing blood vessels, nerves and lymph vessels.

Functions of the kidney

Formation of urine : the kidneys form urine which passes through the ureters to the bladder for storage prior to excretion. The composition of urine reflects the activities of the nephrons in the maintenance of homeostasis. Waste products of protein metabolism are excreted, electrolyte balance is maintained and the pH (acid-base balance) is maintained by the excretion of hydrogen ions. There are three processes involved in the formation of urine:

- simple filtration
- selective reabsorption
- secretion

Simple filtration

Filtration takes place through the semipermeable walls of the glomerulus and glomerular capsule. Water and a large number of small molecules pass through, although some are reabsorbed later. Blood cells, plasma proteins and other large molecules are unable to filter through and remain in the capillaries. The filtrate in the glomerulus is very similar in composition to the plasma with the important exception of plasma proteins. Filtration is assisted by the difference between the blood pressure in the glomerulus and the pressure of the filtrate in the glomerular capsule. Because the diameter of the efferent arteriole is less than that of the afferent arteriole, a capillary hydrostatic pressure of about 7.3 kPa (55mmHg) builds up in the glomerulus. This pressure is opposed by the osmotic pressure of the blood, about 4 kPa (30 mmHg), and by filtrate hydrostatic pressure of about 2 kPa (15mmHg) in the glomerular capsule. The net filtration pressure is, therefore:

$7.3 - (4 + 2) = 1.3$ kPa, or

$55 - (30 + 15) = 10$ mmHg.

The volume of filtrate formed by both kidneys each minute is called the glomerular filtration rate (GFR). In a healthy adult, the GFR is about 125ml/min; i.e. 180litres of dilute filtrate is formed each day by the two kidneys. Most of the filtrate is reabsorbed with less than 1%, i.e. 1 to 1.5 liters, excreted as urine. The difference in volume and concentration is due to the selective reabsorption of some constituents of the filtrate and the tubular secretion of others.

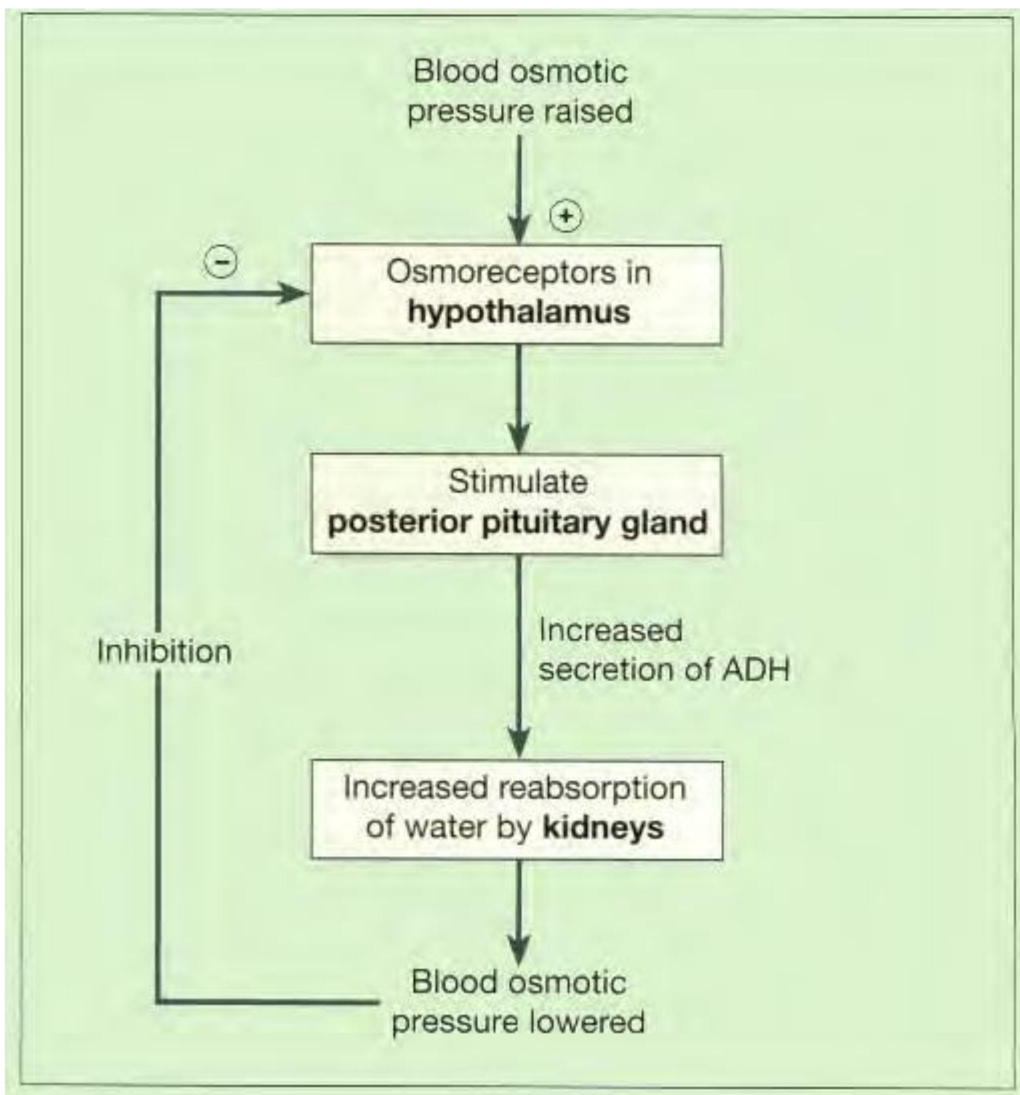
Autoregulation of filtration: Renal blood flow is protected by a mechanism called autoregulation whereby renal blood flow is maintained at a constant pressure across a wide range of systolic blood pressures (from 80 to 200mmHg). Autoregulation operates independently of nervous control; i.e. if the nerve supply to the renal blood vessels is interrupted, autoregulation continues to operate. It is therefore a property inherent in renal blood vessels; it may be stimulated by changes in blood pressure in the renal arteries or by fluctuating levels of certain metabolites, e.g. prostaglandins. In severe shock when the systolic blood pressure falls below 80 mmHg, autoregulation fails and renal blood flow and hydrostatic pressure decrease, impairing filtration within the nephrons.

Selective reabsorption :

Selective reabsorption is the process by which the composition and volume of the glomerular filtrate are altered during its passage through the convoluted tubules, the medullary loop and the collecting tubule. The general purpose of this process is to reabsorb into the blood those filtrate constituents needed by the body to maintain fluid and electrolyte balance and the pH of the blood. Active transport is carried out at carrier sites in the epithelial membrane using chemical energy to transport substances against their concentration gradients. Some constituents of glomerular filtrate (e.g. glucose, amino acids) do not normally appear in urine because they are completely reabsorbed unless they are present in blood in excessive quantities. The kidneys' maximum capacity for reabsorption of a substance is the transport maximum, or renal threshold, e.g. normal blood glucose level is 2.5 to 5.3 mmol/l (45 to 95 mg/100 ml). If the level rises above the transport maximum of about 9 mmol/1 (160 mg/100 ml) glucose appears in the urine because all the carrier sites are occupied and the mechanism for active transfer out of the tubules is overloaded. Other substances reabsorbed by active transport include amino acids and sodium, calcium, potassium, phosphate and chloride. Some ions, e.g. sodium and chloride, can be absorbed by both active and passive mechanisms depending on the site in the nephron. The transport maximum, or renal threshold, of some substances varies according to the body's need for them at the time, and in some cases reabsorption is regulated by hormones. Parathyroid hormone from the parathyroid glands and calcitonin from the thyroid gland together regulate reabsorption of calcium and phosphate. Antidiuretic hormone (ADH) from the posterior lobe of the pituitary gland increases the permeability of the distal convoluted tubules and collecting tubules, increasing water reabsorption. Aldosterone, secreted by the adrenal cortex, increases the reabsorption of sodium and excretion of potassium.

Nitrogenous waste products, such as urea and uric acid, are reabsorbed only to a slight extent.

Directions of selective reabsorption and secretion inthe nephron.



Negative feedback regulation of secretion of antidiuretic hormone (ADH).

Secretion

Filtration occurs as the blood flows through the glomerulus. Substances not required and foreign materials, e.g. drugs including penicillin and aspirin, may not be cleared from the blood by filtration because of the short time it remains in the glomerulus. Such substances are cleared by secretion into the convoluted tubules and excreted from the body in the urine. Tubular secretion of hydrogen (H^+) ions is important in maintaining the homeostasis of blood pH.

Composition of urine

Water 96%

Urea 2%

Uric acid

Creatinine

Ammonia

Sodium

Potassium / 2%

Chlorides

Phosphates

Sulfates

Oxalates

Urine is clear and amber in color due to the presence of urobilin, a bile pigment altered in the intestine, reabsorbed and then excreted by the kidneys.

Water balance and urine output:

Water is taken into the body through the alimentary tract and a small amount (called 'metabolic water') is formed by the metabolic processes. Water is excreted in saturated expired air, as a constituent of the feces, through the skin as sweat and as the main constituent of urine. The amount lost in expired air and in feces is fairly constant and the amount of sweat produced is associated with the maintenance of normal body temperature. The balance between fluid intake and output is therefore controlled by the kidneys. The minimum urinary output, i.e., the smallest volume required to excrete the body's waste products, is about 500ml per day. The amount produced in excess of this is controlled mainly by antidiuretic hormone (ADH) released into the blood by the posterior lobe of the pituitary gland. There is a close link between the posterior pituitary and the hypothalamus in the brain.

Sensory nerve cells in the hypothalamus (osmoreceptors) detect changes in the osmotic pressure of the blood. Nerve impulses from the osmoreceptors stimulate the posterior lobe of the pituitary gland to release ADH.

When the osmotic pressure is raised, ADH output is increased and as a result, water reabsorption by the cells in distal convoluted tubules and collecting ducts is increased, reducing the blood osmotic pressure and ADH output. This feedback mechanism maintains the blood osmotic pressure (and therefore sodium and water concentrations) within normal limits. The feedback mechanism may be opposed when there is an excessive amount of a dissolved substance in the blood. For example, in diabetes mellitus when the blood glucose level is above the transport maximum of the renal tubules, excess water is excreted with the excess glucose. This polyuria may lead to dehydration in spite of increased production of ADH but it is usually accompanied by acute thirst and increased water intake.

Sodium balance

In addition to regulating total volume, the osmolarity (the amount of solute per unit volume) of bodily fluids is also tightly regulated. Extreme variation in osmolarity causes cells to shrink or swell, damaging or destroying the cellular structure and disrupting normal cellular function.

Regulation of osmolarity is achieved by balancing the intake and excretion of sodium with that of water. (Sodium is by far the major solute in extracellular fluids, so it effectively determines the osmolarity of extracellular fluids.)

An important concept is that the regulation of osmolarity must be integrated with the regulation of volume because changes in water volume alone have to dilute or concentrating effects on the bodily fluids. For example, when you become dehydrated you lose proportionately more water than solute (sodium), so the osmolarity of your bodily fluids increases. In this situation the body must conserve water but not sodium, thus stemming the rise in osmolarity. If you lose a large amount of blood from trauma or surgery, however, your loss of sodium and water are proportionate to the composition of bodily fluids. In this situation, the body should conserve both water and sodium.

As noted above, ADH plays a role in lowering osmolarity (reducing sodium concentration) by increasing water reabsorption in the kidneys, thus helping to dilute bodily fluids. To prevent osmolarity from decreasing below normal, the kidneys also have a regulated mechanism for reabsorbing sodium in the distal nephron. This mechanism is controlled by aldosterone, a steroid hormone produced by the adrenal cortex. Aldosterone secretion is controlled two ways:

1.The adrenal cortex directly senses plasma osmolarity. When the osmolarity increases above normal, aldosterone secretion is inhibited. The lack of aldosterone causes less sodium to be reabsorbed in the distal tubule. Remember that in this setting ADH secretion will increase to conserve water, thus complementing the effect of low aldosterone levels to decrease the osmolarity of bodily fluids. The net effect on urine excretion is a decrease in the amount of urine excreted, with an increase in the osmolarity of the urine.

2. The kidneys sense low blood pressure (which results in lower filtration rates and lower flow through the tubule). This triggers a complex response to raise blood pressure and conserve volume. Specialized cells (juxtaglomerular cells) in the afferent and efferent arterioles produce renin, a peptide hormone that initiates a hormonal cascade that ultimately produces

angiotensin II. Angiotensin II stimulates the adrenal cortex to produce aldosterone.

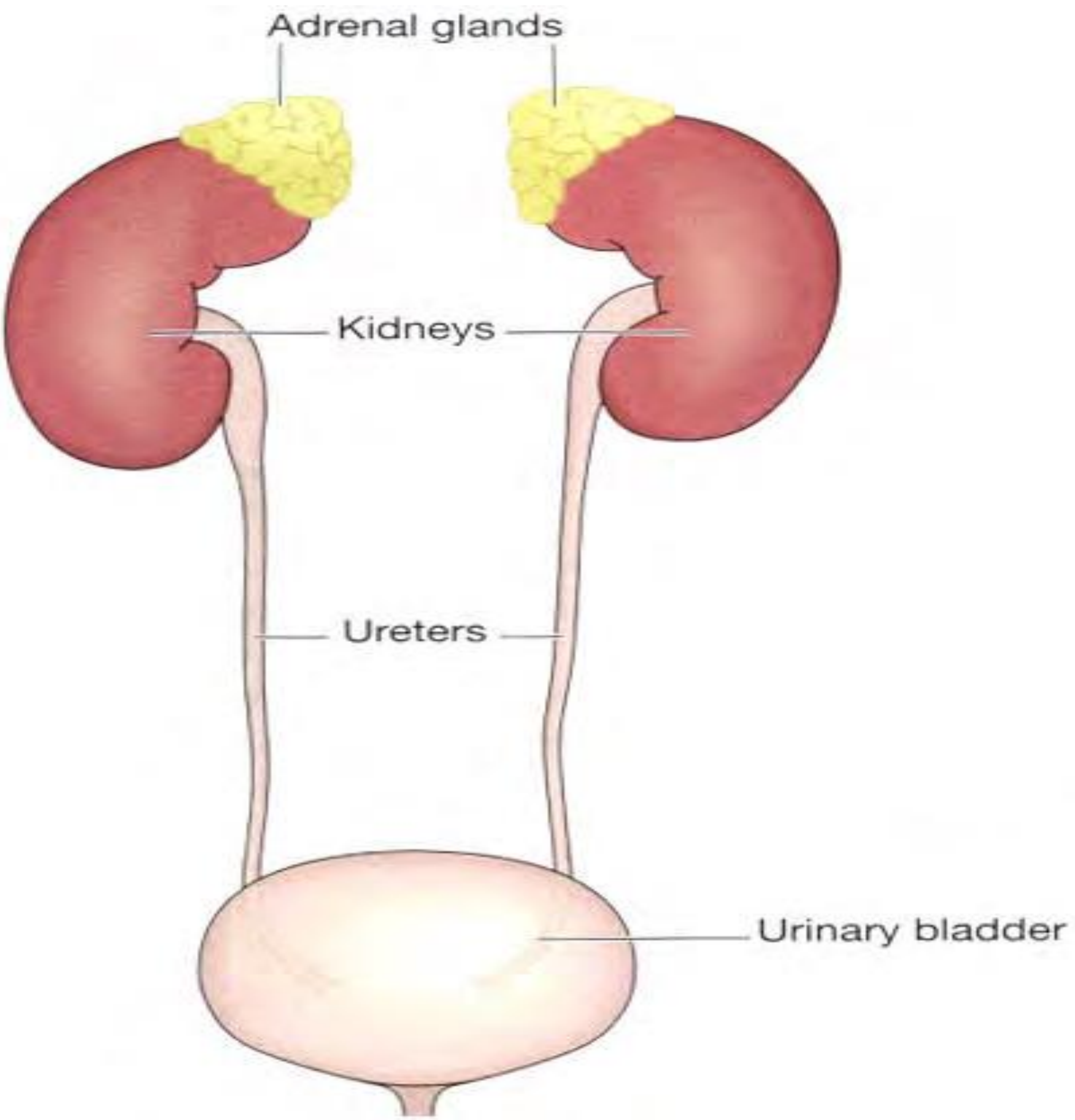
*Note that in this setting, where the body is attempting to conserve volume, ADH secretion is also stimulated and water reabsorption increases. Because aldosterone is also acting to increase sodium reabsorption, the net effect is the retention of fluid that is roughly the same osmolarity as bodily fluids. The net effect on urine excretion is a decrease in the amount of urine excreted, with lower osmolarity than in the previous example.

The ureters:

Function:

The ureters propel the urine from the kidneys into the bladder by peristaltic contraction of the smooth muscle layer. This is an intrinsic property of the smooth muscle and is not under autonomic nerve control. The waves of

contraction originates in a pacemaker in the minor calyces. Peristaltic waves occur several times per minute, increasing in frequency with the volume of urine produced, and send little spurts of urine into the bladder.



The ureters

The ureters are the tubes that convey urine from the kidneys to the urinary bladder. They are about 25 to 30 cm long with a diameter of about 3 mm. The ureter is continuous with the funnel-shaped renal pelvis. It passes downwards through the abdominal cavity, behind the peritoneum in front of the psoas muscle into the pelvic cavity, and passes obliquely through the posterior wall of the bladder arrangement, when urine accumulates and the pressure in the bladder rises, the ureters are compressed and the openings occluded. This prevents the reflux of urine into the ureters (towards the kidneys) as the bladder fills and during micturition when pressure increases as the muscular bladder wall contracts.

The urinary bladder

The urinary bladder is a reservoir for urine. It lies in the pelvic cavity and its size and position vary, depending on the amount of urine it contains. When distended, the bladder rises into the abdominal cavity. The bladder is roughly pear-shaped but becomes more oval as it fills with urine. It has anterior, superior, and posterior surfaces. The posterior surface is the base. The bladder opens into the urethra at its lowest point, the neck.

The urethra

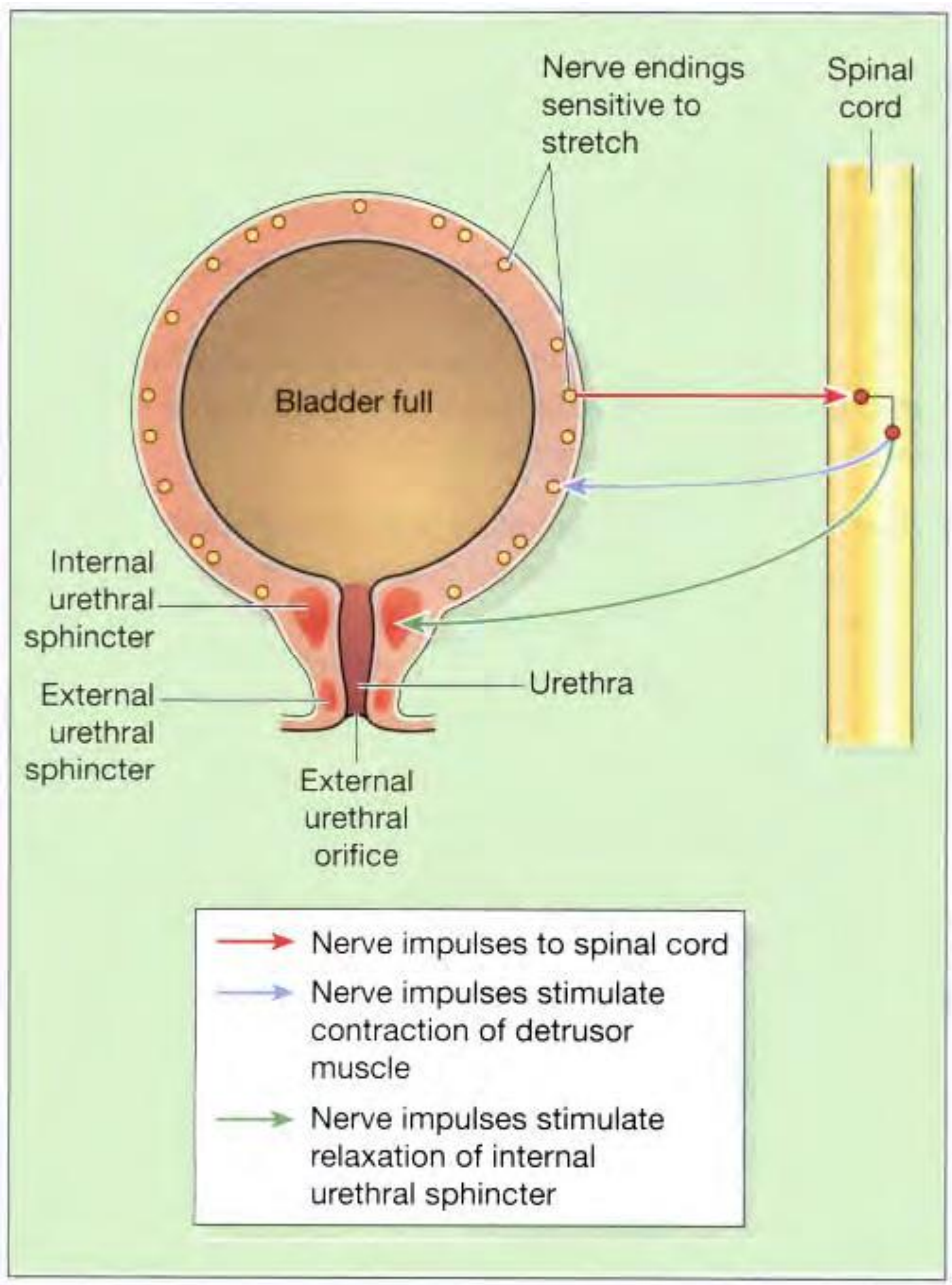
The urethra is a canal extending from the neck of the bladder to the exterior, at the external urethral orifice. Its length differs in the male and in the female. The male urethra is associated with the urinary and productive systems.

MICTURITION

The urinary bladder acts as a reservoir for urine. When 300 to 400 ml of urine have accumulated, afferent autonomic nerve fibers in the bladder wall sensitive to stretch are stimulated. In the infant, this initiates a spinal reflex action and micturition occurs. Micturition occurs when autonomic efferent fibers convey impulses to the bladder causing contraction of the detrusor muscle and relaxation of the internal urethral sphincter. When the nervous system is fully developed the micturition reflex is stimulated but sensory impulses pass upwards to the brain and there is an awareness of the

desire to pass urine. By conscious effort, reflex contraction of the bladder wall and relaxation of the internal sphincter can be inhibited for a limited period of time.

In adults, micturition occurs when the detrusor muscle contracts, and there is reflex relaxation of the internal sphincter and voluntary relaxation of the external sphincter. It can be assisted by increasing the pressure within the pelvic cavity, achieved by lowering the diaphragm and contracting the abdominal muscles (Valsalva's maneuver). Over-distension of the bladder is extremely painful, and when this stage is reached there is a tendency for involuntary relaxation of the external sphincter to occur and a small amount of urine to escape, provided there is no mechanical obstruction.



Simple reflex control of micturition when conscious effort cannot override the reflex action.

The reproductive systems

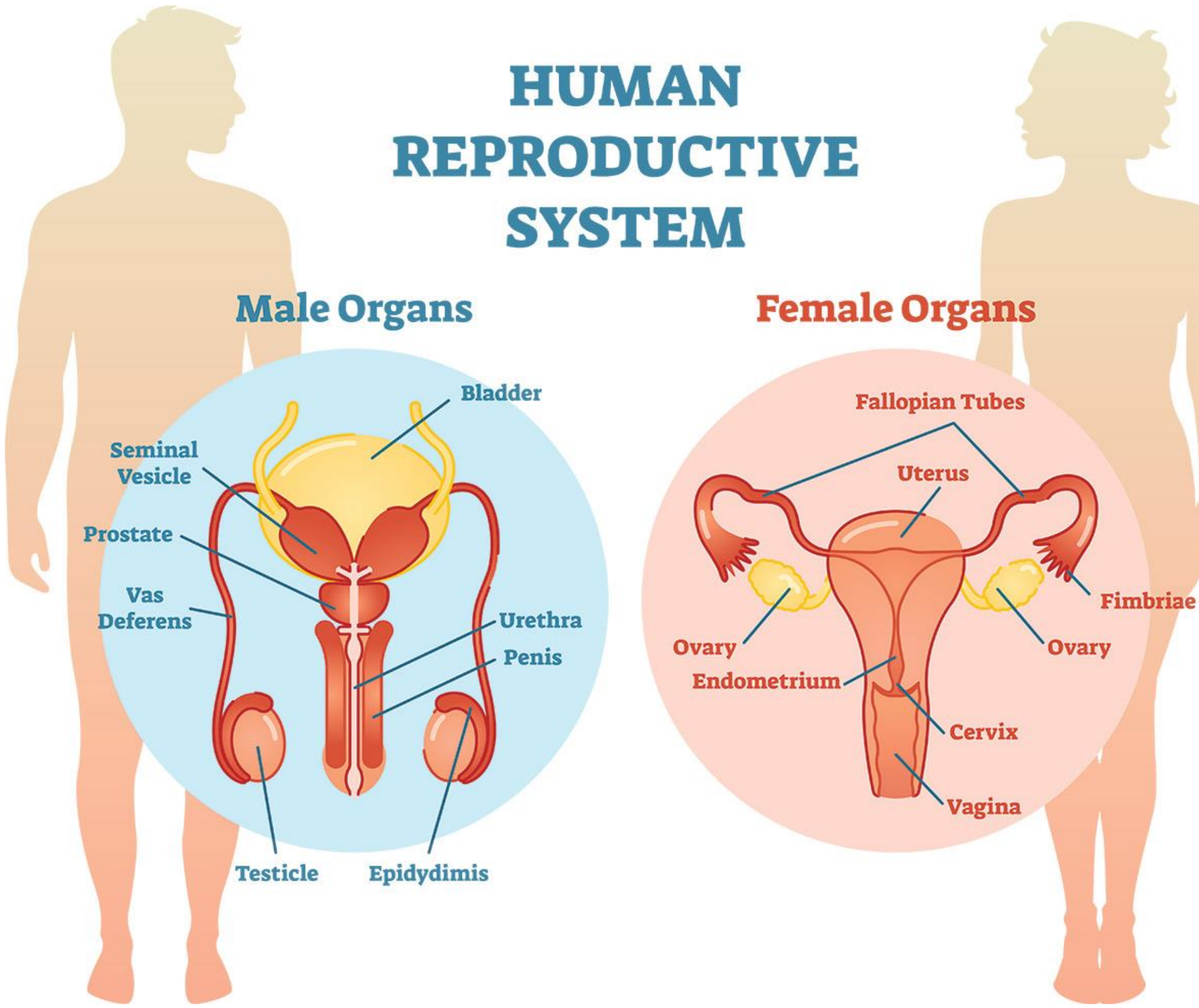
The ability to reproduce is one of the properties which distinguishes living from non-living matter. The more primitive the animal, the simpler the process of reproduction. In human beings, the process is one of sexual reproduction in which the male and female organs differ anatomically and physiologically. Both males and females produce specialized reproductive germ cells, called gametes. The male gametes are called spermatozoa and the female gametes are called ova. They contain the genetic material, or genes, on chromosomes, which pass inherited characteristics on to the next generation. In other body cells, there are 46 chromosomes arranged in 23 pairs but in the gametes, there are only 23, one from each pair. Gametes are formed by meiosis. When the ovum is fertilized by a spermatozoon the resultant zygote contains 23 pairs of chromosomes, one of each pair obtained from the father and one from the mother. The zygote embeds itself in the wall of the uterus where it grows and develops during the 40-week gestation period before birth.

The functions of the female reproductive system are:

- formation of female gametes, ova
- reception of male gametes, spermatozoa
- provision of suitable environments for the fertilization of the ovum by spermatozoa and the development of the resultant fetus
- parturition (childbirth)
- lactation, the production of breast milk, which provides complete nourishment for the baby in its early life.

The functions of the male reproductive system are:

- production of male gametes, spermatozoa
- transmission of spermatozoa to the female.



Male reproductive system

The male has reproductive organs, or genitals, that are both inside and outside the pelvis. The male genitals include:

- the testicles
- the duct system, which is made up of the epididymis and the vas deferens

- the accessory glands, which include the seminal vesicles and prostate gland
- the penis

In a guy who has reached sexual maturity, the two oval-shaped testicles, or testes make and store millions of tiny sperm cells. The testicles are also part of the endocrine system because they make hormones, including testosterone.

Testosterone is a major part of puberty in boys, and as a guy makes his way through puberty, his testicles produce more and more of it. Testosterone is the hormone that causes boys to develop deeper voices, bigger muscles, and body and facial hair. It also stimulates the production of sperm.

Alongside the testicles are the epididymis and the vas deferens, which transport sperm. The epididymis and the testicles hang in a pouch-like structure outside the pelvis called the scrotum. This bag of skin helps to regulate the temperature of testicles, which need to be kept cooler than body temperature to produce sperm. The scrotum changes size to maintain the right temperature. When the body is cold, the scrotum shrinks and becomes tighter to hold in body heat. When it's warm, it gets larger and floppier to get rid of extra heat. This happens without a guy ever having to think about it. The brain and the nervous system give the scrotum the cue to change size.

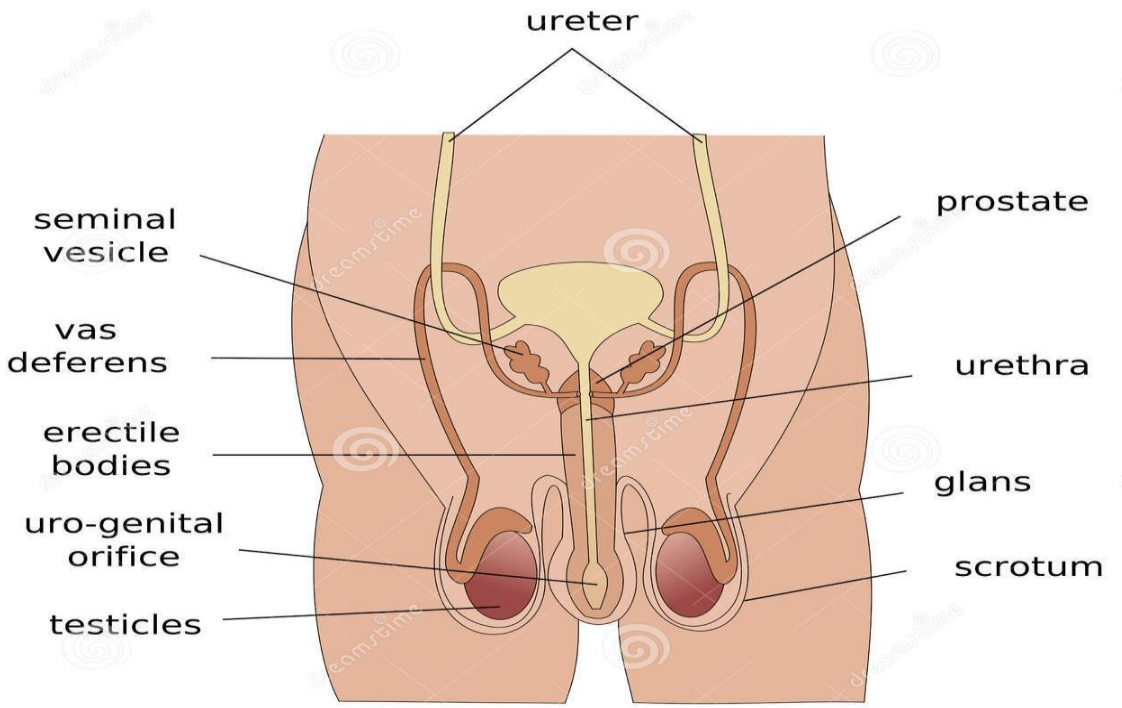
The accessory glands, including the seminal vesicles and the prostate gland, provide fluids that lubricate the duct system and nourish the sperm. The urethra is the channel that carries the sperm (in fluid called semen) to the outside of the body through the penis. The urethra is also part of the urinary system because it is also the channel through which pee passes as it leaves the bladder and exits the body.
The male reproductive system makes semen releases semen into the reproductive system of the female during sexual intercourse produces sex hormones, which help a boy develop into a sexually mature man during puberty When a baby boy is born, he has all the parts of his reproductive system in place, but it isn't until puberty that he is able to reproduce. When puberty begins, usually between the

ages of 9 and 15, the pituitary gland — located near the brain — secretes hormones that stimulate the testicles to produce testosterone. The production of testosterone brings about many physical changes.

Although the timing of these changes is different for every guy, the stages of puberty generally follow a set sequence:

During the first stage of male puberty, the scrotum and testes grow larger.
Next, the penis becomes longer and the seminal vesicles and prostate gland grow.
Hair begins to grow in the pubic area and later on the face and underarms. During this time, a boy's voice also deepens.
Boys also have a growth spurt during puberty as they reach their adult height and weight.

The penis is actually made up of two parts: the shaft and the glans. The shaft is the main part of the penis and the glans is the tip (sometimes called the head). At the end of the glans is a small slit or opening, which is where semen and urine exit the body through the urethra. The inside of the penis is made of spongy tissue that can expand and contract.



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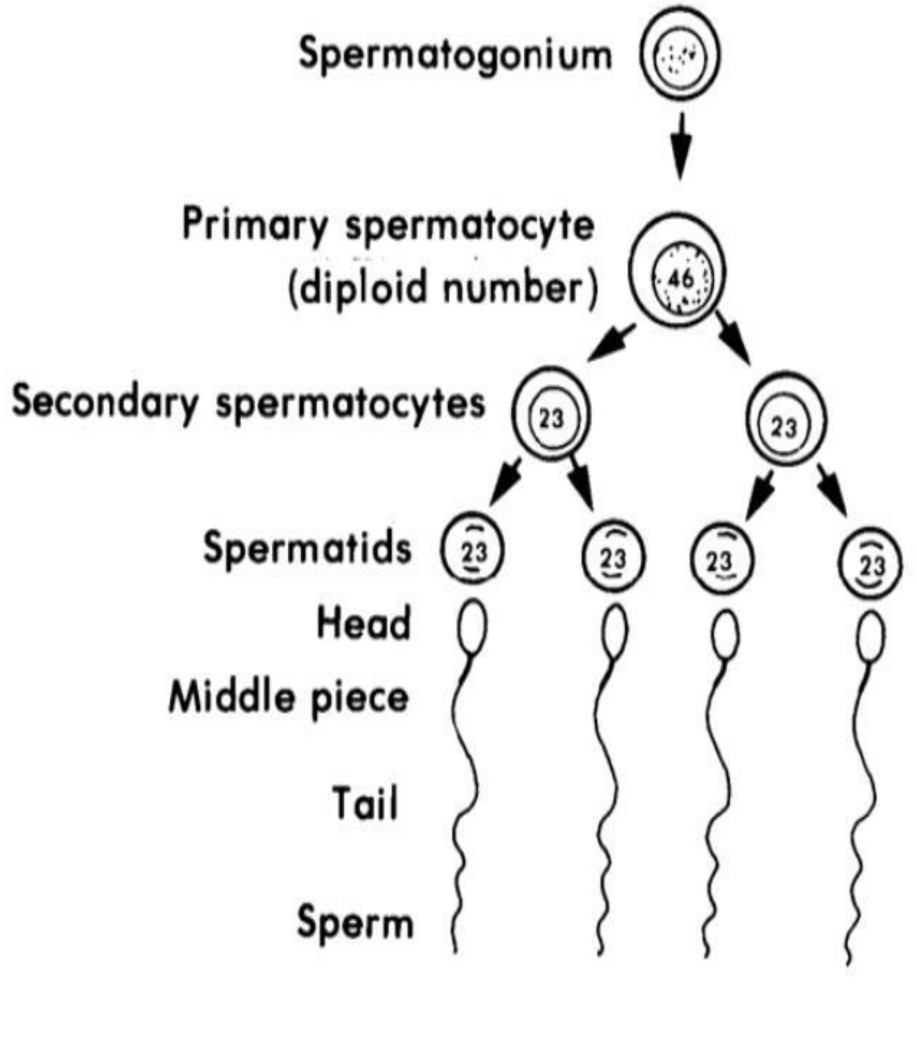


Spermatogenesis

Female reproductive system

While the following structures of the female reproductive system serve different purposes, together, they contribute to the creation and maintenance of an egg:

Ovaries – The ovaries are the female gonads – the primary organ in the female reproductive system. It is mainly responsible for producing egg cells, or ova, as well as hormones such as estrogen and progesterone. These hormones are responsible for controlling various reproductive processes in females and thickening and maintaining the uterus lining.

Fimbriae – The fimbriae are tissues attached to the ovaries that transfer the oocytes (immature eggs) from the ovaries to the fallopian tubes, or oviduct.

Fallopian tubes (oviduct) – The fallopian tubes are a pair of tubes that stretch from the ovaries to the uterus. They are responsible for transporting the oocytes to the uterus. Fertilization normally occurs here.

Uterus – The uterus is a muscular, pear-shaped organ where the fertilized egg will be implanted and developed.

Cervix – The cervix is the lower part of the uterus, a canal between the uterus and the vagina through which the fetus (developing baby) will exit during childbirth.

Vagina – The vagina is a passage leading to the uterus which accommodates the penis during sexual intercourse.

Oogenesis

Oogenesis is the process that produces egg cells. It occurs in the outer layers of the ovaries.

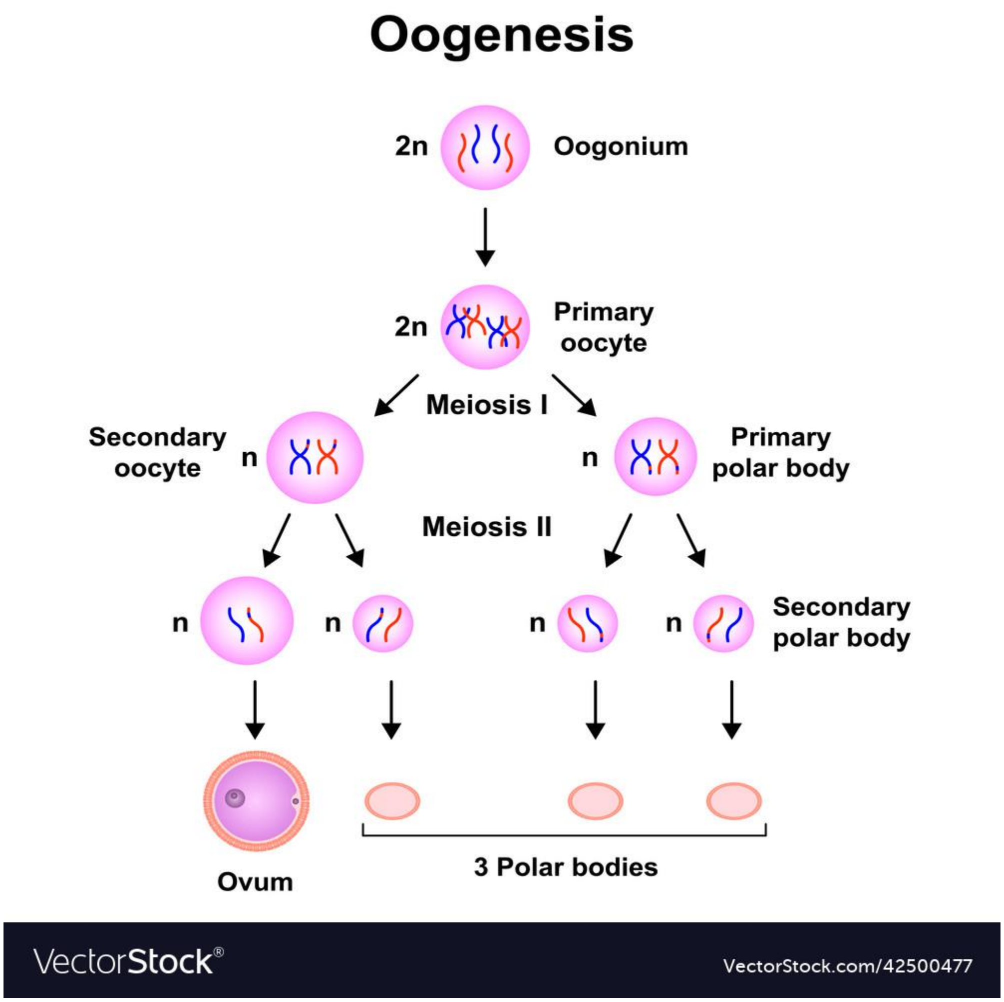
The process of oogenesis

1-Germ cells, which are the body's reproductive cells, undergo cell division several times by mitosis, forming two oogonia. Oogonia are immature reproductive cells containing two complete sets of chromosomes, one from each parent, i.e., they are diploid.

Remember that a diploid cell has two sets of chromosomes with two chromatids each. While chromatids are twins (they contain the same genetic information), paired chromosomes will code for the same traits but might have different alleles for those traits.

2-One oogonium continues to grow into a primary oocyte, an immature egg.

3-The cell (the primary oocyte) then undergoes division by meiosis (1st meiotic division), forming a secondary oocyte (if you need a refresher, check out our article Meiosis). This oocyte is a haploid cell containing only half of the original cell's chromosome. This is now the female set of chromosomes for the zygote. Additionally, small cell buds off the oocyte called a polar body.
Polar bodies are also haploid cells but are generally unable to be fertilized. It usually dies by apoptosis.
4-The secondary oocyte undergoes meiosis (2nd meiotic division), forming an ovum (egg cell) and another polar body. The polar bodies continue to divide and degenerate as the ovum develops. The maturation of the oocyte to form an ovum is arrested, or 'paused', in prophase until ovulation (after puberty). Then, it is allowed to continue until metaphase II, at which stage meiotic division is arrested again until the sperm fertilizes the egg.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Oogonium
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Primary
oocyte
Meiosis I
Secondary
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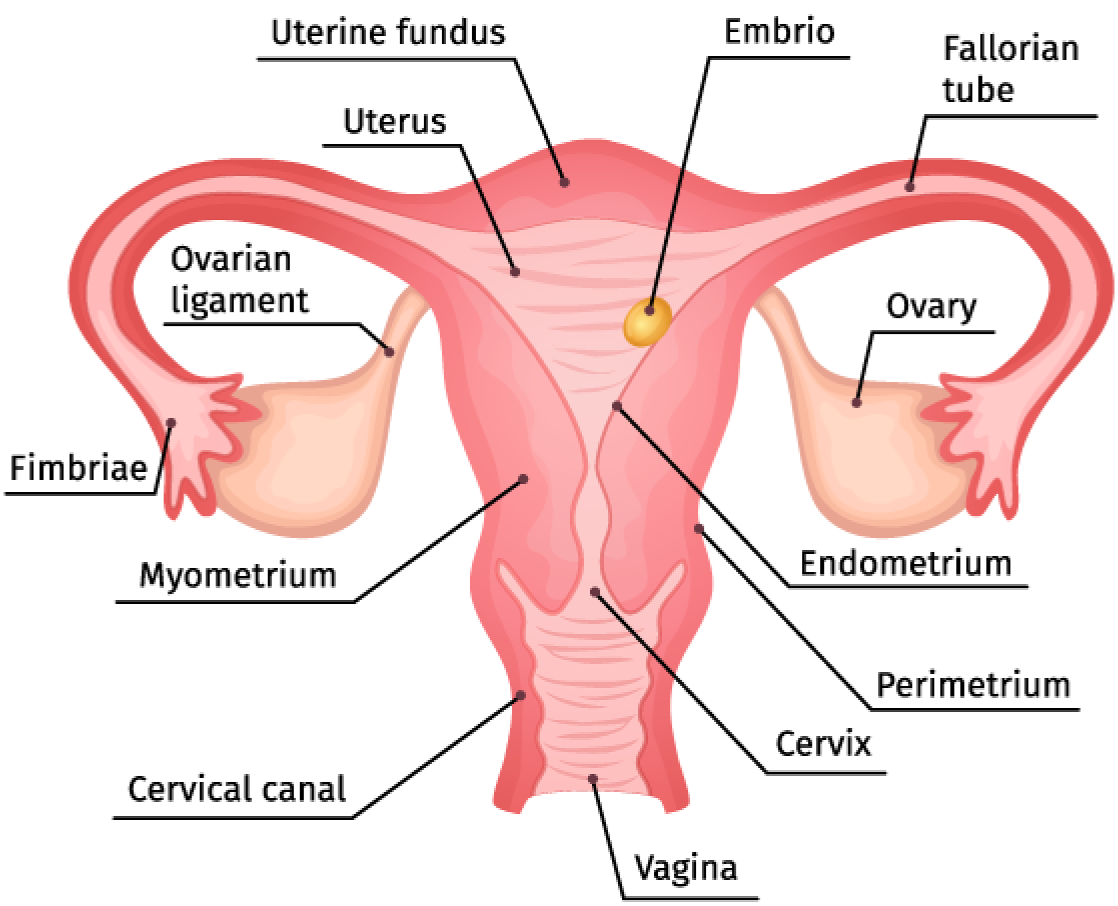
FEMALE REPRODUCTIVE SYSTEM



The skeletal system

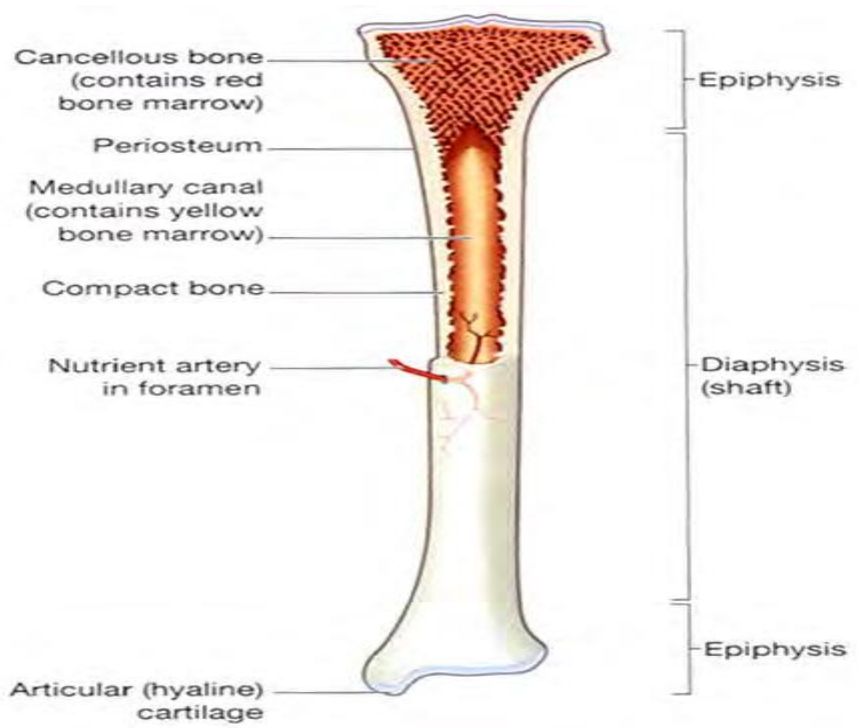
Bone is a strong and durable type of connective tissue.

It consists of:

• water (25%)

• organic constituents including osteoid (the carbon-containing part of the matrix) and bone cells (25%)

• inorganic constituents, mainly calcium phosphate (50%).



A mature long bone - partially sectioned.

Although bones are often thought to be static or permanent, they are highly vascular living structures that are

continuously being remodelled.

Types of bones

Bones are classified as long, short, irregular, flat and

sesamoid.

Long bones. These consist of a shaft and two extremities.

As the name suggests the length is much greater than the

width. Examples include the femur, tibia and fibula.

Short, irregular, flat and sesamoid bones. These have

no shafts or extremities and are diverse in shape and size.

Examples include:

• short bones —carpals (wrist)

• irregular bones—vertebrae and some skull bones

• flat bones —sternum, ribs and most skull bones

• sesamoid bones —patella (kneecap).

Bone cells

The cells responsible for bone formation are osteoblasts

(these later mature into osteocytes). Osteoblasts and chondrocytes (cartilage-forming cells) develop from the same parent fibrous tissue cells. Differentiation into osteogenic cells, rather than chondroblasts, is believed to depend upon an adequate oxygen supply. This may be a factor affecting the healing of fractures, i.e. if the oxygen supply is deficient there may be a preponderance of chondroblasts, resulting in a cartilaginous union of the fracture.

Osteoblasts

These are the bone-forming cells that secrete collagen and other constituents of bone tissue. They are present:

• in the deeper layers of periosteum

• in the centers of ossification of immature bone

• at the ends of the diaphysis adjacent to the epiphyseal

cartilages of long bones

• at the site of a fracture.

Osteocytes

As bone develops, osteoblasts become trapped and remain isolated in lacunae. They stop forming new bone at this stage and are called osteocytes. Osteocytes are nourished by tissue fluid in the canaliculi that radiate from the Haversian canals. Their functions are not clear but they may be associated with the movement of calcium between the bones and the blood.

Osteoclasts

Their function is the resorption of bone to maintain the optimum shape. This takes place on bone surfaces:

• under the periosteum, to maintain the shape of bones during growth and to remove excess callus formed during the healing of fractures

• round the walls of the medullary canal during growth and canalize the callus during healing.

A fine balance of osteoblast and osteoclast activity maintains the normal bone structure and functions.

Development of bone tissue (osteogenesis or ossification)

This begins before birth and is not complete until about the 21st year of life. Long, short and irregular bones develop from rods of cartilage, cartilage models. Flat bones develop from membrane models and sesamoid bones from tendon models. Bone development consists of two processes:

• secretion by osteoblasts of osteoid, i.e. collagen fibers in a mucopolysaccharide matrix which gradually

replaces the original cartilage and membrane models

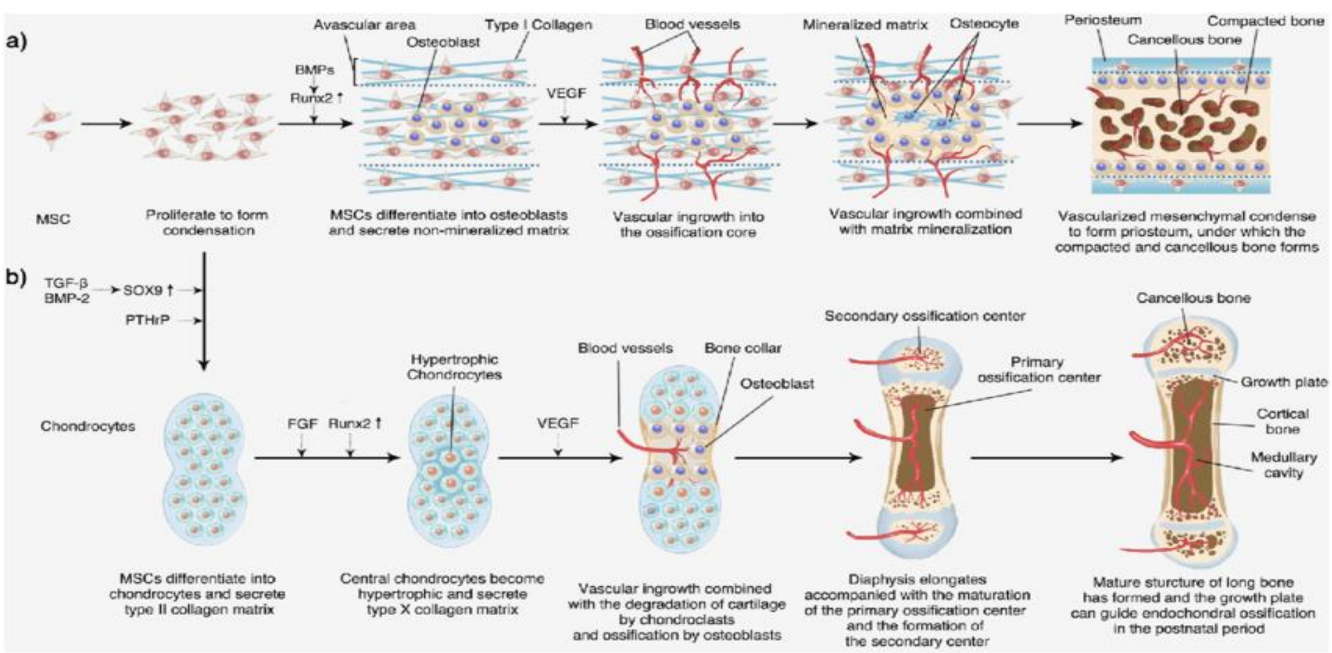
• calcification of osteoid immediately after its deposition.

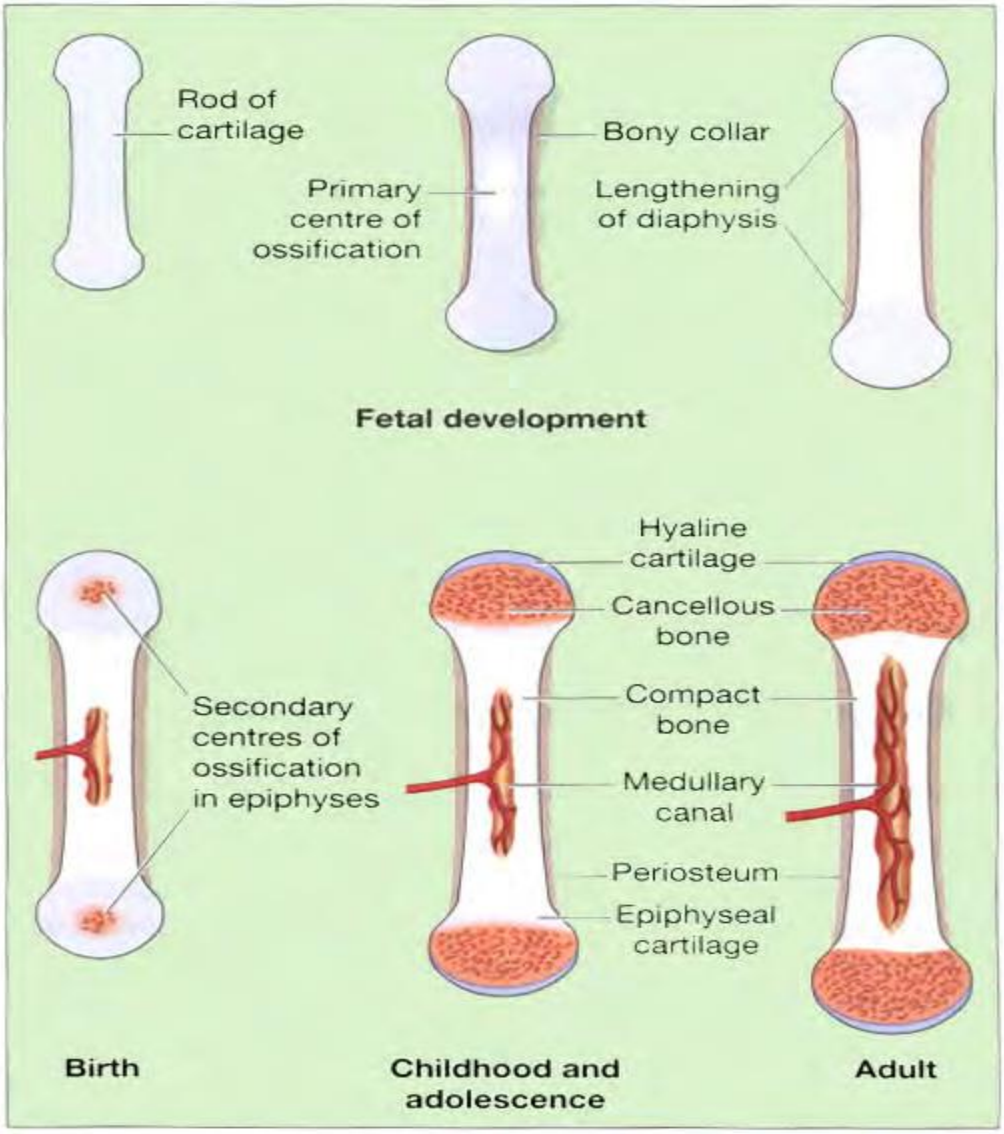
There are two types of arrangement of collagen in osteoid.

Woven (non-lamellar) bone. Collagen fibers are deposited in irregular bundles, then ossified.

This primitive bone structure is part of normal fetal development occurring during the ossification of bones that originate as membrane models, e.g. skull bones. In adults, it is also present in bone tumors and healing fractures. Lamellar bone. The collagen fibers are deposited as in woven bone, organized into characteristic lamellae found

in the compact and cancellous bone then ossified. This occurs when cartilage models are replaced by bone and in the healing of fractures.





The stages of development of a long bone.

Development of long bones

In long bones, the focal points from which ossification begins are small areas of osteogenic cells or centers of ossification in the cartilage model. This is accompanied by the development of a bone collar at about 8 weeks of gestation. Later the blood supply develops and bone tissue replaces cartilage as osteoblasts secrete osteoid components in the shaft. The bone lengthens as ossification continues and spreads to the epiphyses. Around birth, secondary centers of ossification develop in the epiphyses and the medullary canal forms when osteoclasts break down the central bone tissue in the middle of the shaft. After birth, the bone grows in length by ossification of the diaphyseal surface of the epiphyseal cartilages and growth is complete when the cartilages become completely ossified.

Hormonal regulation of bone growth

Hormones that regulate the growth and consistency of size and shape of bones include the following.

- Growth hormone and the thyroid hormones, thyroxine and triiodothyronine, are especially importantduring infancy and childhood; deficient or excessive secretion of these results in abnormal development of the skeleton.

• Testosterone and estrogens influence the physical changes that occur at puberty, i.e. the growth spurt and masculinizing or feminizing changes of specific parts of the skeleton, e.g. the pelvis.

• Calcitonin from the thyroid gland and parathyroid hormone from the parathyroid glands are involved in the homeostasis of blood and bone calcium levels required for bone development.

Although the length and shape of bones do not normally change after ossification is complete, bone tissue is continually being remodelled and replaced when damaged. Osteoblasts continue to lay down osteoid and osteoclasts reabsorb it. The rate in different bones varies, e.g. the distal part of the femur is replaced gradually over a period of 5 to 6 months.

Functions of bones

Bones have a variety of functions. They:

• provide the framework of the body

• give attachment to muscles and tendons

• permit movement of the body as a whole and of parts of the body, by forming joints that are moved by muscles

• form the boundaries of the cranial, thoracic and pelvic cavities, protecting the organs they contain

• contain red bone marrow in which blood cells develop hematopoiesis.

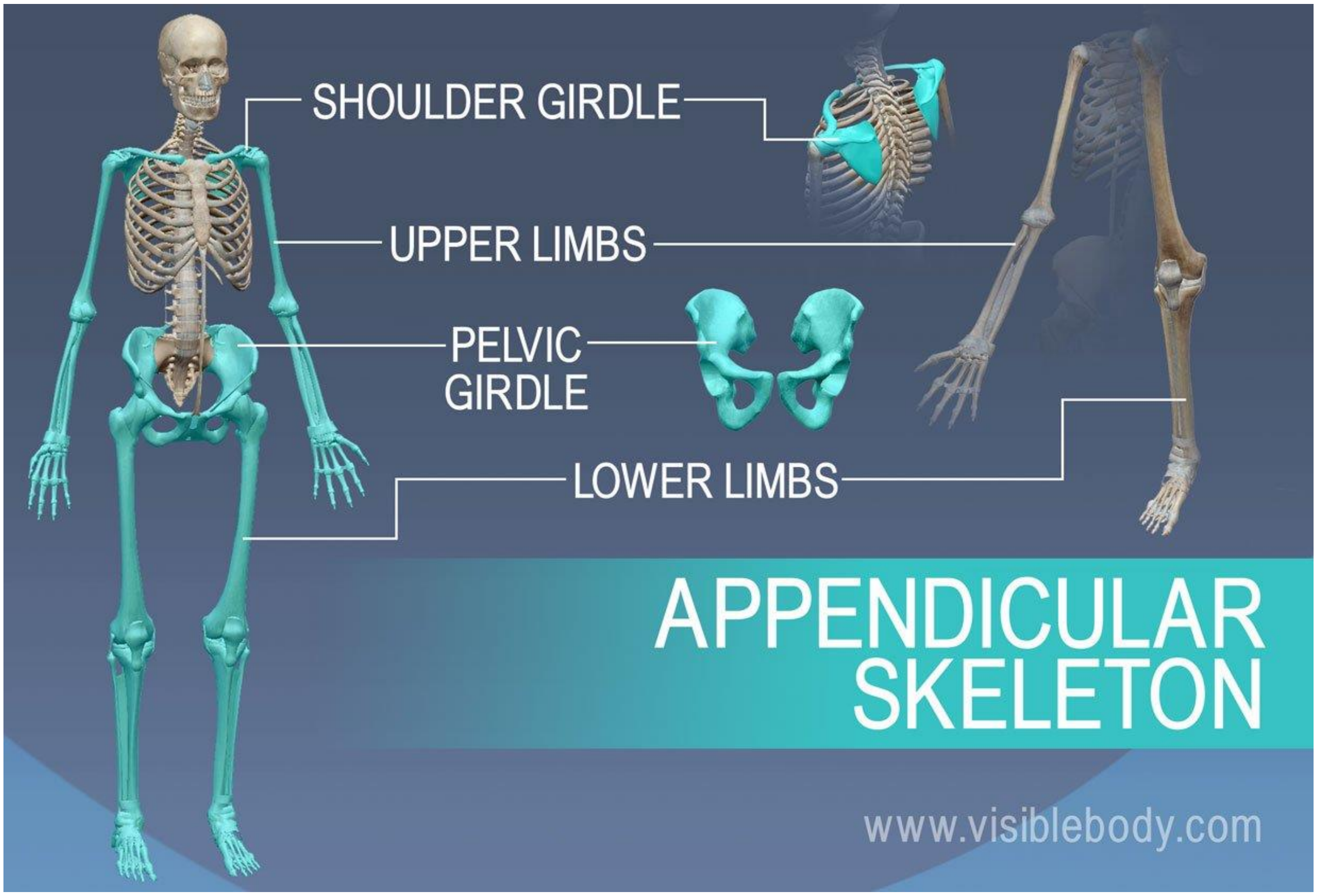
• provide a reservoir of minerals, especially calcium, phosphate.

AXIAL SKELETON:

This part consists of the skull, vertebral column, ribs and sternum. Together the bones forming these structures constitute the central bony core of the body, the axis.

APPENDICULAR SKELETON:

The appendicular skeleton consists of the shoulder girdle with the upper limbs and the pelvic girdle with the lower limbs.



Muscular System

Functions of the Muscular System

Producing movement is a common function of all muscle types, but skeletal muscle plays three other important roles in the body as well.

Producing movement. Mobility of the body as a whole reflects the activity of the skeletal muscles, which are responsible for all locomotion; they enable us to respond quickly to changes in the external environment.

Maintaining posture. We are rarely aware of the skeletal muscles that maintain body posture, yet they function almost continuously, making one tiny adjustment after another so that we can maintain an erect or seated posture despite the never-ending downward pull of gravity.

Stabilizing joints. As the skeletal muscles pull on bones to cause movements, they also stabilize the joints of the skeleton; muscle tendons are extremely important in reinforcing and stabilizing joints that have poorly fitting articulating surfaces.

Generating heat. The fourth function of muscle, generation of body heat, is a by-product of muscle activity; as ATP is used to power muscle contraction, nearly three-quarters of its energy escape as heat and this heat is vital in maintaining normal body temperature.

Muscles:

You control some muscles voluntarily with the help of your nervous system (your body's command center). You make them move by thinking about moving them.

Other muscles work involuntarily, which means you can't control them. They do their job automatically. In order to work, they take cues from other body systems, such as your digestive system or cardiovascular system.

There are three types of muscle tissue in the body. They are:

Skeletal: As part of the musculoskeletal system, these muscles work with your bones, tendons and ligaments. Tendons attach skeletal muscles to bones all over your body. Together, they support the weight of your body and help you move. You control these voluntary muscles. Some muscle fibers contract quickly and use short bursts of energy (fast-twitch muscles). Others move slowly, such as your back muscles that help with posture.

Cardiac: These muscles line the heart walls. They help your heart pump blood that travels through your cardiovascular system. You don’t control cardiac muscles. Your heart tells them when to contract.

Smooth: These muscles line the insides of organs such as the bladder, stomach and intestines. Smooth muscles play an important role in many body systems, including the female reproductive system, male reproductive system, urinary system and respiratory system. These types of muscles work without you having to think about them. They do essential jobs like move waste through your intestines and help your lungs expand when you breathe.

Function:

Muscles play a role in nearly every system and function of the body. Different kinds of muscles help with:

Breathing, speaking and swallowing.

Digesting food and getting rid of waste.

Moving, sitting still and standing up straight.

Pumping blood through the heart and blood vessels.

Pushing a baby through the birth canal as muscles in the uterus contract and relax.

Seeing and hearing.

Structure

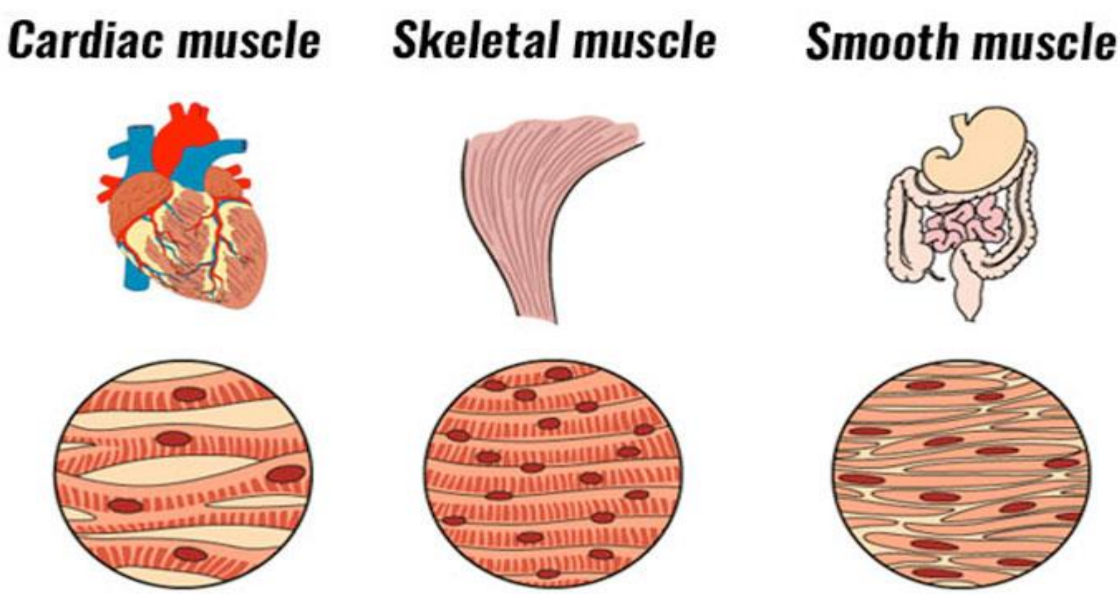
All types of muscle tissue look similar. But there are slight differences in their appearance:

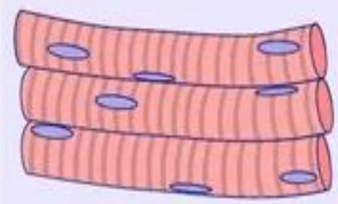
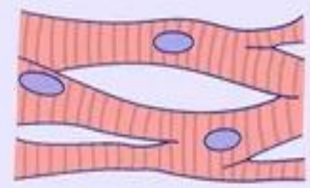
Skeletal muscles: Many individual fibers make up skeletal muscles. Actin and myosin are proteins that make up the fibers. The bundles of fibers form a spindle shape (long and straight with tapered ends). A membrane surrounds each spindle. Providers describe skeletal muscles as striated (striped) because of the striped pattern the spindles create together.

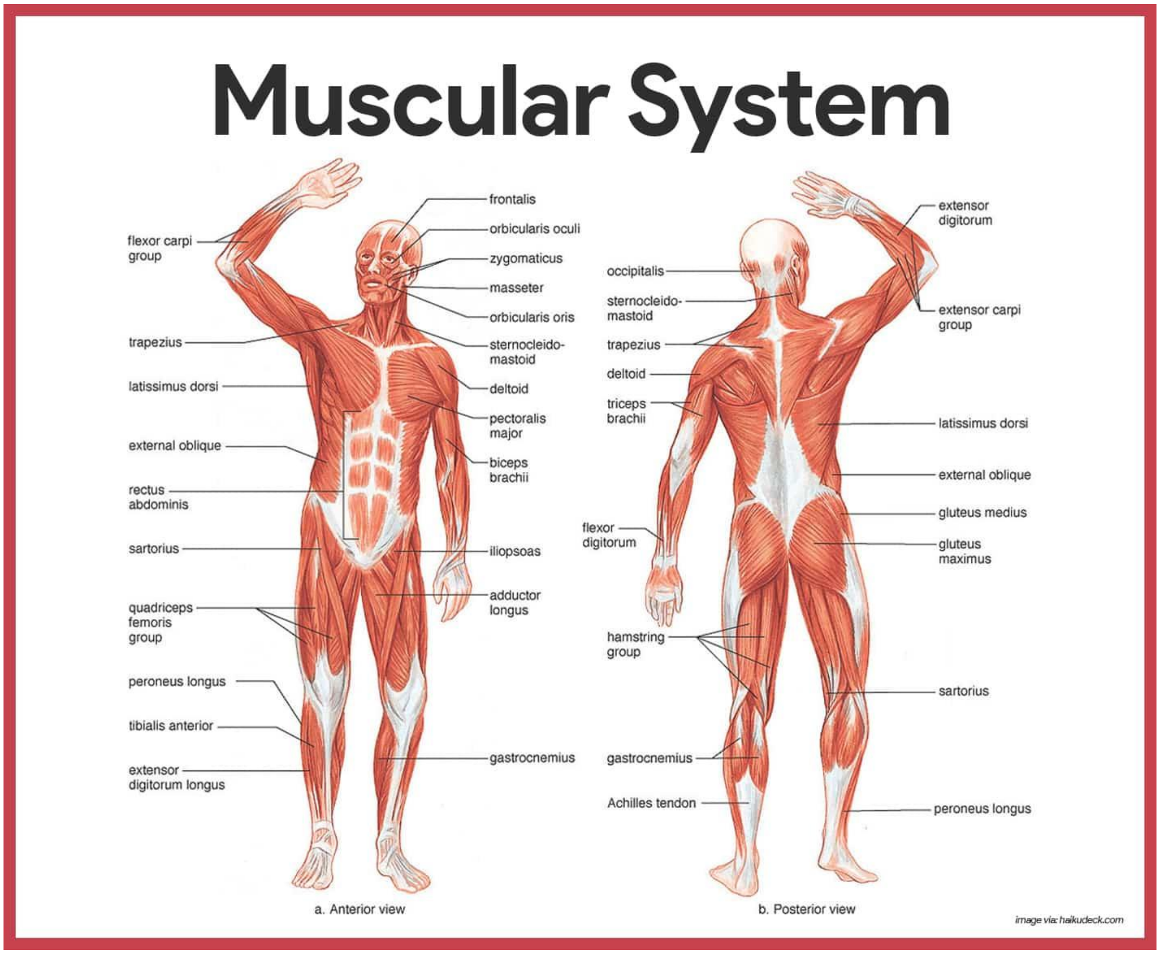
Cardiac muscles: These striated muscles look similar to skeletal muscles. Special cells called cardiomyocytes make up the fibers in cardiac muscles. Cardiomyocytes help your heart beat.

Smooth muscles: The proteins actin and myosin also make up smooth muscle fibers. In skeletal muscles, these proteins come together to form a spindle shape. In smooth muscles, these proteins appear in sheets. The sheets give this muscle tissue a smooth appearance.

You have all sizes of muscles in your body. The largest muscle is the gluteus maximus (the muscle that makes up your bottom). The smallest muscle is the stapedius, which is deep inside your ear. This tiny muscle helps you hear by controlling the vibration and movement of small bones in your ear.



	Main features	Histology
Skeletal muscle	• Fibers: striated, tubular and multi nucleated • Voluntary • Usually attached to skeleton	
Smooth muscle	• Fibers: non-striated, spindle-shaped, and uninucleated • Involuntary • Usually covering wall of internal organs	
Cardiac muscle	• Fibers: striated, branched and uninucleated • Involuntary • Only covering walls of the heart	



Skeletal muscle cells are multinucleate:

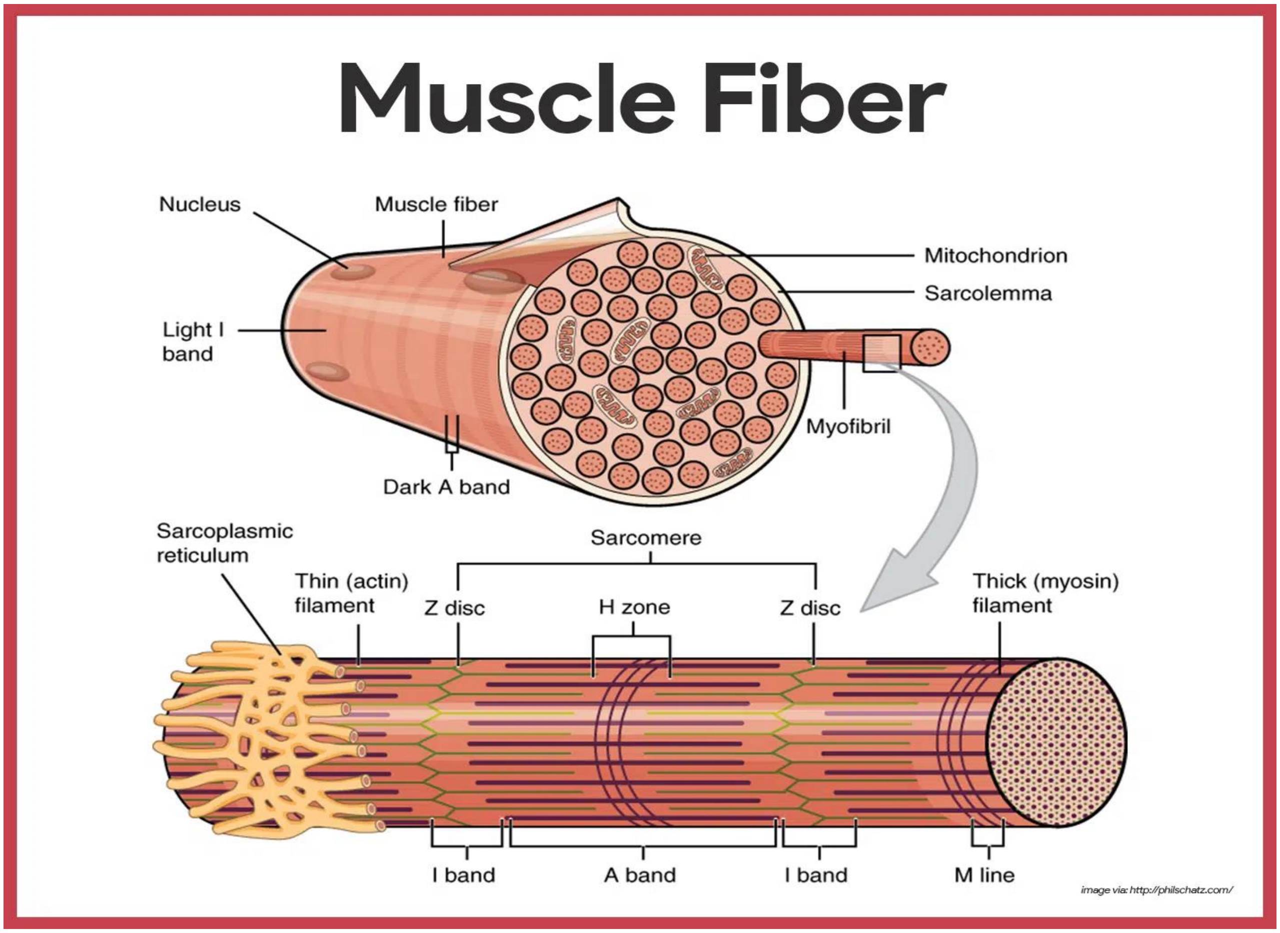
Sarcolemma. Many oval nuclei can be seen just beneath the plasma membrane, which is called the sarcolemma in muscle cells.

Myofibrils. The nuclei are pushed aside by long ribbonlike organelles, the myofibrils, which nearly fill the cytoplasm.

Light and dark bands. Alternating dark and light bands along the length of the perfectly aligned myofibrils give the muscle cell as a whole its striped appearance.

Sarcomeres. The myofibrils are actually chains of tiny contractile units called sarcomeres, which are aligned end to end like boxcars in a train along the length of the myofibrils.

Myofilaments. There are two types of threadlike protein myofilaments within each of our "boxcar" sarcomeres.



Thick filaments. The larger, thick filaments, also called myosin filaments, are made mostly of bundled molecules of the protein myosin, but they also contain ATPase enzymes, which split ATP to generate the power for muscle contraction.

Cross bridges. Notice that the midparts of the thick filaments are smooth, but their ends are studded with thick projections; these projections, or myosin beads, are called cross bridges when they link the thick and thin filaments together during contraction.

Thin filaments. The thin filaments are composed of the contractile protein called actin, plus some regulatory proteins that play a role in allowing (or preventing) myosin-bead binding to actin; the thin filaments, also called actin filaments, are anchored to the Z disc (a disclike membrane).

Sarcoplasmic reticulum. Another very important muscle fiber organelle is the sarcoplasmic reticulum, a specialized smooth endoplasmic reticulum; the interconnecting tubules and sacs of the SR surround each and every myofibril just as the sleeve of a loosely crocheted sweater surrounds your arm, and its major role is to store calcium and to release it on demand.

Muscle Contraction

The process of muscular contraction occurs over a number of key steps, including:

- Depolarisation and calcium ion release
- Actin and myosin cross-bridge formation
- Sliding mechanism of actin and myosin filaments
- Sarcomere shortening (muscle contraction)

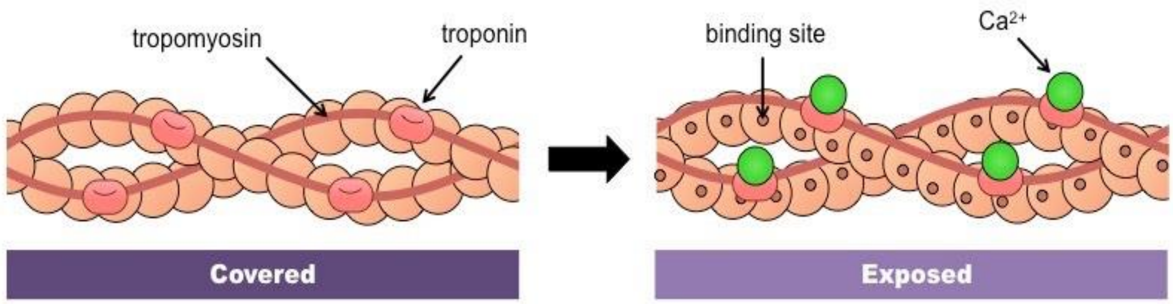
1. Depolarisation and Calcium Ion Release

- An action potential from a motor neuron triggers the release of acetylcholine into the motor end plate
- Acetylcholine initiates depolarisation within the sarcolemma, which is spread through the muscle fibre via T tubules
- Depolarisation causes the sarcoplasmic reticulum to release stores of calcium ions (Ca^{2+})
- Calcium ions play a pivotal role in initiating muscular contractions

2. Actin and Myosin Cross-Bridge Formation

- On actin, the binding sites for the myosin heads are covered by a blocking complex (troponin and tropomyosin)
- Calcium ions bind to troponin and reconfigure the complex, exposing the binding sites for the myosin heads
- The myosin heads then form a cross-bridge with the actin filaments

The Role of Calcium in Cross-Bridge Formation



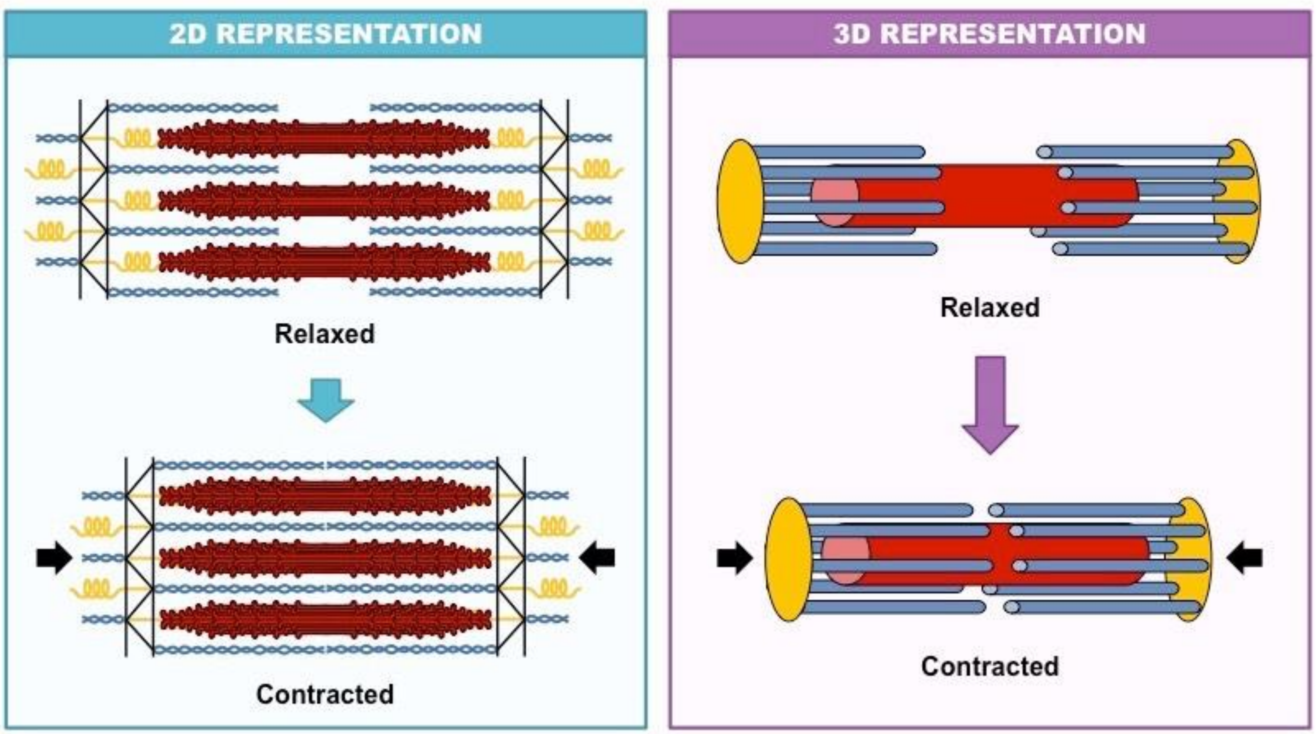
3. Sliding Mechanism of Actin and Myosin

- ATP binds to the myosin head, breaking the cross-bridge between actin and myosin
- ATP hydrolysis causes the myosin heads to change position and swivel, moving them towards the next actin binding site
- The myosin heads bind to the new actin sites and return to their original conformation
- This reorientation drags the actin along the myosin in a sliding mechanism
- The myosin heads move the actin filaments in a similar fashion to the way in which an oar propels a row boat

4. Sarcomere Shortening

- The repeated reorientation of the myosin heads drags the actin filaments along the length of the myosin
- As actin filaments are anchored to Z lines, the dragging of actin pulls the Z lines closer together, shortening the sarcomere
- As the individual sarcomeres become shorter in length, the muscle fibres as a whole contracts

<u>Diagrams of Sarcomere Shortening</u>



Summary of Muscle Contractions

- Action potential in a motor neuron triggers the release of Ca^{2+} ions from the sarcoplasmic reticulum
- Calcium ions bind to troponin (on actin) and cause tropomyosin to move, exposing binding sites for the myosin heads
- The actin filaments and myosin heads form a cross-bridge that is broken by ATP
- ATP hydrolysis causes the myosin heads to swivel and change orientation
- Swiveled myosin heads bind to the actin filament before returning to their original conformation (releasing ADP + Pi)
- The repositioning of the myosin heads move the actin filaments towards the centre of the sarcomere
- The sliding of actin along myosin therefore shortens the sarcomere, causing muscle contraction

The Endocrine System

you may never have thought of it this way, but when you send a text message to two friends to meet you at the dining hall at six, you're sending digital signals that (you hope) will affect their behavior—even though they are some distance away. Similarly, certain cells send chemical signals to other cells in the body that influence their behavior. This long-distance intercellular communication, coordination, and control is critical for homeostasis, and it is the fundamental function of the endocrine system.

Hormones of the endocrine system coordinate and control growth, metabolism, temperature regulation, the stress response, reproduction, and many other functions.

Hormones:

Although a given hormone may travel throughout the body in the bloodstream, it will affect the activity only of its target cells; that is, cells with receptors for that particular hormone. Once the hormone binds to the receptor, a chain of events is initiated that leads to the target cell's response. Hormones play a critical role in the regulation of physiological processes because of the target cell responses they regulate. These responses contribute to human reproduction, growth and development of body tissues, metabolism, fluid, and electrolyte balance, sleep, and many other body functions. The major hormones of the human body and their effects are identified in Table:

Table 1. Endocrine Glands and Their Major Hormones			
Endocrine gland	**Associated hormones**	**Chemical class**	**Effect**
Pituitary (anterior)	Growth hormone (GH)	Protein	Promotes growth of body tissues
Pituitary (anterior)	Prolactin (PRL)	Peptide	Promotes milk production
Pituitary (anterior)	Thyroid-stimulating hormone (TSH)	Glycoprotein	Stimulates thyroid hormone release
Pituitary (anterior)	Adrenocorticotropic hormone (ACTH)	Peptide	Stimulates hormone release by adrenal cortex

Table 1. Endocrine Glands and Their Major Hormones			
Endocrine gland	**Associated hormones**	**Chemical class**	**Effect**
Pituitary (anterior)	Follicle-stimulating hormone (FSH)	Glycoprotein	Stimulates gamete production
Pituitary (anterior)	Luteinizing hormone (LH)	Glycoprotein	Stimulates androgen production by gonads
Pituitary (posterior)	Antidiuretic hormone (ADH)	Peptide	Stimulates water reabsorption by kidneys
Pituitary (posterior)	Oxytocin	Peptide	Stimulates uterine contractions during childbirth

Table 1. Endocrine Glands and Their Major Hormones

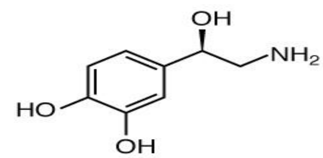
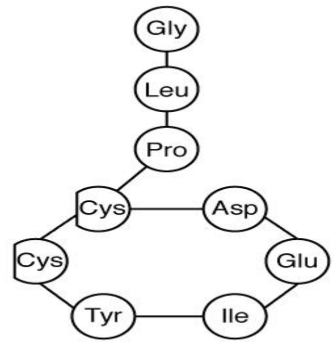
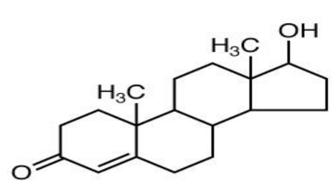
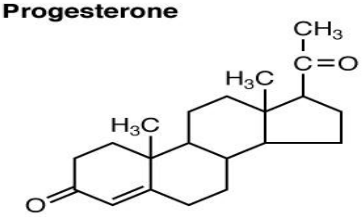
Endocrine gland	Associated hormones	Chemical class	Effect
Thyroid	Thyroxine (T_4), triiodothyronine (T_3)	Amine	Stimulate basal metabolic rate
Thyroid	Calcitonin	Peptide	Reduces blood Ca^{2+} levels
Parathyroid	Parathyroid hormone (PTH)	Peptide	Increases blood Ca^{2+} levels
Adrenal (cortex)	Aldosterone	Steroid	Increases blood Na^{+} levels
Adrenal (cortex)	Cortisol, corticosterone, cortisone	Steroid	Increase blood glucose levels

Table 1. Endocrine Glands and Their Major Hormones			
Endocrine gland	**Associated hormones**	**Chemical class**	**Effect**
Adrenal (medulla)	Epinephrine, norepinephrine	Amine	Stimulate fight-or-flight response
Pineal	Melatonin	Amine	Regulates sleep cycles
Pancreas	Insulin	Protein	Reduces blood glucose levels
Pancreas	Glucagon	Protein	Increases blood glucose levels
Testes	Testosterone	Steroid	Stimulates development of male secondary sex characteristics and sperm production

Table 1. Endocrine Glands and Their Major Hormones			
Endocrine gland	**Associated hormones**	**Chemical class**	**Effect**
Ovaries	Estrogens and progesterone	Steroid	Stimulate development of female secondary sex characteristics and prepare the body for childbirth

Types of Hormones

The hormones of the human body can be divided into two major groups on the basis of their chemical structure. Hormones derived from amino acids include amines, peptides, and proteins. Those derived from lipids include steroids (Figure 1). These chemical groups affect a hormone's distribution, the type of receptors it binds to, and other aspects of its function.

Hormone Class	Components	Example(s)
Amine Hormone	Amino acids with modified groups (e.g. norepinephrine's carboxyl group is replaced with a benzene ring)	**Norepinephrine** 
Peptide Hormone	Short chains of linked amino acids	**Oxytocin** 
Protein Hormone	Long chains of linked amino acids	**Human Growth Hormone** 
Steroid Hormones	Derived from the lipid cholesterol	**Testosterone**  **Progesterone** 

Amine Hormones

Hormones derived from the modification of amino acids are referred to as amine hormones. Typically, the original structure of the amino acid is modified such that a

$-COOH$

$-COOH$, or carboxyl, group is removed, whereas the

NH_3^+

$NH\ _3^+$

, or amine, group remains.

Amine hormones are synthesized from the amino acids tryptophan or tyrosine. An example of a hormone derived from tryptophan is melatonin, which is secreted by the pineal gland and helps regulate circadian rhythm. Tyrosine derivatives include the metabolism-regulating thyroid hormones, as well as the catecholamines, such as epinephrine, norepinephrine, and dopamine. Epinephrine and norepinephrine are secreted by the adrenal medulla and play a role in the fight-or-flight response, whereas dopamine is secreted by the hypothalamus and inhibits the release of certain anterior pituitary hormones.

Peptide and Protein Hormones

Whereas the amine hormones are derived from a single amino acid, peptide and protein hormones consist of multiple amino acids that link to form an amino acid chain. Peptide hormones consist of short chains of amino acids, whereas protein hormones are longer polypeptides. Both types are synthesized like other body proteins: DNA is transcribed into mRNA, which is translated into an amino acid chain.

Examples of peptide hormones include antidiuretic hormone (ADH), a pituitary hormone important in fluid balance, and atrial-natriuretic peptide, which is produced by the heart and helps to decrease blood pressure. Some examples of protein hormones include growth hormone, which is produced by the pituitary gland, and follicle-stimulating hormone (FSH), which has an attached carbohydrate group and is thus classified as a glycoprotein. FSH helps stimulate the maturation of eggs in the ovaries and sperm in the testes.

Steroid Hormones

The primary hormones derived from lipids are steroids. Steroid hormones are derived from the lipid cholesterol. For example, the reproductive hormones testosterone and the estrogens—which are produced by the gonads (testes and ovaries)—are steroid hormones. The adrenal glands produce the steroid hormone aldosterone, which is involved in osmoregulation, and cortisol, which plays a role in metabolism.

Like cholesterol, steroid hormones are not soluble in water (they are hydrophobic). Because blood is water-based, lipid-derived hormones must travel to their target cell bound to a transport protein. This more complex structure extends the half-life of steroid hormones much longer than that of hormones derived from amino acids. A hormone's half-life is the time required for half the concentration of the hormone to be degraded. For example, the lipid-derived hormone cortisol has a half-life of approximately 60 to 90 minutes. In contrast, the amino acid–derived hormone epinephrine has a half-life of approximately one minute.

Pathways of Hormone Action

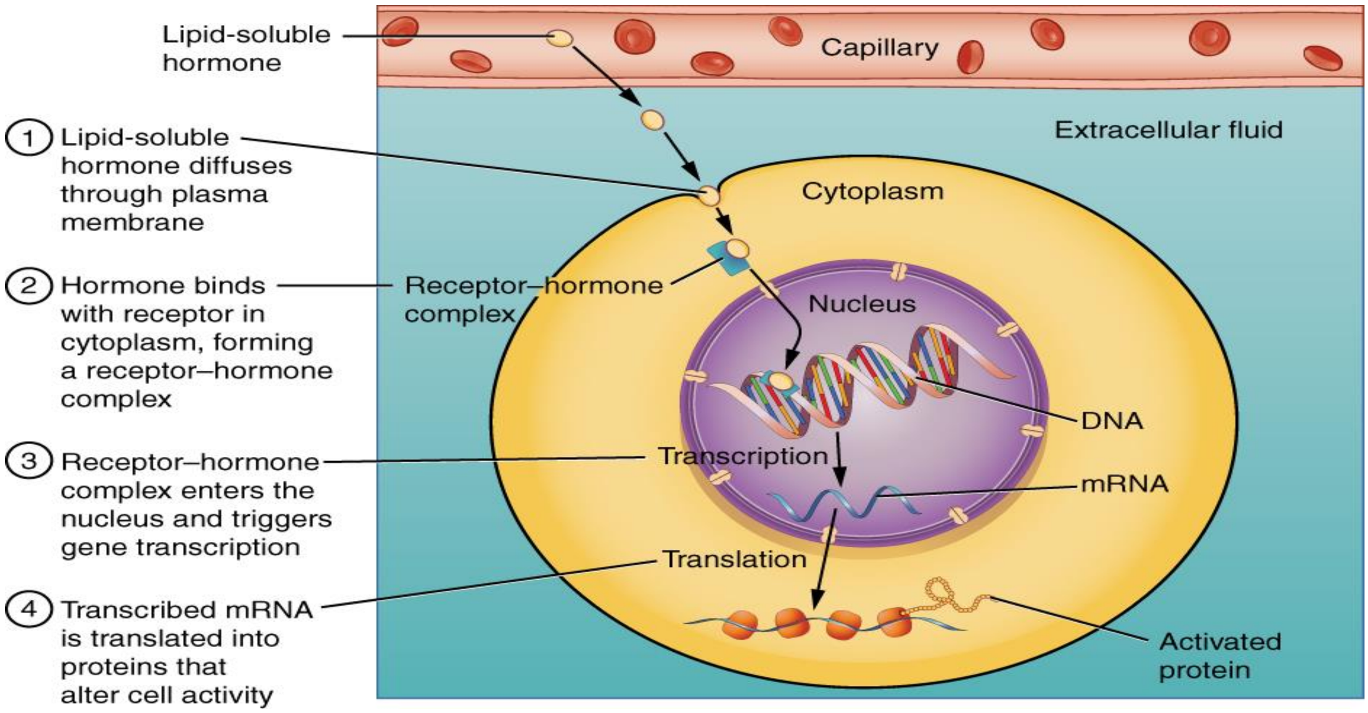
The message a hormone sends is received by a hormone receptor, a protein located either inside the cell or within the cell membrane. The receptor will process the message by initiating other signaling events or cellular mechanisms that result in the target cell's response. Hormone receptors recognize molecules with specific shapes and side groups, and respond only to those hormones that are recognized. The same type of receptor may be located on cells in different body tissues, and trigger somewhat different responses. Thus, the response triggered by a hormone depends not only on the hormone, but also on the target cell.

Once the target cell receives the hormone signal, it can respond in a variety of ways. The response may include the stimulation of protein synthesis, activation or deactivation of enzymes, alteration in the permeability of the cell membrane, altered rates of mitosis and cell growth, and stimulation of the secretion of products. Moreover, a single hormone may be capable of inducing different responses in a given cell.

Pathways Involving Intracellular Hormone Receptors

Intracellular hormone receptors are located inside the cell. Hormones that bind to this type of receptor must be able to cross the cell membrane. Steroid hormones are derived from cholesterol and therefore can readily diffuse through the lipid bilayer of the cell membrane to reach the intracellular receptor (Figure 2). Thyroid hormones, which contain benzene rings studded with iodine, are also lipid-soluble and can enter the cell.

The location of steroid and thyroid hormone binding differs slightly: a steroid hormone may bind to its receptor within the cytosol or within the nucleus. In either case, this binding generates a hormone-receptor complex that moves toward the chromatin in the cell nucleus and binds to a particular segment of the cell's DNA. In contrast, thyroid hormones bind to receptors already bound to DNA. For both steroid and thyroid hormones, binding of the hormone-receptor complex with DNA triggers transcription of a target gene to mRNA, which moves to the cytosol and directs protein synthesis by ribosomes.



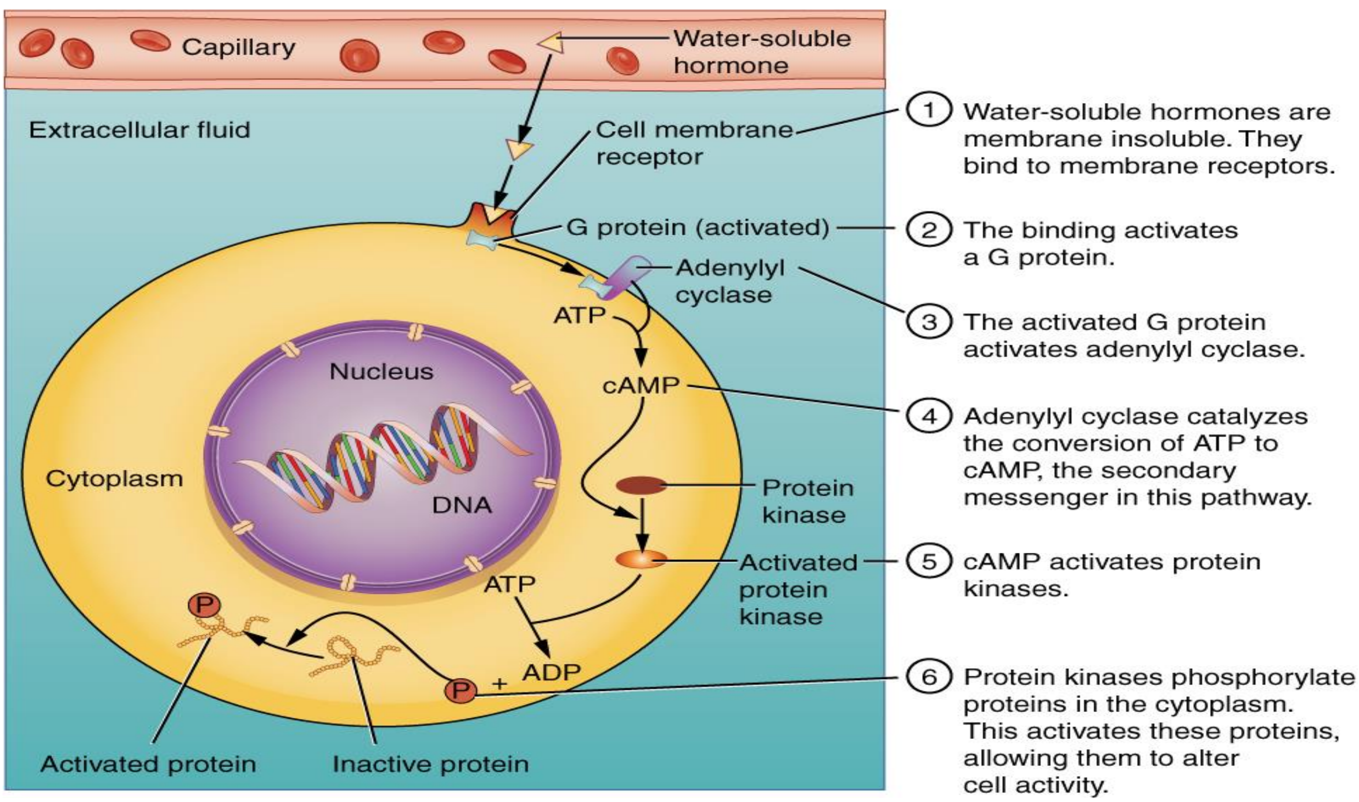
Binding of Lipid-Soluble Hormones

A steroid hormone directly initiates the production of proteins within a target cell. Steroid hormones easily diffuse through the cell membrane. The hormone binds to its receptor in the cytosol, forming a receptor–hormone complex. The receptor–hormone complex then enters the nucleus and binds to the target gene on the DNA. Transcription of the gene creates a messenger RNA that is translated into the desired protein within the cytoplasm.

Pathways Involving Cell Membrane Hormone Receptors

Hydrophilic, or water-soluble, hormones are unable to diffuse through the lipid bilayer of the cell membrane and must therefore pass on their message to a receptor located at the surface of the cell. Except for thyroid hormones, which are lipid-soluble, all amino acid–derived hormones bind to cell membrane receptors that are located, at least in part, on the extracellular surface of the cell membrane. Therefore, they do not directly affect the transcription of target genes, but instead initiate a signaling cascade that is carried out by a molecule called a second messenger. In this case, the hormone is called a first messenger.

The second messenger used by most hormones is cyclic adenosine monophosphate (cAMP). In the cAMP second messenger system, a water-soluble hormone binds to its receptor in the cell membrane (Step 1 in Figure 3). This receptor is associated with an intracellular component called a G protein, and binding of the hormone activates the G-protein component (Step 2). The activated G protein in turn activates an enzyme called adenylyl cyclase, also known as adenylate cyclase (Step 3), which converts adenosine triphosphate (ATP) to cAMP (Step 4). As the second messenger, cAMP activates a type of enzyme called a protein kinase that is present in the cytosol (Step 5). Activated protein kinases initiate a phosphorylation cascade, in which multiple protein kinases phosphorylate (add a phosphate group to) numerous and various cellular proteins, including other enzymes (Step 6).



Binding of Water-Soluble Hormones

Water-soluble hormones cannot diffuse through the cell membrane. These hormones must bind to a surface cell-membrane receptor. The receptor then initiates a cell-signaling pathway within the cell involving G proteins, adenylyl cyclase, the secondary messenger cyclic AMP (cAMP), and protein kinases. In the final step, these protein kinases phosphorylate proteins in the cytoplasm. This activates proteins in the cell that carry out the changes specified by the hormone.

The phosphorylation of cellular proteins can trigger a wide variety of effects, from nutrient metabolism to the synthesis of different hormones and other products. The effects vary according to the type of target cell, the G proteins and kinases involved, and the phosphorylation of proteins. Examples of hormones that use cAMP as a second messenger include calcitonin, which is important for bone construction and regulating blood calcium levels; glucagon, which plays a role in blood glucose levels; and thyroid-stimulating hormone, which causes the release of T_3 and T_4 from the thyroid gland.

Overall, the phosphorylation cascade significantly increases the efficiency, speed, and specificity of the hormonal response, as thousands of signaling events can be initiated simultaneously in response to a very low concentration of hormone in the bloodstream. However, the duration of the hormone signal is short, as cAMP is quickly deactivated by the enzyme **phosphodiesterase (PDE)**, which is located in the cytosol. The action of PDE helps to ensure that a target cell's response ceases quickly unless new hormones arrive at the cell membrane.

Importantly, there are also G proteins that decrease the levels of cAMP in the cell in response to hormone binding. For example, when growth hormone–inhibiting hormone (GHIH), also known as somatostatin, binds to its receptors in the pituitary gland, the level of cAMP decreases, thereby inhibiting the secretion of human growth hormone.

Not all water-soluble hormones initiate the cAMP second messenger system. One common alternative system uses calcium ions as a second messenger. In this system, G proteins activate the enzyme phospholipase C (PLC), which functions similarly to adenylyl cyclase. Once activated, PLC cleaves a membrane-bound phospholipid into two molecules: **diacylglycerol (DAG)** and **inositol triphosphate (IP_3)**. Like cAMP, DAG activates protein kinases that initiate a phosphorylation cascade. At the same time, IP_3 causes calcium ions to be released from storage sites within the cytosol, such as from within the smooth endoplasmic reticulum. The calcium ions then act as second messengers in two ways: they can influence enzymatic and other cellular activities directly, or they can bind to calcium-binding proteins, the most common of which is calmodulin. Upon binding calcium, calmodulin is able to modulate protein kinase within the cell. Examples of hormones that use calcium ions as a second messenger system include angiotensin II, which helps regulate blood pressure through vasoconstriction, and growth hormone–releasing hormone (GHRH), which causes the pituitary gland to release growth hormones.

Factors Affecting Target Cell Response

You will recall that target cells must have receptors specific to a given hormone if that hormone is to trigger a response. But several other factors influence the target cell response. For example, the presence of a significant level of a hormone circulating in the bloodstream can cause its target cells to decrease their number of receptors for that hormone. This process is called downregulation, and it allows cells to become less reactive to the excessive hormone levels. When the level of a hormone is chronically reduced, target cells engage in upregulation to increase their number of receptors. This process allows cells to be more sensitive to the hormone that is present. Cells can also alter the sensitivity of the receptors themselves to various hormones.

Two or more hormones can interact to affect the response of cells in a variety of ways. The three most common types of interaction are as follows:

The permissive effect, in which the presence of one hormone enables another hormone to act. For example, thyroid hormones have complex permissive relationships with certain reproductive hormones. A dietary deficiency of iodine, a component of thyroid hormones, can therefore affect reproductive system development and functioning.

The synergistic effect, in which two hormones with similar effects produce an amplified response. In some cases, two hormones are required for an adequate response. For example, two different reproductive hormones—FSH from the pituitary gland and estrogens from the ovaries—are required for the maturation of female ova (egg cells).

The antagonistic effect, in which two hormones have opposing effects. A familiar example is the effect of two pancreatic hormones, insulin and glucagon. Insulin increases the liver’s storage of glucose as glycogen, decreasing blood glucose, whereas glucagon stimulates the breakdown of glycogen stores, increasing blood glucose.

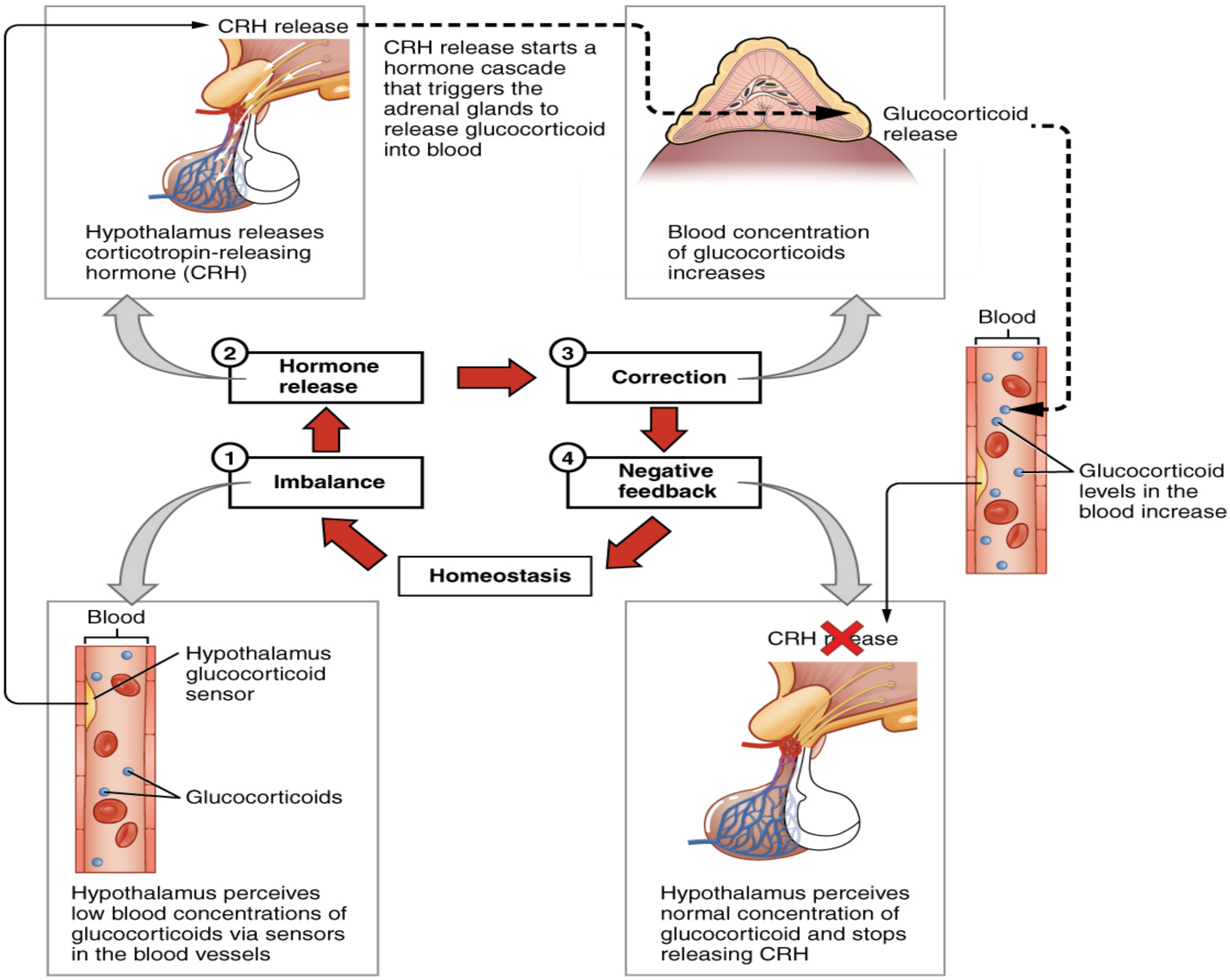
Regulation of Hormone Secretion

To prevent abnormal hormone levels and a potential disease state, hormone levels must be tightly controlled. The body maintains this control by balancing hormone production and degradation. Feedback loops govern the initiation and maintenance of most hormone secretion in response to various stimuli.

Role of Feedback Loops

The contribution of feedback loops to homeostasis will only be briefly reviewed here. Positive feedback loops are characterized by the release of additional hormone in response to an original hormone release. The release of oxytocin during childbirth is a positive feedback loop. The initial release of oxytocin begins to signal the uterine muscles to contract, which pushes the fetus toward the cervix, causing it to stretch. This, in turn, signals the pituitary gland to release more oxytocin, causing labor contractions to intensify. The release of oxytocin decreases after the birth of the child.

The more common method of hormone regulation is the negative feedback loop. Negative feedback is characterized by the inhibition of further secretion of a hormone in response to adequate levels of that hormone. This allows blood levels of the hormone to be regulated within a narrow range. An example of a negative feedback loop is the release of glucocorticoid hormones from the adrenal glands, as directed by the hypothalamus and pituitary gland. As glucocorticoid concentrations in the blood rise, the hypothalamus and pituitary gland reduce their signaling to the adrenal glands to prevent additional glucocorticoid secretion



Negative Feedback Loop

The release of adrenal glucocorticoids is stimulated by the release of hormones from the hypothalamus and pituitary gland. This signaling is inhibited when glucocorticoid levels become elevated by causing negative signals to the pituitary gland and hypothalamus.

Role of Endocrine Gland Stimuli

Reflexes triggered by both chemical and neural stimuli control endocrine activity. These reflexes may be simple, involving only one hormone response, or they may be more complex and involve many hormones, as is the case with the hypothalamic control of various anterior pituitary–controlled hormones.

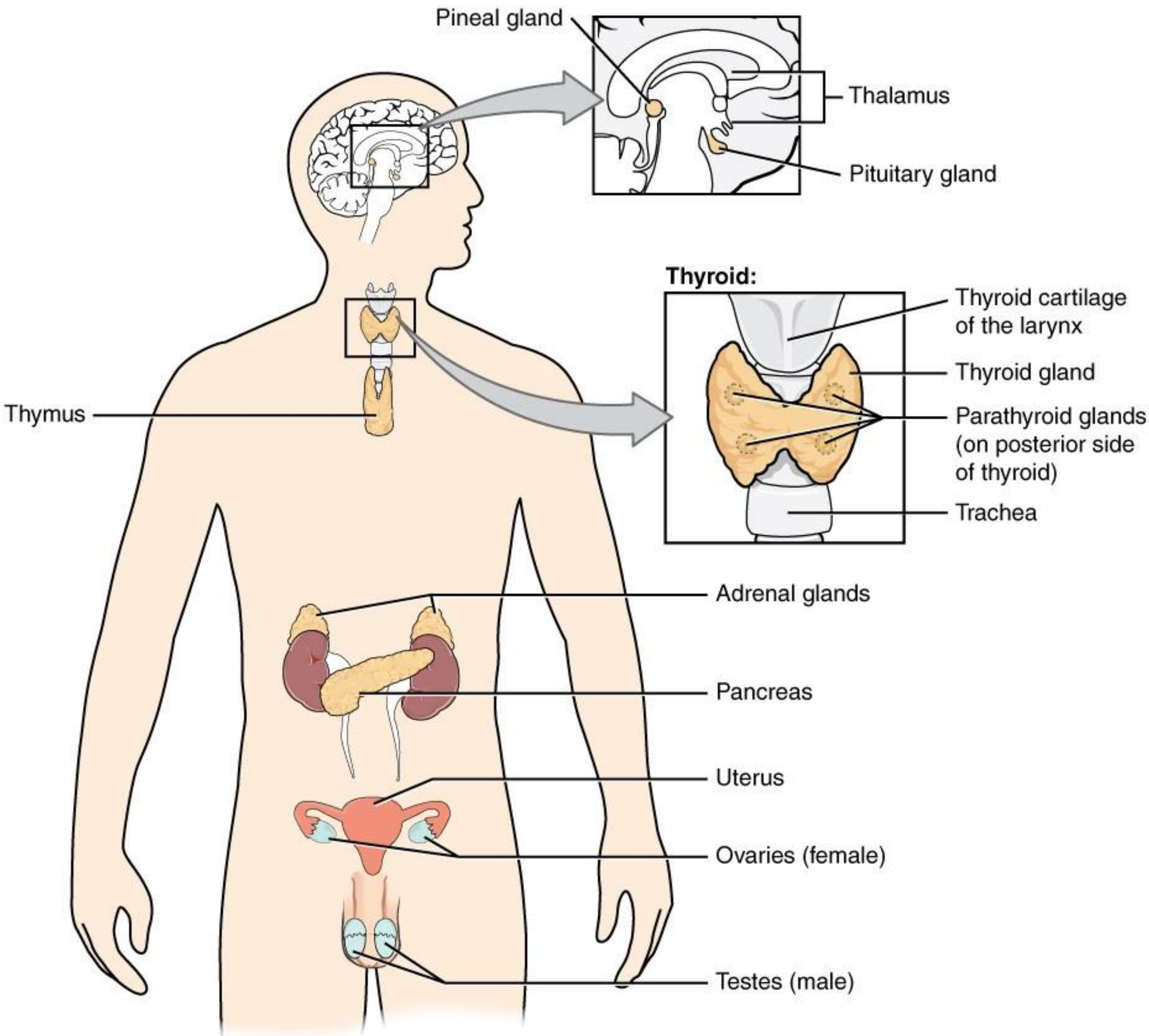
Humoral stimuli are changes in blood levels of non-hormone chemicals, such as nutrients or ions, which cause the release or inhibition of a hormone to, in turn, maintain homeostasis. For example, osmoreceptors in the hypothalamus detect changes in blood osmolarity (the concentration of solutes in the blood plasma). If blood osmolarity is too high, meaning that the blood is not dilute enough, osmoreceptors signal the hypothalamus to release ADH. The hormone causes the kidneys to reabsorb more water and reduce the volume of urine produced. This reabsorption causes a reduction of the osmolarity of the blood, diluting the blood to the appropriate level. The regulation of blood glucose is another example. High blood glucose levels cause the release of insulin from the pancreas, which increases glucose uptake by cells and liver storage of glucose as glycogen.

An endocrine gland may also secrete a hormone in response to the presence of another hormone produced by a different endocrine gland. Such hormonal stimuli often involve the hypothalamus, which produces releasing and inhibiting hormones that control the secretion of a variety of pituitary hormones.

In addition to these chemical signals, hormones can also be released in response to neural stimuli. A common example of neural stimuli is the activation of the fight-or-flight response by the sympathetic nervous system. When an individual perceives danger, sympathetic neurons signal the adrenal glands to secrete norepinephrine and epinephrine. The two hormones dilate blood vessels, increase the heart and respiratory rate, and suppress the digestive and immune systems. These responses boost the body's transport of oxygen to the brain and muscles, thereby improving the body's ability to fight or flee.

Neural and Endocrine Signaling

The nervous system uses two types of intercellular communication—electrical and chemical signaling—either by the direct action of an electrical potential, or in the latter case, through the action of chemical neurotransmitters such as serotonin or norepinephrine. Neurotransmitters act locally and rapidly. When an electrical signal in the form of an action potential arrives at the synaptic terminal, they diffuse across the synaptic cleft (the gap between a sending neuron and a receiving neuron or muscle cell). Once the neurotransmitters interact (bind) with receptors on the receiving (post-synaptic) cell, the receptor stimulation is transduced into a response such as continued electrical signaling or modification of cellular response. The target cell responds within milliseconds of receiving the chemical "message"; this response then ceases very quickly once the neural signaling ends. In this way, neural communication enables body functions that involve quick, brief actions, such as movement, sensation, and cognition.In contrast, the endocrine system uses just one method of communication: chemical signaling. These signals are sent by the endocrine organs, which secrete chemicals—the hormone—into the extracellular fluid. Hormones are transported primarily via the bloodstream throughout the body, where they bind to receptors on target cells, inducing a characteristic response. As a result, endocrine signaling requires more time than neural signaling to prompt a response in target cells, though the precise amount of time varies with different hormones. For example, the hormones released when you are confronted with a dangerous or frightening situation, called the fight-or-flight response, occur by the release of adrenal hormones—epinephrine and norepinephrine—within seconds. In contrast, it may take up to 48 hours for target cells to respond to certain reproductive hormones.



Endocrine glands and cells are located throughout the body and play an important role in homeostasis.

he ductless endocrine glands are not to be confused with the body’s exocrine system, whose glands release their secretions through ducts. Examples of exocrine glands include the sebaceous and sweat glands of the skin. As just noted, the pancreas also has an exocrine function: most of its cells secrete pancreatic juice through the pancreatic and accessory ducts to the lumen of the small intestine.

Pituitary Hormones			
Pituitary lobe	**Associated hormones**	**Chemical class**	**Effect**
Anterior	Growth hormone (GH)	Protein	Promotes growth of body tissues
Anterior	Prolactin (PRL)	Peptide	Promotes milk production from mammary glands
Anterior	Thyroid-stimulating hormone (TSH)	Glycoprotein	Stimulates thyroid hormone release from thyroid
Anterior	Adrenocorticotropic hormone (ACTH)	Peptide	Stimulates hormone release by adrenal cortex
Anterior	Follicle-stimulating hormone (FSH)	Glycoprotein	Stimulates gamete production in gonads

Pituitary Hormones			
Pituitary lobe	**Associated hormones**	**Chemical class**	**Effect**
Anterior	Luteinizing hormone (LH)	Glycoprotein	Stimulates androgen production by gonads
Posterior	Antidiuretic hormone (ADH)	Peptide	Stimulates water reabsorption by kidneys
Posterior	Oxytocin	Peptide	Stimulates uterine contractions during childbirth
Intermediate zone	Melanocyte-stimulating hormone	Peptide	Stimulates melanin formation in melanocytes

thyroid Hormones		
Associated hormones	**Chemical class**	**Effect**
Thyroxine (T_4), triiodothyronine (T_3)	Amine	Stimulate basal metabolic rate
Calcitonin	Peptide	Reduces blood Ca^{2+} levels

Functions of Thyroid Hormones

The thyroid hormones, T3 and T4, are often referred to as metabolic hormones because their levels influence the body's basal metabolic rate, the amount of energy used by the body at rest. When T3 and T4 bind to intracellular receptors located on the mitochondria, they cause an increase in nutrient breakdown and the use of oxygen to produce ATP. In addition, T3 and T4 initiate the transcription of genes involved in glucose oxidation. Although these mechanisms prompt cells to produce more ATP, the process is inefficient, and an abnormally increased level of heat is released as a byproduct of these reactions. This so-called calorigenic effect (calor- = "heat") raises body temperature.

Adequate levels of thyroid hormones are also required for protein synthesis and for fetal and childhood tissue development and growth. They are especially critical for normal development of the nervous system both in utero and in early childhood, and they continue to support neurological function in adults. As noted earlier, these thyroid hormones have a complex interrelationship with reproductive hormones, and deficiencies can influence libido, fertility, and other aspects of reproductive function. Finally, thyroid hormones increase the body's sensitivity to catecholamines (epinephrine and norepinephrine) from the adrenal medulla by upregulation of receptors in the blood vessels. When levels of T3 and T4 hormones are excessive, this effect accelerates the heart rate, strengthens the heartbeat, and increases blood pressure. Because thyroid hormones regulate metabolism, heat production, protein synthesis, and many other body functions, thyroid disorders can have severe and widespread consequences.

Calcitonin

The thyroid gland also secretes a hormone called calcitonin that is produced by the parafollicular cells (also called C cells) that stud the tissue between distinct follicles. Calcitonin is released in response to a rise in blood calcium levels. It appears to have a function in decreasing blood calcium concentrations by:

Inhibiting the activity of osteoclasts, bone cells that release calcium into the circulation by degrading bone matrix

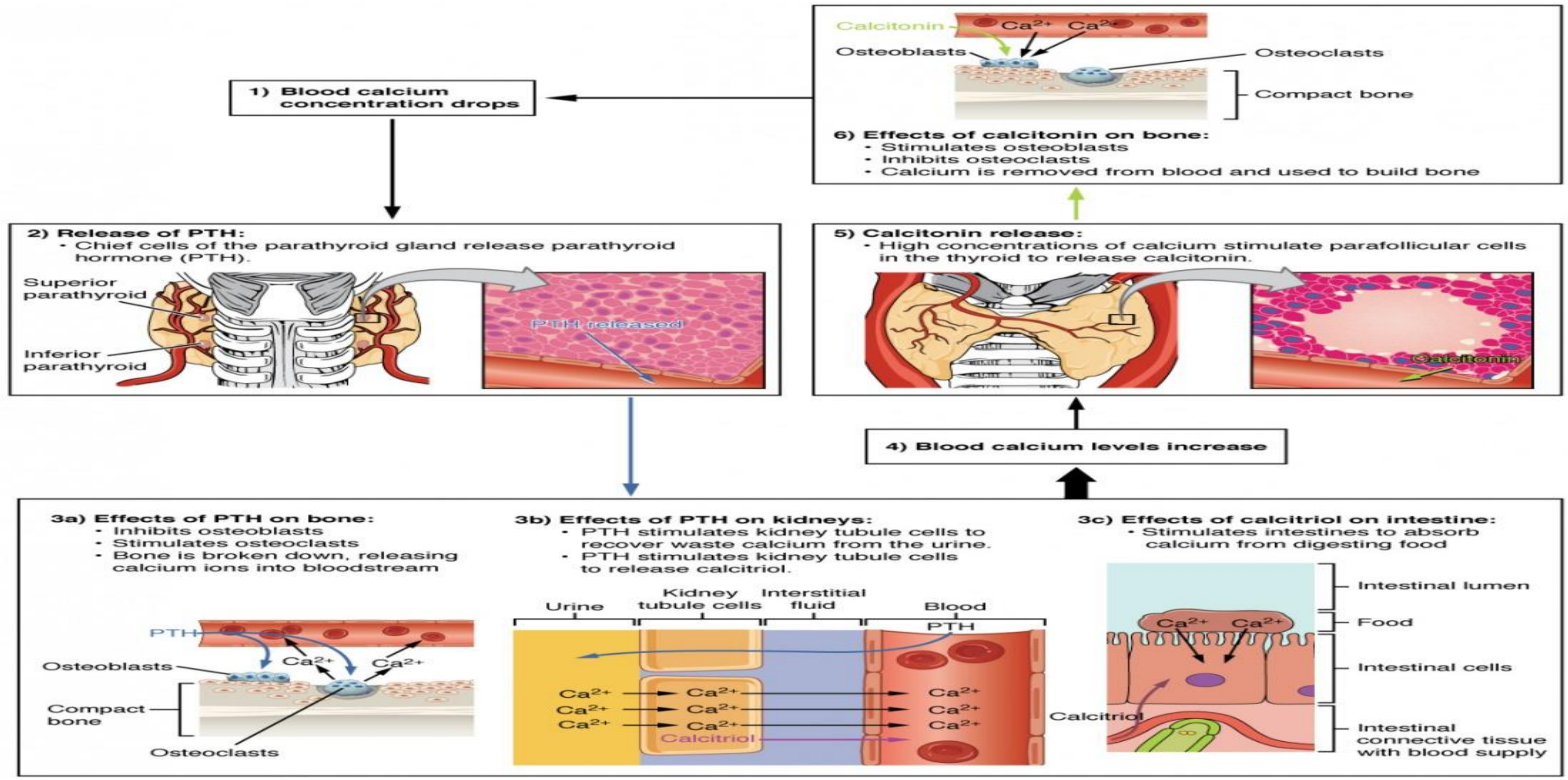
Increasing osteoblastic activity

Decreasing calcium absorption in the intestines

Increasing calcium loss in the urine

Function of parathyroid hormone:

The parathyroid glands produce and secrete PTH, a peptide hormone, in response to low blood calcium levels. PTH secretion causes the release of calcium from the bones by stimulating osteoclasts, which secrete enzymes that degrade bone and release calcium into the interstitial fluid. PTH also inhibits osteoblasts, the cells involved in bone deposition, thereby sparing blood calcium. PTH causes increased reabsorption of calcium (and magnesium) in the kidney tubules from the urine filtrate. In addition, PTH initiates the production of the steroid hormone calcitriol (also known as 1,25-dihydroxyvitamin D), which is the active form of vitamin D3, in the kidneys. Calcitriol then stimulates increased absorption of dietary calcium by the intestines. A negative feedback loop regulates the levels of PTH, with rising blood calcium levels inhibiting further release of PTH.



Parathyroid hormone increases blood calcium levels when they drop too low. Conversely, calcitonin, which is released from the thyroid gland, decreases blood calcium levels when they become too high. These two mechanisms constantly maintain blood calcium concentration at homeostasis.

Hormones of the Adrenal Glands			
Adrenal gland	**Associated hormones**	**Chemical class**	**Effect**
Adrenal cortex	Aldosterone	Steroid	Increases blood Na^+ levels
Adrenal cortex	Cortisol, corticosterone, cortisone	Steroid	Increase blood glucose levels
Adrenal medulla	Epinephrine, norepinephrine	Amine	Stimulate fight-or-flight response

pineal gland

Recall that the hypothalamus, part of the diencephalon of the brain, sits inferior and somewhat anterior to the thalamus. Inferior but somewhat posterior to the thalamus is the **pineal gland**, a tiny endocrine gland whose functions are not entirely clear. The **pinealocyte** cells that make up the pineal gland are known to produce and secrete the amine hormone **melatonin**, which is derived from serotonin.

The secretion of melatonin varies according to the level of light received from the environment. When photons of light stimulate the retinas of the eyes, a nerve impulse is sent to a region of the hypothalamus called the suprachiasmatic nucleus (SCN), which is important in regulating biological rhythms. From the SCN, the nerve signal is carried to the spinal cord and eventually to the pineal gland, where the production of melatonin is inhibited. As a result, blood levels of melatonin fall, promoting wakefulness. In contrast, as light levels decline—such as during the evening—melatonin production increases, boosting blood levels and causing drowsiness.

Reproductive Hormones			
Gonad	**Associated hormones**	**Chemical class**	**Effect**
Testes	Testosterone	Steroid	Stimulates development of male secondary sex characteristics and sperm production
Testes	Inhibin	Protein	Inhibits FSH release from pituitary
Ovaries	Estrogens and progesterone	Steroid	Stimulate development of female secondary sex characteristics and prepare the body for childbirth
Placenta	Human chorionic gonadotropin	Protein	Promotes progesterone synthesis during pregnancy and inhibits immune response against fetus

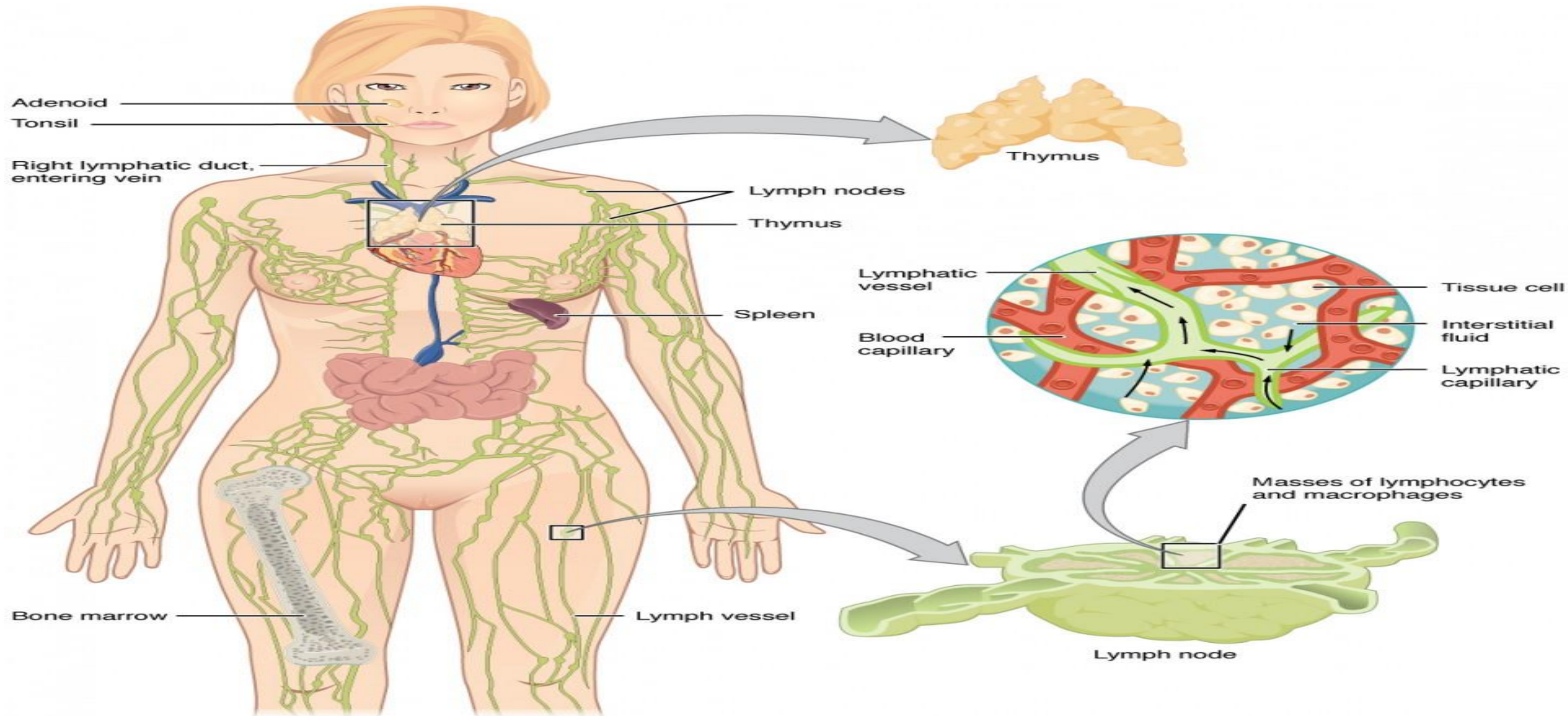
Hormones of the Pancreas		
Associated hormones	**Chemical class**	**Effect**
Insulin (beta cells)	Protein	Reduces blood glucose levels
Glucagon (alpha cells)	Protein	Increases blood glucose levels
Somatostatin (delta cells)	Protein	Inhibits insulin and glucagon release
Pancreatic polypeptide (PP cells)	Protein	Role in appetite

Organs with Secondary Endocrine Functions and Their Major Hormones		
Organ	**Major hormones**	**Effects**
Heart	Atrial natriuretic peptide (ANP)	Reduces blood volume, blood pressure, and Na^{+} concentration
Gastrointestinal tract	Gastrin, secretin, and cholecystokinin	Aid digestion of food and buffering of stomach acids
Gastrointestinal tract	Glucose-dependent insulinotropic peptide (GIP) and glucagon-like peptide 1 (GLP-1)	Stimulate beta cells of the pancreas to release insulin
Kidneys	Renin	Stimulates release of aldosterone
Kidneys	Calcitriol	Aids in the absorption of Ca^{2+}

Organs with Secondary Endocrine Functions and Their Major Hormones		
Organ	**Major hormones**	**Effects**
Kidneys	Erythropoietin	Triggers the formation of red blood cells in the bone marrow
Skeleton	FGF23	Inhibits production of calcitriol and increases phosphate excretion
Skeleton	Osteocalcin	Increases insulin production
Adipose tissue	Leptin	Promotes satiety signals in the brain
Adipose tissue	Adiponectin	Reduces insulin resistance

Organs with Secondary Endocrine Functions and Their Major Hormones		
Organ	**Major hormones**	**Effects**
Skin	Cholecalciferol	Modified to form vitamin D
Thymus (and other organs)	Thymosins	Among other things, aids in the development of T lymphocytes of the immune system
Liver	Insulin-like growth factor-1	Stimulates bodily growth
Liver	Angiotensinogen	Raises blood pressure
Liver	Thrombopoetin	Causes increase in platelets
Liver	Hepcidin	Blocks release of iron into body fluids

The Lymphatic and Immune Systems



The immune system is the complex collection of cells and organs that destroys or neutralizes pathogens that would otherwise cause disease or death. The lymphatic system, for most people, is associated with the immune system to such a degree that the two systems are virtually indistinguishable. The lymphatic system is the system of vessels, cells, and organs that carries excess fluids to the bloodstream and filters pathogens from the blood. The swelling of lymph nodes during an infection and the transport of lymphocytes via the lymphatic vessels are but two examples of the many connections between these critical organ systems.

Functions of the Lymphatic System

A major function of the lymphatic system is to drain body fluids and return them to the bloodstream. Blood pressure causes leakage of fluid from the capillaries, resulting in the accumulation of fluid in the interstitial space—that is, spaces between individual cells in the tissues. In humans, 20 liters of plasma is released into the interstitial space of the tissues each day due to capillary filtration. Once this filtrate is out of the bloodstream and in the tissue spaces, it is referred to as interstitial fluid. Of this, 17 liters is reabsorbed directly by the blood vessels. But what happens to the remaining three liters? This is where the lymphatic system comes into play. It drains the excess fluid and empties it back into the bloodstream via a series of vessels, trunks, and ducts. Lymph is the term used to describe interstitial fluid once it has entered the lymphatic system. When the lymphatic system is damaged in some way, such as by being blocked by cancer cells or destroyed by injury, protein-rich interstitial fluid accumulates (sometimes "backs up" from the lymph vessels) in the tissue spaces. This inappropriate accumulation of fluid referred to as lymphedema may lead to serious medical consequences.

As the vertebrate immune system evolved, the network of lymphatic vessels became convenient avenues for transporting the cells of the immune system. Additionally, the transport of dietary lipids and fat-soluble vitamins absorbed in the gut uses this system.

Cells of the immune system not only use lymphatic vessels to make their way from interstitial spaces back into the circulation, but they also use lymph nodes as major staging areas for the development of critical immune responses. A lymph node is one of the small, bean-shaped organs located throughout the lymphatic system.

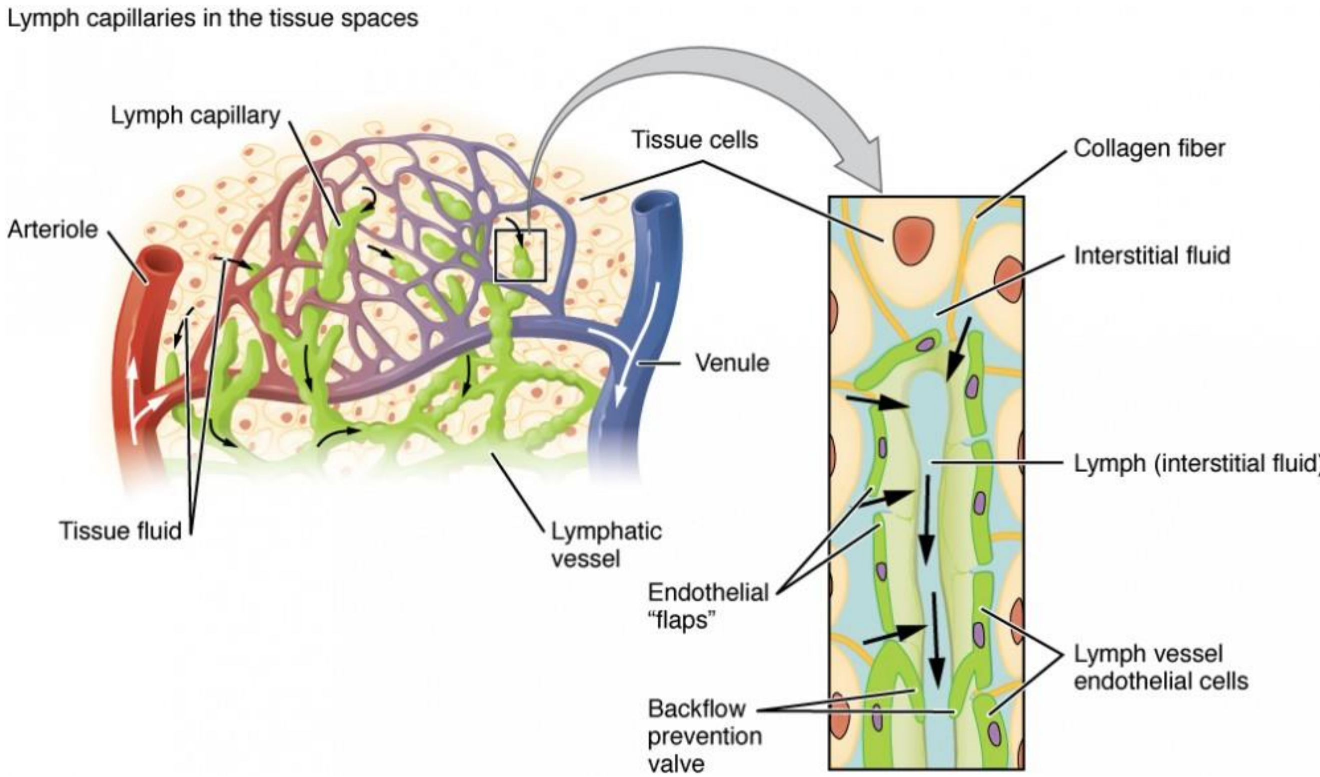
Structure of the Lymphatic System

The lymphatic vessels begin as open-ended capillaries, which feed into larger and larger lymphatic vessels, and eventually empty into the bloodstream by a series of ducts. Along the way, the lymph travels through the lymph nodes, which are commonly found near the groin, armpits, neck, chest, and abdomen. Humans have about 500–600 lymph nodes throughout the body.

A major distinction between the lymphatic and cardiovascular systems in humans is that lymph is not actively pumped by the heart, but is forced through the vessels by the movements of the body, the contraction of skeletal muscles during body movements, and breathing. One-way valves (semi-lunar valves) in lymphatic vessels keep the lymph moving toward the heart. Lymph flows from the lymphatic capillaries, through lymphatic vessels, and then is dumped into the circulatory system via the lymphatic ducts located at the junction of the jugular and subclavian veins in the neck.

Lymphatic Capillaries

Lymphatic capillaries, also called the terminal lymphatics, are vessels where interstitial fluid enters the lymphatic system to become lymph fluid. Located in almost every tissue in the body, these vessels are interlaced among the arterioles and venules of the circulatory system in the soft connective tissues of the body. Exceptions are the central nervous system, bone marrow, bones, teeth, and the cornea of the eye, which do not contain lymph vessels.



Lymphatic capillaries are interlaced with the arterioles and venules of the cardiovascular system. Collagen fibers anchor a lymphatic capillary in the tissue (inset). Interstitial fluid slips through spaces between the overlapping endothelial cells that compose the lymphatic capillary.

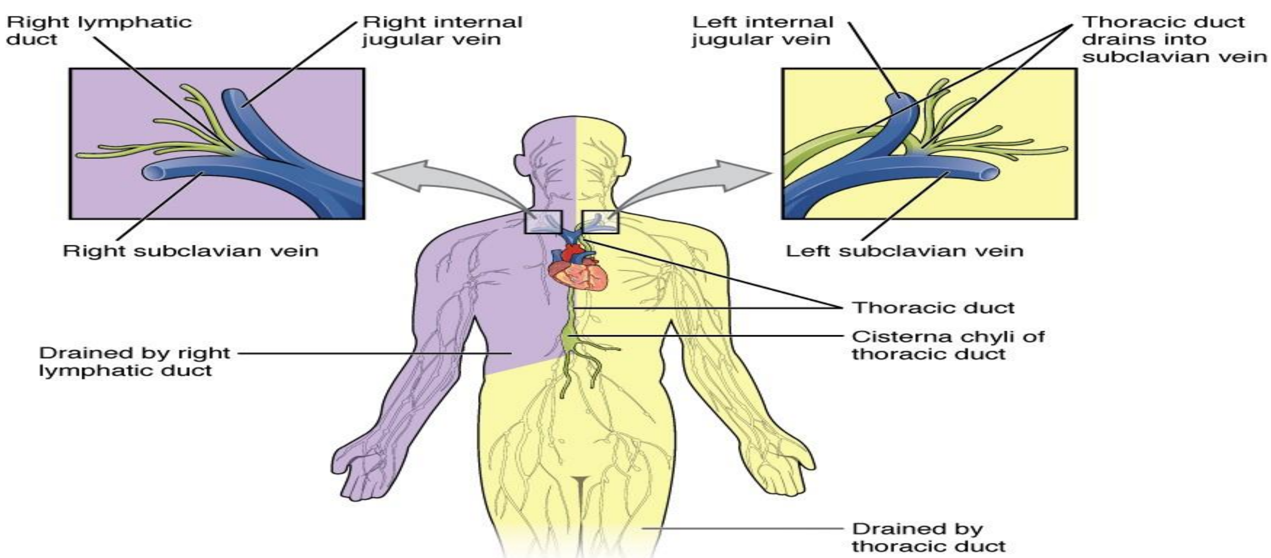
Lymphatic capillaries are formed by a one cell-thick layer of endothelial cells and represent the open end of the system, allowing interstitial fluid to flow into them via overlapping cells. When interstitial pressure is low, the endothelial flaps close to prevent "backflow." As interstitial pressure increases, the spaces between the cells open up, allowing the fluid to enter. Entry of fluid into lymphatic capillaries is also enabled by the collagen filaments that anchor the capillaries to surrounding structures. As interstitial pressure increases, the filaments pull on the endothelial cell flaps, opening up them even further to allow easy entry of fluid.

In the small intestine, lymphatic capillaries called lacteals are critical for the transport of dietary lipids and lipid-soluble vitamins to the bloodstream. In the small intestine, dietary triglycerides combine with other lipids and proteins, and enter the lacteals to form a milky fluid called chyle. The chyle then travels through the lymphatic system, eventually entering the liver and then the bloodstream.

Larger Lymphatic Vessels, Trunks, and Ducts

The lymphatic capillaries empty into larger lymphatic vessels, which are similar to veins in terms of their three-tunic structure and the presence of valves. These one-way valves are located fairly close to one another, and each one causes a bulge in the lymphatic vessel, giving the vessels a beaded appearance.

The superficial and deep lymphatics eventually merge to form larger lymphatic vessels known as lymphatic trunks. On the right side of the body, the right sides of the head, thorax, and right upper limb drain lymph fluid into the right subclavian vein via the right lymphatic duct. On the left side of the body, the remaining portions of the body drain into the larger thoracic duct, which drains into the left subclavian vein. The thoracic duct itself begins just beneath the diaphragm in the cisterna chyli, a sac-like chamber that receives lymph from the lower abdomen, pelvis, and lower limbs by way of the left and right lumbar trunks and the intestinal trunk.



The thoracic duct drains a much larger portion of the body than does the right lymphatic duct.

The overall drainage system of the body is asymmetrical. The right lymphatic duct receives lymph from only the upper right side of the body. The lymph from the rest of the body enters the bloodstream through the thoracic duct via all the remaining lymphatic trunks. In general, lymphatic vessels of the subcutaneous tissues of the skin, that is, the superficial lymphatics, follow the same routes as veins, whereas the deep lymphatic vessels of the viscera generally follow the paths of arteries.

The Organization of Immune Function

The immune system is a collection of barriers, cells, and soluble proteins that interact and communicate with each other in extraordinarily complex ways. The modern model of immune function is organized into three phases based on the timing of their effects. The three temporal phases consist of the following:

Barrier defenses such as the skin and mucous membranes, which act instantaneously to prevent pathogenic invasion into the body tissues

The rapid but nonspecific innate immune response, which consists of a variety of specialized cells and soluble factors

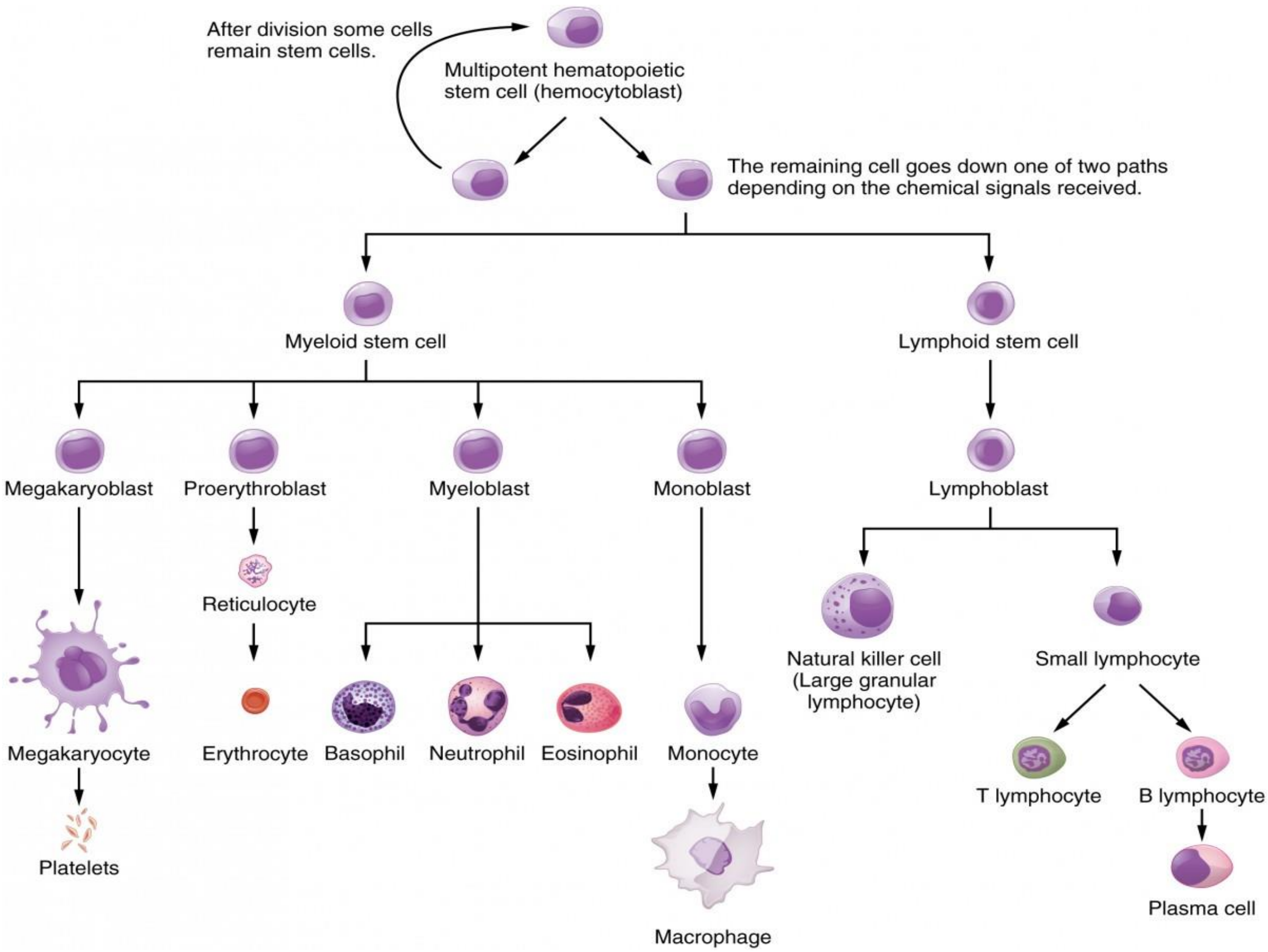
The slower but more specific and effective adaptive immune response, which involves many cell types and soluble factors, but is primarily controlled by white blood cells (leukocytes) known as lymphocytes, which help control immune responses.

The cells of the blood, including all those involved in the immune response, arise in the bone marrow via various differentiation pathways from hematopoietic stem cells. In contrast with embryonic stem cells, hematopoietic stem cells are present throughout adulthood and allow for the continuous differentiation of blood cells to replace those lost to age or function. These cells can be divided into three classes based on function:

Phagocytic cells, which ingest pathogens to destroy them

Lymphocytes, which specifically coordinate the activities of adaptive immunity

Cells containing cytoplasmic granules, which help mediate immune responses against parasites and intracellular pathogens such as viruses.



All the cells of the immune response as well as of the blood arise by differentiation from hematopoietic stem cells. Platelets are cell fragments involved in the clotting of blood.

Lymphocytes

As stated above, lymphocytes are the primary cells of adaptive immune responses (see Table 1 for more details). The two basic types of lymphocytes, B cells and T cells, are identical morphologically with a large central nucleus surrounded by a thin layer of cytoplasm. They are distinguished from each other by their surface protein markers as well as by the molecules they secrete. While B cells mature in red bone marrow and T cells mature in the thymus, they both initially develop from bone marrow. T cells migrate from bone marrow to the thymus gland where they further mature. B cells and T cells are found in many parts of the body, circulating in the bloodstream and lymph, and residing in secondary lymphoid organs, including the spleen and lymph nodes, which will be described later in this section. The human body contains approximately 1012 lymphocytes.

B Cells

B cells are immune cells that function primarily by producing antibodies. An antibody is any of the group of proteins that binds specifically to pathogen-associated molecules known as antigens. An antigen is a chemical structure on the surface of a pathogen that binds to T or B lymphocyte antigen receptors. Once activated by binding to antigen, B cells differentiate into cells that secrete a soluble form of their surface antibodies. These activated B cells are known as plasma cells.

T Cells

The T cell, on the other hand, does not secrete antibody but performs a variety of functions in the adaptive immune response. Different T cell types have the ability to either secrete soluble factors that communicate with other cells of the adaptive immune response or destroy cells infected with intracellular pathogens. The roles of T and B lymphocytes in the adaptive immune response will be discussed further in this chapter.

Plasma Cells

Another type of lymphocyte of importance is the plasma cell. A plasma cell is a B cell that has differentiated in response to antigen binding, and has thereby gained the ability to secrete soluble antibodies. These cells differ in morphology from standard B and T cells in that they contain a large amount of cytoplasm packed with the protein-synthesizing machinery known as rough endoplasmic reticulum.

Natural Killer Cells

A fourth important lymphocyte is the natural killer cell, a participant in the innate immune response. A natural killer cell (NK) is a circulating blood cell that contains cytotoxic (cell-killing) granules in its extensive cytoplasm. It shares this mechanism with the cytotoxic T cells of the adaptive immune response. NK cells are among the body’s first lines of defense against viruses and certain types of cancer.

Lymphocytes	
Type of lymphocyte	**Primary function**
B lymphocyte	Generates diverse antibodies
T lymphocyte	Secretes chemical messengers
Plasma cell	Secretes antibodies
NK cell	Destroys virally infected cells

Nervous system

The nervous system is a network of neurons whose main feature is to generate, modulate and transmit information between all the different parts of the human body. This property enables many important functions of the nervous system, such as regulation of vital body functions (heartbeat, breathing, digestion), sensation and body movements. Ultimately, the nervous system structures preside over everything that makes us human; our consciousness, cognition, behaviour and memories.

The nervous system consists of two divisions;

Central nervous system (CNS) is the integration and command center of the body

Peripheral nervous system (PNS) represents the conduit between the CNS and the body. It is further subdivided into the somatic nervous system (SNS) and the autonomic nervous system (ANS).

Cells of the nervous system

Two basic types of cells are present in the nervous system;

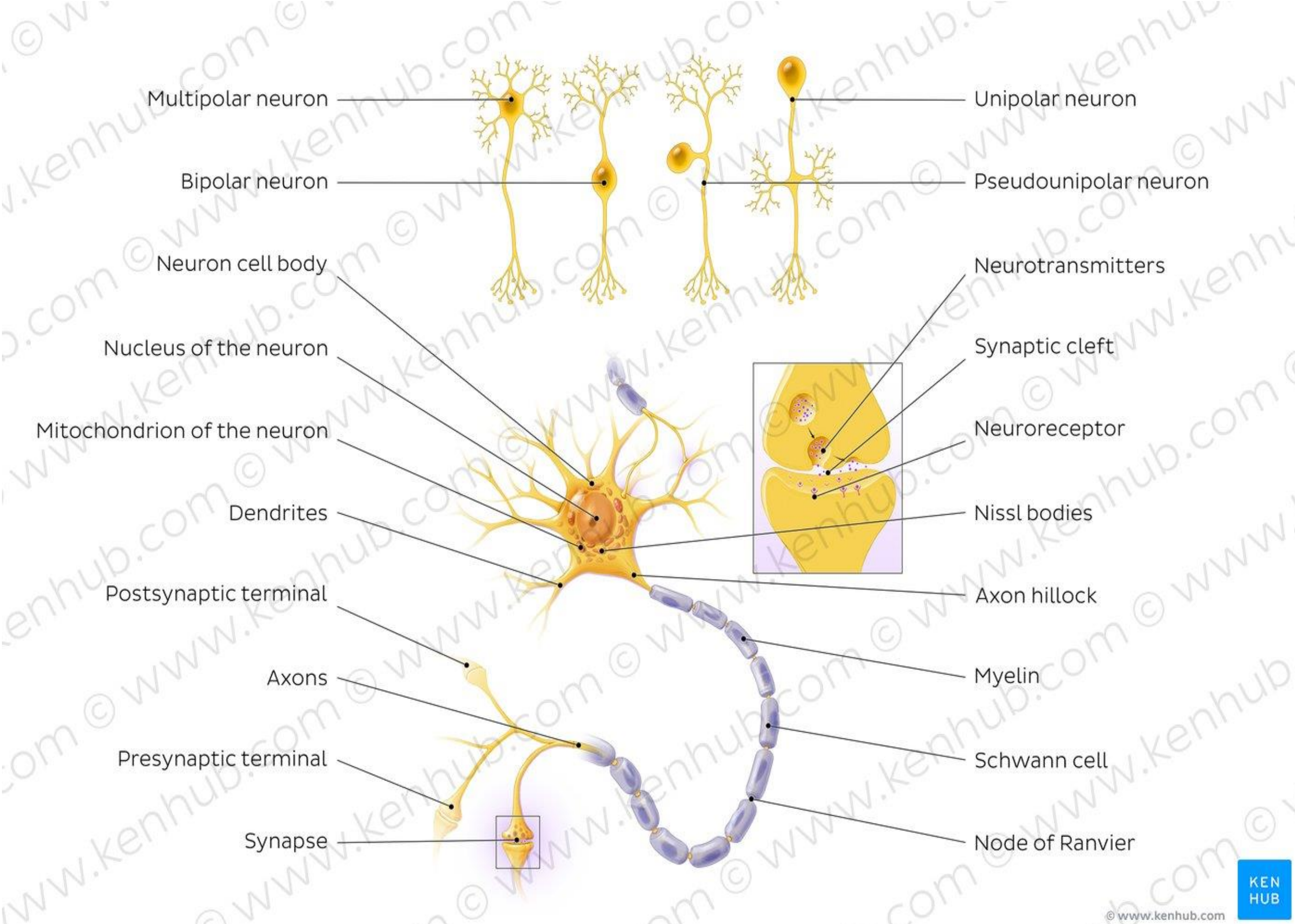
Neurons

Glial cells

Neurons, or nerve cell are the main structural and functional units of the nervous system. Every neuron consists of a body (soma) and a number of processes (neurites). The nerve cell body contains the cellular organelles and is where neural impulses (action potentials) are generated. The processes stem from the body, they connect neurons with each other and with other body cells, enabling the flow of neural impulses. There are two types of neural processes that differ in structure and function;

Axons are long and conduct impulses away from the neuronal body.

Dendrites are short and act to receive impulses from other neurons, conducting the electrical signal towards the nerve cell body. Every neuron has a single axon, while the number of dendrites varies. Based on that number, there are four structural types of neurons; multipolar, bipolar, pseudounipolar and unipolar.



The morphology of neurons makes them highly specialized to work with neural impulses; they generate, receive and send these impulses onto other neurons and non-neural tissues.

There are two types of neurons, named according to whether they send an electrical signal towards or away from the CNS;

Efferent neurons (motor or descending) send neural impulses from the CNS to the peripheral tissues, instructing them how to function.

Afferent neurons (sensory or ascending) conduct impulses from the peripheral tissues to the CNS. These impulses contain sensory information, describing the tissue's environment.

The site where an axon connects to another cell to pass the neural impulse is called a synapse. The synapse doesn't connect to the next cell directly. Instead, the impulse triggers the release of chemicals called neurotransmitters from the very end of an axon. These neurotransmitters bind to the effector cell’s membrane, causing biochemical events to occur within that cell according to the orders sent by the CNS.

Glial cells

Glial cells, also called neuroglia or simply glia, are smaller non-excitatory cells that act to support neurons. They do not propagate action potentials. Instead, they myelinate neurons, maintain homeostatic balance, provide structural support, protection and nutrition for neurons throughout the nervous system.

This set of functions is provided for by four different types of glial cells;

Myelinating glia produce the axon-insulating myelin sheath. These are called oligodendrocytes in the CNS and Schwann cells in the PNS. Remember these easily with the mnemonic "COPS" (Central - Oligodendrocytes; Peripheral - Schwann)

Astrocytes (CNS) and satellite glial cells (PNS) both share the function of supporting and protecting neurons.

Other two glial cell types are found in CNS exclusively; microglia are the phagocytes of the CNS and ependymal cells which line the ventricular system of the CNS. The PNS doesn't have a glial equivalent to microglia as the phagocytic role is performed by macrophages.

Most axons are wrapped by a white insulating substance called the myelin sheath, produced by oligodendrocytes and Schwann cells. Myelin encloses an axon segmentally, leaving unmyelinated gaps between the segments called the nodes of Ranvier. The neural impulses propagate through the Ranvier nodes only, skipping the myelin sheath. This significantly increases the speed of neural impulse propagation.

White and gray matter

The white color of myelinated axons is distinguished from the gray colored neuronal bodies and dendrites. Based on this, nervous tissue is divided into white matter and gray matter, both of which has a specific distribution;

White matter comprises the outermost layer of the spinal cord and the inner part of the brain.

Gray matter is located in the central part of the spinal cord, outermost layer of the brain (cerebral cortex), and in several subcortical nuclei of the brain deep to the cerebral cortex. So nervous tissue, comprised of neurons and neuroglia, forms our nervous organs (e.g. the brain, nerves). These organs unite according to their common function, forming the evolutionary perfection that is our nervous system.

The nervous system (NS) is structurally broken down into two divisions;

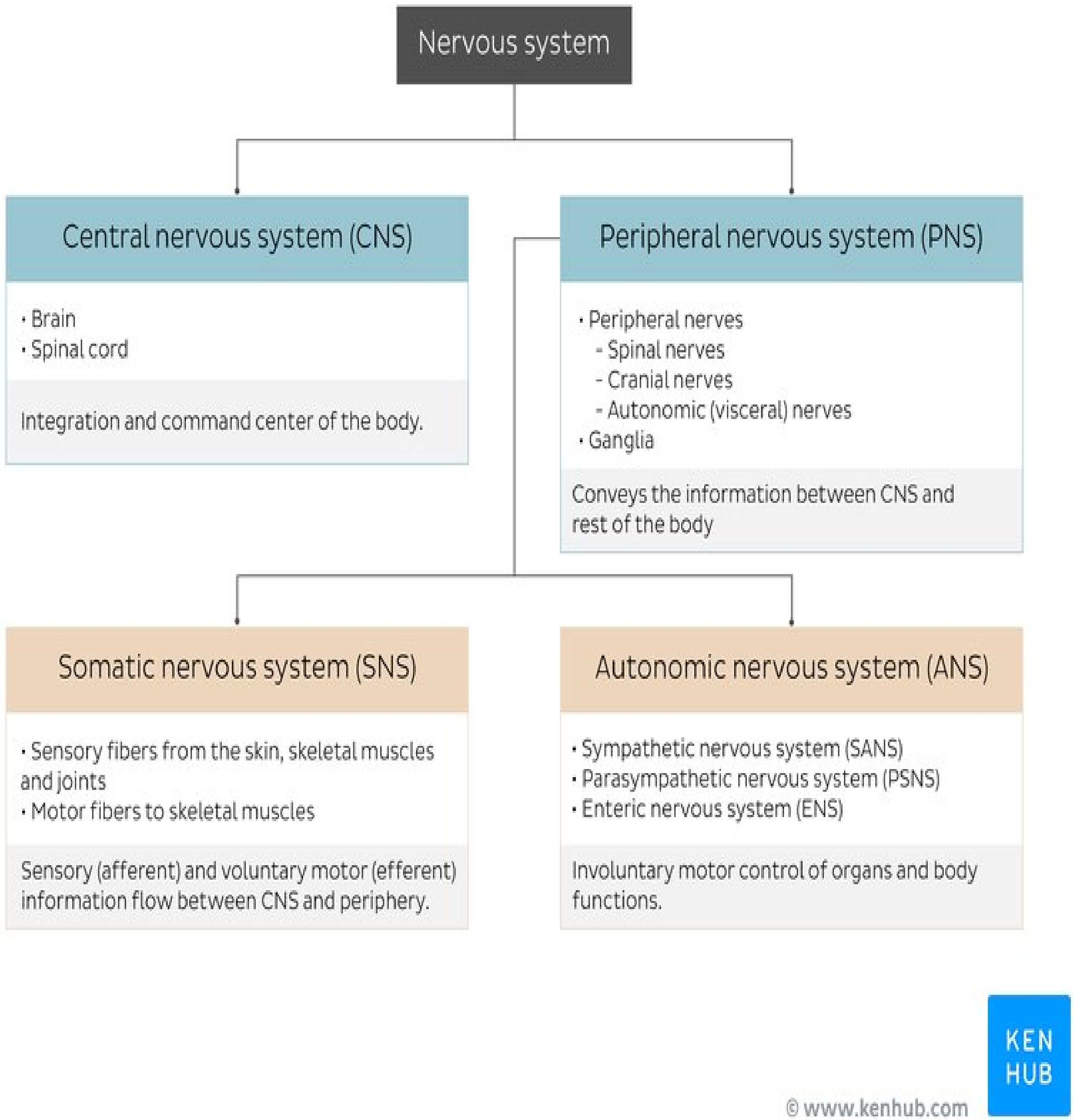
Central nervous system (CNS) - consists of the brain and spinal cord

Peripheral nervous system (PNS) - gathers all neural tissue outside the CNS

Functionally, the PNS is further subdivided into two functional divisions;

Somatic nervous system (SNS) - informally described as the voluntary system

Autonomic nervous system (ANS) - described as the involuntary system.



The central nervous system (CNS) consists of the brain and spinal cord. These are found housed within the skull and vertebral column respectively.

The brain is made of four parts; cerebrum, diencephalon, cerebellum and brainstem. Together these parts process the incoming information from peripheral tissues and generate commands; telling the tissues how to respond and function. These commands tackle the most complex voluntary and involuntary human body functions, from breathing to thinking.

The spinal cord continues from the brainstem. It also has the ability to generate commands but for involuntary processes only, i.e. reflexes. However, its main function is to pass information between the CNS and periphery.

The PNS consists of 12 pairs of cranial nerves, 31 pairs of spinal nerves and a number of small neuronal clusters throughout the body called ganglia.

Peripheral nerves can be sensory (afferent), motor (efferent) or mixed (both). Depending on what structures they innervate, peripheral nerves can have the following modalities;

Special - innervating special senses (e.g. eye) and is found only in afferent fibers

General - supplying everything except special senses

Somatic - innervates the skin and skeletal muscles (e.g. biceps brachii)

Visceral - supplies internal organs.