Chapter 51

Growth, Repair, Regeneration, Ageing & Death

- Growth is **divided into periods of embryonic and post-embryonic growth**.
- Early embryonic developmental stages constitute **prefunctional state.**
- In **post-embryonic period of organism's life**, the cells of the tissues and organs get differentiated for specific functions. These cells lose the capacity of division and perform physiological functions for the survival of the organisms.
- **Growth**, **regeneration and ageing** may be described **as the post-embryonic developmental events**.
- **Growth** is irreversible increase in size, increase in weight, synthesis of new protoplasm.
- Substances synthesized during growth are **protoplasmic** (nucleus and cytoplasm) and **apoplasmic** (substance present outside the cell like matrix of bone marrow or fibres of connective tissue or even water).
- Growth is **always associated with differentiation**.
- **Differentiation** is a change in the anatomy or physiology of a single cell or cell or group of cells (tissue) in multicellular organisms as it matures into a specialised cell or tissue.
- Growth occurs when **anabolism** (synthetic activities) **is higher than catabolism**.
- **Degrowth** takes place when **catabolism is higher than anabolism**.
- **Quantitative growth** may be **defined in terms of individual growth** (a permanent increase in the biomass of a cell or organism) or **population growth** (an increase in the number of individual in a population).
- The **steps involved in cellular growth** are **- cell division, cell enlargement** and **cell differentiation**.
- Cell division is **cell multiplication** (e.g., lens cells grows by multiplication), cell enlargement is **increase in volume of cell without division** (eg., cardiac & skeletal muscles, neurons which grows by extension & growth of axon and dendrites).
- Cell growth occurs **during post-mitotic phase and interphase**.
- During interphase, cells grow by synthesis of new materials such as nucleic acids and proteins.
- Cell multiplication and growth can be studied well in tissue or in culture of unicellular organisms.
- The growth of multicellular organism falls under three categories – **auxetic**, **multiplicative accretionary growth** and **appositional growth**.
- **Auxetic growth** is growth in which volume of body increases due to the growth of cells without any increase in the number of cells. It **occurs in nematodes, rotifers** and **tunicates**.
- **Multiplicative growth** is the growth of the body due to increase in the number of cells. The cells divide mitotically to increase their number but their size remains the same. Eg. the prenatal growth or embryonic development of higher vertebrates.
- Growth due to mitotic multiplication of reserve cells occurring in specific locations of the body is **accretionary growth**. Eg. post-embryonic growth of animals.
- **Examples of accretionary growth** are erythropoietic tissue, matrix secreting chondrocytes and osteocytes.
- **Appositional growth** involves the addition of new layers on the previously formed layers. *For example*, the addition of lamellae in the formation of bone. It is the **characteristic mode of growth in rigid materials**.
- **On the basis of body proportions**, **pattern of growth** are of **two types - isometric growth** (an organ grows at the same rate as the rest of the body, as the organisms grows, the external form of body

does not change, eg., fish and certain insects) and **allometric growth** (an organ grows at a rate different from that at which the body grows, as the organisms grows, the external form of body changes, eg. mammal).

- The usual s**hape of growth curve** is **sigmoidal**.
- Growth curve is the **graphic representation of growth against time**.
- The increase in weight of an animal if plotted against time, a characteristic **S shaped curve** is obtained. It is called **sigmoid curve or growth curve**.
- The sigmoidal or S-shaped growth curve is the **characteristic growth curve of all higher animals** including man.
- The sigmoid curve **represents the growth pattern of all organisms**, **plants or animals**, **unicellular or multicellular forms at various interval**.
- The sigmoid curve consists of the following stages – **lag phase** (**little growth** means slow increase in body weight); **exponential/acceleration phase/log phase** (**maximum growth**, the point where the exponential growth begins to slow down is known as **inflexion point); senescent/decelerating phase** (**declining growth** *i.e.* growth with decreasing rate); and **steady phase** (**no growth**).
- **Exponential growth** of cells is characteristic feature of **tissue culture cells.**
- **Auxanology** is the study of growth.
- **Maximum growth in human foetus** occurs at the age of **four months**.
- Growth in the first 10-13 years of age is controlled by **thymosin**.
- Growth at the end of childhood and during puberty is controlled by **thyroxine and GH.**
- In human beings, **growth stops completely at the age of 22-23 years**.
- As compared to adult male, the **female has more fat**.
- In human beings **brain shows the minimum increase in weight from birth to adulthood.**
- As compared to the whole body the **head of the new born human baby is 1/4**.
- In human beings **muscles shows the maximum increase in weight from birth to adulthood.**
- In animals growth rate is **differential**.
- **Healing of cuts and wounds** is called **repair**.
- Repair is **effected by cell proliferation & migration**.
- **Regeneration** is the ability to restore lost or damaged tissues, organs or limbs. It is a **common feature in invertebrates**, but far more limited in most vertebrates.
- Two principal **categories of animal regeneration** are: **reparative regeneration** and **restorative regeneration**.
- **Reparative regeneration** is **common in both invertebrates and vertebrates**.
- Animals with higher and complex organization have reparative regeneration only.
- **Restorative regeneration** is **common in some invertebrate groups**.
- Animals with simple organization have greater power of restorative regeneration.
- *Hydra and Planaria* have the **power of repetitive regeneration**.
- **Based on cellular mechanism**, regeneration is of two types : **morphallaxis** and **epimorphosis**.
- **T. H. Morgan** for the **first time recognise the following two mechanisms of regeneration in animals**.
- **Morphallaxis (morphallactic regeneration)** is the reconstitution of the whole body from small fragments.
- Morphallaxis occurs mainly by the re-pattening or remodelling of existing tissues and the re-establishment of boundaries. It involves little new growth, e.g. regeneration of *Hydra* and *Planaria* from a segment of the animals.
- **Epimorphosis (epimorphic regeneration)** is the regeneration of lost body part through dedifferentiation of adult structures, cell proliferation and differentiation, e.g. regeneration of lost limb in salamander (amphibian).
- During epimorphosis, the epidermis spreads and covers the wound. In the next few days a mass of cells forms a **regeneration bud** or **blastema**. Finally the blastema undergoes differentiation to restore internal and external structure of lost limb.
- **Blastema** is the accumulation of cells and formation of a bud at the site of amputation.
- Regeneration of a limb or a tail is an **example of epimorphosis.**
- Regeneration of a lost limb occurs in two major steps - **first** de-differentiation of adult cells into a stem cell state similar to embryonic cells and **second**, development of these cells into new tissue more or less the same way it developed the first time. Some animals like *Planarians* instead keep clusters of non-differentiated cells within their bodies, which migrate to the parts of the body that need healing.

- **Phases of wound healing** are - preblastema stage, phase of blastema formation (includes phase of de-differentiation and pseudodifferentiation) and redifferentiation and morphogenesis.
- The **process of regeneration** was **first discovered** in *Hydra* by **Trembley**.
- **Liver possesses good regenerating power in mammals**.
- **Regeneration is controlled** by the **neural and hormonal factors.**
- **Sponge** has the **greatest regenerating capacity**.
- The voluntary casting off a part of the body when an animal is attacked is known as **autotomy.**
- Autotomy is **recorded in legs of crabs, tail of lizards** and **arms of star fishes**.
- Salamander is capable to regenerate **limbs, tail and external gills**.
- **Regeneration is possible in tadpoles** for **amputated tail and hindlegs.**
- Regeneration that produces a part different from the lost part is called **heteromorphosis**.
- Power of **regeneration in flatworm** is **highest at head region** and **lowest towards the tail end**.
- To take over the function of one removed organ is a type of **compensatory regeneration** or **compensatory hypertrophy** (eg. mammalian liver).
- Human body regularly loses cells in the region of **skin surface, lining of gut and red blood cells**.
- **During regeneration,** differentiation, cell division, cell movement and tissue differentiation takes place.
- **Ageing** is the time related deterioration of the physiological functions necessary for survival and fertility. It is largely caused by wear and tear.
- **Pigment of ageing** is **lipofuschin.**
- With ageing an impairment of physiological functions occurs. It is called **senescence**.
- The number of years an individual can expect to live is known as **life expectancy**.
- During ageing different organs and organ systems show decline in functioning like –
  - Heart grows slightly larger with age and maximal O_2 consumption during exercise declines.
  - The vital capacity of lungs decline by 40% between the age of 20 and 70.
  - Brain loses some cells (neurons) and other become damaged.
  - Kidney gradually becomes less efficient and bladder capacity declines.
  - There is a redistribution of fat to deeper part of the body. In woman it occurs in hips and thighs and in man it is in abdominal area.
  - There is a decline in muscle mass.
  - Difficulty in focussing close up in the 40s and inability to distinguish fine details may begin to decline in 70s.
  - Impairment in hearing ability with age.
- The **bones of old persons become brittle** due to **accumulation of calcium**.
- **During ageing**, **collagen** present in intercellular spaces **become less permeable, rigid and insoluble.**
- Disappearence of elastic fibres in association of collagen protein **results in wrinkling of the skin in old age.**
- **Vitamin C** is **required for collagen synthesis** thats why vitamic C is much required in old age for the maintenance of long bones, teeth and cartilage.
- On an average, 20% of nerve cells in the brain die at the age of 70 years.
- Ageing is characterised by decline in **metabolic activity.**
- The **pumping capacity of heart** in 70 years old person as compared to 30 years old person is 65%.
- In an **ageing person,** there is an increase in collagen rigidity of connective tissue and gradual alteration of components of connective tissue.
- The **part of the lung affected by ageing** are **pulmonary arteries, pulmonary veins and alveoli.**
- Ageing is **faster in human males** than in human females.

Table : Regenerative ability in animals

Animals	Parts regenerated
Sponges, *Hydra*, and *Planaria*	The whole body
Earthworms	Few body segments
Mollusca	Parts of eye, eye-stalk, head, foot, etc.
Insects, crustaceans and spiders	Limbs
Starfishes	Arms
Salamander and Axolotl	Limbs, tail, external gills, jaws, intestine, etc.
Tadpoles	Tail and hindlegs
Fishes	Fins
Lizards	Tail
Birds	Beak
Mammals	Liver

- **Dedifferentiation** is the ability of differentiated or specialized cells to change into cells capable of division and grow.
- There are two types of theories for ageing : **programmed theories** and **damage or error theories**.
- **Programmed theories** hold that ageing follow a biological time-table. **It has three sub-categories** –
  - **Endocrine theory** holds that biological clock act through hormones to control the pace of ageing.
  - **Programmed senescence theory** of ageing is the result of the sequential switching on and off of certain genes, causing **programmed cell death** or **apoptosis**.
  - **Immunological theory** - According to this the gradual atrophy and disappearance of thymus gland disturbs the defence mechanism of the body of combating germs and pathogens. With the disappearance of this gland, the body produces a great number of harmful abnormal cells which cause the increased rate of the change and destruction of tissues.

Thymus is ductless gland located in the upper anterior portion of the chest cavity. It is **most active during puberty after which it shrinks in size** and activity in most individuals and is replaced with fat. The thymus plays an important role in the development of the immune system in early life and its cells forms a part of the body's normal immune system.

- **Damage or error theories** maintains that the environmental assaults to our systems make the things to go wrong resulting in ageing.
- The **damage or error theories of ageing includes-** rate of living (metabolism), free radicals, crosslinking, wear and tear, error catastrophe and somatic mutation theories. Although ageing is largely caused by wear and tear, it is also under genetic control.
- **Compromise theory** advocates that ageing is an outcome of interaction between the genes present in the body of an individual and the environment in which the individual lives.
- **Metabolic theory** postulates that the animals with a high rate of metabolic activity age earlier and die sooner than with a lower rate of metabolism.
- In **wear and tear theory** an organism has to achieve a balance between the energy it puts into reproduction and the energy it puts into maintenance. The better the maintenance, the more the organism approaches immortality. However, some energy must always be put into reproduction or the species would die.
- **According to the free radical theory** more free radicals are produced with age which cause damage by reacting with nucleic acids, lipids and proteins. Free radicals, highly reactive chemical compounds, are ubiquitous in living organisms. Several enzymes (superoxide dismutase, catalase, glutathione peroxidase) and vitamins (vitamin E, C, carotenes) protect cells from oxidative attack.
- *Hydra* is an immortal organism not subjected to ageing.

Why *Hydra* is virtually immortal ?

Hydra is virtually immortal because interstitial cells, present in the growth zone below the tentacles, give rise to all other cells of body. With the formation of new cells, old cells are pushed towards the ends of tentacles and pedal disc, from where they are shed outside. This process of cell replacement is an endless process. It has been also shown that if interstitial cells are destroyed, the *Hydra* lives only for a few days.

- The branch of science which deals with the study of ageing process is called **gerontology**. Father of gerontology is **Korenchevsky**.
- **Geriatrics** is a branch of medicine that focuses on health promotion and prevention and treatment of disease and disability in later life.
- **Average life-span of women** is **longer** than that of men.
- **Death** is a biological phenomenon for maintaining the balance of nature. It **results in irreversible breakdown of the body functions**. Whatever the cause, the death results from the failure of either of heart, blood or nervous system. Natural death is preceded by ageing.
- **Clinical death** means **death of the brain** which results in no pulse or heart beat, no breathing and fixed dilated pupil with no reaction to light. Brain death occurs if no oxygen is supplied to it for approx. 3 - 5 minutes.
- **Thanatology** is the scientific study of death that almost involves death bed wishes.
- **Conditions leading to brain death** results in swelling of brain tissue and a rise in intracranial pressure, eventually shutting off all blood flow within the skull.

End of the Chapter