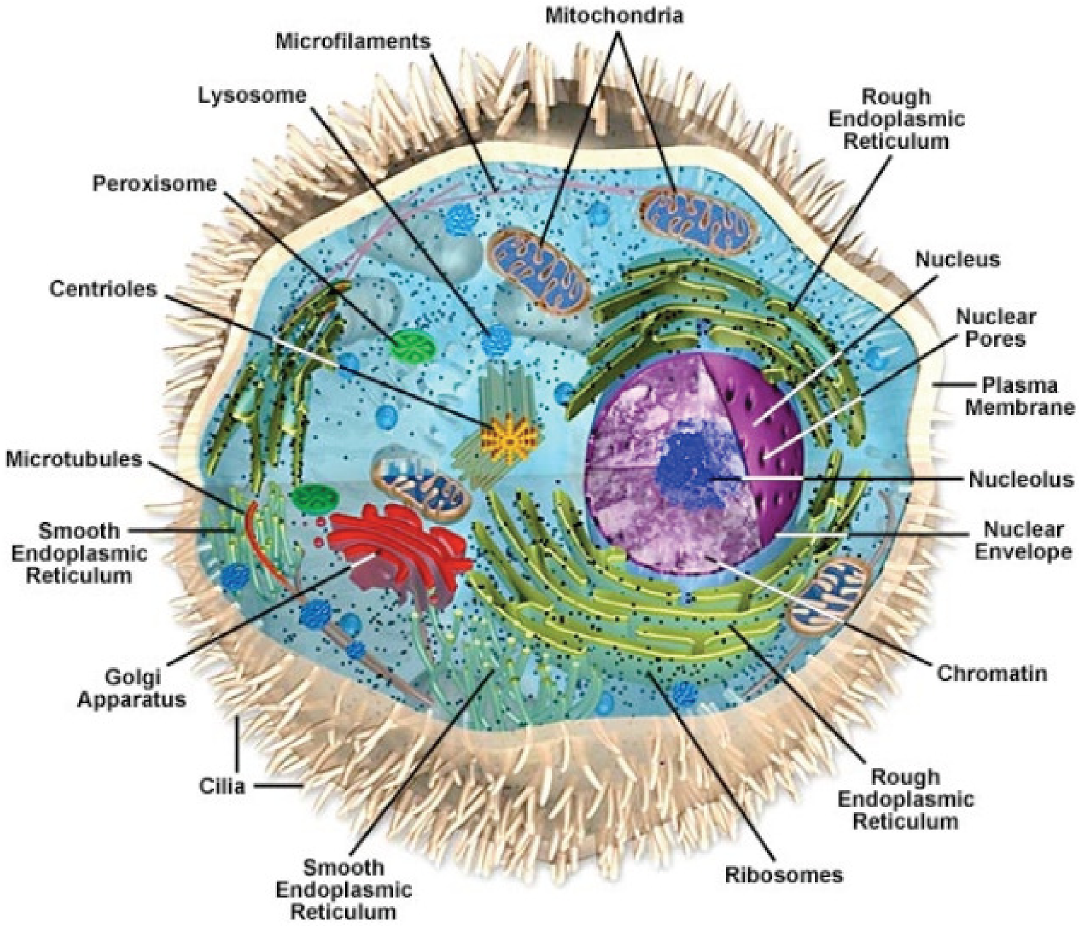
Cell Structure

•Cell Theory:
-A cell is the basic structural and functional unit of living organisms. So when you define cell properties you are defining the properties of life.
-The activity of an organism depends on both the individual and the collective activities of its cells.
-According to the principle of complementarity of structure and function, the biochemical activities of cells are dictated by the relative number of their specific subcellular structures.
-Continuity of life from one generation to another has a cellular basis

-Eukaryotic cell has membrane bound nucleus + organelles
-Organelles (small organs) compartmentalize chemical (enzyme) reactions so they don't negate each other.
-Cellular respiration:
Glucose + O_2 –cellular respiration→ CO_2 + H_2O + ATP
-ATP when broken down to Adenosine diphosphate, releases energy

•Structures and functions of a cell

Organelle	Function
Nucleus	Directs cell's life processes, contains the chromosomes, contains one or more nucleoli.
Nuclear membrane	-Separates the nucleus from the cytoplasm. Controls the highly-selective two-way exchange between the nucleus and cytoplasm. -Contains nuclear pores which controls mRNA movement from nucleus to cytoplasm
Nucleolus	Ribosomal RNA is synthesised and combined with proteins. Ribosomes assemble
Cytoplasm	Semi-fluid material (Cytosol) filling the space between plasma and nuclear membranes in which the organelles are found.
Cytoskeleton	Cellular scaffolding/ skeleton: -Microtubules: produced by centrioles, found in cilia and flagella -Intermediate filaments -Microfilaments
Cell membrane (plasma membrane)	-Regulates movement of substances into and out of the cell. -Phospholipid bilayer: hydrophilic phosphate molecules form the outer layer while the hydrophobic lipid tails are towards the middle – clear distinction from the extracellular environment to prevent the high concentration of proteins from being dissipated by the water -Protein channel: passive channel which doesn't require energy when channeling ions or molecules
Centriole	Produces microtubules during mitosis and meiosis
Mitochondrion	Produces ATP (Adenosine triphosphate) by cellular respiration
Rough endoplasmic reticulum	Site of protein synthesis and transport.
Smooth endoplasmic reticulum	Site of lipid synthesis to allow detoxification of poisons (drug, alcohol)
Golgi body	Storage, modification and packaging of secretory products.
Lysosome	Contains digestive enzymes; cellular digestion.
Ribosome (~~organelle~~)	Translation of mRNA to form protein precursors; protein synthesis



•Surface area to volume ratios in relation to cells

-The rate of diffusion into or out of a cell decreases as the cell increases in size because there is less surface area per unit of volume across which to exchange substances.

-The maximum size to which a cell can grow is determined by the rate of diffusion of nutrients and gases across the cell surface. A cell can increase the maximum size to which it can grow by developing an intracellular transport system (membrane systems, e.g. ER), compartmentalise processes (organelles)

-Heat loss per unit surface area is equal in the two animals, but the smaller animal will lose heat at a faster rate relative to its volume because the surface area to volume ratio (SA:V) is increasing with decreasing size. Likewise, larger cells have a lower SA:V ratio so their overall heat loss relative to surface area will be lower than that of smaller cells.

-The principle also applies to substances that are transported in organism, or across a cell membrane (e.g. water, oxygen, wastes). Small cells have a large SA:V ratio compared to large cells. As cell size increases, the rate of movement of substances across the surface becomes insufficient to serve all the volume of the cell.

•Cell metabolism: the sum of all the chemical reactions in the cell

-The energy released from the breakdown of food molecules is used to produce ATP (Adenosine triphosphate)

-Aerobic respiration occurs when oxygen is available. The aerobic respiration of a glucose molecule produces 36 to 38 ATP molecules. When oxygen is not available anaerobic respiration occurs, producing (in animals) lactic acid.

•Structure of DNA

Deoxyribonucleic acid (DNA) is the genetic material that organisms inherit from their parents; DNA determines the structural and functional characteristics of the cell by specifying the inherited structure of a cell's proteins. A long molecule of DNA (with associated proteins) makes up a chromosome, with sections of that DNA molecule forming genes. Each chromosome usually consists of between several hundred to more than 1000 genes.

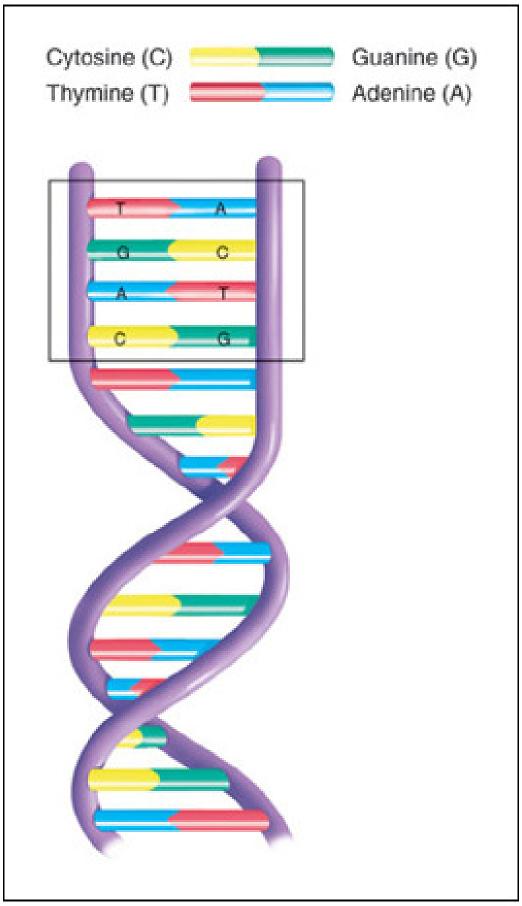
Gene = A sequence of nucleotides in a DNA molecule that specifies the structure of a protein or RNA molecule

DNA exists in the nucleus of a cell and consists of a double strand (double helix structure) of building blocks called nucleotides.

Each nucleotide consists of three groups of atoms:
-a sugar (deoxyribose) – side of the ladder
-a phosphate group – side of the ladder
-a nitrogen base – rungs of the ladder

Each strand of DNA is composed of linked sugar - phosphate groups. A base is attached to each sugar in the strand.

One end of a single strand, a 3 prime hydroxyl group of the sugar is free while at the other end of the same strand the 5 prime hydroxyl group of the sugar at the end is free (or may contain a free phosphate). The dissimilarity of the two ends of a strand creates polarity and two strands of DNA orientate in opposite directions (antiparallel)



There are four types of complementary base pairs in DNA:
Adenine - A
Cytosine - C
Guanine - G
Thymine - T

The bases along one strand link onto the bases of the second strand of DNA via hydrogen bonds.
Chargaff's rule:
A only joins with T, via double hydrogen bonds
G only joins with C, via triple hydrogen bonds

•How DNA replicates
Semiconservative DNA replication is the process in which one double-stranded DNA molecule is used to create two double-stranded molecules with identical DNA sequences. The two DNA strands are split and the DNA replication machinery is assembled at the replication fork. The two split DNA strands are used as template strands to create newly synthesized DNA strands by adding nucleotides using Chargaff's rule (A/T G/C). One double-stranded DNA molecule provides the information to create two double-stranded molecules with identical base sequences. Each copy contains one newly synthesized and one original strand; half of the DNA molecules is conserved from the original molecule.

-The replication of DNA begins at a sequence of nucleotides called the origin of replication.
-Helicase unwinds the double-stranded DNA helix and single-strand binding proteins react with the single-stranded regions of the DNA and stabilize it.
-DNA polymerase III is the major enzyme involved in DNA replication. DNA polymerase III can only add a nucleotide to the 3' end of a pre-existing chain of nucleotides and it cannot initiate a nucleotide chain.
-Therefore, an RNA polymerase, called a primase, constructs an RNA primer, a sequence of about 10 nucleotides, complementary to the parent DNA.
-DNA polymerase III can then add deoxyribonucleotides to synthesize the new complementary strand of DNA.
-Because the two parent strands of DNA are antiparallel, they are orientated in opposite directions and must therefore be elongated by different mechanisms.
-The leading strand elongates toward the replication fork by adding nucleotides continuously to its growing 3' end.
-In contrast, the lagging strand, which elongates away from the replication fork, is synthesized discontinuously as a series of short segments, called Okazaki fragments.
-When the DNA polymerase III reaches the RNA primer on the lagging strand, it is replaced by DNA polymerase I, which removes the RNA and replaces it with DNA. DNA ligase then attaches and forms phosphodiester bonds.
-The DNA is further unwound, new primers are made, and DNA polymerase III jumps ahead to begin synthesizing another Okazaki fragment.

-The current view of DNA polymerase III is that the two subunits function together with the DNA on the lagging strand folding to allow the dimeric DNA polymerase molecule to replicate both strands of the parental DNA duplex simultaneously.

•Gene expression: production of proteins from the information stored in DNA
-DNA (information store – genes) → Transcription (information stored in DNA is copied to form mRNA) → mRNA (Intermediate carrier of information) → Translation (mRNA goes to ribosomes, where it directs the synthesis of proteins) → Protein (product of information)

•Protein Synthesis
-The information contained within DNA molecules directs the production of proteins within cells.
-Proteins are used by the cell as structural components or as enzymes that regulate the chemical reactions in the cell.
-The synthesis of proteins involves making a copy of the information in a gene, transcription, and converting that copied information into a protein, translation.
-Protein synthesis requires three types of RNA, messenger RNA (mRNA), transfer RNA (tRNA) and ribosomal RNA (rRNA). RNA exists as a single strand, having Uracil replacing Thymine to align with Adenine. Its sugar backbone is made of Ribonucleotides not Deoxybribonucloetides.
-There are three possible reading frames in the mRNA but usually only 1 actually codes for protein.
-4 nucleotides (A, C, G, T) and 20 amino acids – 3 nucleotides are needed to code for one amino acid – 1 protein has about 500 amino acids

-During transcription, in the cell nucleus, RNA polymerase transcribes RNA from DNA.
-Introns are removed from the RNA transcript and the remaining exons are spliced together, producing mRNA which is transported out of the nucleus through nuclear pores.
-Translation is initiated by formation of an initiation complex consisting of the ribosomal subunits binding to mRNA and tRNA (one end of tRNA bound to the first amino acid and the other end having the anticodon)
-The 70S ribosome has two sites to which tRNA-carrying amino acids can bind. One is called the peptidyl or P site and the other is called the acceptor or A site.
-The initiating tRNA, carrying its amino acid, binds to the P site. A tRNA that recognizes the next codon and carries the second amino acid then moves in to the A site.
-Peptide bonds form between the amino acids at the P site, and tRNAs in the P site exit the ribosome.
-The polypeptide chain grows with new amino acids added as the mRNA continuously moves through the ribosome by one codon each.
-Elongation of the polypeptide is terminated when the ribosome reaches a stop codon.
-The ribosome dissociates into the smaller and larger subunits and the mRNA and protein are released.

•Stages of the cell cycle

Cell cycle: continuous repetition of growth and division in cells in eukaryotes

Term	**Definition**
Chromosome	A gene-carrying structure found in the nucleus. Each consists of a long single DNA molecule, wrapping around histones.
Chromatid	A replicated chromosome that is connected to another at the centromere. Each chromatid consists of a single DNA molecule.
Centromere	The centralised region that joins two chromatids. Spindle fibres also attach to this region during mitosis/meiosis. (The kinetochore, a protein structure, provides a point of attachment for microtubules during cell division.)
Nucleus	The chromosome-containing organelle of a eukaryotic cell.
Spindle	The structure formed between opposite poles of a cell during mitosis/meiosis; it is formed by microtubules and guides the movement of chromosomes.
Centriole	A structure in animal cells that produces the spindle during mitosis/meiosis.

-During cell division, DNA becomes packaged within protein structures known as chromosomes.
-There are 23 pairs of chromosomes in human cells: 22 pairs of autosome chromosomes and 1 pair of sex chromosomes.

1) INTERPHASE: Replication of DNA + Cell growth + Normal metabolic functions
The cell grows and copies its chromosomes in preparation for mitosis. The DNA is stretched out in the nucleus so that the genes in the DNA can be expressed.

Stages of Interphase	Events
G1 (Gap 1)	Normal cell metabolism + cell growth occur
S (Synthesis)	DNA is synthesized. The chromosomes are replicated so that there are two copies of each chromosome (chromatids).
	Sister chromatids are joined together at the centromere so that these identical copies can be moved orderly and be separated at the appropriate time into identical daughter cells.
G2 (Gap 2)	The centrioles replicate and move to opposite ends of the cell. Components of the mitotic spindle begin to form between them.

2) MITOSIS: Division of cell nucleus
The nucleus divides to form two genetically identical daughter nuclei which have the identical DNA (asexual reproduction) as the parent nucleus. The cells necessary for growth and repair of an organism are formed through mitosis.

Stages of Mitosis	Events
Prophase	Long thin chromatid pairs condense, becoming shorter and thicker.
	The nuclear envelope breaks down.
	The centrioles move to opposite ends of the cell and microtubules grow out of them to form the spindle fibers.
Metaphase	The chromatid pairs line up on the spindle by the centromere at the cell equator, each sister chromatid attached to the spindles from opposite poles.
Anaphase	The spindle fibers begin to shorten pulling the centromeres apart.
	The chromatid pairs are separated into single chromosomes, moved away from each other along its spindle fiber.
Telophase	The chromosomes reach the poles of the original cell. As nuclear membrane forms around each daughter nucleus, the chromosomes uncoil and lengthen. The spindle disappears.

3) CYTOKINESIS: Division of cell cytoplasm
A cleavage furrow is formed to divide the cytoplasm, forming new separate daughter cells.

The Skeletal System

-Anatomical position: when body is standing erect, eyes looking forward, arms at the sides of the body and palms and toes directed forward.

Superior	Higher than
Inferior	Lower than
Anterior	Front of the body
Posterior	Back of the body
Medial	Towards the middle compared to
Lateral	To the side of the body compared to
Proximal	Closer to the trunk of the body compared to
Distal	Further away from the trunk compared to

Sagittal	Divides body into right and left parts.
Midsagittal	Divides body into equal halves
Transverse	Divides body into superior and inferior parts
Coronal	Divides the body into anterior and posterior

Diaphysis	Elongated body of long bone (centre part)
Epiphysis	Proximal and distal ends of long bone (ends of the bone)
Symphysis	Joints between bones formed by fibrocartilage
Articular surfaces	Where bones form joins
Facet	Smooth, nearly flat, articular surface
Condyle	Rounded articular projection
Process	Large, distinct bony projection
Spine	Slender, often pointed, bony projection
Fossa	Shallow depression
Foramen	Hole; opening in bone
Meatus	Canal-like passageway
Sinus	Cavity within a bone, filled with air

Articular cartilage	A thin layer of cartilage at the ends of long bones that articulate with each other at the joints
Medullary cavity	A central cavity within the bone
Red marrow	In foetal life and early childhood, the long bones are filled with red bone marrow which produces new red blood cells and gives rise to white blood cells. This undergoes degeneration to fatty yellow marrow in adulthood (except at the very ends of the marrow cavity)
Periosteum	A dense fibrous connective tissue layer which facilitates the nutrients into the bone and where osteogenic stem cells reside

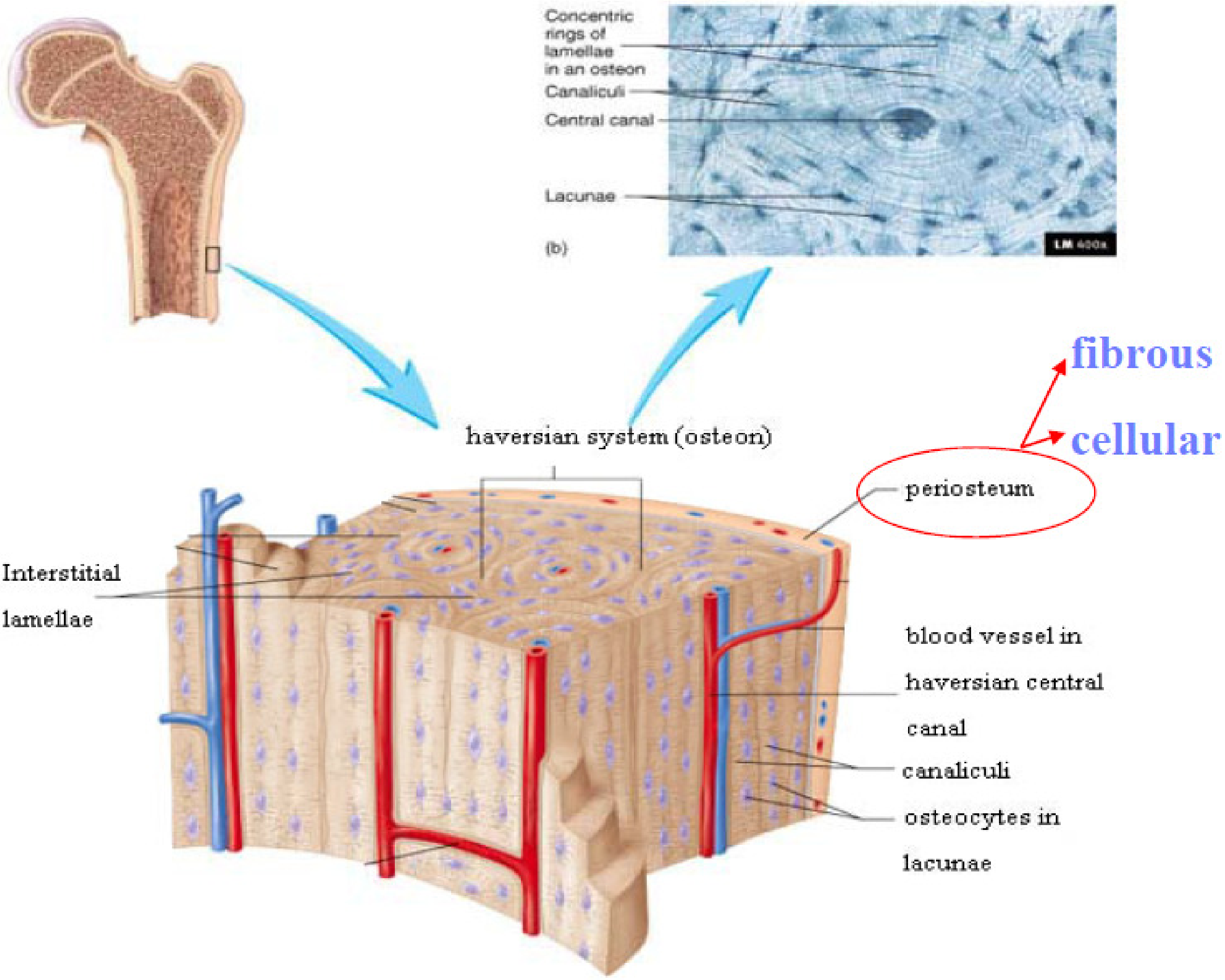
•The anatomy and structure of bone
-Bone is living tissue with long/short/flat/irregular shapes.
-Osteogenic stem cell types: Osteogenic stem cells differentiate into:
  -Osteoblasts: build the bone matrix – secretes bone collagen and deposits organic matrix on a surface
  -Osteocytes: maintain – receive nutrients and eliminate wastes through canaliculi containing blood vessels connected to the circulation
  -Osteoclasts: breakdown – provides acidic environment for removal or resorption of bone

-Composition:
  -25% organic: bone collagen – flexibility
  -50% inorganic: calcium and phosphate – rigidity and strength
  -25% water – living tissue needs water for chemical reactions

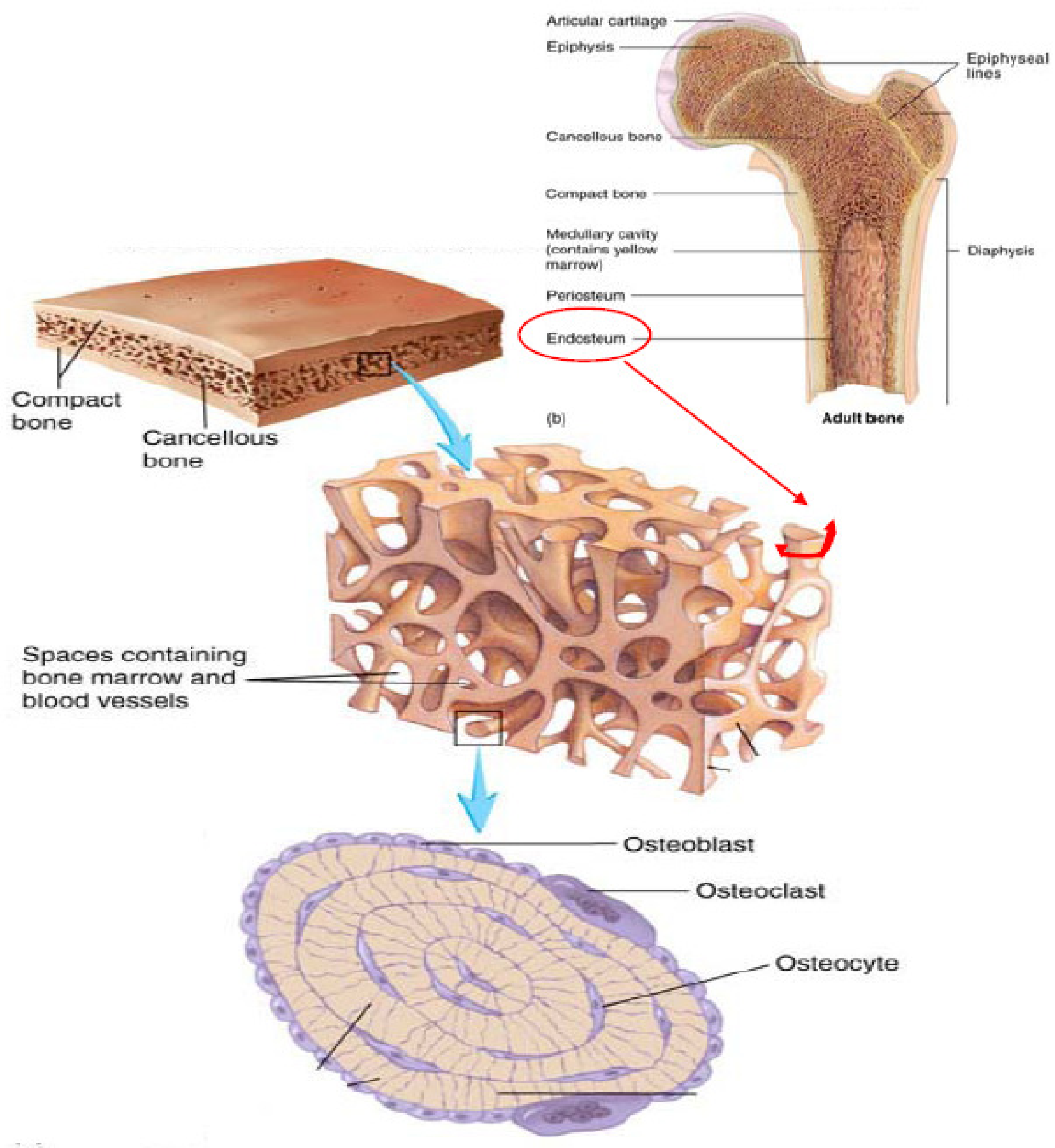
-Function: Support, storage, protection, movement and blood cell production

<u>2 Types of bone</u>: Compact bone covers the cancellous bone of the epiphyses

1) Compact bone = the outer, denser bone of the diaphysis
-It has a solid, strong and rigid matrix
-It is perforated by a series of Haversian canals each containing blood vessels and nerves
-Osteocytes are arranged around the Haversian canals in a series of concentric circles. Each series and the canal form a Haversian system.
-Central canal – blood vessel
-The matrix is secreted in a way that forms a series of thin, concentric cylinders, the concentric lamellae, around the Haversian canals.
-Osteocytes lie in lacunae which are linked together by a series of thin canals, canaliculi. These contain cytoplasmic processes from the cells, which penetrate the matrix and carry nutrients to and wastes from the osteocytes from/to blood vessels.
-The external surface of the bone is surrounded by periosteum. The marrow cavity of the bone is lined by the endosteum.



2) Cancellous (Spongy) bone
-Honey comb matrix
-It does not contain Haversian canals.
-It contains trabeculae – interconnecting plates of bone surrounded by endosteum
-The spaces of the trabeculae are filled with bone marrow:
-red – red, white cells and blood elements
-yellow (mature) – fat cells – deposition of fat cells and red is restricted to epiphyses

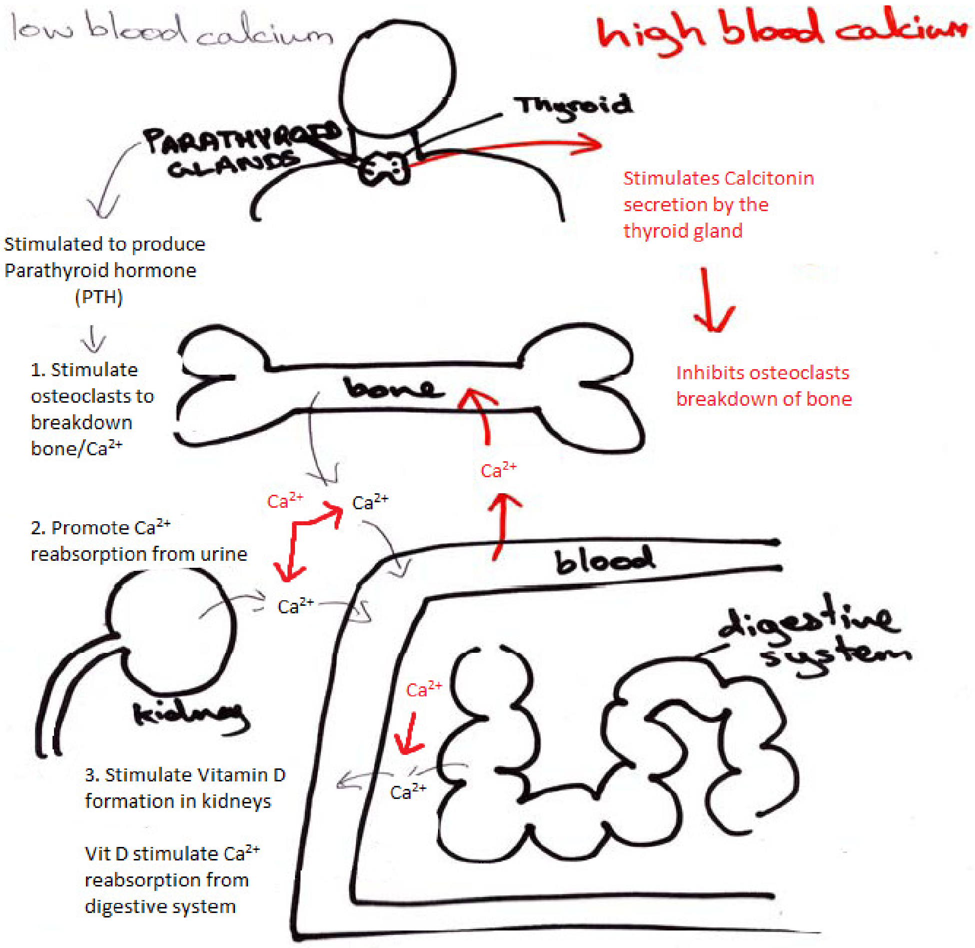


•Formation of bone – Ossification
1) Intramembranous ossification (outer compact bone surfaces and cancellous centres)
Membrane is used as a template for ossification. Osteoblasts deposit collagen onto the template to form bones.

2) Endochondrial ossification
Cartilage is used as a template for ossification. Osteoblasts build the matrix. Blood cells from blood vessel infiltrate the template and provide nutrients to osteoblasts to help them build faster. However, the growth is restricted by the ends of growth plate.

-Bones are continuously remodelled. Epiphyseal lines lengthen the compact bone. Periosteum and endosteum work together to remodel the cancellous bone.

-Calcium homeostasis: Hormones regulate Calcium release and reabsorption
∴ ↑[PTH] → ↑blood [Ca^{2+}]
↑[Calcitonin] → ↓blood [Ca^{2+}]



•Bones of the axial and appendicular skeletons and their functions

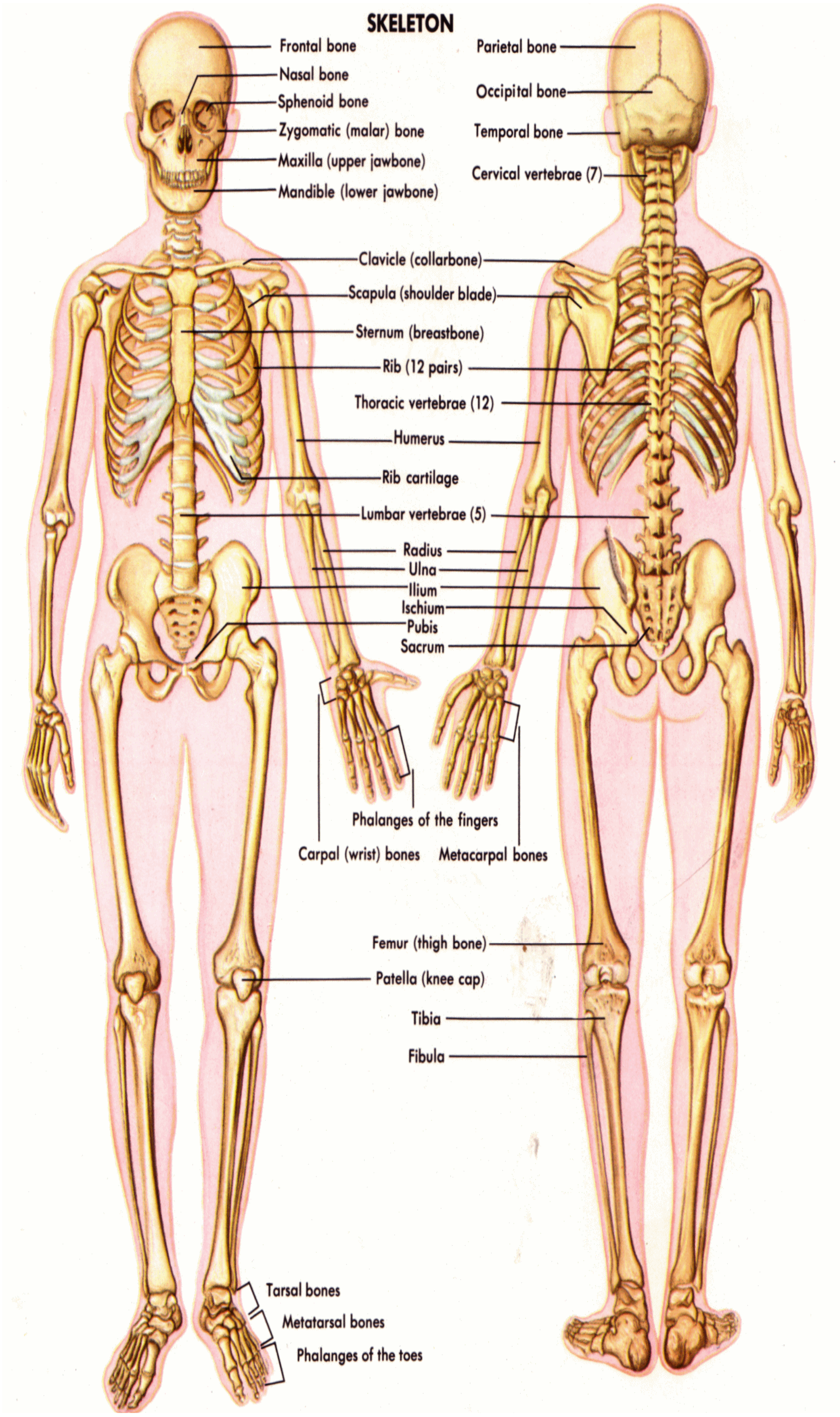
Skeletal system has:

1. Axial skeleton			
Skull and mandible	Frontal	Forms the forehead	
	Parietal	Protects the brain from top and sides	
	Temporal	External auditory meatus through which sound passes to the inner eat is located	
	Occipital	Foramen magnum (connecting spinal cord and brain) is located	
Vertebral column	Cervical	Neck	Provides flexible support and protects the spinal cord
	Thoracic	Chest	
	Lumbar	Abdominal	
	Sacral (sacrum)	Hip	
	Coccygeal (Coccyx)	Tail	
Ribs and sternum	12 pairs of ribs	Protects the thoracic organs and changes volume during respiration	

2. Appendicular skeleton		
Pectoral girdle	Clavicle	Holds the shoulders distal, permitting free movement of the arm
	Scapula	Attachment site for shoulder, back and arm muscles
Pelvic girdle	Coxa	Support and movement
Upper limb	Humerus	Arm
	Radius & Ulna	Forearm
	Carpal	Wrist
	Metacarpal	Hand
	Phalanges	Fingers (3 in all fingers except 2 in thumbs)
Lower limb	Femur	Thigh

	Patella	Knee
	Tibia & Fibula	Lower leg
	Tarsal	Ankle
	Metatarsal	Foot
	Phalanges	Toes

-Brain is contained within the cranial vault
-Zygomatic, frontal, maxilla bones make up the outer margin of the orbit (eye socket)
-Maxilla supports the upper row of teeth
-The occipital condyles are two crescent-shaped, smooth, raised regions of the occipital bone which lie anteriorly (in front) on either side of the foramen magnum. They serve for articulation with the atlas.



•Types of joints:
-Fibrous joints – fixed sutures
-Cartilaginous joints – partial movement – bones joined by cartilage
-Synovial joints – free moving – capsule surrounding articulating bones filled with synovial fluid

•Structure of a typical vertebra

Feature	**Description**
Vertebral body	Bony cylinder with flat ends
Vertebral arch	Posterior arch of bone above the vertebral body
Vertebral foramen	Hole through which the spinal cord runs
Pedicle	Forms the lateral walls of the vertebral foramen
Lamina	Forms the posterior wall of the vertebral foramen
Spinous process	Posterior projection of the vertebral arch, provides attachment for ligament and muscle
Transverse process	Provides surfaces for attachment of muscle
Articular processes	Superior and inferior projections containing articular facets to strengthn the vertebral column and allow for movement
Articular facet	Surface for articulation between vertebrae
Intervertebral notches	Form intervertebral foramina between two adjacent vertebrae through which spinal nerves exit the vertebral canal

The vertebrae of each region have a distinctive structure, indicating different functions in relation to support and movement.

The first two cervical vertebrae are further modified to allow greater movement in the neck region. The first cervical vertebra (C1) is called the atlas and the second cervical vertebra (C2) is called the axis.
The superior articular facets on the atlas allow a nodding motion of the head.
The superior articular facets on the axis allow the skull and atlas to rotate around the odontoid process. They allow a rotational "no" movement of the head.

The thoracic vertebrae possess two sets of facets for articulating with the rib. The facets for the tubercle of the rib are located on the transverse processes; the facets for articulation with the head of the rib are found at the junction between the vertebral arch and the vertebral body.

-The functions of the vertebral column are: supporting the weight of the head, protecting the spinal cord and providing a site for muscle attachment.
-The function of the large hole in each vertebra is to allow vertical passage of the spinal cord.
-The function of the bony projections on the vertebrae is to allow for articulations with ribs (thoracic vertebrae) and also serve as attachment points for ligaments/muscles and muscles/ligaments.
-The intervertebral disc is a pad of cartilage between the vertebrae which allows slight movement of the vertebral column. It is responsible for bearing gravitational pressures and other major forms of stress that are transmitted through the vertebral column i.e. cushioning the adjacent vertebrae.
-The vertebrae are prevented from moving any large distance by the superior and inferior articulating facets and by ligaments joining the vertebrae.
-Each spinal nerve passes through a space between adjacent vertebrae. The space is called the intervertebral foramen and there is one on each side of the vertebral column.