SPECIALISATION

Content Statements:

B2.3.1	Production of unspecialised cells following fertilisation and their development into specialised cells by differentiation
B2.3.2	Properties of stem cells
B2.3.3	Location and function of stem cell niches in adult humans
B2.3.4	Differences between totipotent, pluripotent and multipotent stem cells
B2.3.5	Cell size as an aspect of specialisation
B2.3.6	Surface area-to-volume ratios and constraints on cell size

CELL SIZE

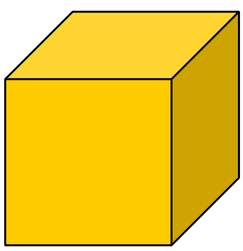
All living things are comprised of cells, however the characteristics of a cell may vary according to the exact function it performs. Cell size is one feature which varies in multicellular organisms based on cell function.

- Red blood cells need to squeeze through narrow capillaries and so have a diameter of only 7 – 8 µm
- Neurons need to transmit signals throughout the body and can be over 1 m in length (e.g. sciatic nerve)
- Striated muscle fibres consist of fused muscle cells, resulting in widths of 100 µm and lengths of >12 cm
- Adipocytes (fat cells) may vary greatly in size (<20 – 300 µm) due to their role in the storage of lipids
- A human ovum is one of the largest cells (diameter = 120 µm), while a sperm cell is very small (~ 5 µm)

SURFACE AREA : VOLUME RATIO

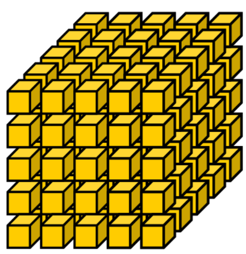
Surface area and volume are important determinants in the limitation of cell size. Cells must remain small in order to maintain a viable surface area : volume ratio. Cells need to produce chemical energy to survive (via metabolism) and this requires the exchange of materials with the environment (nutrition / excretion).
The rate of metabolism of a cell is a function of its mass / volume (larger cells will need more energy)
The rate of material exchange is a function of a cell's surface area (more membrane = more exchange)

If the metabolic rate (volume) exceeds the rate of material exchange (surface area), the cell will be unable to maintain homeostasis and will eventually die. Hence, a cell will require a **high SA : Vol ratio** in order for it to survive. However, as a cell grows, the volume (cubic units) increases more rapidly compared to the surface area (squared units), leading to a decreased ratio. Consequently, growing cells will tend to **divide** and remain small in order to maintain a viable SA : Vol ratio. Additionally, certain cells and tissues that are specialised for material exchange (e.g. lung and intestinal tissues) may modify their structure to increase their surface area and optimise material transfer (e.g. cell membranes may be ruffled to form **microvilli**).



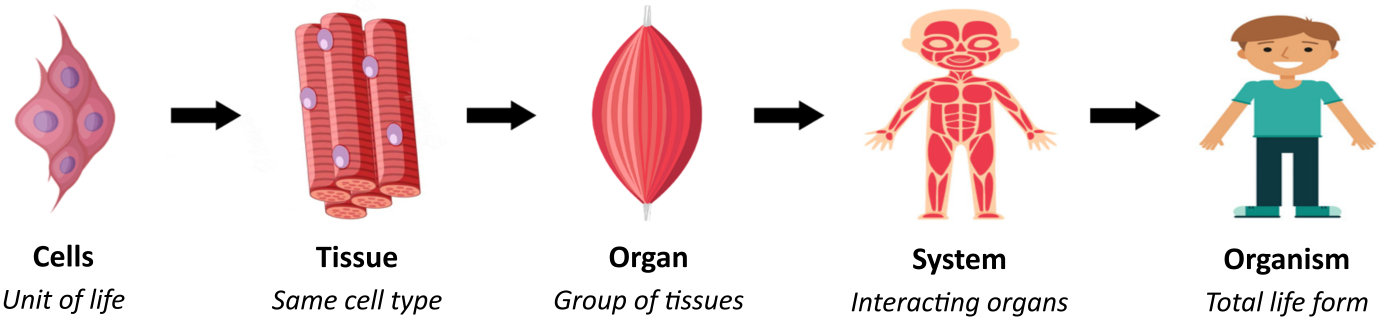
SINGLE STRUCTURE
Volume = 125 units^3
Surface Area = 150 units^2
SA:Vol Ratio = **1.2** *(low)*

DIVIDED STRUCTURE
Volume = 125 units^3
Surface Area = 750 units^2
SA:Vol Ratio = **6** *(high)*



MULTICELLULAR ORGANISMS

Multicellular organisms are composed of multiple cells combining to complete synergistic functions. While all cells in a multicellular organism are clones (genetically identical), groups of cells may differentiate in order to specialise and perform specific functions. A group of cells of the same type that perform a common function is called a **tissue**. Different tissues may interact to form specific **organ systems** that carry out a particular function (e.g. circulatory system transports materials around body) within an **organism**.



STEM CELLS

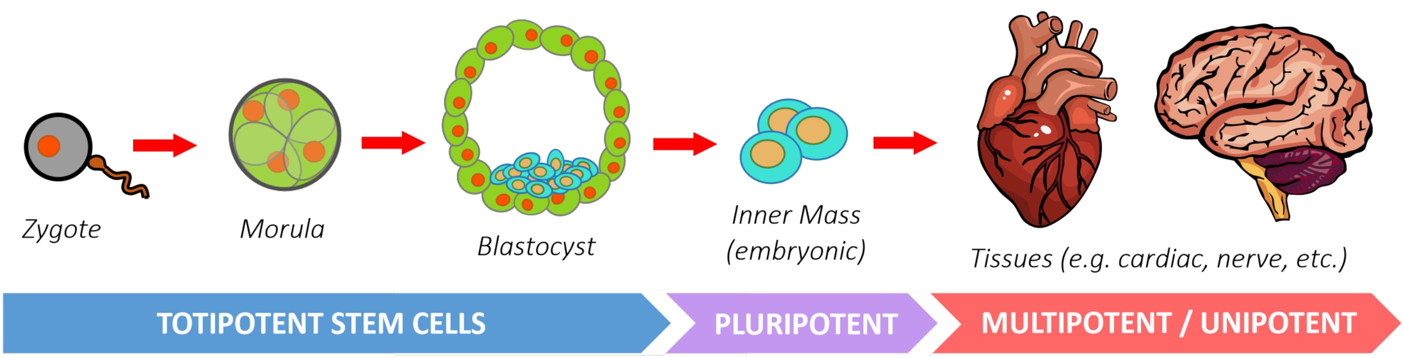
Stem cells are *unspecialised* cells from which all other cell types may be derived in a multicellular organism. They possess two key traits which allow them to form the myriad of different tissues and organs in a body:

- **Self-Renewal:** They have an unlimited capacity for growth (they can continuously divide and replicate)
- **Potency:** They retain the capacity to differentiate into specialised cell types (they are progenitor cells)

TYPES OF STEM CELLS

There are four main categories of stem cells that are present at various stages of organismal development:

- **Totipotent** – Can form any cell type, as well as extra-embryonic tissues like the placenta (e.g. zygote)
- **Pluripotent** – Can form any cell type, but cannot form autonomous life (e.g. embryonic stem cells)
- **Multipotent** – Can differentiate into a number of closely related cell types (e.g. adult stem cells)
- **Unipotent** – Cannot differentiate, but are capable of self-renewal (e.g. precursor cells / tissues)

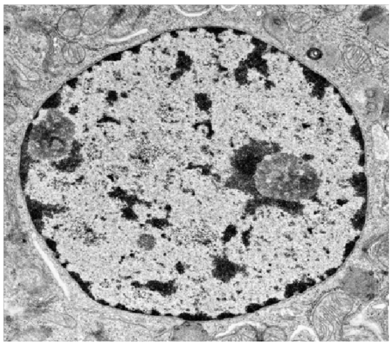


EMBRYO DEVELOPMENT

Following fertilisation, an unspecialised zygote will divide and develop into a mass of specialised cells (early embryo) via differentiation. This process is driven by the release of gene regulating chemicals (transcription factors) called **morphogens**. The impact of the morphogen will be determined by its relative concentration (which decreases as the morphogen diffuses from the source cell). Cells closer to the morphogen source will receive higher concentrations of morphogen, resulting in the activation of more genes. Cells further away from the morphogen source receive lower concentrations of morphogen, resulting in the expression of fewer genes. Hence **morphogen gradients** control the expression of genes within an early-stage embryo.

DIFFERENTIATION

All cells of a multicellular organism share an **identical genome** – each cell contains the *entire set of genes* for that organism. Differentiation is the process whereby new cells become more specialised and distinct as they mature. Differentiation is caused by the activation of different genes within a given cell (triggered by chemical signals). Within the nucleus of eukaryotes, the DNA is packaged to form **chromatin**. The active genes are packaged in an expanded form *(euchromatin)*, whereas inactive genes are packaged in a condensed form *(heterochromatin)*. Specialised cells have their identical genomes packaged differently according to their function.

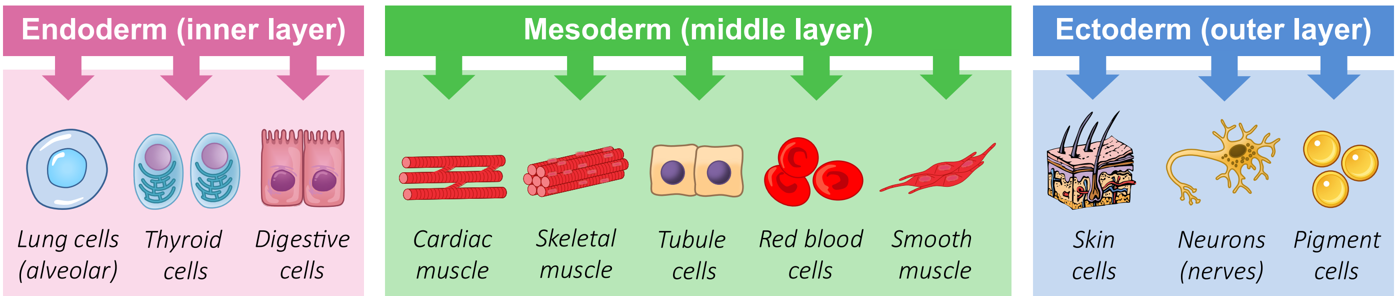


Euchromatin | *Heterochromatin*

EMBRYONIC STEM CELLS

Gastrulation is an early phase of embryogenesis whereby embryonic stem cells differentiate into three germ layers – the ectoderm (outer layer), the mesoderm (middle layer) and the endoderm (inner layer).

- **Ectoderm:** Forms the nervous system and outer surfaces (such as skin, pigment cells and hair cells)
- **Mesoderm:** Forms the majority of body organs, including muscle, vessels, kidney, heart and skeleton
- **Endoderm:** Forms the respiratory and digestive tracts, along with associated organs (liver, pancreas)



ADULT STEM CELLS

Adult stem cells are partially differentiated (multipotent) and have a limited capacity to differentiate. They can form a number of closely related cell types and function as a stock source of cells from which specific tissues can be replenished. Stem cell niches are sites within the body where pools of adult stem cells are maintained in preparation for future proliferation. Niche locations include the bone marrow (which gives rise to the different blood cells) and hair follicles (produces the cells for hair growth and vascularisation).

STEM CELL THERAPY

Embryonic and adult stem cells can be used therapeutically to treat diseases by replacing damaged cells with healthy ones. Embryonic stem cells have a greater potency (can treat more conditions) but there are ethical issues associated with their use (involves the generation and destruction on an embryo). Adult stem cells have less ethical issues and a lower chance of graft rejection (involves use of patient's own cells), but have lower potency and are therefore limited in their potential use (can only treat very specific conditions).