

## 1.4 (B.2.3) Cell specialization

### Unspecialized cells

A zygote, following fertilization and development, will turn into specialized cells via differentiation.

The zygote and embryonic cells are unspecialized stem cells.

As cells continue to grow and divide, they begin to specialize in structure and function.

### Properties of stem cells

- Can divide repeatedly.
- Can differentiate into specific cell types (along different pathways).

In adults, they are found in the bone marrow, skin, liver, placenta and umbilical cord (pregnancy).

**Morphogens** are signaling molecules that direct cell fate. They control proliferation (= multiplication) and differentiation during embryonic development to determine the formation of tissues and organs. The concentration of morphogens (gradients) influences the initiation or inhibition of gene expression, and hence differentiation.

There are three main types of stem cells present at various stages of human development:

### Totipotent, pluripotent and multipotent stem cells

**Totipotent** – The only cells that can form any cell type (e.g. zygote). They are formed after fertilization of the ovum by a spermatozoon.

**Pluripotent** – They are formed after the totipotent. Can form any cell type, but not the extra-embryonic cells/tissues (placenta). Most prevalent in early embryonic development of a multicellular organism (e.g. fetal cells, embryonic stem cells).

**Multipotent** – Can differentiate into a number of closely related cell types (e.g. haematopoietic adult stem cells, immune system cells).

Totipotent → Pluripotent → Multipotent

(all → many → few)

Can form ... cell types.

| Feature                               | Totipotent Cells                                                                                         | Pluripotent Cells                                                                                    | Multipotent Cells                                                              |
|---------------------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| <b>Definition</b>                     | Cells that can differentiate into <i>all cell types</i> , including embryonic and extraembryonic tissues | Cells that can differentiate into <i>almost all body cell types</i> , but not extraembryonic tissues | Cells that can differentiate into a <i>limited range</i> of related cell types |
| <b>Differentiation potential</b>      | Highest (can form a whole organism)                                                                      | High (can form any body tissue except extraembryonic)                                                | Moderate (restricted to specific lineages)                                     |
| <b>Can form placenta?</b>             | Yes                                                                                                      | No                                                                                                   | No                                                                             |
| <b>Examples</b>                       | Zygote and early embryo cells (up to ~8-cell stage)                                                      | Embryonic stem cells (blastocyst inner cell mass)                                                    | Adult stem cells such as hematopoietic stem cells (bone marrow)                |
| <b>Developmental stage</b>            | Earliest embryo                                                                                          | Early embryo (blastocyst stage)                                                                      | Found in later development and adult tissues                                   |
| <b>Level of specialization</b>        | Completely unspecialized                                                                                 | Unspecialized but more restricted                                                                    | More specialized than pluripotent cells                                        |
| <b>Range of cell types produced</b>   | All cell types (including extraembryonic)                                                                | All body cell types                                                                                  | Only specific related cell types (blood cells)                                 |
| <b>Relevance in research/medicine</b> | Early developmental studies                                                                              | Regenerative medicine, research                                                                      | Tissue repair & maintenance (blood, skin)                                      |

### Surface area to volume ratio

The surface area to volume ratio has important implications for processes involving transport across membranes. Activities like gas exchange and transport of useful or waste material can be done more efficiently where there is a large SA:V ratio.

- **Exchange** of materials across a cell surface depends on its **area**, whereas,
- **The need** for exchange depends on cell **volume**

Fill in the table:

Elina Hatzidimitriou MSc, MEd

| Cube size | Surface area                                                       | Volume                                                             | Surface area to volume ratio |
|-----------|--------------------------------------------------------------------|--------------------------------------------------------------------|------------------------------|
| 2 cm cube | $2 \times 2 \times 6 = 24 \text{ cm}^2$<br>(2 cm x 2 cm x 6 sides) | $2 \times 2 \times 2 = 8 \text{ cm}^3$<br>(height x width x depth) | 24 to 8 = 3:1                |
| 3 cm cube |                                                                    |                                                                    |                              |
| 4 cm cube |                                                                    |                                                                    |                              |
| 5 cm cube |                                                                    |                                                                    |                              |

### Examples of adult stem cells (stem cell niches).

1. **Bone marrow** within the skeleton is the site of blood cell formation (also known as haematopoiesis). In human adults, it contains osteoblasts (cells regulating new bone creation) and haematopoietic stem cells. HSCs produce red blood cells, white blood cells, platelets and plasma.
2. **Hair follicle cells** are structures of mammalian skin that regenerate to produce new hair. These stem cells are **multipotent** and increase rapidly. Certain stem cells act as pigment-producing cells. An imbalance in stem cell differentiation and altered activity can lead to hair loss with age.

### Cell size is another aspect of cell specialization.

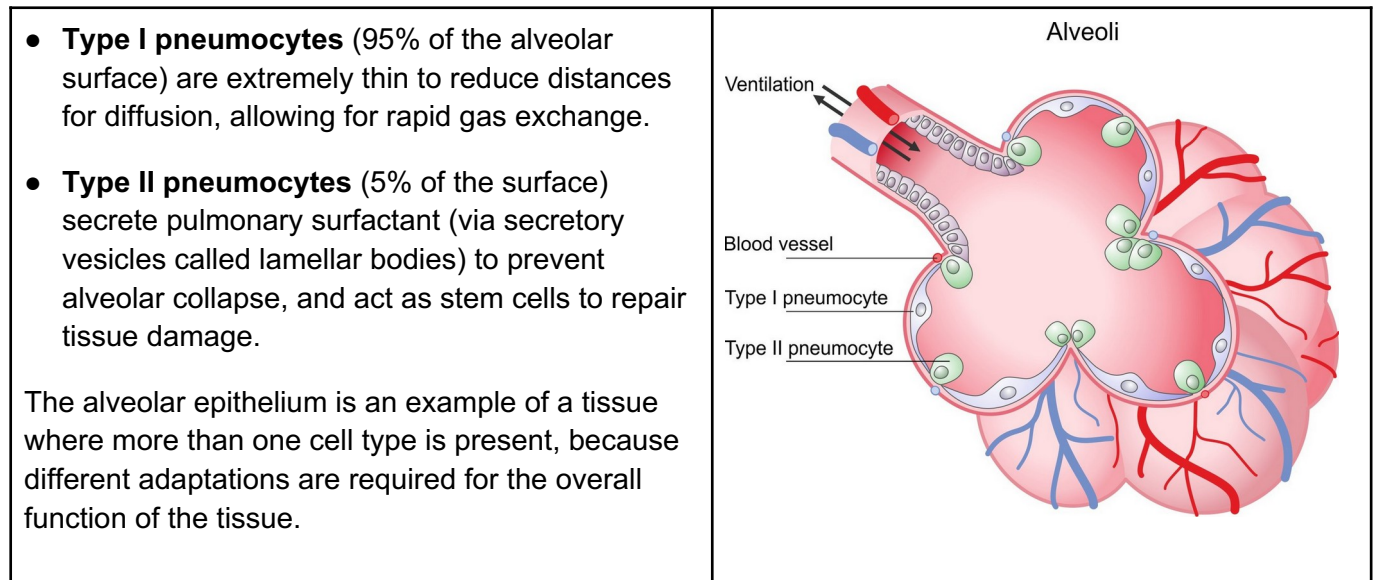
The range of cell size in humans is wide, including male and female gametes, red and white blood cells, neurons and striated muscle fibres.

## Higher Level

### Adaptations to increase surface area-to-volume ratios of cells

**Alveoli** are tiny air sacs at the end of the air tubes in human lungs that perform gas exchange.

Adaptations of *type I* and *type II* pneumocytes in alveoli (two different cell types in lungs).



### Size-related adaptations of human gamete cells.

1. **Sperm cells** are 50µm long, which is longer than most cells, but are also extremely narrow, reducing resistance when swimming towards the egg.
2. **Egg cells** are 110µm in diameter, the largest of any human cell. It allows large food reserves to be stored in the cytoplasm (see yolk in eggs).

### More adaptations of cells that maximize the SA: volume ratio.

**Red blood cells** are wide/thin like flattened discs, thus reducing the distances from one end of the cell to the other, so they are able to load and unload millions of O<sub>2</sub> rapidly.

**Small intestine epithelium cells** are adapted with specialised structures to absorb nutrients.

- Finger-like projections called microvilli, greatly increase the surface area for absorption.
- Invaginations are infoldings of the plasma membrane to increase the surface area for absorption.

**Kidney cells** are able to re-absorb useful substances rapidly similarly to the small intestine.

*\*We will see more adaptations in cardiac muscle cells and striated muscle fibres in chapter 8 Physiology.*