Chapter 1

The cell and body tissue

Peter S. Vickers

Aim

The aim of this chapter is to introduce the reader to the various cells and tissues of the body in order to develop their insight and understanding.

Learning outcomes

On completion of this chapter, the reader will be able to:

- Outline the structure and function of a human cell.
- Name and describe the functions of the organelles.
- Explain the cellular transport system.
- Describe the structures and functions of the various tissues of the body, namely: epithelial, connective, muscle and nervous tissues.

Keywords

- cytoplasm
- plasma membrane
- organelles
- nucleus
- passive transport
- active transport
- epithelial tissue
- muscle tissue
- connective tissue
- mitochondria

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Test your prior knowledge

1. What are the characteristics of human cells?
2. Describe the ways in which substances can pass through the cell membrane.
3. What is the role of the cell nucleus?
4. What are the four main roles of connective tissue?
5. How many different types of muscle tissue are there?
6. Where is epithelial tissue to be found within the body?

CELLS

Introduction

What is a cell? Put simply, a cell is a building block for the formation of all life and, particularly in this case, for the formation and development of the human body. There are many different types of cells and they play different roles in both the structure and functioning of the body. For example, certain cells come together to form skin (a tissue), which acts as a cover and protector for our internal organs (tissues). Other cells combine to form bone (tissue) and hence our skeleton. Then there are other different cells which combine to make up the brain and neurological tissue (nerves). Outside the cells that form our structure are the cells that help to keep us functioning, for example, the cardiac cells, which combine to make the heart (tissue), which in turn keeps blood (cells and a tissue) flowing around our body carrying nutrients to all our cells and tissues and removing waste products from them. Some cells are involved in protecting us from infectious organisms, whilst others form muscles (tissues) which allow us to work and move. So, it can be seen that cells are the basic building blocks of our bodies – indeed, our very 'being'.

All these different types of cells are actually produced from just two cells – ovum and sperm – which fuse together at the moment of conception. Within those two cells are all the plans and schemata for producing the number and diversity of cells that make a human body – truly a miracle! Once they fuse together at conception, they begin to multiply and divide into the different types of cells. This manufacture and diversification of cells is dictated by the genes carried in all of our cells (see Chapter 2, Genetics).

This chapter will give a brief overview of the structure of cells and their roles within the body. In addition, it will discuss some of the problems that can occur and how these can affect the working and health of the body, commencing with the common characteristics of cells (Fig. 1.1).

Characteristics of cells

- Cells are active – carrying out specific functions.
- Cells require nutrition to survive and function. They use a system known as endocytosis in order to catch and consume nutrients – they surround and absorb organisms such as bacteria and then absorb their nutrients. These nutrients are used for the storage and release of energy, as well as for growth and for repairing any damage to themselves.
- Cells can reproduce themselves by means of asexual reproduction in which they first develop double the number of organelles (the organs of a cell) and then divide, with the same number and types of organelle and structure present in each half. This is known as simple fission.
- Cells excrete waste products.

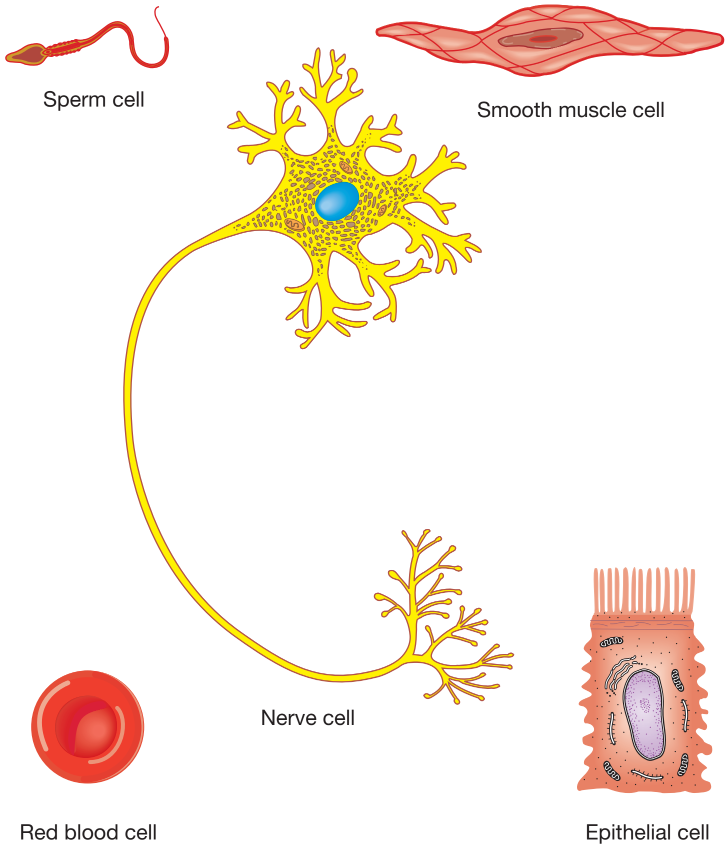

Figure 1.1 Examples of different types of cells in the body. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

- Cells react to things that irritate or stimulate them – for example, in response to threats from chemicals and viruses.

The structure of the cell

There are four main compartments of the cell:

- cell membrane
- cytoplasm
- nucleus
- nucleoplasm.

Within these compartments are many organelles (or small organs). These organelles perform numerous roles to keep cells alive and functioning.

The cell membrane

As can be seen in Fig. 1.2, the various structures of the cell are contained within a cell membrane (also known as the plasma membrane). This cell membrane is a semi-permeable biological membrane separating the interior of the cell from the outside environment, and protecting the cell from its surrounding environment. It is semi-permeable because it allows only certain substances to pass through it for the benefit of the cell itself. For example,

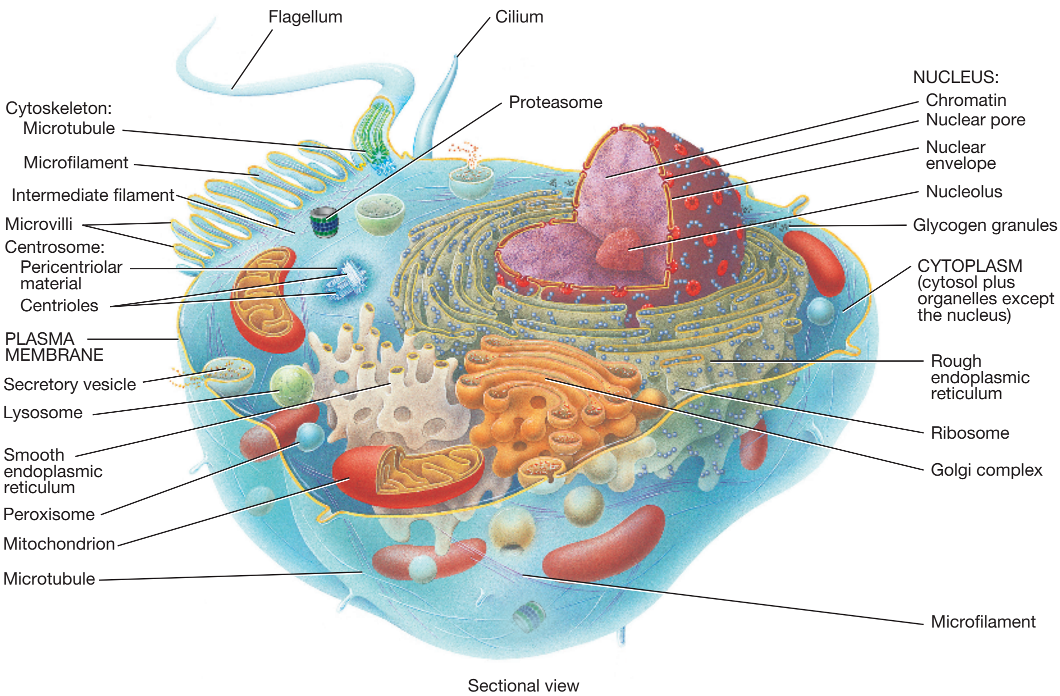

Figure 1.2 Structure of the cell. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

it is selectively permeable to certain ions and molecules (Alberts *et al.*, 2014). Inside the cells are the cytoplasm and the organelles, which include, for example, the lysosomes, mitochondria, and the nucleus of the cell.

The cell membrane, which can vary in thickness from 7.5 nm (nanometres) to 10 nm (Vickers, 2009) is made up of a self-sealing double layer (bilayer) of phospholipid molecules with protein molecules interspersed amongst them (Fig. 1.3). A phospholipid molecule consists of a polar 'head', which is hydrophilic (mixes with water), and a tail that is made up of non-polar fatty acids, which are hydrophobic (repel water). In the bilayer of the cell membrane, all the heads of each phospholipid molecule are situated on the outer and inner surfaces of the cell facing outwards, whilst the tails point into the cell membrane; it is this central part of the cell membrane consisting of hydrophobic tails that makes the cell impermeable to water-soluble molecules (Marieb, 2014). In addition to the phospholipid molecules, the cell membrane contains a variety of molecules, mainly proteins and lipids, and these are involved in many different cellular functions, such as communication and transport. The proteins inserted within the cell membrane are known as plasma member proteins (PMPs), which can be either integral or peripheral. Integral PMPs are embedded amongst the phospholipid tails whilst others completely penetrate the cell membrane. Some of these integral PMPs form channels for the transportation of materials into and out of the cell, others bind to carbohydrates and form receptor sites (e.g., attaching bacteria to the cell so they can be destroyed). Other examples of integral PMPs include those that transfer potassium ions in and out of cells, receptors for insulin, and types of neurotransmitters (Vickers, 2015). On the other hand, peripheral PMPs bind loosely to the membrane surface, and so can be easily separated from it. The reversible attachment of proteins to cell membranes has been shown to regulate cell signalling, as well as acting as enzymes to catalyse cellular reactions through a variety of mechanisms (Cafiso, 2005).

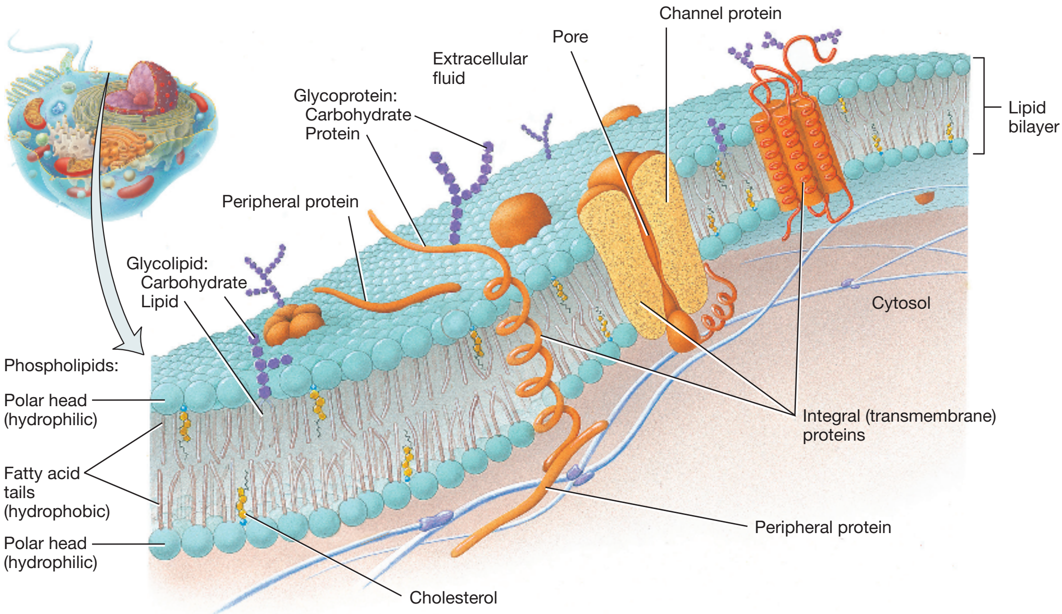

Figure 1.3 Cell membrane. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

Functions of the cell membrane

Briefly, the two major physiological functions of the cell membrane are endocytosis and exocytosis. These are both concerned with the transport of fluids and other essential particulates and waste matter into and out of the cell.

- **Endocytosis** is the passing of fluids and small particles into the cell. There are three types of endocytosis, namely:
  - **Phagocytosis** – the ingestion of large particulates, such as microbial cells
  - **Pinocytosis** – the ingestion of small particulates and fluids
  - **Receptor-mediated** – involving large particulates, such as protein. It is also highly selective as to which particulates are taken up.

Endocytosis involves part of the cell membrane being drawn into the cell interior, along with particulates or fluid, in order to facilitate their ingestion. This part of the membrane is then 'pinched off' to form a vesicle within the cell. At the same time, the cell membrane reseals itself. Once inside the cell, the fate of this vesicle depends upon the type of endocytosis involved and the material that is contained within the cell membrane surrounding it. In some cases, the vesicle may ultimately fuse with a lysosome (an organelle), following which the ingested material can be processed. Endocytosis is also the means by which many simple organisms – such as amoeba – obtain their nutrients.

The cell membrane and transport

Selective permeability, as mentioned in the previous section, is very important to the process of transporting materials into and out of the cell, allowing certain materials to pass through the membrane, whilst preventing others that could harm the cell. This process depends upon the hydrophobicity of some of its molecules (as mentioned earlier). Because the phospholipid molecule tails are composed of hydrophobic fatty acid chains, it is difficult for hydrophilic (water-soluble) molecules to penetrate the membrane. Hence it forms an effective barrier for these types of molecules, which can only be penetrated by means of specific transport systems that control what can enter or leave the cell. For example, the membrane controls the process of metabolism by restricting the flow of glucose and other water-soluble metabolites into and out of cells – as well as between subcellular compartments. In addition, the cell stores energy in the form of transmembrane ion gradients by allowing high concentrations of particular ions to accumulate on one side of the membrane. Ions can pass through the membrane from inside the cell to the outside – or vice versa – so that there are more supplies of these ions just outside the cell or inside it. The membrane controls the speed/rate at which these ions pass through the membrane. The controlled release of such ions on the gradients can be used for:

- extracting nutrients from the fluids around the cells
- passing electrical messages (nerve excitability)
- controlling the volume of the cell.

Cell membrane permeability

There are four factors involved in the degree of permeability of a cell membrane, namely:

1. The size of molecules – large molecules cannot pass through the integral membrane proteins, whilst small molecules (e.g., water, amino acids) can.
2. Solubility in lipids (fats) – substances that easily dissolve in lipids (e.g., oxygen, carbon dioxide, steroid hormones) can pass through the membrane more easily than non-lipid soluble substances can.
3. If an ion has an electrical charge that is the opposite of that found in the membrane, then it is attracted to the membrane and so can more easily pass through it.
4. Carrier integral proteins can bind to substances and carry them across the membrane, regardless of the three processes above, i.e., size, ability to dissolve in lipids, or membrane electrical charge.

Movement of substances across the membrane

There are two ways for this to occur, namely, passive and active.

Passive processes

A passive process is one in which the substances move under their own volition down a concentration gradient from an area of high concentration to an area of lower concentration. In this process, the cell expends little energy on the process (like rolling down a hill).

There are four types of passive transport processes, namely:

- diffusion
- facilitated diffusion
- osmosis
- filtration.

Diffusion is the most common form of passive transport. A substance in an area of higher concentration moves to an area of lower concentration (Colbert *et al.*, 2012). The difference seen between areas of different concentrations is known as the concentration gradient. This particular passive transport process is essential for respiration. It is through diffusion that oxygen is transported from the lungs to the blood and carbon dioxide from the blood into the lungs.

Although similar to diffusion, facilitated diffusion differs from it by the use of a substance (a facilitator) to help in the process (see Fig. 1.4). As an example, glucose is moved

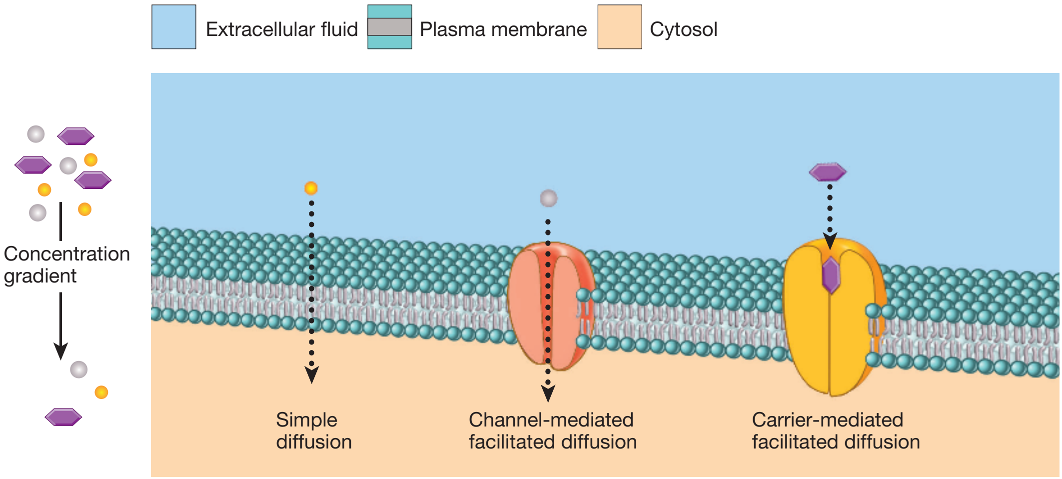

Figure 1.4 Facilitated diffusion. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

using this process. To be able to pass through a membrane, glucose needs to attach itself to a carrier/transport protein (McCance & Huether, 2014).

Osmosis is the process by which water travels through a selectively permeable membrane so that concentrations of a solute (a substance that is soluble in water) are equal on both sides of the membrane. This gives rise to osmotic pressure. The higher the concentration of the solute on one side of the membrane, the higher the osmotic pressure available for the movement of water (Colbert *et al.*, 2012).

If osmotic pressure rises too much, then it can cause damage to the cell membrane, so the body attempts to ensure that there is always a reasonable constant pressure between the cell's internal and external environments. We can see the possible damage if, for example, a red blood cell is placed in a low concentrated solute, then it will undergo haemolysis. On the other hand, if it is placed in a highly concentrated solute, the result will be a crenulated cell. If the red blood cell is placed in a solution with a relatively constant osmotic pressure, it will not be affected because the net movement of water in and out of the red blood cell is minimal.

Filtration is similar to osmosis, with the exception that physical pressure is used in order to push water and solutes across a cell membrane. This is seen in renal filtration, where the heart beating exerts pressure as it pushes blood into the kidneys, where filtration of the blood can then take place to remove any impurities (Colbert *et al.*, 2012).

Active processes

Active processes are:

- active transport pumps
- endocytosis
- exocytosis.

An active process is one in which substances move against a concentration gradient from an area of lower to higher concentration. In order for this to happen, the cell must expend energy, which is released by the splitting of adenosine triphosphate (ATP) into adenosine diphosphate (ADP) and phosphate.

ATP is a compound of a base, a sugar and three phosphate groups (triphosphate), and is held together by phosphate bonds, which release a high level of energy when they are

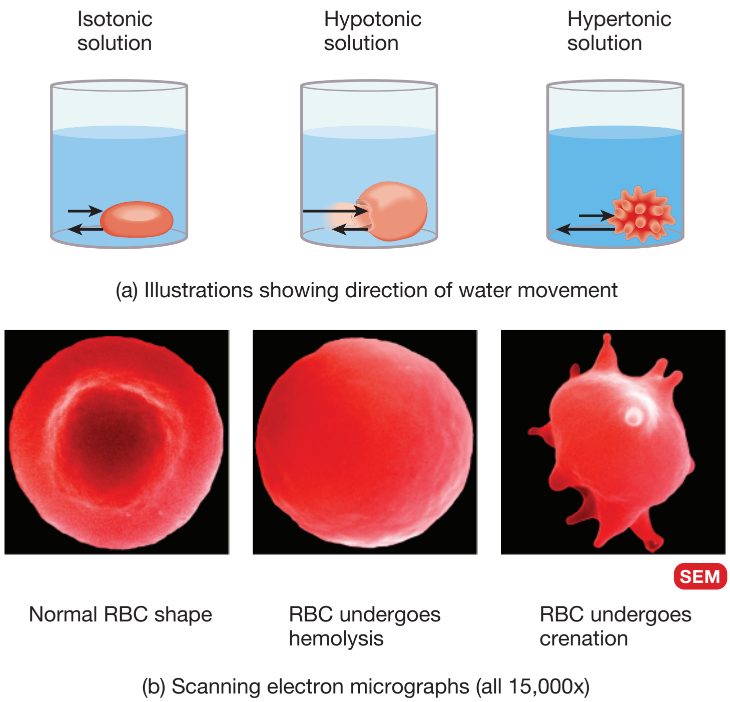

Figure 1.5 Effect of solute concentration on a red blood cell. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

broken. Once one of the phosphate bonds is broken and phosphate has been released, that compound then becomes ADP. The 'spare' phosphate will then join another ADP group, so forming ATP (with energy stored in the phosphate bond). This process is continually recurring within the body.

Active transport pumps need energy to be able to function. This energy occurs as a result of the reaction mentioned earlier. It is necessary when the body is attempting to move an area that already has a high concentration of that substance. The higher the concentration already present, the more energy is required to move further molecules of that substance into that area. Fig. 1.5 demonstrates the effect of solute concentration on a red blood cell.

The organelles

These are rather like small 'organs' within the cells. The following sections give a brief overview of the many cell organelles and their functions.

Cytoplasm

Although, not strictly speaking, an organelle, the cytoplasm is a very important and integral part of the cell interior. Cytoplasm is ground substance (a 'matrix') in which various cellular components are found. It forms part of the protoplasm of the cell (protoplasm is the collective name for everything within a cell). Cytoplasm is a thick, semi-transparent, elastic fluid containing suspended particles along with the cytoskeleton (the cell framework). The cytoskeleton provides support and shape to the cell and is involved in the movement of structures within the cytoplasm – for example, phagocytic cells. Chemically, cytoplasm is made up of 75–90% water along with solid compounds, particularly carbohydrates, lipids and inorganic substances.

The role of the cytoplasm

- Cytoplasm is the substance within the cell in which chemical reactions occur.
- It receives raw materials from the external environment (e.g., from digested food) and converts them/breaks them down into usable energy by means of decomposition reactions.
- It is the site where new substances are synthesised (produced), which can then be used by the cell for its various functions.
- It is the place where various essential chemicals are packaged either for use by itself or transported out for other cells of the body to use.
- The cytoplasm is also the place where various chemicals help with the excretion of waste materials.

The nucleus (see Fig. 1.2)

The cell nucleus is the control centre of a family of cells known as eukaryotes. Eukaryotic cells are found in animals (including humans) and plants. These cells include the prokaryotic cells that are very typical of bacteria – these cells tend to be less complex and often smaller than eukaryotic cells. However, not all human cells have a nucleus. A good example is the red blood cell. The mature red blood cell has lost its nucleus and consequently is concave in shape because it has 'collapsed in' on itself. There are also some human cells (some muscle fibre cells) that have more than one nucleus (see Fig. 1.1).

Some facts about the nucleus

- The nucleus is the largest structure in a human cell.
- It is surrounded by a nuclear membrane (just as the cell is surrounded by a cell membrane).
- It has its own protoplasm, although rather than 'cytoplasm' it is called 'nucleoplasm'.
- The nucleus is responsible for the reproduction of the cell and for making us what we are (see later) – it is where the processes of meiosis and mitosis take place.
- Within the nucleus is found all our genetic material, including DNA leading to chromosomes.
- In humans, there are normally 23 pairs of chromosomes in each cell that contains a chromosome, apart from sperms and ova, which only have 23 single chromosomes (see Chapter 2).

Cell reproduction

In order for the body to grow and also for the replacement of body cells that die or are damaged, our cells must be able to reproduce themselves. In order that the genetic information contained in the cells of the body is not lost, this must be achieved accurately.

As mentioned earlier, in humans there are a total of 23 pairs of chromosomes in each human cell that contains a nucleus. Cells reproduce by means of two processes: mitosis and meiosis, with most cells being reproduced by mitosis, whilst meiosis is restricted to the gender cells, namely the spermatozoa and the ova.

The majority of the cells that are reproduced by mitosis are exact replicas of the parent cells, and contain the full complement of 23 pairs of chromosomes, whilst those cells reproduced by meiosis are totally different in that they only contain one of each of the 23 chromosomes.

To ensure that all the genetic information is passed on accurately, in mitosis, the chromosomes reproduce themselves and then the cell divides into two, ensuring that one pair of each of the chromosomes is found in each new cell. Meiosis, however, is different in that, although initially the process is the same as in mitosis, the cells then undergo other procedures so that the end product is cells with only one copy of each chromosome. This is essential for the reproduction, not of cells, but of humans, as explained briefly in the following paragraph.

During the reproduction of humans, an egg (ovum) is penetrated by a sperm (spermatozoa), which then releases its chromosomes containing DNA which will then combine with the DNA of the egg. Because these two cells (ovum and spermatozoa) only contain one copy of each chromosome rather than the two carried by all other cells of the body, the ovum will only have two copies of each chromosome containing DNA. If the process of meiosis did not take place and the egg and sperm were like all the other cells in the body and had the normal two copies of each chromosome, then the resulting embryo would end up with four copies of each chromosome. If this process was repeated, then the next generation would end up with eight copies of each chromosome, and the following generation with 16 copies …, and so on. This is obviously not practical, which is why the ova and spermatozoa undergo meiosis to ensure that only two copies of the chromosomes are present in each succeeding generation. This will be explored more fully in Chapter 2.

Other organelles

All cells contain many organelles, and these are discussed in the following sections.

Endoplasmic reticulum

The endoplasmic reticulum (ER) consists of membranes that form a series of channels known as cisternae (see Fig. 1.6). These divide the cytoplasm into compartments. There are two types of cisternae:

1. granular ER (rough), which is associated with ribosomes (see Chapter 2)
2. agranular ER (smooth), which is free of ribosomes.

Ribosomes include tiny particles of RNA – these are formed in the cell nuclei and are associated with the synthesis of proteins need by the cell.

- The membranes of the ER contain many enzymes that speed up chemical reactions within the cells.
- ER consists of a series of channels (cisternae), which are concerned with the transport of materials – particularly proteins.
- ER contains a number of enzymes that are important for cell metabolism – such as digestive enzymes, enzymes that are involved in the synthesis (production) of steroids, and enzymes that lead to the removal of toxic substances from the cell (McCance & Huether, 2014).
- The alteration/addition of proteins exported from the cell also occurs in the cisternae.
- ER is also present in liver cells, where it has a role to play in drug detoxification.
- Granular ER is particularly found in cells that actively synthesise and export proteins.
- Agranular ER is found in steroid hormone-secreting cells, such as the cells of the adrenal cortex or, in males, the testes.

Golgi complex (Fig. 1.2)

The Golgi complex (also known a Golgi apparatus) is a collection of membranous tubes and elongated sacs. These are actually flattened cisternae that are stacked together. The Golgi complex has two major roles:

1. Helping to concentrate and package some of the substances that are made in the cell itself, for example, lysozymal enzymes.

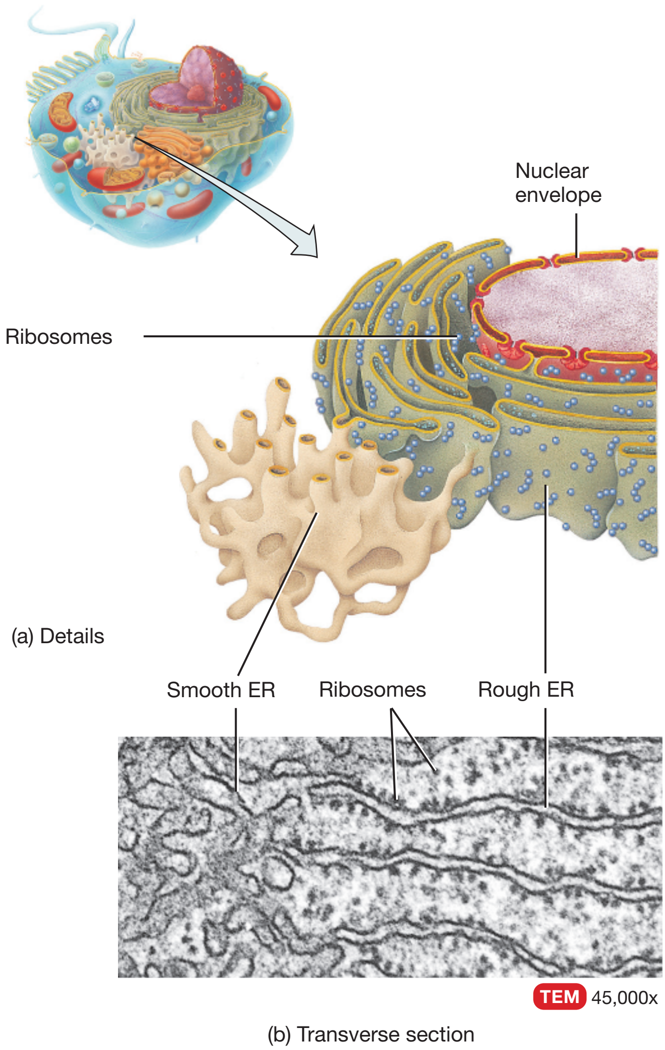

Figure 1.6 Endoplasmic reticulum. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

2. Helping with the assembly of substances for secretion outside of the cell. Secretory cells (such as those found in the mucus membrane) have many Golgi stacks, whilst non-secretory cells have few Golgi stacks per cell.

Proteins for export from the cell are, first of all, synthesised on the ribosomes. They then travel through the ER to the Golgi vesicles (a vesicle is a fluid-filled sac). The vesicles leaving the Golgi complex then fuse with the cell membrane by the process of exocytosis. This allows the contents of the vesicles to be exported out of the cell.

In addition, the Golgi complex is itself involved in the formation of glycoproteins.

Lysosomes (Fig. 1.2)

Lysosomes are organelles that are bound to the cell membrane and they contain a variety of enzymes. They have a number of functions:

- They are responsible for the digestion of material (e.g., pathogenic organisms) taken up by the process of endocytosis.
- They can break down components within the cell when they are not needed. For example, during the development of a human embryo, the fingers and toes of the embryo are webbed and the lysosomal enzymes remove the cells making up the webbing from between the digits.
- After the baby's birth, the uterus (which can weigh around 2 kg at full term) is invaded by phagocytic cells that are rich in lysosomes. These then reduce the uterus to its non-pregnant weight of approximately 50 g within about 9 days.
- In normal cells, some of the synthesised proteins may be faulty, and so, consequently, it is the lysosomes that are responsible for their removal and destruction.

It is crucially important that lysosomes do not rupture and release their contents inside living cells that we need to function, otherwise the lysosomal enzymes would start to digest and destroy the cell that is needed. If this occurs, the results can be seen in certain degenerative diseases, such as rheumatoid arthritis. The rupturing and breaking down of lysosomes from macrophages causing the release of lysosomal enzymes may be a significant factor in the attacking and destruction of essential living cells and tissues.

Lysosomes also contribute to the production of hormones, such as thyroxine. Thyroxine is a hormone that affects a wide range of physiological activities, such as the rate of metabolism throughout the body.

Peroxisomes (Fig. 1.2)

Peroxisomes are organelles that are similar in structure to lysosomes. However, they are much smaller. These organelles are particularly abundant in the cells of the liver, and they contain several enzymes that are toxic to cells of the body.

The role of peroxisomes in cells appears to be one of detoxification of harmful substances – such as alcohol and formaldehyde – within the cell. Importantly, they also neutralise dangerous free radicals. Free radicals are highly reactive chemicals that contain electrons that have not been 'paired off', and so are 'free' to disrupt the structure of molecules (Marieb, 2014).

Mitochondria (Fig. 1.2)

Mitochondria (mitochondrion, singular) are often thought of as the 'power houses' of the cell because they generate most of the cell's supply of adenosine triphosphate (ATP), used as a source of energy. The mitochondria are often found concentrated in regions of the cell associated with intense metabolic activity.

Anatomically, mitochondria consist of two membranes (an inner and an outer) and an intermembrane space.

The inner membrane has many folds (cristae) that increase the surface area available for chemical reactions to occur, such as the production of ATP (adenosine triphosphate – a coenzyme used as an energy carrier in the cells of all known organisms, which is responsible for the process in which energy is moved throughout the cell). This process is collectively known as internal respiration. The inner membrane is of the same thickness as the outer membrane and is responsible for oxidative phosphorylation.

The mitochondrial matrix is the name given to the space that is surrounded by the inner membrane. It contains enzymes of the tricarboxylic acid (TCA) cycle, as well as those enzymes involved in fatty acid oxidation. About two-thirds of the total protein is found in mitochondria, and, with the inner membrane, they play an important role in the production of ATP, and contain a very concentrated mixture of hundreds of enzymes.

The intermembrane space: Because the outer membrane is freely permeable to small molecules, there is a high concentration of small molecules, such as ions and sugars. However, larger molecules cannot enter this space unless they possess a specific signalling code that allows them to be able to pass through the outer membrane.

The outer mitochondrial membrane encloses the entire organelle. It contains large numbers of integral membrane proteins, known as porins, which form channels in the membrane to allow small molecules to diffuse easily from outside the mitochondria to the intermembrane space, and vice versa. Any disruption of the outer membrane allows proteins in the intermembrane space to leak into the intercellular fluid in the cell (cytosol), leading to certain cell death.

By using ATP, the mitochondria are able to generate the energy needed by the cell for it to be able to function by converting the chemical energy contained in molecules of food. The production of ATP, therefore, requires the breakdown of food molecules, and it occurs in several stages, each requiring the appropriate enzyme. Note that an enzyme is a protein that can initiate and speed up a chemical reaction (it acts as a catalyst). The enzymes in the mitochondria are stored in the membranes in the required order so that the chemical reactions occur in the correct sequence. This mechanism is very important, as it would be disastrous if the chemical reactions occurred out of sequence.

Mitochondria are self-replicating, in that, although most of a cell's DNA is contained in the cell nucleus (see Chapter 2), the mitochondrion has its own independent genetic organisation that is really quite similar to that of bacteria. DNA that is incorporated into the mitochondrial structure controls its own replication system.

The cytoskeleton

The cytoskeleton is a lattice-like collection of fibres and fine tubes and these are found in the cytoplasm of the cell. It is involved with the cell's ability to maintain and alter its shape as required (see Fig. 1.7).

There are three components that make up the cytoskeleton:

- microfilaments
- microtubules
- intermediate filaments.

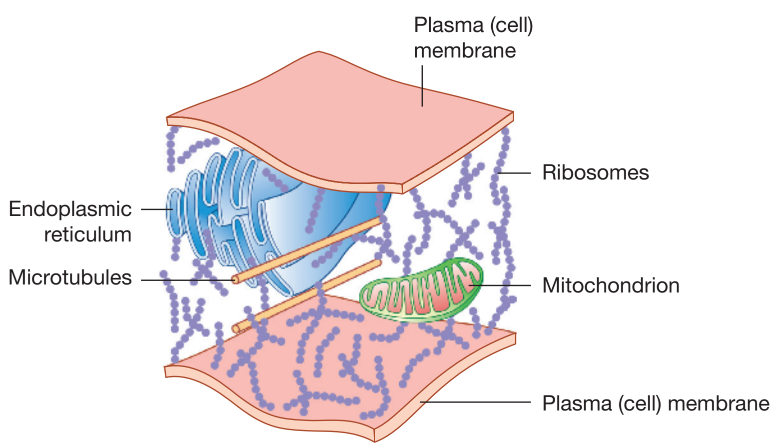

Figure 1.7 The cytoskeleton. *Source:* Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

Microfilaments

Microfilaments are rod-like structures that are approximately 6 nanometres (6 nm) in diameter and are made of a protein called actin. In muscles, both actin (which is thick) and another protein – myosin (which is thin) combine together to allow the contraction of muscle fibres. In non-muscle cells, microfilaments help to provide support and shape to the cell. Microfilaments also assist in the movement of the cells themselves, as well as movement within the cells.

Microtubules

Microtubules are relatively straight, slender cylindrical tubules that range in diameter from 18 to 30 nm. They consist of another protein – tubulin.

- Microtubules and microfilaments help to provide shape and support for cells.
- They provide conducting channels – like tunnels – through which various substances can move through the cytoplasm.
- They also assist in the movement of pseudopodia (false arms/legs) – temporary projections of eukaryotic cell membranes. The functions of pseudopodia include locomotion (movement) and the capturing of prey. Pseudopodia sense prey that can then be engulfed. The engulfing pseudopodia are used by phagocytic white cells.

Intermediate filaments

These help to determine the shape of a cell, and range in size from 8 to 12 nm. Examples of intermediate filaments are neurofilaments, which are found in nerves.

Centrioles

These cylindrical structures are found in most animal cells, and are composed of nine sets of microtubule cylinders arranged in a circular pattern. They are particularly involved in cell reproduction. Centrioles are involved in the organisation of the mitotic spindle (see Chapter 2).

Cilia and flagella

These 'hair-like' structures extend from the surface of some cells. They possess the facility to bend, which causes the cells to move.

In humans, cilia generally have the function of moving fluid or particulates over the surface of the cells. However, ciliated cells of the respiratory tract have a very important role to play in our immune and respiratory system in that they are able to move mucus that has trapped foreign particles, including bacteria and viruses, over the surface of respiratory tissues and towards the mouth or nose, thus preventing them from causing illness.

A flagellum (singular of flagella) is usually a much larger structure than a cilium (singular of cilia), and it is often used like a fish's tail to propel the cell forward. The only example of a human cell with a flagellum is a spermatozoon, where the flagellum acts as a tail and propels the spermatozoon towards an ovum.

Conclusion

This ends the section on cells; an understanding of them and their roles in the anatomy and physiology of bodies is of utmost importance in allowing us to understand how the human body functions. The next section in this chapter will look at the various structures and organs of our bodies – all of which are made up of billions of cells.

TISSUES

Introduction

Each of us, as humans, began life as a single cell – a fertilised egg. As soon as fertilisation takes place, the egg divides continuously into many cells by division, leading to the development of an embryo, then a fetus, and finally to a baby (see Chapter 2). However, these cells do not just divide endlessly and haphazardly. Rather, they divide and grow together in such a way that they become specialised and form, for example, muscle cells, skin cells, blood cells, and so on. These specialised cells then group together to become tissues, which themselves join with other tissues to form a human being. So tissues are simply groups of cells that are similar in structure and generally perform the same functions (McCance & Huether, 2014).

There are four primary types of tissues:

- epithelial
- connective
- muscle
- nervous.

These four primary tissue types then interweave to form the fabric of the body (Marieb, 2014). Each of the four types of tissue has a specific role to perform within the body. In simple terms:

- Epithelial tissue is concerned with covering and/or lining the body, both internally and externally.
- Connective tissue is concerned with supporting the body and the tissues and organs that make up the body.
- Muscle tissue is concerned with movement – both of the body and within the body.
- Nervous tissue is concerned with the control of the body – both internally and externally (Marieb, 2014).

These specialist cells form themselves into tissues in one of two ways.

1. The first way is by means of a process known as 'mitosis' (see Chapter 2, for a description of the process of mitosis). Cells formed as a result of the process of mitosis are clones of the original cell. Therefore, if one cell with a specialised function undergoes mitosis, and subsequent generations of daughter cells continue to undergo mitosis, then the resulting hundreds and thousands of cells will all be identical and of the same type, meaning that they will all have the same function. If these identical cells join together, they will become a specialised tissue. So, for example, epithelial cell sheets (such as skin) are formed as a result of mitosis (McCance & Huether, 2014).
2. The second way is by migrating to the site of tissue formation and assembling with other cells to form a tissue. This is particularly seen during the development of the embryo when, for example, cells migrate to sites in the embryo where they differentiate and assemble into a variety of tissues (McCance & Huether, 2014). This movement of cells is known as 'chemotaxis'. Chemotaxis is the movement of cells along a chemical gradient caused by chemical attraction (McCance & Huether, 2014).

Types of tissues

Epithelial tissue

Epithelial tissue lines and covers areas of the body – both outside and inside, as well as forming the glandular tissue of the body. Thus, the exterior of the body (i.e., skin) is covered by one type of epithelial tissue whilst other types of epithelial tissue line digestive organs, such as the stomach and the small intestines, along with the kidneys, and so on. So it can be seen that epithelial tissue covers or lines most of the internal and external surfaces of the body.

Classification

Epithelial tissue is classified in two ways:

1. The number of cell layers:
   - simple – where the epithelium is formed by a single layer of cells (Fig. 1.8)
   - stratified – where the epithelium has two or more layers of cells (Fig. 1.9)
2. Shape:
   - squamous
   - cuboidal
   - columnar.

Simple epithelial tissue is most concerned with absorption, secretion and filtration of fluids and particulates. However, because this tissue is usually very thin, it is not involved in protection.

Simple squamous epithelium rests on a basal layer known as the 'basement membrane'. This is composed of a structural material that is secreted by the cells themselves (Marieb, 2014). The basement membranes provide a layer of cells that supports and separates epithelial tissue from the underlying connective tissue (Fig. 1.10). The squamous epithelial cells fit very closely together to give a thin sheet forming the tissue. This type of epithelial tissue is found in the alveoli of the lungs as well as in the walls of capillaries. It is this very thin tissue that easily allows for rapid diffusion into and out of the cell, thus facilitating oxygen and carbon dioxide exchange through the epithelial tissue that is lining the alveoli of the lungs, and allowing nutrients and gases to pass easily through the epithelial tissue from the cells into the capillaries – and vice versa.

Simple squamous epithelial cells also form the serous membranes that line certain body cavities and organs.

Simple cuboidal epithelial tissue consists of one layer of cells resting on a basement membrane (Fig. 1.11). However, because cuboidal epithelial cells are thicker than squamous epithelial cells, they are found in different places within the body and also perform

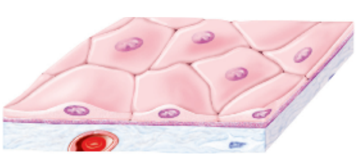

Figure 1.8 Simple epithelium. *Source:* Nair & Peate 2013, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

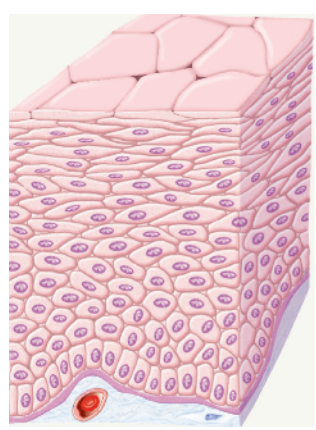

Figure 1.9 Stratified epithelium. *Source:* Nair & Peate 2013, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

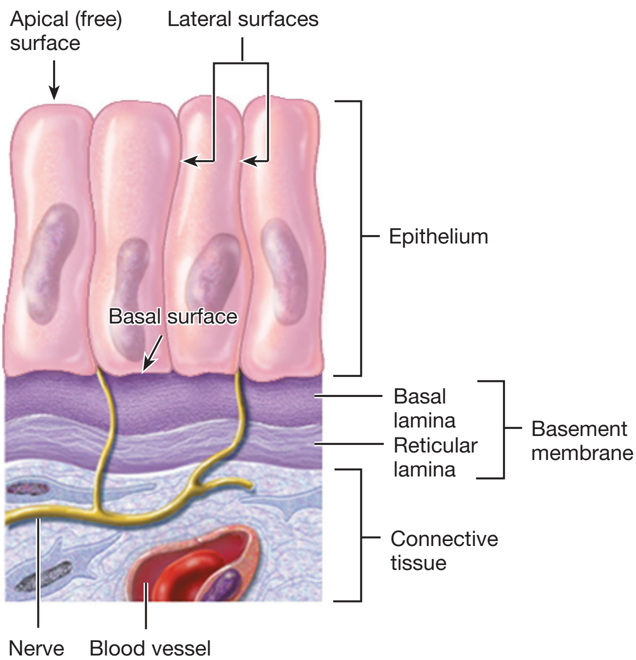

Figure 1.10 Connective tissue reinforces epithelial tissue. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

different functions. This type of epithelial tissue is to be found in glands, such as the salivary glands and the pancreas. In addition, they form the walls of the kidney tubules as well as covering the surface of the ovaries (Marieb, 2014).

Simple columnar epithelium (Fig. 1.12) is the third type of simple epithelial tissue. Like the other types of simple epithelium, it is composed of a single layer of cells, although these cells are relatively tall. However, similar to the other types, they still fit closely together. It is this type of epithelial tissue, which also contains goblet cells, that lines the entire length of the digestive tract from the stomach to the anus. Goblet cells produce mucus, and so, consequently, the simple columnar epithelial tissues that line all the body cavities that are open to the exterior of the body are known as mucous membranes (Marieb, 2014).

Stratified epithelial tissue, unlike simple epithelial tissue, consists of two or more cell layers – so they lie in strata (hence the name). Because these stratified epithelial tissues

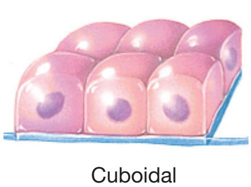

Figure 1.11 Simple cuboidal. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

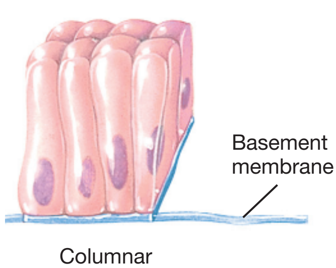

Figure 1.12 Simple columnar. *Source:* Tortora & Derrickson 2009, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

have more than one layer of cells, they are stronger and hardier than simple epithelia. As a consequence, a primary function of stratified epithelia is protection.

Stratified squamous epithelial tissue consists of several layers of cells and is the most common stratified epithelium found within the human body (Marieb, 2014). Despite being called 'squamous epithelium', it is not composed entirely of squamous cells. Only the cells at the free edges of the epithelial tissue are squamous cells, while those cells that are close to the basement membrane are made up of either cuboidal or columnar cells. This tissue is to be found in parts of the body that are most at risk of everyday damage, such as the oesophagus, the mouth, and the outer layer of the skin.

Stratified cuboidal epithelial tissue has just two layers of cells and is only found in the ducts of large glands, such as the sweat glands, mammary glands, and salivary glands where its role is to protect the ducts of these glands.

Stratified columnar epithelial tissue is also found only in a few particular places in the body, such as in the conjunctiva of the eye, parts of the pharynx and anus, the uterus, and the male urethra and vas deferens. It is also to be found in ducts located within the salivary glands.

Transitional epithelium is a highly modified stratified squamous epithelium and forms the lining of just a few organs and other structures – all of which form part of the urinary system, namely the urinary bladder, the ureters, and part of the urethra. This tissue has been modified so that it can cope with the considerable stretching that takes place within these organs. When one of these organs/structures is *not* being stretched, the tissue is seen to have many layers, with the superficial cells (i.e., those in the top layer) having a rounded appearance like domes. However, when one of these organs/structures is distended with urine, then the epithelium becomes thinner as the surface cells flatten and become just like normal squamous cells. These transitional cells are able to slide past one another and change their shape, thus allowing the wall of the ureters, for example, to stretch as a greater volume of urine flows through it. This type of 'elastic' epithelium allows for more urine to be stored in the bladder, until micturition takes place.

Case Study Epidermolysis bullosa (EB)

Thomas, aged 6 months, was admitted to hospital because his skin was constantly blistering after even the smallest amount of friction. Unfortunately, the parents were not with Thomas as they were being investigated by Social Services for suspected child abuse and neglect.

Fortunately, Thomas was seen by an experienced child dermatologist who recognised the blistering as a medical condition known as junctional epidermolysis bullosa (EB) rather than because of parental abuse. EB occurs as a result of a rare genetic mutation, which can either be dominantly or recessively inherited (see Chapter 2) – although sometimes it can occur as a result of a new genetic mutation in the child's DNA.

Human skin consists of two layers: an outer layer – the epidermis, and beneath that a second layer – the basement membrane, also known as the dermis. These two layers are connected and held together by protein filaments that anchor them to each other. The anchors prevent the two layers from moving independently of each other – known as 'shearing'. In EB, there is a defect in certain genes that are responsible for coding for these anchoring filaments. As a consequence, the skin is extremely fragile and easily damaged by very minor trauma, such as rubbing or pressure. This will cause the layers of the skin to separate and form blisters and intensely painful sores. In addition, there is an increased risk of malignancies (cancers) developing. In severe cases of EB, it is not only the skin that can develop blisters, other membranes, such as those found in the mouth, oesophagus, and digestive tract, can also be affected.

There are three main types of EB, with EB simplex – the least serious – making up over 90% of those born with the condition. Approximately 1% of people with EB have junctional EB – like Thomas. Research is ongoing to find a cure or better treatment for this condition, with bone marrow transplants as a possible cure, and using the patient's own immune system to reduce the effects of the disorder.

Once this diagnosis had been confirmed, the parents were cleared of any ill treatment of Thomas and were able to be with him in hospital to learn about the disorder and, more particularly, how to help care for him.

It was vitally important for the parents to receive psychosocial counselling and support after their ordeal and to help them face the future with Thomas. They will also require genetic counselling in case they wish to have other children. The counselling offered will depend upon the mode of transmission of Thomas's type of EB. Above all, they will need the support of the nurses who are looking after Thomas so that they will learn how to care for him.

Unfortunately, at the present time there is no cure for EB, so palliative care and prevention of complications is essential. In addition, as Thomas grows and develops, he will face further challenges, not only medical, but also physical and psychosocial challenges, which will have to be met not just by his parents and nursing and medical staff (in hospital and the community), but also by social workers, psychologists, educational staff and schoolteachers, along with patient and parent support groups. All these people and groups will require education in dealing with children who have this rare disorder, as well as much support themselves.

Red Flag

Because of the rareness of this condition, many social workers are contacted by GPs and non-specialist doctors and nurses in general hospitals who see the blistering and the damaged skin and assume parental abuse to be the cause. This can lead to the parents being falsely accused of child neglect and cruelty. Thus, once their child has been finally diagnosed with EB, parents can be very guarded and 'difficult' when faced with any authority, including the nurses looking after their child. Consequently, the nurse has to gain their trust and respect by being totally honest, caring and compassionate – not just with the child, but also with the parents and any relatives.

Investigations

To confirm the diagnosis of EB, in addition to the signs and symptoms and medical history, skin biopsies will be necessary to make a definitive diagnosis. Two skin biopsies will be required:

1. One of the intact blisters will need to be excised for histology, which if EB is present, will show a sub-epidermal blister, with infiltration of neutrophils.
2. A biopsy of peri-lesional skin (within 2 cm of the blister) will also need to be taken for direct immunofluorescence (DIF). The sample is put on plain gauze soaked in normal saline and must be examined on the day it is taken. If EB is present, then DIF may show deposits of IgG, IgM and IgA.

Great care must be taken when obtaining these specimens, particularly to prevent infection occurring, and also to prevent further pain and discomfort – thus a local anaesthetic will be injected into the area before obtaining the samples.

Glandular epithelium

Glandular epithelial tissue is to be found within the glands. According to Marieb (2014), a gland consists of several cells that make and secrete a particular product.

There are two major types of glands developed from sheets of epithelial cells:

- exocrine glands
- endocrine glands.

Exocrine glands have ducts leading away from them, and their secretions empty through these ducts to the surface of the epithelium. Examples of exocrine glands include the sweat gland, the liver, and the pancreas.

On the other hand, endocrine glands do not possess ducts. Rather, their secretions diffuse directly into the blood vessels that are found within the glands. All endocrine glands secrete hormones, and include the thyroid, adrenal glands, and the pituitary gland.

Connective tissue

Connective tissue is found everywhere in the body and, as the name suggests, it connects body parts to one another (see Fig. 1.10).

It is the most abundant and widely distributed of all four primary tissue types. Although connective tissues perform many functions and vary considerably in their structure, they all have four main functions:

- protection
- support
- binding together of other tissues (Marieb, 2014)
- acting as storage sites for excess nutrients (McCance & Huether, 2014).

However, the most common structure and function of connective tissue is to act as a framework on which the epithelial cells gather in order to form the organs of the body (McCance & Huether, 2014).

There are several common characteristics of connective tissue, a major one being that there are actually few cells in the tissue. However, these few cells are surrounded by a lot of what is known as 'extracellular matrix'. This extracellular matrix is composed of ground substance and fibres, and it varies in consistency from fluid to a semi-solid gel. The fibres themselves are constructed from fibroblasts. There are three types of fibres in connective tissue:

- collagenous (white) fibres
- elastic (yellow) fibres
- reticular fibres.

The ground substance is composed mainly of water plus some adhesion proteins and large polysaccharide molecules. The adhesion proteins serve as a glue that allows connective tissue cells to attach to fibres. The change of consistency within the ground substance from fluid to a semi-solid gel depends on the number of polysaccharide molecules present; an increase in polysaccharide molecules causes the matrix to change from a fluid to a semi-solid gel. The ground substance can store large amounts of water, and thus acts as a water reservoir for the body.

Collagen fibres have great strength, whilst elastic fibres are able to be stretched and to recoil. The reticular fibres form the internal 'skeleton' of soft organs, such as the spleen.

Connective tissue forms a 'packing' tissue around organs of the body, and so helps to protect them. It is able to bear considerable weight as well as withstand stretching and various traumas, such as abrasions. There is a wide variation in types of connective tissue.

For example, fat tissue is composed mainly of cells and a soft matrix, whilst bone and cartilage have very few cells, but they contain large amounts of hard matrix – which makes them strong.

There are variations in blood supply to the tissue. Although most connective tissues have a good blood supply, there are some types, for example, tendons and ligaments, which have a poor blood supply, while cartilage has no blood supply. This is the reason why these tissues heal slowly when they are damaged. Bone, which has a good blood supply, will heal much quicker than a damaged tendon or ligament (Marieb, 2014).

Types of connective tissue

Bone

Bone is the most rigid of the connective tissues, and it is composed of bone cells surrounded by a very hard matrix containing calcium and large numbers of collagen fibres. Because of their hardness, bones provide protection, support, and muscle attachment.

Cartilage

Cartilage is not as hard as bone, but is more flexible. It is found in only a few places in the body (see Fig 1.13). For example, hyaline cartilage supports the structures of the larynx. It also attaches the ribs to the sternum and covers the ends of bones where they form joints. Another type of cartilage is fibrocartilage, which can be compressed and forms the discs between the spinal and neck vertebrae. Elastic cartilage is found in the external ear, where a degree of elasticity is necessary.

Dense connective tissue

This forms strong, stringy structures such as tendons (which attach skeletal muscles to bones) and the more elastic ligaments (which connect bones to other bones at joints). Dense connective tissue also makes up the lower layers of skin (the dermis). These tissues have collagen fibres as the main matrix element, with many fibroblasts found between the collagen fibres. Fibroblasts are involved in the manufacture of fibres.

Loose connective tissue

These tissues are softer and contain fewer fibres but more cells than other types of connective tissue (with the exception of blood). There are four types of connective tissue:

- areolar tissue
- adipose tissue
- reticular tissue
- blood.

Areolar tissue

Areolar tissue is the most widely distributed connective tissue type in the body. It is a soft tissue that cushions and protects the body organs that it surrounds. It also helps to hold the internal organs together. It has a fluid matrix that contains all types of fibres forming a loose network. This gives it softness and pliability. It also provides a reservoir of water and salts for the surrounding tissues.

All body cells obtain their nutrients from this tissue fluid and they also release their waste into it. It is in this area that, following injury, swelling (oedema) can occur because the areolar tissue soaks up the excess fluid causing it to become puffy (Marieb, 2014).

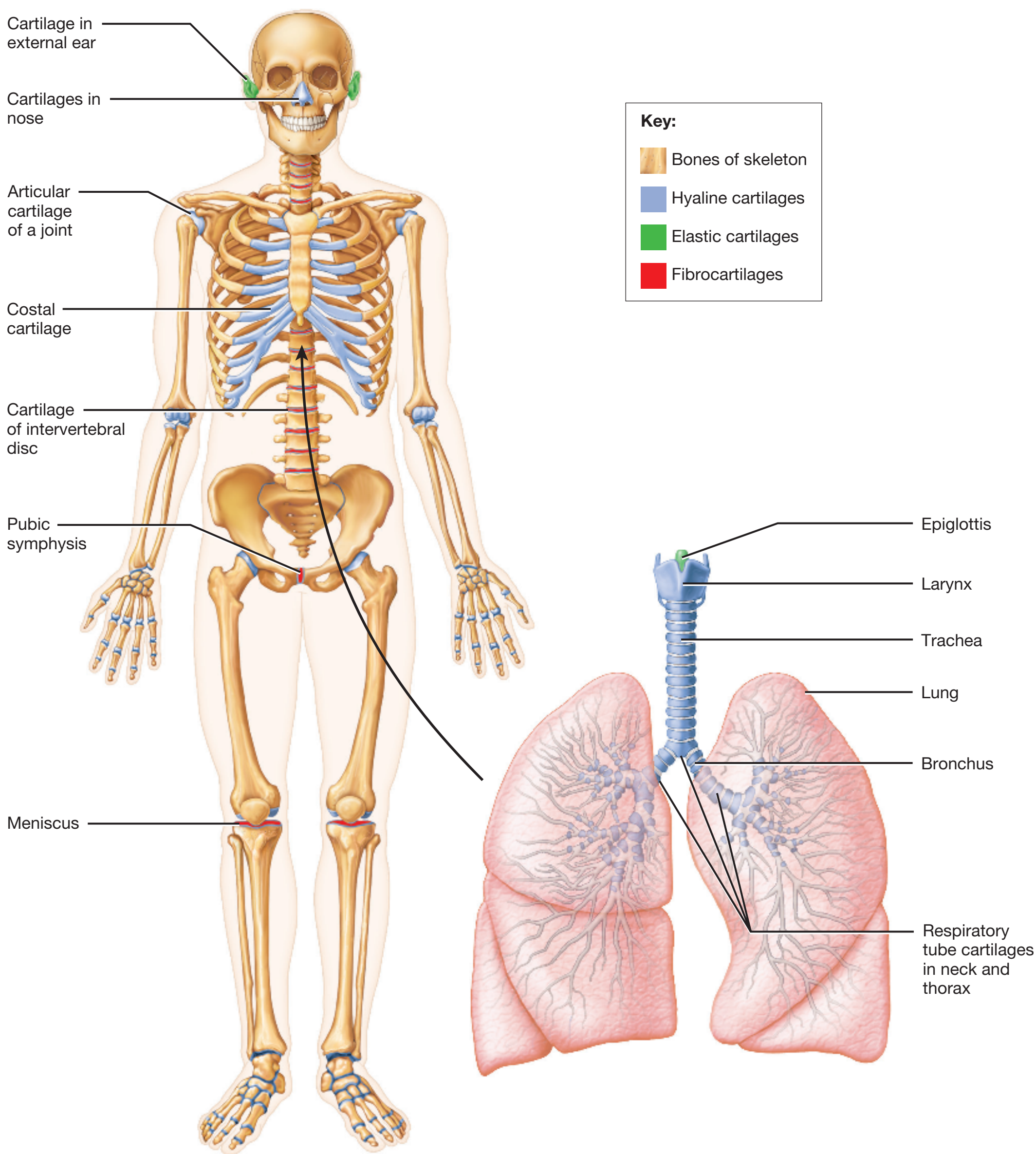

Figure 1.13 Where cartilage is found in the body. *Source:* Jenkins & Tortora 2013, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

Adipose tissue

This tissue is commonly known as 'fat'. It is actually adipose tissue in which there is a preponderance of fat cells. This tissue forms the subcutaneous tissue that lies just below the skin, and its role is to insulate the body and protect it from extremes of heat and cold. It also protects some organs such as the kidney and eyeballs.

Reticular connective tissue

This tissue consists of a delicate network of reticular fibres that are associated with reticular cells. It forms an internal framework to support many free blood cells – mainly the lymphocytes – in the lymphoid organs, such as the lymph nodes, spleen, and bone marrow.

Blood

Blood (or vascular tissue) is considered to be a connective tissue. The reason for this is that it is surrounded by a non-living, fluid matrix – blood plasma. Blood is concerned with the transport throughout the body of nutrients, waste materials, gases (oxygen and carbon dioxide), and many other substances.

Muscle tissue

There are three types of muscle tissue. These are responsible for helping the body to move, and for moving substances around the body. The three types of muscle tissue are:

- skeletal muscle
- cardiac muscle
- smooth muscle.

See Figs. 1.14 and 1.15 for examples of skeletal muscle cells and smooth muscle.

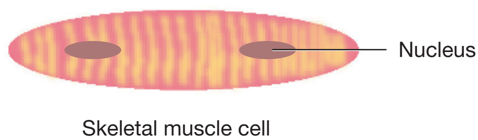

Figure 1.14 Skeletal muscle cells. *Source:* Nair & Peate 2013 in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

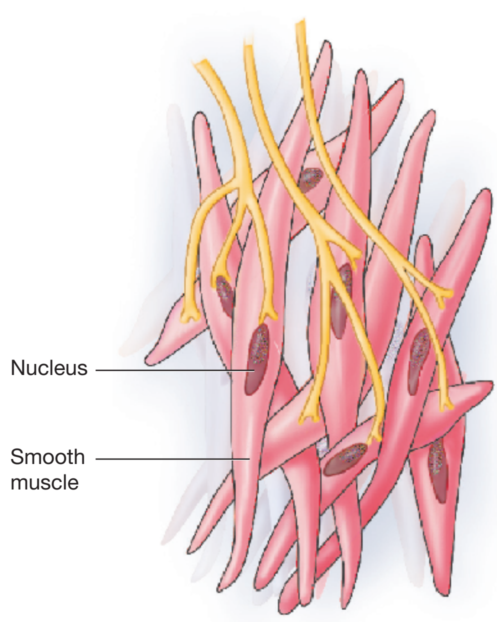

Figure 1.15 Smooth muscle. *Source:* Nair & Peate 2013 in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

Skeletal muscle

Skeletal muscle is attached to bones and is involved in the movements of the skeleton. These muscles can be controlled voluntarily and form the 'bulk' of the body – the flesh. The cells of skeletal muscles are long, cylindrical, and have several nuclei (Fig. 1.14). In addition, they appear striated (striped). They work by contracting and relaxing, with pairs working antagonistically against each other – i.e., one muscle contracts and the opposite muscle relaxes. So, if the muscles in the front of the arm contract, then the ones at the back relax, which causes the arm to bend.

Cardiac muscle

Cardiac muscle is only found in the heart and its role is to pump blood around the body. It also achieves this by contracting and relaxing. However, unlike skeletal muscles, cardiac muscle works in an involuntary way – the activity cannot be consciously controlled. The cells of the muscle do not have a nucleus.

Smooth muscle

Also known as visceral muscle, smooth muscle is found in the walls of hollow organs – for example, the stomach, bladder, uterus, and blood vessels. Like cardiac muscle, smooth muscle works in an involuntary way. It causes movement in the hollow organs; for example, as smooth muscle contracts, the cavity of the organ constricts – becomes small in volume – and when it relaxes the organ becomes larger in volume (dilates). This allows substances to be propelled through the organ in the right direction, for example, faeces in the intestine. As smooth muscle contracts and relaxes, it forms a wave-like motion (peristalsis) to push the faeces through the intestines to the rectum (see Fig. 1.16).

Nervous tissue

Nervous tissue is concerned with control and communication within the body by means of electrical signals. The neuron (Fig. 1.17) is the main type of cell found in nervous tissue.

All neurons receive and conduct electrochemical impulses around the body. The structure of neurons is very different from other cells. The cytoplasm is found within long processes or extensions – some in the leg are more than a metre long. These neurons receive

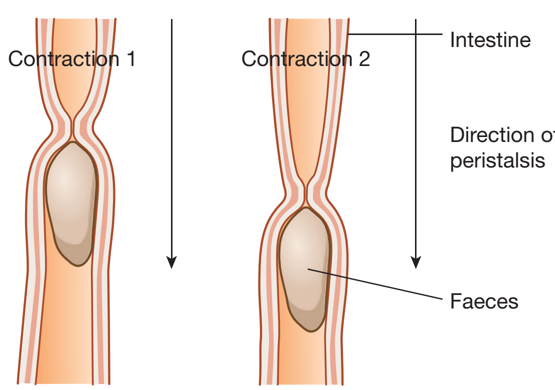

Figure 1.16 Peristalsis. *Source:* Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

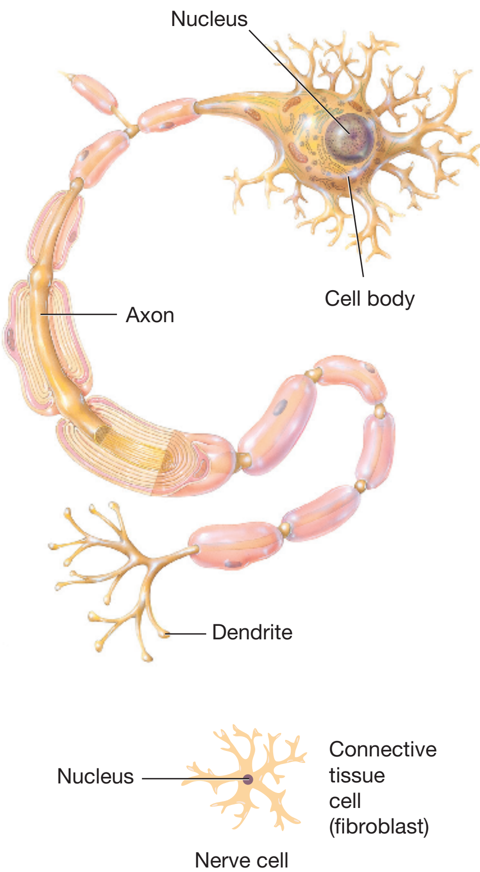

Figure 1.17 Nerve cell. *Source:* Nair & Peate 2013, in: Peate & Gormley-Fleming 2015. Reproduced with permission of Wiley.

and transmit electrical impulses very rapidly from one to the other across junctions (known as synapses). Synapses also allow electric impulses to pass from neurons to muscle cells. The total number of neurons is fixed at birth and cannot be replaced if lost or damaged (McCance & Huether, 2014).

In addition to neurons, nervous tissue includes some cells known as neuroglia (supporting cells). These cells insulate, support and protect the delicate neurons. The neurons and supporting cells comprise the structures of the nervous system, namely:

- brain
- spinal cord
- nerves.

Tissue repair

The many tissues of the body are always at risk of injury or disease. Inflammation is the body's immediate reaction to tissue injury or damage, because when this occurs, it stimulates the body's inflammatory and immune responses to spring into action so that the healing process can begin almost immediately.

Conclusion

This chapter has looked at the building blocks of the human body, namely the cells and tissues. Cells are extremely complicated parts of the body, but an understanding of them and their functions is important to comprehend how the human body itself functions. Cells form tissues, which then form the various structures, systems, and organs of the body. The remainder of this book will look at these systems, structures, and organs – how they function and what can go wrong with them.

Test your knowledge

1. How many primary tissue groups are there?
2. What is the difference between an exocrine and an endocrine gland?
3. What is the function of muscle tissue?
4. Discuss the two main classifications of cells: the prokaryotes and eukaryotes.
5. Each cell is surrounded by a membrane, what is the function of this membrane?

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