EUKARYOTE CELL BIOLOGY

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Summary

Cells form the basic unit of life on our planet. They are well organized systems which perform all the essential tasks of eating, respiring, replicating and excreting waste products. The first cells, which are thought to have evolved about 3.8 billion years ago, much resembled present day prokaryotes. Eukaryotes developed later with the development of membrane-bound organelles in the cytoplasm. The endosymbiont theory suggests that mitochondria and chloroplasts were once free living bacteria which were incorporated into a large, phagocytic cell giving rise to the eukaryotic plant and animal cells of today. Eukaryotes can exist as unicellular organisms such as yeast cells, or in multicellular forms as plants or animals. Each cell contains certain basic structures. The outer cell membrane tightly regulates the intake and release of compounds. In some organisms an extracellular matrix exists outside the cell membrane, in the form of a cell wall in plant cells, or connective tissue in animal cells. A nucleus containing the hereditary material of the cell and all the machinery required for DNA replication and RNA synthesis, is the most prominent feature in the cell. The endoplasmic reticulum membrane system, together with the Golgi apparatus, is responsible for protein processing and modification and lipid synthesis. Animal cells have a well regulated cell cycle which is controlled by cyclin-dependent protein kinases. The process of cell division, mitosis, results in two diploid daughter cells being formed. Meiosis leads to the formation of haploid gametes carrying a single copy of the chromosomes. Cells interact with their neighbors and external environment by signal transduction. A messenger or signal molecule binds to the cell surface and initiates a cascade of signals and pathways inside the recipient cell. These processes illustrate how dynamic life on earth is. Scientists study cells and organisms in the laboratory to further characterize important biochemical processes of life.

1. Introduction

Cells form the basic units of fully functional, replicative life on earth. They are small, fragile units of chemicals in an aqueous soup, enclosed in a membrane. The urge of humans to organize things into neat compartments, has led to a major classification of cells into prokaryotes and eukaryotes, each with it's own definitive characteristics and life cycle. The scope of this section is to investigate the structure and diversity found amongst eukaryotic cells, as well as to look at the general structural and functional organization inside the cell.

1.1. The first cell

Life on earth probably started about 3.8 billion years ago with the appearance of the first primordial cell. The first cells had relatively simple structures: so-called prokaryotic organisms. Fossil records dating to that period indicate the presence of early cyanobacteria in stromatolites, some of which still exist in Western Australia to this day. Fossils of stromatolites exist all over the world and allow insight into the diversity and organization of these early organisms. Present day cyanobacterial strains show definite structural similarities to their earlier prokaryotic counterparts.

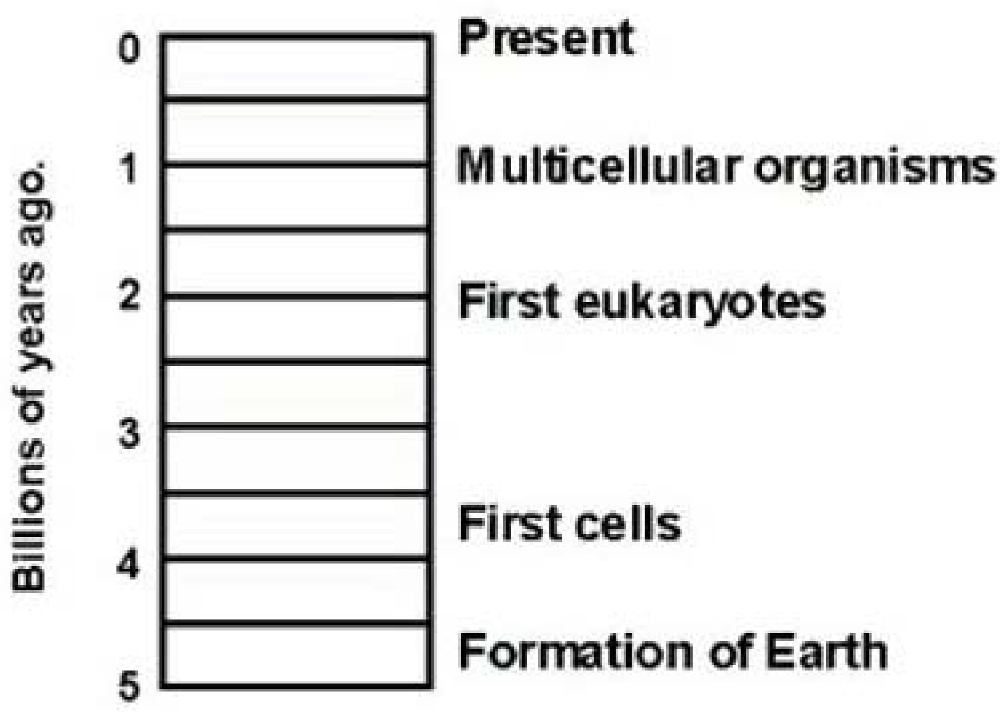

Figure 1. Diagram illustrating geological time and the origin of life.

The origin of the first cell is speculative, but a couple of theories, based on simulations done in the laboratory, have been put forward.

The climate on early Earth was violent—fraught with torrential downfalls, lightening tearing through the chemical soup existing on the surface. There was no protection from the sun's radiation, and oxygen was rapidly degraded.

During the 1920s it was thought that simple molecules polymerized at random, eventually leading to organic molecules capable of regenerating themselves. Stanley Miller performed an experiment in the mid 1950s whereby he showed that, by discharging sparks in a flask containing methane, ammonia and hydrogen gas in the presence of water vapor, he could generate the formation of basic organic molecules. Although this is not a true representation of the precise prehistoric conditions on early Earth, it demonstrated that the formation of organic molecules without life being present, was possible.

The development of macromolecules would have had to precede the development of the first cell. It is known that heating of amino acids, the building blocks of proteins, leads to their polymerization into chains resembling proteins. Nucleotides are also able to form long polymers in the form of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Long carbohydrate chains also exist, like those found in cell walls of plants. The major constraint on any newly developing molecule of life would have been the ability to replicate itself. Once a polymer has formed, it can encourage the formation of other polymers. This is particularly applicable to nucleotide chains which, due to their unique structure, are able to encourage complementary base pairing, encouraging the formation of another polymer chain of nucleotides.

The first cell probably arose through enclosure of the long chains of macromolecules by a phosopholipid bilayer. These compounds have distinct electrostatic domains that either attract or repel water, leading to the formation of fatty drops of double layers of phospholipids encircling organic compounds. In some cases, these drops would encircle a polymer capable of self replication. The RNA polymer suits the requirements for early hereditary material as it can store information, can be translated into proteins and, in some cases, is able to act as an enzyme itself. DNA, the present day hereditary material, probably developed later as a more stable storage molecule. The isolation of RNA and polypeptides in the closed environment inside the droplet, would have offered them protection from external influences and given them the time needed to evolve into functional systems, capable of self regeneration. It took several million years more for these cells to organize and develop into eukaryotic organisms containing delineated organelles and diploid genetic information.

In 1665, Robert Hook made a significant breakthrough when he observed that plant tissues were divided into small compartments. These he called *cellulae*. Two centuries later, improvements in microscopes led Theodore Schwann to observe in 1840 that all organisms were made up of cells. Sizes vary between bacteria and eukaryotes: one to ten μm and ten to one hundred μm respectively. It was found that, whatever the size of the organism being investigated, the size of the cell remains fairly constant. Plant cells are slightly larger than those of mammals, but the cells found in fleas are virtually identical in size to those found in humans, or their pets. The complex processes occurring inside the cell require a minimum volume within which to complete their reactions. They also have restrictions as to the maximum size which will allow diffusion of essential compounds from the cell surface to penetrate into the center of the cell matrix.

2. Origin of Eukaryotes

Two fundamentally different cell types exist: prokaryotes and eukaryotes. Prokaryotes predate the eukaryotes by approximately 1.5 billion years, to primordial times. Investigations into the molecular origins of the eukaryotes show that the prokaryotes and eukaryotes are as divergent as the eubacteria and archaebacteria. This suggests that the three evolutionary cell lines diverged from the last common ancestor cell, early in the evolutionary process. The defining difference between prokaryotes and eukaryotes is the presence of membrane structures in the cytoplasm of eukaryotes, specifically, a membrane bound nucleus. Mitochondria and chloroplasts are membrane-bound organelles found inside some eukaryotic cells. They contain their own genetic material and synthesize certain of their proteins themselves. This provides evidence to suggest that these organelles were once primitive bacteria which were incorporated into a robust prokaryote. The prokaryote scavenger thereby acquired additional metabolic functions, enabling it to survive in a rapidly changing environment. The process of incorporation of a foreign organism into another, is referred to as endosymbiosis. In this process, both organisms obtain an advantage: the larger organism obtains a novel and essential biochemical process, which may allow it to survive in a hostile environment, while the engulfed organism obtains protection and nutrients from the host. The arrangement of the DNA in present day mitochondria and chloroplasts resembles that of prokaryotes more closely than that of its eukaryotic host. Their protein synthesis machinery is also more closely related to that of prokaryotes.

The endosymbiont theory of eukaryote origin is now generally accepted amongst scientists. Chloroplasts evolved from early photosynthetic bacteria and mitochondria from aerobic bacteria. The incorporation of the organelles into the host would provide it with features that would provide an advantage over their competitors in the same environmental niche. Over time, certain aspects of the organelle's genetic information was incorporated into that of the host. The two organisms would thus be linked in a permanent association of mutual benefit.

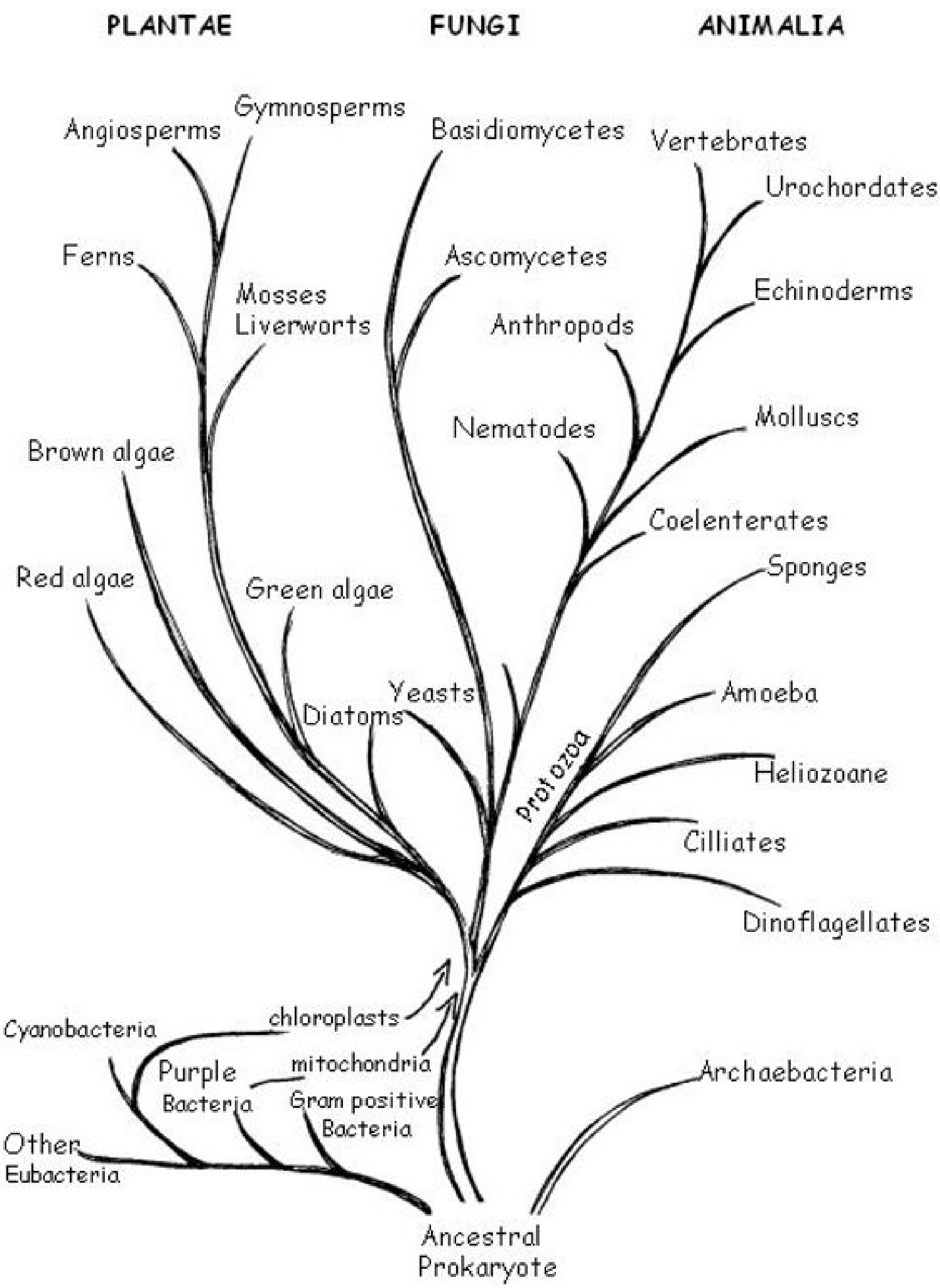

Figure 2. The evolutionary tree of life.

3. Cellular differentiation in multicellular organisms

Yeast is the simplest eukaryotic organism. It is a unicellular organism capable of replication in the same way as prokaryotes. The most commonly studied yeast is *Saccharromyces cerrevisiae*, used in the making of bread and beer. It is 6 µm in diameter and contains 14 million base pairs of DNA, almost three times larger than the average bacterial genome. Other larger, unicellular organisms are able to perform specialized functions. Algae contain chloroplasts and perform photosynthesis to produce complex compounds. Still other unicellular eukaryotes, such as *Amoeba proteus,* are able to move using pseudopodia, cytoplasmic extensions that allow it to move and engulf other organisms.

Multicellular organisms probably arose about one billion years ago. Several examples exist of unicellular eukaryotes having aggregated to form a more complex association of cells. This improved performance and offered each individual cell protection. An example is the cells of the green alga, *Volvox,* which associate with one another to form colonies. These clumps of cells are thought to have been the precursors of modern day plants.

Further specialization led to the change from aggregates of cells to complex associations of differentiated cells. Complex organisms have a broad diversity of cells, each with its own structure and function, yet they all have one common genetic code. Further differentiation and specialization lead to the formation of organs and defined tissue structures.

3.1. Plants

Plants have fewer types of cells than animals, but they are still clearly differentiated into various tissues, each with its own structure and function. There are three main tissue types in plants: ground tissue, dermal tissue and vascular tissue.

Ground tissue contains parenchyma cells that carry out the metabolic functions of the plant such as photosynthesis. Ground tissues consist of two specialize cell types: collenchyma and sclerenchyma cells. Their thick cell walls provide the structural support needed by the plant to maintain its upright shape.

Dermal tissues cover the plant surface and form the epiderm. Epidermal cells are specialized cells which protect the plant from the environment, and allow absorption of nutrients from the surrounding area.

The vascular system consists of elongated cells that constitute the xylem and phloem. These tissues facilitate the transport of water and nutrients throughout the plant.

3.2. Animals

Animal cell types present considerably more diversity than plants. Approximately 200 cell types are divided into five tissue types: epithelial, connective, nervous and muscle tissues, and blood.

The epithelial cells cover the outside of the body and line the surfaces of the internal organs. They are specialized to perform certain distinct functions, such as the salivary glands for secretion, intestinal cells for absorption and the skin for protection.

Connective tissues include the bone (osteoblast cells), cartilage (chondrocytes) and adipose (adipocytes) tissues as well as the loose connective tissue that holds the organs and tissues together—the fibroblast cells.

Neurons are highly specialized nerve cells that transmit signals throughout the body. Certain nerve cells have specialized functions such as sensory cells for the five senses of sight (the eye), smell (nose), taste (tongue), touch and sound (ear).

Blood contains a great diversity of cells that fulfill three major functions: oxygen transport by the red blood cells or erythrocytes, inflammation using granulocytes, monocytes and macrophages and the immune response involving lymphocytes.

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Biographical Sketch

Michelle Gehringer is a visiting scientist at the School of Biotechnology and Biomolecular Sciences of the University of New South Wales in Sydney, Australia. She is continuing her work on the toxic effects of the cyanobacterial toxins, microcystin and cylindrospermopsin, on humans and animals that accidently ingest them from contaminated drinking water sources. This research has provided insight into the way the body deals with the toxin as well as potential means of offering dietary protection to potential victims. Dr Gehringer has several year lecturing experience form the University of Port Elizabeth, South Africa, where she was actively involved in introducing the topics of Biochemistry and Microbiology to the general public and school goers. Her MSc was obtained at the University of Cape Town, South Africa where she worked on means to control Cucumber Mosaic Virus infections of crop plants.