1.3: Classification - The Three Domain System

Skills to Develop

1. Define phylogeny.
2. Name the 3 Domains of the 3 Domain system of classification and recognize a description of each.
3. Name the four kingdoms of the Domain Eukarya and recognize a description of each.
4. Define horizontal gene transfer.

The Earth is 4.6 billion years old and microbial life is thought to have first appeared between 3.8 and 3.9 billion years ago; in fact, 80% of Earth's history was exclusively microbial life. Microbial life is still the dominant life form on Earth. It has been estimated that the total number of microbial cells on Earth on the order of $2.5 \times 10^{30}$ cells, making it the major fraction of biomass on the planet.

Phylogeny refers to the evolutionary relationships between organisms. The Three Domain System, proposed by Woese and others, is an evolutionary model of phylogeny based on differences in the sequences of nucleotides in the cell's ribosomal RNAs (rRNA), as well as the cell's membrane lipid structure and its sensitivity to antibiotics. Comparing rRNA structure is especially useful. Because rRNA molecules throughout nature carry out the same function, their structure changes very little over time. Therefore similarities and dissimilarities in rRNA nucleotide sequences are a good indication of how related or unrelated different cells and organisms are.

There are various hypotheses as to the origin of prokaryotic and eukaryotic cells. Because all cells are similar in nature, it is generally thought that all cells came from a common ancestor cell termed the last universal common ancestor (LUCA). These LUCAs eventually evolved into three different cell types, each representing a domain. The three domains are the Archaea, the Bacteria, and the Eukarya.
More recently various fusion hypotheses have begun to dominate the literature. One proposes that the diploid or 2N nature of the eukaryotic genome occurred after the fusion of two haploid or 1N prokaryotic cells. Others propose that the domains Archaea and Eukarya emerged from a common archaeal-eukaryotic ancestor that itself emerged from a member of the domain Bacteria. Some of the evidence behind this hypothesis is based on a "superphylum" of bacteria called PVC, members of which share some characteristics with both archaea and eukaryotes. There is growing evidence that eukaryotes may have originated within a subset of archaea. In any event, it is accepted today that there are three distinct domains of organisms in nature: Bacteria, Archaea, and Eukarya. A description of the three domains follows.

Intermediaries between Bacteria, Archaeae, and Eukarya Domains?

There is a "superphylum" of bacteria called PVC, referring to the three members of that superphylum: the Planctomycetes, the Verrucomicrobia, and the Chlamydiae. Members of the PVC, while belonging to the domain Bacteria, show some features of the domains Archaea and Eukarya.

Some of these bacteria show cell compartmentalization wherein membranes surround portions of the cell interior, such as groups of ribosomes or DNA, similar to eukaryotic cells. Some divide by budding or contain sterols in their membranes, again similar to eukaryotes. Some lack peptidoglycan, similar to eukaryotes and archaea. It has been surmised that these bacteria migh be an intermediate step between an ancestor that emerged from a bacterium (domain Bacteria) and an archael-eukaryotic ancestor prior to its split into the domains Archaea and Eukarya.
The Archaea (archaebacteria)

The Archaea possess the following characteristics:

a. Archaea are prokaryotic cells.

b. Unlike the Bacteria and the Eukarya, the Archaea have membranes composed of branched hydrocarbon chains (many also containing rings within the hydrocarbon chains) attached to glycerol by ether linkages (Figure 3).

c. The cell walls of Archaea contain no peptidoglycan.

d. Archaea are not sensitive to some antibiotics that affect the Bacteria, but are sensitive to some antibiotics that affect the Eukarya.

e. Archaea contain rRNA that is unique to the Archaea as indicated by the presence molecular regions distinctly different from the rRNA of Bacteria and Eukarya.


Figure 3: Membrane Lipids of Bacteria and Eukarya. The Bacteria and the Eukarya have membranes composed of unbranched fatty acid chains attached to glycerol by ester linkages. The Archaea have membranes composed of branched hydrocarbon chains attached to glycerol by ether linkages.
Archaea often live in extreme environments and include methanogens, extreme halophiles, and hyperthermophiles. One reason for this is that the ether-containing linkages in the Archaea membranes is more stable than the ester-containing linkages in the Bacteria and Eukarya and are better able to withstand higher temperatures and stronger acid concentrations.

The Bacteria (eubacteria)

Bacteria (also known as eubacteria or "true bacteria") are prokaryotic cells that are common in human daily life, encounter many more times than the archaeabacteria. Eubacteria can be found almost everywhere and kill thousands upon thousands of people each year, but also serve as antibiotics producers and food digesters in our stomachs. The Bacteria possess the following characteristics:

a. Bacteria are prokaryotic cells.
b. Like the Eukarya, they have membranes composed of unbranched fatty acid chains attached to glycerol by ester linkages (Figure \( \PageIndex{3} \)).
c. The cell walls of Bacteria, unlike the Archaea and the Eukarya, contain peptidoglycan.
d. Bacteria are sensitive to traditional antibacterial antibiotics but are resistant to most antibiotics that affect Eukarya.
e. Bacteria contain rRNA that is unique to the Bacteria as indicated by the presence molecular regions distinctly different from the rRNA of Archaea and Eukarya.

Bacteria include mycoplasmas, cyanobacteria, Gram-positive bacteria, and Gram-negative bacteria.

The Eukarya (eukaryotes)

The Eukarya (also spelled Eucarya) possess the following characteristics:

a. Eukarya have eukaryotic cells.
b. Like the Bacteria, they have membranes composed of unbranched fatty acid chains attached to glycerol by ester linkages (Figure \( \PageIndex{3} \)).
c. Not all Eukarya possess cells with a cell wall, but for those Eukarya having a cell wall, that wall contains no peptidoglycan.
d. Eukarya are resistant to traditional antibacterial antibiotics but are sensitive to most antibiotics that affect eukaryotic cells.
e. Eukarya contain rRNA that is unique to the Eukarya as indicated by the presence molecular regions distinctly different from the rRNA of Archaea and Bacteria.

The Eukarya are subdivided into the following four kingdoms:

1. Protista Kingdom: Protista are simple, predominantly unicellular eukaryotic organisms. Examples includes slime molds, euglenoids, algae, and protozoans.
2. Fungi Kingdom: Fungi are unicellular or multicellular organisms with eukaryotic cell types. The cells have cell walls but are not organized into tissues. They do not carry out photosynthesis and obtain nutrients through absorption. Examples include sac fungi, club fungi, yeasts, and molds.
3. Plantae Kingdom: Plants are multicellular organisms composed of eukaryotic cells. The cells are organized into tissues and have cell walls. They obtain nutrients by photosynthesis and absorption. Examples include mosses, ferns, conifers, and flowering plants.
4. Animalia Kingdom: Animals are multicellular organisms composed of eukaryotic cells. The cells are organized into tissues and lack cell walls. They do not carry out photosynthesis and obtain nutrients primarily by ingestion. Examples include sponges, worms, insects, and vertebrates.

It used to be thought that the changes that allow microorganisms to adapt to new environments or alter their virulence capabilities was a relatively slow process occurring within an organism primarily through mutations, chromosomal rearrangements, gene deletions and gene duplications. Those changes would then be passed on to that microbe's progeny and natural selection would occur. This gene transfer from a parent organism to its offspring is called vertical gene transmission.

It is now known that microbial genes are transferred not only vertically from a parent organism to its progeny, but also horizontally to relatives that are only distantly related, e.g., other species and other genera. This latter process is known as horizontal gene transfer. Through mechanisms such as transformation, transduction, and conjugation, genetic elements such as plasmids, transposons, integrons, and even chromosomal DNA can readily be spread from one microorganism to another. As a result, the old three-branched "tree of life" in regard to microorganisms (Figure \(\PageIndex{1}\)) now appears to be more of a "net of life."

Microbes are known to live in remarkably diverse environments, many of which are extremely harsh. This amazing and rapid adaptability is a result of their ability to quickly modify their repertoire of protein functions by modifying, gaining, or losing their genes. This gene expansion predominantly takes place by horizontal transfer.

Summary

1. Phylogeny refers to the evolutionary relationships between organisms.
2. Organisms can be classified into one of three domains based on differences in the sequences of nucleotides in the cell's ribosomal RNAs (rRNA), the cell's membrane lipid structure, and its sensitivity to antibiotics.
3. The three domains are the Archaea, the Bacteria, and the Eukarya.
4. Prokaryotic organisms belong either to the domain Archaea or the domain Bacteria; organisms with eukaryotic cells belong to the domain Eukarya.
5. Microorganism transfer genes to other microorganisms through horizontal gene transfer - the transfer of DNA to an organism that is not its offspring.

Contributors

- Dr. Gary Kaiser (COMMUNITY COLLEGE OF BALTIMORE COUNTY, CATONSVILLE CAMPUS)