Molecular Cell Biology

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Module 1

Prokaryotic and Eukaryotic Cells

Lecture 1

Introduction to Molecular Cell Biology, Life and Evolution

Molecular Cell Biology – Welcome message

- Welcome to this course on Molecular Cell Biology
- The course is meant for post-graduate students. So I assume that you already have some basic knowledge in Biology and want to learn more about the molecular aspects of Cell Biology
- The course covers most of the important aspects of Cell Biology at a molecular level
- Broadly this would cover the structure and functions of cell organelles, transport of biomolecules, methods to study biomolecules and visualize cells, signal transduction pathways, molecular biology of cancer and infection.

Introduction

- Biology as you know is the science of life. By life we mean the host of living organisms that we know of.
- This could be somewhere between 4 and 5 million different species
- This includes bacteria and other microorganisms, plants and animals including human beings
- Cells are the structural and functional units for all living organisms just like the atoms in the case of chemicals
- As I mentioned, all of them have the cellular units without which they cannot function independently and the minimum requirement is one cell that constitutes the unicellular organisms
- Living cells have the machinery to handle energy. They can metabolize (synthesis of biomolecules and catabolism)
- They can respond to stimuli
- They can adapt to changing environments
- They can reproduce and create their progeny
- Interestingly, all the diverse organisms have similar biochemical machinery and genetic code

Cells

- We cannot see the cells with our naked eyes limited by the fact that we cannot resolve two points separated by less than 0.1 mm
- Hence we need a light microscope to see them
- Cells are smaller and could be at the range of 1 micrometer for bacteria and 30 micrometers for epithelial cells
- Cellular components are still smaller and we need an electron microscope to see them

Cell theory

- The term “Cell” was first coined by Robert Hooke in 1655.
- He used magnifying glass to observe the structure of cork and used the term “cell” to refer to the hollow space (Cella in Latin) found in corks
- Brown (1831) stated that all cells have a nucleus and the cell content was called protoplasm. Later karyoplasm was used to refer to the protoplasm within the nucleus
- Cell theory states that all living organisms should have cells and cell products. Schleiden and Schwann (1839)
- Virchow (1855) stated “Omnis cellulae e cellula” meaning that all cells arise from preexisting cells

Modern Cell Biology

- Gregor Mendel discovered the fundamental laws of heredity (1865)
- Miescher (1871) isolated nuclein, what is now called DNA, from white blood cells
- Thomas Hunt Morgan provided convincing evidence that chromosomes are the location of Mendel’s heritable factors
- Structure of DNA by Watson and Crick (1953). A copying mechanism proposed by them was revolutionary and could explain as to how the genetic material could be transferred from the parent to the offspring.

- “Nothing in biology makes sense except in the light of evolution” (Theodosius Dobzhansky 1900-1975)
- The Theory of Evolution by Natural Selection and the Central Dogma of Molecular Biology are the twin pillars supporting Modern Biology

Classification of living organisms

Although many people have classified the living organisms in many different ways, Whittaker suggested one of the recent classifications.

Living organisms can be classified into kingdoms such as

- Monera – bacteria, blue-green algae
- Protista – protozoa, chrysophytes
- Fungi – Slime molds, true fungi
- Plantae – green algae, red algae, brown algae, brophytes, tracheophytes
- Animalia – metazoan

Autotrophs and heterotrophs

- All of you know that the light energy from the sun is converted into chemical energy by plants by the process of photosynthesis
- Based on this kind of energy extracting mechanisms, various organisms can be classified into autotrophs and heterotrophs
- Autotrophs are organisms that make their own food such as the green plants which use photosynthesis to transform CO_2 and H_2O into organic molecules such as glucose and then into polysaccharides
- Heterotrophs are organisms that depend on food made by autotrophs. Animals for example obtain energy from carbohydrates, proteins and fats synthesized by autotrophs
- The energy from these molecules is primarily released by oxidation using O_2 from the atmosphere (aerobic respiration)

- By aerobic respiration these organisms release water and CO_2.
- Photosynthetic bacteria and blue green algae are autotrophs
- There are also heterotrophic bacteria which absorb soluble nutrients from the medium
- Fungi and animals are heterotrophs
- Most of the plants are autotrophs

Classification of Cells

- We are not going to discuss the classification of living organisms in detail but instead would learn more about cells
- Two broad types of living cells are known
- Prokaryotes and Eukaryotes
- Only the monera kingdom has prokaryotes (bacteria, blue green algae)
- Other kingdoms have eukaryotes
- Karyon in Greek means nucleus and prokaryotes lack nuclear envelope and thus do not have a true nucleus or well defined nucleus
- The space occupied by prokaryotic chromosome is called nucleoid
- Eukaryotes have well defined nucleus with the envelope
- Prokaryotes are thought to be the ancestors of eukaryotes. Prokaryotes were the first living organisms to evolve on earth
- Prokaryotes have a single chromosome composed of a naked DNA
- They divide by binary fission
- They do not have well defined mitochondria but do have respiratory and photosynthetic enzymes in the plasma membrane
- They also do not have a nucleolus.
- Prokaryotes are everywhere and are found wherever other organisms live but also thrive in habitats that are too cold, too hot, too salty, too acidic, or too alkaline for any eukaryote

Primary Production

- Via photosynthesis microbes can transform light energy into chemical energy (food)
- Can transform simple inorganic chemicals into complex organic matter
- Produce O_2 and serve as the bottom of the food chain (or web)

Nutrient Cycling

- Some bacteria can “fix” atmospheric nitrogen (N2) into organic forms (NH3)
- Serve as oxidizers and reducers (accepting or supplying electrons for oxidation-reduction (redox) reactions (e.g., sulfur and iron)
- Some fix inorganic carbon to form organic molecules
- Some degrade cellulose and decompose organic matter
- Microbes supply more than half of the oxygen available on earth – used during respiration.

Food Production

- Bread
- Ethanol – alcohol in the form of beer and wines
- Yogurt
- Cheese
- Production of vitamins, amino acids and flavors

Medical

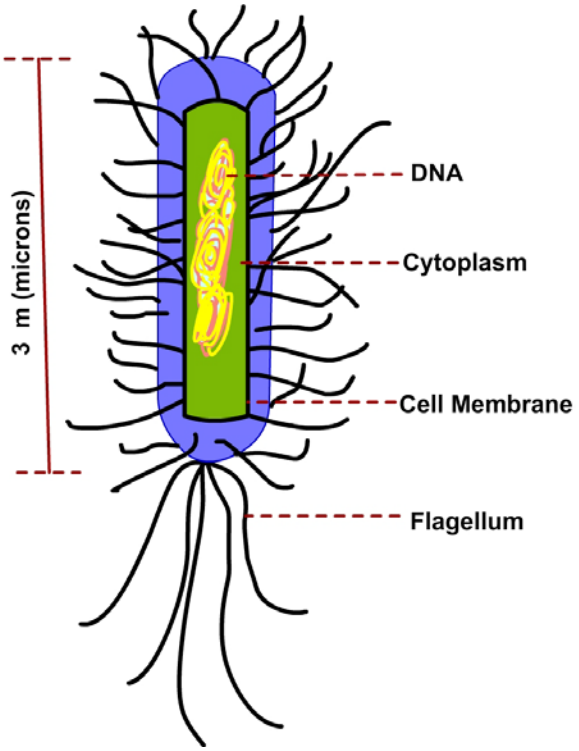
- Microbes can be beneficial to the mankind
- Many have been the source of anti-bacterials
- Produce vitamins in intestine which are necessary to optimal human health
- Digest cellulose in ruminants
- Many prokaryotes can be harmful as well
- 14th century bubonic plague killed 25% of humans
- During Civil War more died of infections than any other cause

- In the 1800s 25% of women died at or after childbirth from infections
- Disease (TB, cholera, STDs)
- Food poisoning

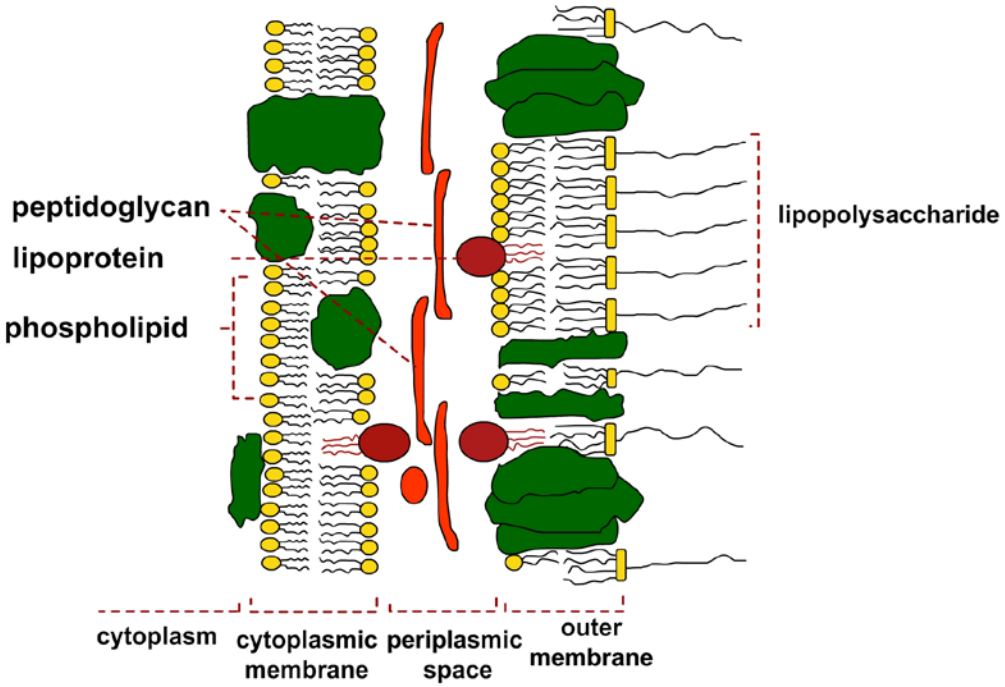
Structural features of E. coli

- E. coli can be cultured easily in the laboratory and it is the most well studied bacterium (prokaryote)
- In a regular medium containing glucose and inorganic ions at 37^0C it can double in 60 mins and this can be reduced to 20 mins if some more components (purines, pyrimidines and amino acids) are added into the medium
- The time taken to double the no. of bacteria is called generation time
- It has a cell wall that forms the outer layer and a plasma membrane that forms the inner layer
- The space between these two layers is called periplasmatic space
- The cell wall is thick and gives mechanical protection and contains poly saccharides, proteins and lipids
- Diffusion of solutes takes place through a protein called porin that forms a channel with 6 to 8 subunits in the cell wall
- The periplasmatic space contains proteoglycans or mucoproteins that are basically polysaccharides in association with proteins forming a gel
- The inner layer is the plasma membrane that serves as a barrier with its lipoprotein structure
- E. Coli is gram negative (does not take up the Gram stain)

E. coli Bacterium



Cell wall and plasma membrane of *E. coli*



Bacterial chromosome

- The bacterial chromosome is a single circular molecule made up of tightly coiled DNA
- It is about 1 mm long if uncoiled
- It encodes about 2000-3000 proteins
- The chromosome is attached to plasma membrane at one point
- After replication the two chromosomes are attached to the membrane at some adjacent points and the membrane in between slowly migrates inward and separates them during binary fission
- Some bacteria contain extrachromasomal circular DNA called plasmid
- Plasmids may confer resistance to antibiotic and are widely used in genetic engineering to transfer genes

Bacterial protoplasm

- The bacterial protoplasm also contains 25000 – 30000 ribosomes that are composed of RNA molecules and proteins. Ribosomes are the sites of protein synthesis.
- Ribosomes containing a large and small subunit exist in groups called polysomes or polyribosomes .Some bacterial contain hair-like projections called flagella, useful in locomotion.
- Mostly the prokaryotic cells are in the range of 1-10 mm in diameter although some blue green algae are known to be in the range of 60 mm.

Mycoplasmas and viruses

- The smallest bacteria known are called mycoplasmas
- They are 0.1 - 0.25 mm in diameter
- They can cause infections in animals and humans

- Viruses are also very small in size (30-300 nm) but are not considered as true cells and may be described as pseudo organisms
- Bacteriophages are viruses that use bacteria as their hosts.
- Viruses mutate and reproduce their genetic material but are always dependent on the host for all their activities.
- Many viruses contain capsids formed by protein subunits called capsomeres that give them icosahedral symmetry.
- This symmetry offers stability so that the capsids can exist at a state of minimum energy.
- Small viruses such as OX174 have 12 capsomeres.
- Large adenoviruses can have as many as 252 capsomeres.
- Like some macromolecules viruses can be crystallized as they are simply inactive molecules outside the host.
- Viruses contain DNA or RNA as their genetic material.
- Viral coats called capsids are made up of proteins synthesized using the host biosynthetic machinery.
- Viruses range in size between 30 and 300 nm.
- From our discussion it may be clear that all the living organisms have a genetic material with a specific copying mechanism for reproduction.
- Although viruses also have a genetic material for reproduction, they depend on the host cells for all other activities and lack the machineries that the living cells possess.
- These include a cell membrane, metabolic machinery and biosynthetic machinery for the synthesis of proteins.

The origin of cells

- It is relevant and important to think about how the prokaryotes and eukaryotes have evolved on earth.
- From the fossil records it looks like the prokaryotes were formed about 3.5×10^9 years ago.

- Before this there must have been a chemical evolution as the living organisms are formed with lifeless molecules.
- During this period the carbon compounds, amino acids, sugars and nucleic acids must have been formed.
- By polymerization the simple molecules were converted to macromolecules as we know them today

Prebiotic period

- Prebiotic times, that are the period before life evolved, should have had an atmosphere that was mostly reducing (without oxygen).
- It contained mostly nitrogen, hydrogen, ammonia, methane, carbon monoxide and carbon dioxide.
- Water was there on the earth's surface as vapors covering its surface.
- Molecular interactions occurred because of energy derived from UV radiation, lightning (electrical discharges) and heat.
- There was no protective ozone layer and hence the UV rays could have strongly interacted with the molecules and gave rise to intermediates such as formaldehyde, acetaldehyde and hydrogen cyanide.
- From these intermediates it is possible that simple fatty acids and amino acids could have been formed.

Study Questions

1. Why we cannot see cells of an organism with our naked eyes?

2. What are autotrophs and heterotrophs?

3. Identify the smallest bacteria among the following

   a) viruses b) mycoplasmas c) E. coli d) Lactobacillit

4. Match the following

Viruses	Plasmid
Bacteria	Karyon
Nucleus	Laws of heredity
Gregor Mendel	Capsomeres

5. The term “cell” was first coined by ----------