CHAPTER 34: BACTERIA

CHAPTER SYNOPSIS

Bacteria represent the oldest forms of life. Bacteria are enormously important to the ecology of the earth in their role as decomposers. The earliest photosynthetic bacteria were responsible for the large quantities of oxygen now present in the atmosphere. They are commercially important in both chemical and food production and have applications in genetic engineering as well.

Morphologically, bacteria appear either spherical (cocci), rod-shaped (bacilli), or spirally coiled (spirilla). Bacteria are fundamentally single-celled organisms even when grown in mass. There are few integrated activities between cells and no true specialization of cells as found in even the most primitive multicellular organisms. Bacteria do not possess chromosomes like eukaryotes. Their genes are contained in a single, double-stranded ring of DNA found in the nucleoid region of the cell. They lack internal comparmentalization and do not have any membrane-bound organelles. Internally, they have a complex membrane system formed from invaginations of the plasma membrane. Photosynthetic and/or respiratory enzymes may be associated with these membranes. Like eukaryotes, they have ribosomes, but they are distinctly different in protein and RNA content. They may possess rigid, helical flagella or hairlike pili. The bacterial cell wall is characterized as either gram-negative or gram-positive. Some bacteria form thick-walled endospores that are extremely resistant to heat. There are few structural differences among bacteria; therefore they are classified by their metabolic processes. Each species of bacteria utilizes the components of specially defined media on which it is grown in a certain characteristic manner. They may utilize only certain carbohydrates or other carbon sources, produce various fermentative gases and pigments, or cause pH changes due to acid production or utilization.

Archaebacteria are distinctly different from the Eubacteria. They have a unique cell wall composition and different kinds of lipids in their membranes. Their gene translation machinery is more like that of eukaryotes than eubacteria and they have some genes with introns, something completely lacking in eubacteria. Genetic variation in eubacteria results from exchange of DNA fragments or by mutation. A high rate of mutation coupled with a very short generation time can rapidly change the characteristics of a bacterial population. Bacteria have evolved a multitude of extremely diverse metabolisms. Photoautrotrophs carry out photosynthesis in sunlight and build organic molecules from carbon dioxide. Chemoautrophs oxidize inorganic compounds, including ammonia, nitrates, sulfur, and hydrogen gas. Photoheterotrophs, exemplified by the purple nonsulfur bacteria, use light but obtain their carbon from carbohydrates or alcohols. Chemoheterotrophs obtain both carbon and energy from organic molecules and include decomposers and pathogenic bacteria.

Bacteria are serious plant and human pathogens. Most plant pathogens are rod-shaped pseudomonads while animal pathogens are extremely diverse. They cause a wide variety of human diseases including cholera, leprosy, tetanus, bacterial pneumonia, whooping cough, and diphtheria. Tuberculosis is the leading cause of death from a single infectious agent. Dental caries are caused by a wide variety of bacteria, exacerbated by high sugar diets. The many sexually transmitted diseases (STDs) are causing widespread problems throughout society. The viral STDs currently have no cure and even the bacterial STDs previously controlled with antibiotics are becoming resistant. Among the most prevalent STDs are gonorrhea, syphilis, genital herpes, chlamydia, and genital warts.

CHAPTER OBJECTIVES

- ä Differentiate between prokaryotes and eukaryotes.
- ä Know the structure of a bacterium, its cell wall, and how it is affected by certain antibiotics.
- ä Describe the interior features of a eubacterial cell.
- ä Compare Archaebacteria and Eubacteria.
- ä Understand why mutation is important to the genetic diversity of bacteria.
- ä Differentiate among photosynthetic, chemoautotrophic, and heterotrophic bacteria in terms of how they obtain energy to sustain their numerous metabolic processes.
- ä Illustrate the importance of bacteria as plant and human pathogens.
- ä Explain the importance of nitrogen-fixing bacteria.

KEY TERMS

autotroph	flagellum (flagella)	nucleoid region
bacillus (bacilli)	gram-negative	peptidoglycan
cell wall	gram-positive	pilus (pili)
chlamydia	Gram stain	spirillus (spirilla)
coccus (cocci)	heterotroph	spore
dental caries	nucleoid	syphilis
endospore		

CHAPTER OUTLINE

34.0 Introduction

I. SIMPLEST ORGANISMS ARE BACTERIA

A. Resemble First Living Organisms

B. Most Abundant of All Organisms — fig 34.1
1. Only organisms to have prokaryotic structure
2. Are vitally important to all ecosystems
3. Responsible for first photosynthesis and oxygen in atmosphere
4. Research provides insights into genetics, ecology, and disease

34.1 Bacteria are the smallest and most numerous organisms

I. THE PREVALENCE OF BACTERIA

A. Bacteria Are a Unique Group of Living Organisms
1. Represent the oldest form of life, 3.5 to 3.8 billion years old
    a. Only representatives of the prokaryotes
    b. Abundant for 2 billion years before eukaryotes appeared — fig 4.11
2. Important to the existence other life forms
    a. Early cyanobacteria filled atmosphere with oxygen from photosynthesis
    b. Vitally important in productivity and cycling of essential substances
    c. Only organisms that can fix atmospheric nitrogen

3. Great variety found in many habitats
   a. 5000 different kinds known, thousands more to be identified fig 34.2
   b. New forms discovered in new habitats
4. Classification of archaebacteria in 1970s
5. Few major structural differences among bacterial types
6. Species differentiation based on metabolic and genetic processes
   a. Characterized by growth on certain defined media
   b. Activities altered by growth conditions and chemicals
7. Bacteria are ubiquitous, live whereever eukaryotes do
   a. Extreme environments hostile to other life forms
      1) Hot springs would cook other forms
      2) Hyper-saline environments would dehydrate other organisms
      3) Toxic gas atmospheres would kill other organisms
   b. Hostile environments similar to early conditions on early Earth
   c. Bacteria retain ability to exploit these areas, rest of world has changed

B. Bacterial Form
1. Cell shape
   a. Straight and rod-shaped: Bacillus (pl. bacilli)
   b. Spherical: Coccus (pl.cocci)
   c. Long and helical-shaped: Spirillus (pl. spirillus)
      1) Also called spirochetes
      2) Do not form associations with other cells, swim through environment
      3) Complex structure within cell membrane causes spin of corkscrew-shaped bodies
2. Some rod-shaped and spherical bacteria form colonies
   a. Adhere end to end forming chains fig 34.2
   b. Some colonies form stalked structures or filaments that give rise to spores
3. Some filamentous bacteria have a gliding, rotating motion

C. Prokaryotes versus Eukaryotes
1. Multicellularity
   a. Bacteria are fundamentally single-celled
   b. May adhere within matrix, some form filaments, especially cyanobacteria
   c. Cells retain individuality, cytoplasm not directly interconnected
   d. Few integrated activities between cells
   e. Primitive colonial forms include gliding bacteria fig 34.3
2. Cell size
   a. Extremely small individual cell size, 1 micrometer or less
   b. Eukaryotes are over 10 times larger
3. Chromosomes
   a. Eukaryotes have membrane-bound nucleus
   b. Bacterial non-membrane-bound DNA is circular and lacks proteins
   c. DNA localized in zone of cytoplasm called the nucleoid
4. Cell division and genetic recombination
   a. Eukaryote division via mitosis with spindles of microtubules
   b. Bacteria exhibit simple division via binary fission
   c. True sexual reproduction absent, genetic recombination less regular
5. Internal compartmentalization
   a. Eukaryotic cellular respiration enclosed in mitochondria
   b. Bacteria lack membrane-bound organelles
   c. Enzymes are bound to cell membrane
   d. Only organelles present are ribosomes

6. Flagella
   a. Bacteria possess simple flagella — fig 34.4
   b. Composed of single flagellin fiber
   c. Lack 9 + 2 structure of eukaryotic flagella and cilia — fig 5.27
   d. Flagellar motion resembles spinning propeller, not whip-like eukaryotic motion
7. Metabolic diversity
   a. Eukaryotes exhibit only one form of photosynthesis, release oxygen
   b. Bacterial photosynthesis occurs on membranes
   c. Bacteria exhibit several patterns of photosynthesis, aerobic and anaerobic
   d. Some are chemoautotrophic

34.2 Bacterial cell structure is more complex than commonly supposed

I. THE BACTERIAL SURFACE

A. Cell Wall Structure
1. Maintains shape of cell, protects cell from swelling and rupturing
2. Peptidoglycan wall: Polysaccharide network with polypeptide crosslinks
   a. Thick, complex network around outer surface, interlaced with peptide chains
   b. Some have thin layer sandwiched between two plasma membranes
   c. Outer membrane contains lipopolysaccharides
3. Identified by Gram stain process
   a. Gram-positive
      1) Have thick peptidoglycan wall
      2) Stain purple color — fig 34.5
      3) Susceptible to antibiotics that interfere with cell wall synthesis
   b. Gram-negative
      1) Contain less peptidoglycan
      2) Do not retain purple dye, stain red instead
      3) Less susceptible to antibiotics that interfere with cell wall synthesis
4. May be surrounded by gelatinous capsule
5. Rigid, helical flagella composed of flagellin protein — fig 34.6
   a. From 3 to 12 micrometers in length
   b. Very thin, only 10 to 20 nanometers thick
   c. Anchored in cell wall, spin like a propeller
6. Hairlike pili occur on cells of some bacteria — fig 34.4
   a. Shorter than flagella, 7.5 to 10 nanometers thick
   b. Help bacteria attach to substrates and exchange genetic information
7. Some form thick-walled endospores when exposed to nutrient-poor conditions
   a. Form around chromosome and small part of cytoplasm
   b. Resistant to environmental stress, especially heat
   c. Germinate after decades or centuries

II. THE CELL INTERIOR

A. Prokaryotic Organization
1. Most fundamental characteristic
2. Lack extensive functional compartmentalization of eukaryotes

B. Common Features
1. Internal membranes
   a. Invaginations of the plasma membrane
   b. Function in respiration or photosynthesis — fig 34.7

2. Nucleoid region
    a. Lack nuclei, do not possess complex chromosomes of eukaryotes
    b. Genes encoded in single double-stranded ring of DNA
    c. Located in nucleoid region of cell
    d. May also possess small, independently-replicating circles of DNA called plasmids
    e. Plasmids contain only a few genes, not necessary for survival
3. Ribosomes
    a. Smaller than eukaryotic ribosomes
    b. Differ in protein and RNA content
    c. Tetracycline and chloramphenicol bind to block protein synthesis

34.3 Bacteria exhibit considerable diversity in both structure and metabolism

I. BACTERIAL DIVERSITY

A. Not Easily Classified
1. Early classification based on differential stains and Gram stain
2. Other early key characteristics used in classification
    a. Photosynthetic or nonphotosynthetic
    b. Motile or nonmotile
    c. Unicellular or multicellular
    d. Formation of spores or dividing by transverse binary fission
3. Genetic and molecular approaches divulge evolutionary relationships
    a. Analysis of amino acid sequences of key proteins
    b. Analysis of nucleic acid base sequences, establish percent of C and G
    c. Nucleic acid hybridization
        1) Mix single-stranded DNA from two species
        2) Determine amount of base pairing
        3) More base pairing indicates closer relationship
    d. Nucleic acid sequencing, especially of ribosomal RNA
4. Description of major 16 phyla — tbl 34.1

B. Kinds of Bacteria
1. Diverse in internal chemistry and details of assembly
2. Have adapted to many kinds of environments, some very harsh
    a. Invaded waters that are very salty, very acidic/alkaline
    b. Very hot locations like hot springs, or cold like underneath Antarctic ice
3. Much examination of bacteria in the laboratory
    a. Can only study forms that can be grown in culture
    b. Field studies indicate far greater number that cannot yet be cultured
4. Bacteria split into two lines early in their history
    a. As different from each other as each is to eukaryotes
    b. Domain archaebacteria
        1) Despite name, not as ancient as other domain
        2) Many live in extreme environments, others in non-extreme habitats
    c. Domain eubacteria include true bacteria, almost all named species

C. Comparing Archaebacteria and Eubacteria
1. Cell walls
    a. Both have cell wall to cover plasma membrane and strengthen cell
    b. Eubacteria walls composed of peptidoglycan complex
    c. Archaebacteria walls lack peptidoglycan

2. Plasma membranes
    a. All have plasma membrane with lipid-bilayer architecture
    b. Each uses different kinds of lipids
3. Gene translation machinery
    a. Ribosomal proteins and RNA polymerase of eubacteria different from eukaryotes
    b. Those of archaebacteria similar to those of eukaryotes
4. Gene architecture
    a. Eubacteria genes not interrupted by introns
    b. Some genes of archaebacteria have introns

II. BACTERIAL VARIATION

A. Bacteria Replicated by Fission Are Identical
1. Forms a large clone of cells
2. Mutation and genetic recombination create variation

B. Mutation
1. Can arise spontaneously as errors in DNA replication occur
    a. Likelihood increased by radiation, ultraviolet light, various chemicals
    b. About 5,000 genes in typical bacterium, *Escherichia coli*
    c. One in 200 bacteria will have mutation fig 34.8
    d. Spoonful of soil has billion bacteria, thus 5 million mutants
2. Rapid multiplication in short time period
    a. Increase number with favorable mutations
    b. Rapidly changes characteristics of a population
3. Example: Development of antibiotic resistance
    a. Strains of *Staphylococcus aureus* resistant to penicillin and other antibiotics
    b. Result from mutation and intense selection in hospital environments
    c. Have serious medical implications
    d. Harmful consequences of extensive use of antibacterial soaps

C. Genetic Recombination
1. Transfer of genes via viruses or conjugation
2. Examples
    a. Rapid transfer of antibiotic resistant genes
    b. Transfer of pathogenic characteristics among enteric bacteria

III. BACTERIAL METABOLISM

A. Evolved Diverse Ways to Acquire Carbon and Energy
1. Autotrophs obtain carbon from inorganic carbon dioxide
    a. Photoautotrophs obtain energy from sunlight
    b. Chemoautotrophs obtain energy from inorganic chemicals
2. Heterotrophs obtain some carbon from organic molecules like glucose
    a. Photoheterotrophs obtain energy from sunlight
    b. Chemoheterotrophs obtain energy from organic molecules
3. Photoautotrophs
    a. Carry out photosynthesis with sunlight
    b. Build organic molecules from carbon dioxide
    c. Cyanobacteria
        1) Use chlorophyll *a* as light-capturing pigment
        2) Use water as electron donor
        3) Leave oxygen gas as byproduct
    d. Other bacteria

1) Use bacteriochlorophyll as pigment
2) Hydrogen sulfide is electron donor
3) Elemental sulfur is byproduct

4. Chemoautotrophs
   a. Oxidize inorganic substances
   b. Nitrifiers oxidize ammonia or nitrate to form nitrate (taken up by plants)
   c. Others oxidize sulfur, hydrogen gas
   d. Bacteria around deep-sea vents oxidize hydrogen sulfide
5. Photoheterotrophs
   a. The purple nonsulfur bacteria use light
   b. Obtain carbon from carbohydrates or alcohols produced by other organisms
6. Chemoheterotrophs
   a. Obtain both carbon and energy from organic molecules
   b. Include decomposers and most pathogens

B. How Heterotrophs Infect Host Organisms
1. Gram-negative *Yersinia* produce and secrete large amounts of proteins
   a. Proteins lacked either of two signal sequences required to transport across membrane
   b. Proteins secreted by new system, type III system
2. Genes for type III system found in other pathogens
   a. Genes are more closely related than bacteria that contain them
   b. Genes are similar to ones that code for bacteria flagella
3. Function of genes under investigation
   a. Some proteins transfer virulence proteins into nearby eukaryotic cells
   b. May form flagella-like structure that shoots proteins into host cell
   c. Virulence proteins may determine host's response to pathogen
4. Return to *Yersinia* example
   a. Proteins injected into macrophages
   b. Disrupt signals to tell macrophages to engulf bacteria
5. Example: *Salmonella* and *Shigella*
   a. Use type III proteins to enter cytoplasm of eukaryotic cells
   b. Protected from host immune system
6. Example: *E. coli*
   a. Alter cytoskeleton of nearby intestinal cells
   b. Results in bulge onto which bacteria bind
7. Searching for ways to disarm bacteria
   a. Release virulence proteins before reaching eukaryotic cells
   b. Studying target proteins and how they are affected

C. Bacteria as Plant Pathogens
1. Heterotrophic bacteria cause costly plant diseases
   a. Symptoms are generally spots on stems, leaves, or fruit
   b. Include blights, soft rots, and wilts
2. Most pathogens are rod-shaped pseudomonads — fig 34.2a

34.4 Bacteria are responsible for many human diseases but also make important contributions to ecosystems

I. HUMAN BACTERIA DISEASES

A. Cause Many Human Diseases — tbl 34.2
1. Include cholera, leprosy, tetanus, bacterial pneumonia, whooping cough, diphtheria, and lyme disease
2. *Streptococcus* causes scarlet and rheumatic fevers, pneumonia, infections — fig 34.2b

3. Tuberculosis is a leading cause of human death
4. Some cause infections spread through water vapor in air
5. Many bacterial diseases spread through food or water
6. Insect vectors spread diseases like typhus

B. Tuberculosis
1. One-third of all people infected with *Mycobacterium tuberculosis* fig 34.9
2. Eight million new cases each year, three million deaths
3. Leading cause of death from a single infectious agent
4. Eradication programs dismantled in U.S. in 1980s
   a. Experiencing a dramatic resurgence of the disease
   b. Complicated by social factors, declining public health infrastructure
   c. Associated with prevalence of HIV
5. Multidrug resistant strains of TB are developing
   a. Requires more time and expense to treat
   b. May prove to be fatal
   c. Ensure treatment of infected individuals who are not yet sick

C. Dental Caries
1. Involves many species of bacteria including *Actinomyces*
2. Dental plaque composed of bacteria and polysaccharide matrix
3. Causes tooth decay and cavities
4. High sugar diets harmful
   a. Bacteria convert sugars to lactic acid
   b. Acid destroys hard tissue of tooth
5. Control via fluoride by retarding loss of calcium
6. Germ-free animals do not develop decay even with improper diet

D. Sexually Transmitted Diseases
1. STDs caused by a number of bacteria fig 34.10
2. Gonorrhea
   a. Most prevalent communicable disease, caused by *Neisseria gonorrhoea* bacterium
   b. Transmitted during sexual activities through transfer of body fluids
   c. Can spread to eyes (conjunctivitis) and internal organs, cause arthritic meningitis
   d. In women, can cause pelvic inflammatory disease, eventual sterility
3. Syphilis
   a. Less common as a result of blood-screening procedures and antibiotic treatment
   b. Caused by spirochaete bacterium, *Treponema palladum*
   c. Transmitted during intercourse, direct contact with sore
      1) Can be transmitted from mother to fetus
      2) Causes damage to heart, eyes, nervous system
   d. Disease progresses in four distinct stages
      1) Primary stage characterized by chancre sore, highly infectious stage
      2) Secondary stage distinguished by body rash, sore throat
      3) Third stage shows no symptoms, may last years
      4) Fourth stage is heart disease, mental deficiency, nerve damage, loss of motor functions, blindness
4. Chlamydia
   a. "Silent STD" caused by *Chlamydia trachomatis* bacterium
      1) Has both bacterial and viral characteristics
      2) Susceptible to antibiotics like bacterium
      3) Depends on host cell to replicate, like virus
      4) Is an obligate internal parasite
   b. Transmitted via sexual intercourse

c. Women usually do not experience symptoms until infection is established
  1) Can cause pelvic inflammatory disease
  2) Can lead to sterility
d. Infection of reproductive tract by chlamydia can cause heart disease
  1) *Chlamydia* cells produce peptide similar to one produced by heart muscle
  2) Peptide recognized as antibodies try to fight infection
  3) Immune system confused, T cells attack heart muscle
  4) Causes inflammation of heart
e. Two tests to detect chlamydia in discharge of men and women
f. Treatment via antibiotics mostly tetracycline, penicillin not effective

5. Sexual activity must be done with certain precautions and extreme care
6. Responsibility for protection lies with each individual

II. IMPORTANCE OF BACTERIA

A. Bacteria Have Altered the Nature of the Planet
1. Responsible for creating properties of atmosphere and soils
2. Are metabolically diverse
  a. Autotrophic, photosynthetic, and chemosynthetic
  b. Contribute to world carbon balance
  c. Are heterotrophic and break down organic compounds
  d. Only a few genera of bacteria are capable of fixing atmospheric nitrogen
3. Involved in industrial processes and chemical syntheses
  a. Produce acetic acid, vinegar, amino acids, enzymes
  b. Production of various milk products, bread, and ethanol
  c. Antibiotics derived from bacterial sources
  d. Proving valuable in removing environmental pollutants fig 34.11

B. Bacteria and Genetic Engineering
1. Non-polluting insect control agents
  a. *Bacillus thuringiensis* attacks insects naturally
  b. New strains developed
2. Useful in attempts to understand genetics

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

The differences between prokaryotes and eukaryotes are presented again. If your course is organized in the same order as this text, you may be able to skip this material.

Stress that although the initial classification of bacteria is related to structure (shape, flagella, morphology, Gram reaction, endospores), the remaining classification is based on metabolic differences. It is difficult to maintain bacteria so that they exhibit their characteristic metabolic traits since they mutate so readily. The American Type Culture Collection (ATCC) characterizes bacteria to ensure their proper metabolic identity for biological research. One can periodically compare the biochemical tests of a laboratory strain against the ATCC standard.

Bacterial pathogens are a serious threat to the food industry. Detection of contaminants requires time-consuming culturing to detect relatively large quantities of bacteria. Frequently contamination is only recognized after people become sick or die. Water is checked for sewage contamination by determining the presence of non-pathogenic bacteria that are present in greater numbers than the harmful forms. Recent advances in molecular technology and monoclonal antibodies provide much faster identification of such pathogens. These tests also detect much smaller quantities of harmful bacteria.

Legumes (peas, clover) possess root nodules containing *Rhizobium* bacteria that fix nitrogen. These nodules contain a protein called leghemoglobin that is produced by the plant. It is structurally related to animal hemoglobin and is also red in color. It binds free oxygen in the nodule, enabling the obligate anaerobe to reproduce and metabolize.

Researchers at the University of Georgia have developed a cheap and effective way to kill bacteria on food and utensils – electrolyzed water. The water is prepared by running an electrical current through a dilute saltwater solution. The antimicrobial effect may be a result of the chlorine that is produced. The water is also highly acidic and contains substantially less oxygen than normal water.

Iceminus pseudomonas has been genetically engineered to prevent frost formation in the citrus industry. Other pseudomonads have caused problems in the hot tub industry as they thrive in warm water that may not be sufficiently chlorinated.

Many companies are taking advantage of the public's fear of microorganisms causing health problems. Under normal household circumstances there is absolutely no need to use antibacterial soaps! Soap and hot water are sufficient to deal with the kinds of bacteria present in homes. Overuse of such antibacterial products may result in the same kind of resistance now experienced with antibiotics taken to combat disease.

VISUAL RESOURCES:

Electron micrographs of bacteria are much more impressive than light micrographs. In addition, bring in samples of live bacteria in petri dishes. There is a wide variety of colorful organisms available. Many biological supply companies sell already prepared plates, others sell "instant" media in the form of culture impregnated cellulose pads or a gel that is activated simply by adding sterile water. If you have your students prepare random inoculations by exposure to the air, coughing on plates, and so forth, make sure the plates stay sealed for safety!