Bacteria

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Definition

Bacteria are prokaryotes (unicellular organisms with no membrane-enclosed nucleus) with simple structures that typically range in size from about 0.5 to 20 micrometers.

Classification

Bacteria are named according to the binomial (two-name) system of nomenclature first used by Swedish botanist Carolus Linnaeus in the eighteenth century. The first name, or generic name, indicates the genus of the bacteria (a group of closely related species). The second name, or specific name, indicates the species (a group of bacteria that share a number of characteristics). Examples of generic names include *Staphylococcus* and *Esherichia; aureus* and *coli* are examples of specific names.

The genus and species names of bacteria often reflect their shape; for example, the *Bacillus* family of bacteria are bacillior rod-shaped. Others are named for their founders (e.g. *Yersinia pestis*, the causative agent of bubonic plague, is named for Alexandre Yersin) or for their preferred habitat (e.g., *Thermoplasma* prefer temperatures up to 149°F, or 65°C).

Under a **microscope**, different families of bacteria have different shapes. Typical cell shapes are straight rods (bacilli), spheres (cocci), bent or curved rods (vibrios), spirals (spirochetes), or thin filaments. Some bacteria exist as single cells, while others form clusters of

various shape and complexity. *Acetobacter aceti*, for example, excretes a substance called cellulose that surrounds the cells to form a skinlike layer. *Staphylococcus aureus* forms grapelike clusters of cells.

Many groups of bacteria have a cell wall, a structure surrounding the cell. Peptidoglycan (a chemical composed of **carbohydrates** and **proteins**) is a major component of the cell wall, although the exact composition of peptidoglycan varies according to bacteria group. Gram-positive organisms have a relatively thick layer of peptidoglycan and stain violet when applied with certain dyes; gram-negative organisms have a thin layer of peptidoglycan covered by an outer membrane and stain red under the same application of dyes. Gram staining is therefore an important method for identifying bacteria.

Bacteria may be classified by their biochemical composition, and analysis of the protein and lipid content of an organism is often a means of identification. Growth requirements are often used as a means of classification: *Mycobacterium tuberculosis*, for example, is an obligate aerobe and therefore requires oxygen for growth, while the presence of oxygen is toxic to the anaerobe *Clostridium tetani.*

The most precise method of classification, however, is genetic analysis. Each species of bacteria has a unique genetic makeup, and therefore a unique sequence of deoxyribonucleic acid (DNA) bases. Some sequences remain constant by genus or species, while others vary considerably. These distinguishing factors are used to trace genetic relatedness and are often used for identification of unknown organisms.

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Bacterial structure

Although prokaryotic organisms such as bacteria are considered to be "simple" in structure, each cell is equipped with all of the structures and macromolecules necessary for growth and survival. Complex functions such as energy production, synthesis of biomolecules, and assembly of new structures take place in a highly organized manner.

The genetic material of bacteria is carried on double-stranded molecules of DNA (deoxyribonucleic acid), which is arranged into a circular structure called the chromosome. The region of the cytoplasm where the chromosome is located is called the nucleoid and is not enclosed by a membrane, as in eukaryotic cells. Many bacteria carry additional genetic information (often required for survival in specific environments) on structures called plasmids, smaller circular strands of DNA that are independent of the chromosome. Also found in the cytoplasm are ribosomes, small cellular components important in the process of translating genetic information into proteins. The total collection of genes is called the bacterial genome.

Directly bordering the cytoplasm of the bacteria is the cytoplasmic membrane, which is important for various functions such as energy production and transport of materials in and out of the cell. The cell wall surrounds the cytoplasmic membrane of most bacteria. In gram-negative organisms, the cell wall is composed of a thin layer of peptidoglycan enclosed by an outer membrane. Lipopolysaccharide (LPS; also called endotoxin) is a major constituent of the outer membrane. The cell wall of gram-positive bacteria is distinctly different. Multiple peptidoglycan layers envelop the cytoplasmic membrane, and no outer membrane is present. The peptidoglycan layers form a meshlike shell around the cell that is important for maintaining structure, for replication, and for protection in extreme or toxic conditions. Proteins, **lipids**, and polysaccharides may also be found in the cell wall.

Many bacteria have additional means of protection in hostile conditions. Some have the ability to form a capsule, layers of polysaccharides and proteins attached to the cell wall, that provides protection against toxic substances and helps inhibit host **immune response**. Spores are made by some gram-positive bacteria. Under favorable conditions, the cells exist in a vegetative state; but when introduced to a hostile environment, the cells convert to a spore state and become dormant, awaiting conditions in which they may once again prosper.

The flagellum is a filamentous structure attached to many prokaryotes that provides motility. With flagella, bacteria may move toward food and away from toxins, a process called chemotaxis. Pili are hairlike structures shorter than flagella found on many bacteria; they are used for adherence to other bacteria and surfaces such as host cells.

Energy requirements for growth

All living organisms must find in their environment a source of energy to fuel cellular processes. Bacteria are no different. Phototrophs are organisms that use light as an energy source; those that require organic carbon are called heterotrophs. Autotrophs use carbon dioxide. Lithotrophs oxidize inorganic compounds such as hydrogen or ammonia for energy.

Many bacteria have structures and processes that allow them to adapt to hostile environments, and they can exist under an enormous range of conditions. Those that require oxygen for growth are called obligate aerobes. In contrast, obligate anaerobes will not grow in the presence of oxygen. Acidophiles are bacteria that grow optimally under acidic conditions (pH of less than 7.0), while alkaphiles prefer alkaline or basic conditions (pH of greater than 7.0). Organisms that require a temperature near 99°F (37°C) (the body temperature of warm-blooded animals) for growth are called mesophiles; those that grow at temperatures above 113°F (45°C) are called thermophiles; and psychrophiles are able to grow at temperatures near 32°F (0°C). Halophiles require sodium chloride (salt) for growth; osmophiles are able to grow in environments high in sugar; and xerophiles grow under dry conditions.

Binary fission and the growth curve

Bacteria grow and replicate in a process known as binary fission. In this process, one parent cell divides to produce two daughter cells. The process begins with the growth of the parent cell; the chromosome unwinds and replicates, each copy moving to opposite ends of the cell. The cell is then partitioned in half by the production of a dividing wall (called the septum). The cell is cleaved at the septum, and the two daughter cells are freed. The daughter cells then go on to reproduce as parent cells(i.e., if necessary nutrients and energy sources are present).

The dynamics of a population of bacteria change during binary fission. The doubling time, or time required for one parent cell to produce two daughter cells, varies by bacteria species and strain and also by the environmental conditions. All bacteria exhibit a characteristic pattern of growth when introduced to a new medium; this is known as the growth curve. There are four phases of the growth curve:

- During the lag phase, bacteria are adapting to the medium and begin to produce the cellular components necessary for **cell division**. There is no increase in cell population during the lag phase.
- Cell division occurs at a maximal rate during the log or exponential phase. The doubling time remains constant, so the number of cells increases exponentially.
- Cells stop growing exponentially and therefore remain constant during the stationary phase. This occurs when the medium begins to run out of the nutrients necessary for growth or when toxic products accumulate.
- The number of cells begins to decrease during the death phase as cells begin to die, usually due to toxic conditions or lack of nutrients.

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Normal flora

Only a small percentage of the vast population of bacteria is pathogenic (disease-causing) to humans. Many species of bacteria colonize the human body and are called the normal flora. Organisms of the normal flora are normally found on surface tissues (i.e., the skin, mucous membranes, and the gastrointestinal system). It is when bacteria enter normally sterile areas of the body (e.g., the **brain**, **blood**, muscle, etc.) that disease may result.

Some organisms of the normal flora neither harm nor provide benefit to the human body; this relationship is called commensalism. Normal commensals are bacteria that can always be found on or in healthy individuals and rarely cause disease. Bacteria that occasionally colonize the human body without causing disease are called occasional commensals. Although a human fetus is sterile *in utero,* colonization with normal flora bacteria begins with birth when the baby comes into contact with the mother's vaginal bacteria; this continues with breast-feeding and subsequent contact with the environment.

Many other types of bacteria interact with the human body in a relationship called mutualism, from which both organisms benefit. There are a number of ways that bacteria benefit the human host:

- Normal flora bacteria on the skin such as *Staphylococcus epidermidis* protect against colonization by path ogenic bacteria, through a process called microbial competition.
- Bacteria in the vagina (e.g., *Lactobacillus acidophilus)* help to establish an acidic environment that inhibits colonization of pathogenic bacteria and yeast.
- The normal flora in the gastrointestinal (GI) tract (e.g., *Escherichia coli)* secrete **vitamins** such as K and B_{12} that are essential for humans. The development of some GI tissues is stimulated by normal flora bacteria.

- Ruminants (animals with a four-chambered **stomach**) rely on enzymes secreted by bacteria such as *Ruminococcus albus* to digest cellulose (a major component of plant cell walls).

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Pathogenic bacteria

Although normal flora bacteria are not normally pathogenic, disease may result from invasion of normal flora into normally sterile areas or if the host **immune system** is deficient. When bacteria that normally reside in the GI tract (such as *E. coli*) are introduced to the urinary tract, for example, a urinary-tract **infection** may result. This is considered an endogenous infection.

Exogenous infections result from invasion of noncommensal organisms (i.e., those not normally found on the human body). Transmission of exogenous bacteria may occur by various routes, including inhalation of aerosolized organisms, ingestion (e.g., contaminated food or utensils), or direct contact of a wound or mucous membrane with organisms.

When bacteria first enter the body, local inflammation may be the first sign of infection. Physical symptoms such as **pain**, erythema (redness), **edema** (swelling), or pus formation result from the response of the immune system against the invading bacteria. If the bacteria spread to the bloodstream (bacteremia), they may disseminate to and colonize at various sites in the body.

VIRULENCE FACTORS. Bacteria have developed numerous mechanisms that allow them to invade a host and colonize an otherwise inhospitable site to cause disease. Many of these mechanisms enhance their ability to cause disease in humans; such traits are called virulence factors. Some common virulence factors include:•

- Bacterial growth. The byproducts of normal bacterial growth may cause tissue destruction if colonization has occurred in a normally sterile site. For example, *Clostridium perfringens* is a normal flora bacteria of the GI tract but may cause gas **gangrene** if it infects a wound or trauma site.
- Release of toxins. Some pathogenic bacteria produce proteins (toxins) that are inevitably toxic to the host. An endotoxin is composed of lipopolysaccharides found in the outer membrane of gram-negative bacteria. Exotoxins are proteins produced intracellularly and secreted by either gram-negative or gram-positive bacteria.
- Capsule formation. The polysaccharide layers of a capsule form a protective shield around a bacteria and help the cell to evade immune response.
- Internalization. Some bacteria are able to escape intra-cellular killing when internalized by phagosomes and go on to survive in the cytoplasm (e.g.,

Mycobacterium tuberculosis). In this way they are protected from anti-body-mediated immune responses.
- Granuloma formation. A granuloma is a lesion formed in response to infection by some intracellular pathogens. Viable bacteria are walled off in the granuloma and thus prevented from further colonization.
- Antigenic mimicry. A bacterial cell may be able to trick the immune system by presenting antigens (molecules recognized by antibodies) that are similar to host antigens. Immunological cells therefore have difficulty distinguishing between the bacterium and a host cell.

Antibiotic resistance

The emergence of bacterial strains that are resistant to treatment by current **antibiotics** is an important public-health concern. Antibiotics are chemical substances produced by microorganisms that inhibit bacterial growth or kill bacterial cells. Narrow-spectrum antibiotics target only a limited variety of bacteria, while broad-spectrum antibiotics have the ability to inhibit or kill a wide variety of bacteria.

Bacteria can resist the action of antibiotics using one or more of four basic mechanisms:

- inactivation or modification of the drug
- modifying the drug's target binding site
- decreasing uptake of the drug into the cell
- altering the biochemical pathway that the drug is targeting

In many developing countries, antibiotics are freely distributed as over-the-counter drugs, leading to their widespread use for viral or noninfectious illnesses. This practice, coupled with the overuse of antibiotics in veterinary medicine, farming, and plant culture, has contributed to the spread of antibiotic-resistant bacteria.

Common diseases and disorders

The following list describes some of the most common bacteria that are pathogenic to humans.

- *Staphylococcus.* Staphylococci are gram-positive bacteria found as part of the normal flora of most individuals. *S. aureus* is the causative agent of many infections, including toxic shock syndrome (TSS), staphylococcal **food poisoning**, impetigo, and furuncles (**boils**). *S. saprophyticus* causes urinary-tract infections in sexually active women. *S. epidermidis* may infect damaged or artificial **heart** valves and cause a condition called endocarditis.
- *Streptococcus.* Streptococci are gram-positive bacteria that commonly colonize the oropharynx (the area of the throat at the back of the mouth). Example syndromes include pharyngitis (**sore throat**), scarlet **fever**, necrotizing fasciitis

(streptococci are popularly known as the "flesh-eating bacteria"), and rheumatic fever. *S. pneumoniae* is a common cause of bacterial **pneumonia** and meningitis.

- *Neisseria. N. gonorrhoeae* is the causative agent of gonorrhea, a leading sexually transmitted disease (STD). *N. meningitidis* is a leading cause of adult meningitis.
- *Escherichia. E. coli* is the most commonly encountered species of this genus. The bacteria is a common cause of gastroenteritis (inflammation of the lining of the stomach and intestines) but also causes urinary-tract infections and neonatal meningitis.
- *Salmonella.* Most *Salmonella* infections result from ingestion of contaminated food and lead to enteritis. The febrile (fever-inducing) illness typhoid fever is caused by *S. typhi.*
- *Vibrio.* The most commonly known *Vibrio* infection is cholera, caused by *V. cholerae.* Spread by ingestion of contaminated food or water, cholera infection is an important cause of diarrheal disease in developing countries.
- *Clostridium. C. perfringens* causes a variety of human diseases, including myonecrosis (gas gangrene), clostridial food **poisoning**, and soft-tissue infections (cellulitis and fasciitis). Tetanus (also known as lockjaw) is caused by *C. tetani; C. botulinum* causes food-borne botulism.
- *Mycobacterium.* **Tuberculosis**, caused by infection with *M. tuberculosis,* is a highly prevalent pulmonary disease. Hansen's disease (also known as leprosy) is caused by *M. leprae.*
- *Chlamydia.* Chlamydiae, once thought to be **viruses** because of their small size, cause numerous human diseases. *C. trachomatis* is the causative agent of conjunctivitis (inflammation of the outer surface of the eye), infant pneumonia, and urogenital chlamydia. Bronchitis, pneumonia, and sinusitis are often caused by *C. pneumoniae.*

KEY TERMS

Antibiotics—Chemicals produced by microorganisms that inhibit bacterial growth or kill bacterial cells.

Binary fission—The process by which a single parent cell divides to produce two identical daughter cells.

Flagellum—A filamentous structure attached to some bacteria that provides motility.

Gram-negative—A class of bacteria that have a cell wall composed of a thin layer of peptidoglycan surrounded by an outer membrane made of polysaccharides and proteins.

Gram-positive—A class of bacteria that have a cell wall composed of a thick layer of peptidoglycan.

Growth curve—A characteristic growth pattern of bacteria when introduced into a new medium; it includes four phases (lag, log, stationary, and death).

Normal flora—Species of bacteria that colonize the human body and do not normally cause disease.

Nucleoid—Cytosolic region of a bacterial cell in which the chromosome is located.

Pathogen—A disease-causing microbe.

Peptidoglycan—A chemical composed of carbohydrates and proteins that is a major component of the bacterial cell wall.

Prokaryote—A unicellular organism lacking a membrane-enclosed nucleus.

Ribosome—A cytosolic structure important in the translating of genetic information into proteins.

Toxins—Proteins produced by bacteria that are toxic to host cells. Endotoxin is a component of the cell wall of gram-negative bacteria; exotoxin is secreted by both gram-negative and gram-positive bacteria.

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ORGANIZATIONS

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