Bacteria – Friend or Foe?

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What is the first thing that comes to mind when you hear “bacteria”?
Introduction to Bacteria
Bacterial nomenclature

• Bacteria are referred to by their **genus** and **species**, with genus coming first and species coming last:

  *Escherichia coli*
  Escherichia: genus
  Species: coli

Bacteria names are ALWAYS italicized.
Genus names are capitalized and species names are not.

Sometimes, the genus is abbreviated by its first initial: *E. coli*
Bacteria are prokaryotes.
What are prokaryotes?

- Plasma membrane separates the cell from its surrounding environment
- Cytoplasm contains organelles
- Contain DNA consisting of a single large, circular chromosome
- Ribosomes make proteins
Prokaryotes v. Eukaryotes

Image from: https://www.difference.wiki/prokaryotic-cell-vs-eukaryotic-cell/
How do these organisms differ?

**Prokaryotes**
- circular DNA
- no nucleus
- no membrane bound organelles
- small - less than 10μm
- unicellular

**Eukaryotes**
- linear DNA (found in nucleus)
- nucleus
- membrane bound organelles
- larger than 10μm
- can be unicellular and multicellular
Bacteria are very small.
How big are bacteria?

Bacteria are very small: 0.1 – 5.0 micrometers. A micrometer (μm) is 0.000001 meters or 0.001 millimeters (mm). For comparison, a human hair is 30 – 100 μm.
Bacteria are classified by phenotype or genotype.
How are bacteria classified?

• Cell wall make up:
  • Gram positive – thick peptidoglycan* layer in cell wall
  • Gram negative – thin lipopolysaccharide layer in cell wall

The technique used here is called Gram staining

*Peptidoglycan or murein- polymer consisting of sugars and amino acids that forms a mesh-like layer outside the plasma membrane
How are bacteria classified?

BACTERIA SHAPES

**SPHERES (COCCI)**
- *Diplococci* (Streptococcus pneumoniae)
- *Tetrad*
- *Staphylococci* (Staphylococcus aureus)
- *Sarcina* (Sarcina ventriculi)

**RODS (BACILLI)**
- *Streptococci* (Streptococcus pyogenes)
- *Chain of bacilli* (Bacillus anthracis)
- *Flagellate rods* (Salmonella typhi)
- *Spore-former* (Clostridium botulinum)

**SPIRALS**
- *Vibrios* (Vibrio cholerae)
- *Spirilla* (Helicobacter pylori)
- *Spirochaetes* (Treponema pallidum)

How are bacteria classified?

<table>
<thead>
<tr>
<th>Classification</th>
<th>Oxygen Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obligate aerobes</td>
<td>Required to survive</td>
</tr>
<tr>
<td>Microaerophiles</td>
<td>Require low levels of oxygen (lower than found in the atmosphere)</td>
</tr>
<tr>
<td>Facultative anaerobes</td>
<td>Survive in presence and in absence of oxygen</td>
</tr>
<tr>
<td>Aerotolerant anaerobes</td>
<td>Oxygen can be tolerated, but not used</td>
</tr>
<tr>
<td>Obligate anaerobes</td>
<td>Die in presence of oxygen</td>
</tr>
</tbody>
</table>

Image and information from: https://courses.lumenlearning.com/microbiology/chapter/oxygen-requirements-for-microbial-growth/
How are bacteria classified?

• Biochemical Reactions
  • Hydrogen sulfide production
  • Indole test
  • Oxidase test
  • Oxidative fermentation
  • Phenylalanine deaminase test
  • Antibiotic susceptibility tests

How are bacteria classified?

• Phylogenetic analysis: the study of the evolutionary past of an organism

• We study gene sequences from genetic material, like DNA and RNA, to understand when organisms started to diverge and differentiate from their ancestors

• Pictured here is a phylogenetic tree of life

For more information on phylogenetic trees visit: https://www.khanacademy.org/science/high-school-biology/hs-evolution/hs-phylogeny/a/phylogenetic-trees
Bacteria live everywhere.
Where do bacteria live?

• Everywhere!
  • High temperatures
  • Low temperatures
  • Alkaline environments
  • Acidic environment
  • High pressure
  • High salinity environments
  • Desiccant environments
  • Soil
  • Water
  • Air
  • Other living creatures

Why should I care about bacteria?

• Some bacteria can make you sick: *pathogenic* bacteria
• Some bacteria neither help nor harm humans: *commensal* bacteria
• Some bacteria are an integral part of our health: *symbiotic* bacteria
• Bacteria are important for:
  • Human health
  • Food production
  • Medication development
  • Environmental clean up
  • Fuel production
  • Science
Summary of Characteristics of Bacteria

• Bacteria are **prokaryotes**.
  • Prokaryotes are single celled organisms that lack a nucleus and membrane-bound organelles.

• Bacteria are very small: 0.1 – 5.0 **micrometers**.
  • A micrometer (µm) is 0.000001 meters or 0.001 millimeters (mm)
  • For comparison, a human hair is 30 – 100 µm

• Bacteria are classified by their **phenotype** or **genotype**.
  • Phenotype: Observable characteristics of an individual resulting from the interaction of its genetic make-up with the environment.
  • Genotype: The genetic make-up of an organism.

• Bacteria are found everywhere!
  • Soil, air, water, animals, even extreme environments. **Extremophiles** live in extreme environments

• Some bacteria are **symbiotic**, some are **commensal** while others are **pathogenic**
  • Symbiotic bacteria get something from us and help us in return
  • Commensal bacteria neither hurt nor harm healthy people
  • Pathogenic bacteria make you sick – “germs”!

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The Good Guys
Microbiome
Microbiome

- **Microbiota or Microbiome**: the population of symbiotic, commensal, and pathogenic microorganisms (often called “flora”) of the human body.

- Members of our microbiota include:
  - Bacteria
  - Fungi
  - Protists
  - Viruses

Images from: Sanford and Gallo 2014
THE HUMAN MICROBIOME PROJECT SAYS THE HUMAN BODY HAS 100 TRILLION MICROSCOPIC LIFE FORMS LIVING IN IT.

YOU CALL THIS LIVING?
Mouth Microbiota

• Refers to all the microorganisms that reside in the human oral cavity

• 2nd largest community of microorganisms in human body

• Around 700 species of prokaryotes have been identified

• The bacteria found in the mouth form a biofilm (a layer of bacteria) that covers teeth

• The oral microbiome is important to protect teeth against periodontal disease

Skin Microbiota

• The skin is the largest organ of the human body

• The skin microbiome includes bacteria, fungi, viruses and even mites

• The skin microbiome protects us by producing molecules that inhibit the colonization of other microorganisms or alter their behavior

• It also helps to educate the adaptive and innate immune system

Gut Microbiota

• More than 100 trillion microbes live in the human gut

• Most gut microbes are strict anaerobes

• Most microbes are from the phyla Bacteroidetes & Firmicutes

• The gut microbiome plays important roles in many processes including digestion, protection of the host and interacting with cells of the immune system

Image from: Laukens et al. 2015
Gut Metabolism

• Produce vitamin K and various members of the vitamin B family
  • I.e. *Escherichia coli*

• Synthesize essential and nonessential amino acids
  • I.e. *Clostridia, Proteobacteria, and Bacillus-Lactobacillus-Streptococcus* group

• Produce secondary bile acids
  • I.e. *Clostridium*

• Breakdown otherwise nondigestible carbohydrates, including starches, cellulose, hemicellulose, pectins, and gums
  • I.e. *Bacteroides thetaiotaomicron*

Host Protection & Immune-system Development

- Produce antimicrobial agents (bacteriocins) to prevent colonization of pathogens
  - I.e. *Lactobacillus*
- Compete with pathogens for nutrients, preventing colonization by pathogens: barrier or competitive-exclusion effect
- Modulate the gut-mucosal immune system
- Prevention of allergies
Gut-Brain Axis

The mechanisms by which gut microbes and the brain might communicate are unclear, but there are several tantalizing leads for researchers to follow.

1. **Peripheral Serotonin**: Cells in the gut produce large quantities of the neurotransmitter serotonin, which may have an effect on signalling in the brain.

2. **Immune System**: The intestinal microbiome can prompt immune cells to produce cytokines that can influence neurophysiology.

3. **Bacterial Molecules**: Microbes produce metabolites such as butyrate, which can alter the activity of cells in the blood-brain barrier.

Health
Probiotics

• **Probiotics** are live “micro-organisms that, ...when administered in adequate amounts, confer a health benefit on the host”

• Probiotics can be in the form of food (often yogurt), dietary supplements, and topical creams

• Probiotics may be helpful in preventing diarrhea caused by infections and antibiotic uses, as well as for mitigation of irritable bowel symptoms

• *Lactobacillus* and *Bifidobacterium* are two common genera found in probiotics

Fecal Transplant

• **Fecal transplant**: A method to restore the normal gut flora by introducing healthy bacteria through transplant of stool by colonoscopy, enema, or mouth via capsules from a healthy donor.

• Used as a treatment for recurrent, antibiotic resistant *Clostridium difficile*. 

Image from: https://emojiisland.com/products/poop-emoji-icon
Botox

• Botox comes from the deadliest toxin known to man: botulinum toxin

• *Clostridium botulinum* (and a few related species) produce this toxin

• Botulinum toxin prevents the release of a neurotransmitter, acetylcholine, from axon ends at neuromuscular junctions, causing paralysis

• Botox is used for removing wrinkles, but also for taming muscle spasms and chronic migraines

What are antibiotics?
Antibiotics

• Any substance that can specifically kill or inhibit the growth of bacteria
• Naturally produced by bacteria and fungi to protect against other organisms
• Used commonly to treat bacterial infections
• Broad spectrum antibiotics are compounds that are effective against multiple types of bacteria

The first antibiotic, penicillin, was discovered by Alexander Fleming in the late 1920’s. It was produced by the mold *Penicillium notatum*.

Image and information from https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/flemingpenicillin.html
Antibiotics & Antimycotics*

<table>
<thead>
<tr>
<th>Antibiotic</th>
<th>Producer organism</th>
<th>Activity</th>
<th>Site or mode of action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacitracin</td>
<td><em>Bacillus subtilis</em></td>
<td>Gram-positive bacteria</td>
<td>Wall synthesis</td>
</tr>
<tr>
<td>Polymyxin B</td>
<td><em>Bacillus polymyxa</em></td>
<td>Gram-negative bacteria</td>
<td>Cell membrane</td>
</tr>
<tr>
<td>Amphotericin B</td>
<td><em>Streptomyces nodosus</em></td>
<td>Fungi</td>
<td>Cell membrane</td>
</tr>
<tr>
<td>Erythromycin</td>
<td><em>Streptomyces erythreus</em></td>
<td>Gram-positive bacteria</td>
<td>Protein synthesis</td>
</tr>
<tr>
<td>Neomycin</td>
<td><em>Streptomyces fradiae</em></td>
<td>Broad spectrum</td>
<td>Protein synthesis</td>
</tr>
<tr>
<td>Streptomycin</td>
<td><em>Streptomyces griseus</em></td>
<td>Gram-negative bacteria</td>
<td>Protein synthesis</td>
</tr>
<tr>
<td>Tetracycline</td>
<td><em>Streptomyces rimosus</em></td>
<td>Broad spectrum</td>
<td>Protein synthesis</td>
</tr>
<tr>
<td>Vancomycin</td>
<td><em>Streptomyces orientalis</em></td>
<td>Gram-positive bacteria</td>
<td>Protein synthesis</td>
</tr>
<tr>
<td>Gentamicin</td>
<td><em>Micromonospora purpurea</em></td>
<td>Broad spectrum</td>
<td>Protein synthesis</td>
</tr>
<tr>
<td>Rifamycin</td>
<td><em>Streptomyces mediterranei</em></td>
<td>Tuberculosis</td>
<td>Protein synthesis</td>
</tr>
</tbody>
</table>

* Antimycotics- substances that kill or inhibit the growth of fungi

Information from: http://archive.bio.ed.ac.uk/jdeacon/microbes/penicill.htm
Science
The first example of this occurred in 1978 when Herbert Boyer, took a version of the human insulin gene and inserted it into the bacterium *Escherichia coli* to produce synthetic "human" insulin.

Four years later, it was approved by the U.S. Food and Drug Administration.
Gene editing by CRISPR/Cas9

- Based on a defense mechanism used by some bacteria against viruses
- CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats)- DNA sequences found in prokaryotes that are derived from viral DNA
- Cas9- enzyme that recognizes the CRISPR repeats and can break apart the viral DNA
- We can now use this system to edit genes in bacteria, plants, animals and even as potential therapies for diseases

For more information on CRISPR/Cas9 visit: https://www.brainfacts.org/in-the-lab/tools-and-techniques/2019/crispr-explained-071519
Environment
Plastic Clean Up

• *Ideonella sakaiensis* were identified by Japanese scientists outside of a plastic bottle recycling plant

• Bacteria secrete PETase to break down Polyethylene terephthalate (PET), polymers that made up plastic, by cleaving ester bonds

• Scientists are working to use PETase from bacteria in reactors to recycle plastics and clean up the environment

Image from: https://metro.co.uk/2018/02/06/how-to-reduce-plastic-waste-10-simple-changes-you-can-make-today-7291656/
Food
Can you think of any foods that bacteria help us make?
Bacteria are used to Ripen Cheese

Image and information on how cheese is produced from: https://www.cheesescience.org/cheese_types/
Bacteria are important in other foods too
Conclusion

• Bacteria are GOOD for many reasons:
  • Microbiome
  • Health
  • Science
  • Environment
  • And many other reasons we didn’t have time to cover!
The Bad Guys

It was on a short-cut through the hospital kitchens that Albert was first approached by a member of the Antibiotic Resistance.

Image from: https://www.tujawellness.com/antibiotic-resistance-armageddon/
The Bad

Estimated minimum number of illnesses and deaths caused by antibiotic resistance:

At least 2,049,442 illnesses
23,000 deaths

STDS IN THE UNITED STATES

CHLAMYDIA 1,758,668
TOTAL CASES IN 2018
2.0% INCREASE SINCE 2017

GONORRHEA 583,405
TOTAL CASES IN 2018
5.0% INCREASE SINCE 2017

SYPHILIS 115,045
TOTAL CASES IN 2018
13.3% INCREASE SINCE 2017

CONGENITAL SYphilis 1,186
TOTAL CASES IN 2018
10.7% INCREASE SINCE 2017

PRIMARY AND SECONDARY SYphilis 35,063
TOTAL CASES IN 2018
14.4% INCREASE SINCE 2017

STDs tighten their grip on the nation's health as rates increase for a fifth year.

Source: U.S. Centers for Disease Control and Prevention

Images from:
- top left: https://blogs.cdc.gov/safehealthcare/files/2015/02/Estimated-Illness_AR.jpg
- top right: https://www.cdc.gov/nchhstp/newsroom/images/multimedia/stds-us-2018_higRes.jpg
- bottom center: https://www.cdc.gov/foodsafety/images/food-Safety-symptoms-500px.png
**Food Poisoning**

Organisms: *Salmonella* & *Escherichia coli*

Two of the most common causes of food poisoning

**Sources:** Contaminated eggs, poultry, meat, unpasteurized milk or juice, cheese, contaminated raw fruits and vegetables

**Symptoms:**
- Diarrhea, fever, abdominal cramps, vomiting

bottom- https://www.giantmicrobes.com/us/media/catalog/product/cache/2/small_image/9df78eab33525d08d6e5fb8d27136e95/e/c/ecoli_2.jpg,
Tetanus

Organism: *Clostridium tetani*

Source: soil, saliva, dust and manure

Enters through a puncture or skin cut

Symptoms:

- Begins with jaw muscle spasms and could lead to spasms of many body muscles

Mechanism: Tetanus toxin initially binds to peripheral nerve terminals

Image from: https://phil.cdc.gov//PHIL_Images/20041014/19f02a819c8f4352804bc5abbdd820c0/6374_lores.jpg
Botulism

Organism: *Clostridium botulinum*

Botulinum toxin- blocks nerve function, causing nerve paralysis

Bacterial spores found in soil and water, low acid foods improperly stored (including pickled things and honey)

Infant botulism- floppy infant syndrome (acute muscular hypotonia)

Symptoms:

- Muscle weakness typically occurs starting with cranial nerves

Image from: http://casemed.case.edu/clerkships/neurology/NeurLrngObjectives/floppy.jpg
Anthrax

Organism: *Bacillus anthracis*

Spreads through contact with bacterial spores either breathing, eating or through open skin

Affects skin, lungs and gastrointestinal tract

Symptoms:

- Can lead to inflammation of the mediastinum and pneumonia that can lead to shock and sudden death

Image from: https://www.cdc.gov/anthrax/images/illustrations/anthrax-life-cycle.jpg
Sexually Transmitted Diseases (STDs)

Organisms: *Chlamydia trachomatis*, *Neisseria gonorrhoeae*, *Treponema Pallidum*

Diseases: Chlamydia, Gonorrhea, Syphilis

Transmitted from one person to another during vaginal, anal, and oral sex

Prevented by avoiding unprotected sex

Image from: https://www.cdc.gov/std/stats18/images/infotweet-1-2018.png
Antimicrobial Resistance

- Occurs when bacteria and fungi become resistant to antibiotics and antimycotics and can no longer be killed by them

- It is considered one of the greatest public health threats of our time

Methicillin-Resistant *Staphylococcus aureus* (MRSA)

Common in hospitals, prisons and nursing homes

Presents as red bumps in the skin, fever and rash. As time passes the bumps become painful and filled with pus

Began as a hospital acquired infection

Resistant to broad spectrum antibiotics

Cholera

Organism: *Vibrio cholerae*

Cholera toxin- activates the enzyme adenylate cyclase that produce cAMP. High levels of cAMP leads to secretion of chloride ions that promote the accumulation of fluid in the gut.

Spreads through contaminated water and food.

Only affects humans.

Symptoms:

- Watery diarrhea, severe dehydration, vomiting, muscle cramps

Image from: https://www.cdc.gov/cholera/images/cholera-banner.jpg
Tuberculosis

Organism: *Mycobacterium tuberculosis*

Spreads through the air.

Affects lungs and sometimes brain

10% of infections progress to active disease

Symptoms:

- Cough with bloody sputum, fever, night sweats and weight loss

Image from: https://www.health.harvard.edu/media/content/images/medical-illustrations/tuberculosis-dreamstime_s_47704368.jpg
Bubonic Plague

Organism: *Yersinia pestis*

Also known as Black Death - acral necrosis (gangrene)

Spread by fleas from small animals (i.e. rats)

Symptoms:

- Chills, fever, infected and enlarged lymph nodes (buboes), seizures, vomiting blood

Hansen’s Disease

Organism: *Mycobacterium leprae*

May spread through coughing or contact with fluids of infected person, however **prolonged (over many months) close contact** with **someone untreated** for Hansen’s disease would be **required** to get the disease

Not very contagious

Usually infections remain without symptoms for 5-20 years

Symptoms:

- Pinkish patches of skin that become insensitive to pain or temperature, numbness in hands and feet, secondary infections can lead to tissue loss
What can we do to protect ourselves?

- For more information about vaccines visit: [https://www.cdc.gov/vaccines/vac-gen/default.htm](https://www.cdc.gov/vaccines/vac-gen/default.htm)

- For more information about antimicrobial resistance visit: [https://www.cdc.gov/drugresistance/about.html](https://www.cdc.gov/drugresistance/about.html)