Teacher's Guide

Lesson Title

BSCS Biology: Understanding for Life
Infectious Diseases: How Can Bacterial Infections Make Us Sick, And Why Are They Getting Harder To Treat?

Learning Objectives

1. Understand the causes and transmission of infectious diseases.
2. Distinguish between bacterial and viral infections and explain bacterial structure and function
3. Explain bacterial pathogenesis and the development of antibiotic resistance
4. Evaluate societal, medical, and ethical responses to infectious disease and antibiotic resistance

NGSS Standards Alignment

Disciplinary Core Ideas (DCIs)

LS1: Structure and Function (MS-LS1, HS-LS1)

- MS-LS1–2: Systems of specialized cells work together
- HS-LS1–2: Structure and function at different levels explain biological outcomes

LS2: Interactions, Energy, and Dynamics (MS-LS2, HS-LS2)

- MS-LS2–2: Organisms interact with biotic and abiotic factors
- HS-LS2–8: Human activity impacts biological systems

LS3: Inheritance and Variation of Traits (HS emphasis)

- HS-LS3–1 and HS-LS3–2: Genetic variation → phenotype → survival advantage

LS4: Natural Selection and Evolution (MS-LS4, HS-LS4)

- MS-LS4–4: Natural selection leads to population change
- HS-LS4–2 & HS-LS4–4: Evolution results from genetic variation and environmental pressures

Science and Engineering Practices (SEPs)

Asking Questions & Defining Problems

- Anchoring questions ("Why do I need to know this?")
- Societal challenges framing (antibiotic resistance)

Analyzing & Interpreting Data

- world maps of disease distribution
- resistance trends
- surveillance data

Constructing Explanations

- linking cell structures to infection
- explaining resistance mechanisms
- explaining treatment failure

Engaging in Argument from Evidence

- vaccine skepticism
- antibiotic stewardship
- public health decision-making
- ethical research discussions

Obtaining, Evaluating, and Communicating Information

- clinical trial phases
- whole genome sequencing
- animal vs human research roles

Crosscutting Concepts (CCCs)

- Cause and Effect
  - antibiotics → selection → resistance
- Systems and System Models
  - host + pathogen + environment
- Structure and Function
  - bacterial cell components
- Stability and Change
  - microbiome balance vs dysbiosis
- Scale, Proportion, and Quantity
  - cellular → organism → population → global health

Middle School vs High School Fit

Middle School (MS)

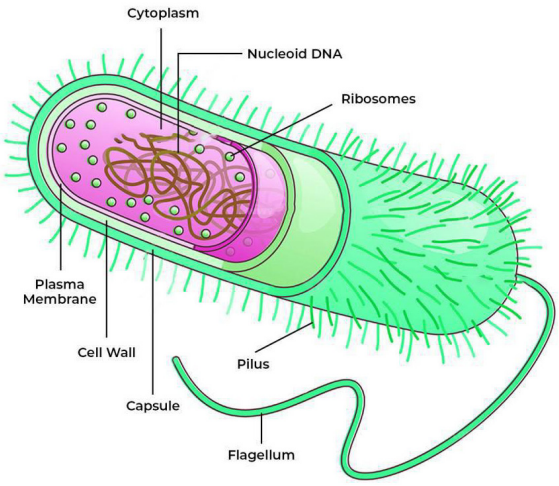
Best aligned sections:

- basic infectious disease definitions
- differences between bacteria and viruses
- transmission routes
- good vs bad bacteria
- basic antibiotic resistance concept (without molecular depth)

High School (HS)

- NGSS-aligned HS biology
- BSCS Biology: Understanding for Life
- phenomena-driven units on health and disease

Materials



Ask students for different kinds of harmful bacteria.
Share a list with students via overhead, white/black board, or computer.

Harmful Bacteria

Mycobacterium tuberculosis (Causes tuberculosis (TB)

- Salmonella, Found in raw meat, eggs, and unpasteurized dairy. Causes foodborne illness with diarrhea and fever.
- Staphylococcus aureus, Common on skin; some strains can cause skin infections, pneumonia, or food poisoning. MRSA is a drug-resistant form that can be hard to treat.
- Clostridium botulinum, Produces a powerful toxin that causes botulism, a rare but deadly illness.
- Listeria monocytogenes, Found in contaminated food. Dangerous for pregnant women, newborns, and people with weakened immune systems.
- Helicobacter pylori, Lives in the stomach lining and can cause ulcers and increase the risk of stomach cancer.
- Vibrio cholerae, Causes cholera, leading to severe diarrhea and dehydration, often through contaminated water.

ASK Students to name examples that cause skin infections, food poisoning, respiratory illness, etc.

Examples for discussion if students need assistance:

Pseudomonas aeruginosa

- Typical infections: Pneumonia, urinary tract infections, wound infections, and bloodstream infections.
- Opportunistic behavior: Often infects individuals with weakened immune systems, such as those with cystic fibrosis, burns, or cancer patients undergoing chemotherapy.

Staphylococcus epidermidis

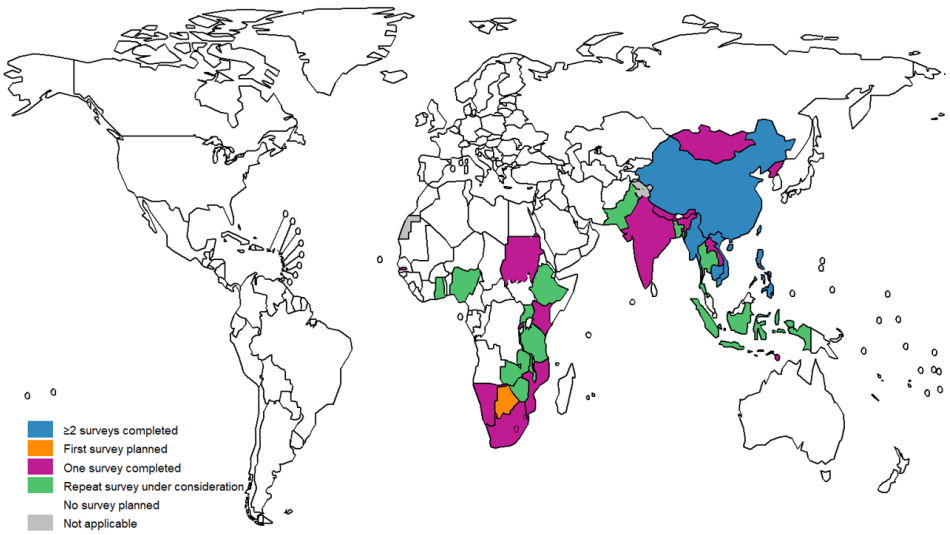
- Typical infections: Bloodstream infections, endocarditis, infections associated with medical devices (e.g., catheters, prosthetics).
- Opportunistic behavior: Normally a harmless skin commensal, but can cause infection in individuals with indwelling medical devices or compromised immune systems (e.g., cancer or transplant patients).

- Importance: This allows bacteria to multiply and spread in the body, often leading to more severe infections.

3. Toxin Production and Damage to Host Tissues
   - Concept: Many pathogenic bacteria produce toxins that directly damage host cells and tissues.
   - Mechanism: There are two main types of bacterial toxins:
     - Exotoxins: Secreted proteins that can disrupt cellular functions (e.g., Clostridium botulinum producing botulinum toxin, which causes paralysis).
     - Endotoxins: Components of the bacterial cell wall (e.g., E. coli or Salmonella) that, when released, trigger intense immune reactions, leading to inflammation and, in some cases, septic shock.
   - Importance: Toxin production can cause symptoms like fever, diarrhea, and tissue necrosis, and it plays a major role in the severity of the disease.

Share world map of common pathogenic bacteria distribution.

Global Distribution of TB from the World Health Organization



New Cases: Approximately 8.2 million people were newly diagnosed with TB in 2023, marking the highest number recorded since WHO began global TB monitoring in 1995.

Total Cases: The estimated total number of people falling ill with TB in 2023 was 10.8 million.

Deaths: TB-related deaths decreased from 1.32 million in 2022 to 1.25 million in 2023, but it remains the leading infectious disease killer globally, surpassing COVID-19.

BSCS Biology: Understanding for Life

Infectious Diseases: How Can Bacterial Infections Make Us Sick, And Why Are They Getting Harder To Treat?

What are Infectious Diseases?

Infectious diseases are illnesses caused by pathogenic microorganisms, such as bacteria, viruses, fungi, or parasites. These can be transmitted from one host to another, and from animals to humans and humans to animals. These diseases spread through various means, including air-borne transmission, infected surfaces, bodily contact, contaminated food or water, or vector-borne transmission.

Most bacteria are harmless, and some actually are good helpers for the body; by digesting food, destroying disease-causing microbes, and providing essential nutrients. Fewer than 1% of bacteria cause diseases in people.

Unlike bacteria, most viruses do cause disease, and they're quite specific about the cells they attack. For example, certain viruses attack cells in the respiratory system, or stomach, or in blood. In some cases, viruses target bacteria.

Infectious diseases can be mild to severe and may require treatment with medications such as antibiotics, antivirals, or antifungals, depending on the type of pathogen involved. Preventive measures, including vaccinations, proper hygiene and hand-washing, insect-control, and safe food practices are crucial in controlling the spread of infectious diseases.

Definitions

Infectious Disease – illnesses caused by pathogens like bacteria, viruses, fungi, and parasites. They can spread from one person to another, either directly or indirectly. Examples include the common cold, influenza, and HIV/AIDS. Animals are also subject to infectious diseases.

Pathogenic – the ability of an organism, such as bacteria, viruses, fungi, or parasites, to cause disease in a host. Pathogenic organisms are capable of invading a host's tissues, evading its immune responses, and disrupting normal physiological functions, which can result in illness.

Vector-borne Transmission – the process by which infectious diseases are spread to humans or other animals through vectors.

Vectors – organisms – Typically arthropods like mosquitoes, ticks, fleas, and sandflies. Possible other definition: the spread of diseases from one host to another through a vector, which is a living organism (i.e., mosquitoes, ticks, or fleas) that carries the disease causing pathogen or agent.

Airborne Infection – Airborne diseases are bacteria or viruses that are most commonly transmitted through small respiratory droplets.

Opportunistic Infection – Illnesses caused by pathogens—bacteria, viruses, fungi, or parasites—that take advantage of weakened immune systems (e.g., HIV/AIDS, cancer, transplant patients) to cause severe disease.

MRSA– Methicillin-resistant Staphylococcus aureus (MRSA) infection is caused by a type of staph bacteria that's become resistant to many of the antibiotics used to treat ordinary staph infections.

MDR – Multidrug resistance

Fomites - Objects or materials which are likely to carry infection, such as clothes, utensils, and furniture.

Examples of Infectious Diseases

- Tuberculosis (TB) - A bacterial infection that primarily affects the lungs but can also impact other parts of the body. It was once known as consumption. Glocally, 1.25 million people die from tuberculosis (TB) each year.
- HIV/AIDS - A viral infection that attacks the immune system.
- Malaria - A parasitic infection transmitted by mosquitoes.
- COVID-19 - A viral respiratory illness caused by the coronavirus SARS-CoV-2.
- Influenza "the flu" - A viral infection that affects the respiratory system.
- Strep Throat - A contagious bacterial infection of the throat and tonsils caused by *Group A Streptococcus* bacteria.
- Mononucleosis "Mono" - An infection that typically causes fever, sore throat, fatigue, and/or enlarged lymph nodes in the neck. Also called the "kissing disease".

What Is The Difference Between Viral Infections and Bacterial Infections?

Unlike bacteria, which can sit on surfaces and survive in the air, viruses can't survive without a host. Viruses reproduce by attaching and entering into the host's cells and then using the components of the host cell to generate copies of itself. Unlike viruses, bacteria are living cells that can reproduce on their own. In most cases, viruses reprogram cells to make new viruses until the cell bursts and dies. In other cases, they can turn normal cells into malignant or cancerous cells or remain dormant until activated through stress. Antibiotics work for a bacterial infection in most cases, although antibiotic-resistant bacterial infections are becoming more prevalent. Antibiotics do not work against viruses. Vaccines can prevent viruses, but cannot treat them. While the association with vaccines is usually viruses, some bacterial infections can be prevented by vaccines as well.

Often it is a combination of a virus first, followed by a secondary bacterial infection that makes a killer.

For example, during the 1918 Flu (the Spanish Flu) pandemic,patients were first infected with the H1N1 influenza A *virus*, but it was the secondary *bacterial* pneumonia that killed them.

While all types of infectious diseases are fascinating to learn about, we will be discussing bacterial infections today, and some basic information about bacteria will be a good place to start.

Cellular Components of Bacteria

The basic bacterial cell structure consists of a cell wall, membrane, cytoplasm, ribosomes, and a nucleoid containing the genetic material. Some bacteria also possess specialized structures like flagella, pili, and capsules that enhance their survival and function.

- Cell Wall: This rigid outer layer, composed primarily of peptidoglycan, provides shape and protection to the bacterial cell.
- Cell Membrane: This membrane, also known as the cytoplasmic membrane, encloses the cytoplasm and controls the movement of substances in and out of the cell. It's a phospholipid bilayer with embedded proteins.

- Cytoplasm: This gel-like substance within the cell membrane houses various cellular components like ribosomes and the nucleoid. It's where many metabolic processes occur.
- Ribosomes: These are responsible for protein synthesis in the cell. They are found throughout the cytoplasm.
- Nucleoid: This region contains the cell's primary genetic material, a circular chromosome of DNA.
- Plasmids: These are small, circular DNA molecules that can carry genes that provide advantages to the bacteria, such as antibiotic resistance.
- Flagella: These whip-like appendages enable bacteria to move.
- Pili (also called Fimbriae): These hair-like structures help bacteria adhere to surfaces and can also play a role in genetic exchange.
- Capsule: This outer layer, not found in all bacteria, provides additional protection and can aid in attachment to surfaces.

Now that we know the backstory for bacteria, let's talk about those healthy bacteria - the "good" bacteria. These are *beneficial microorganisms* that live in and on a living organism — for humans this is especially in our "guts". They help with things like: digesting food, producing vitamins (like B12 and K), fighting harmful bacteria, supporting your immune system, and maintaining a healthy gut lining. Some common types of healthy bacteria include: Lactobacillus, Bifidobacterium, Streptococcus thermophilus, and Saccharomyces boulardii.

Pathogenesis of Bacteria

While most bacteria are good or neutral, some aren't - they are pathogenic. These are bacteria that can cause disease. They can reproduce quickly in your body and some give off toxins that can cause infections. Can you think of examples of pathogenic bacteria that cause skin infections, food poisoning, respiratory illness, and others?

For example, common ones that infect humans today are E. coli or Strep Throat. Then there are complicated ones, like Pneumonia or meningitis which can actually be caused by bacteria *or* viruses - it depends on the type. There is also the concept of "Opportunistic Pathogens". These are bacteria that do not normally cause disease in healthy individuals, but can cause infections when the host's immune system is weakened or compromised. These pathogens often take advantage of changes in the host's environment, such as immune suppression, injury, or disruption of the normal microbiota. Remember where we mentioned the 1918 Flu Pandemic above? The pneumonia that was the killer was an opportunistic infection.

The pathogenesis of bacteria refers to the process by which bacteria cause disease in a host. It involves several complex interactions between the bacteria and the host's immune system.

Adherence, immune evasion, and toxin production.

These three concepts—adherence, immune evasion, and toxin production—are central to how bacteria cause disease and are key targets for treatments like vaccines, antibiotics, and immune-boosting therapies.

Bacterial Pathogenesis and Antibiotic Resistance

The antibiotic cliff is a metaphor for the impending crisis of multidrug-resistant bacteria. EXPLAIN this more. Use TB as an example.

The main causes are overuse of antibiotics for unnecessary reasons, and a weak pipeline for new antibiotics.This is the process where the bacteria has resistance to antibiotics because it has evolved mechanisms to survive exposure to drugs designed to kill or inhibit it. The development of antibiotic resistance can complicate the treatment of bacterial infections and impact the severity and spread of diseases.

Mechanisms of Antibiotic Resistance:

- Genetic Mutations: Random mutations in bacterial DNA can lead to resistance to certain antibiotics. For example, mutations can change the target sites of antibiotics, making them less effective (e.g., mutations in the ribosome can make bacteria resistant to tetracycline).
- Horizontal Gene Transfer: Bacteria can acquire resistance genes from other bacteria through processes like conjugation (transfer of plasmids), transduction (viral-mediated gene transfer), or transformation (uptake of free DNA from the environment). This allows resistance to spread rapidly.
- Efflux Pumps: Some bacteria possess efflux pumps that actively pump antibiotics out of the cell before they can have an effect. This mechanism contributes to resistance against multiple antibiotics, including macrolides and fluoroquinolones.
- Enzymatic Inactivation: Bacteria can produce enzymes that break down or modify antibiotics, rendering them ineffective. For example, *Beta-lactamase* enzymes produced by bacteria like *Staphylococcus aureus* can destroy penicillin and other beta-lactam antibiotics.
- Altered Permeability: Bacteria can change their cell membrane's permeability, preventing antibiotics from entering the cell. For example, changes in the outer membrane of Gram-negative bacteria can prevent drugs from reaching their target.

Antibiotic Resistance and Superbugs

Antibiotic resistance can result in the development of superbugs—bacteria that are resistant to multiple antibiotics. Methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus faecalis* (VRE) are prominent examples. Multidrug-resistant (MDR) bacteria, such as extended-spectrum beta-lactamase (ESBL)-producing *E. coli*, are resistant to multiple classes of antibiotics, making infections harder to treat.

The Link Between Pathogenesis and Antibiotic Resistance

- Virulence Factors: Many bacteria that are highly virulent (capable of causing severe disease) also have mechanisms that contribute to antibiotic resistance. For instance, *Pseudomonas aeruginosa* is not only resistant to multiple antibiotics but also produces biofilms, which make it harder for both the immune system and antibiotics to reach the bacteria.
- Antibiotics in the Environment: The overuse and misuse of antibiotics in healthcare and agriculture (where antibiotics are given to cows to keep them healthy, gain weight, and/or produce more milk, are major contributors to the rise of antibiotic resistance.

Clostridium difficile (C. diff)

- Typical infections: Diarrhea, colitis, and potentially life-threatening pseudomembranous colitis.
- Opportunistic behavior: Usually found in the intestines without causing harm, but after the normal microbiota is disrupted (e.g., by broad-spectrum antibiotics), it can overgrow and cause disease.

Escherichia coli (E. coli)

- Typical infections: Urinary tract infections (UTIs), neonatal meningitis, bloodstream infections.
- Opportunistic behavior: While some strains of E. coli are part of the normal gut flora, other strains (or when in abnormal locations like the urinary tract or bloodstream) can cause disease, especially in immunocompromised individuals or those with medical devices (e.g., catheters).

Klebsiella pneumoniae

- Typical infections: Pneumonia, urinary tract infections, liver abscesses, and bloodstream infections.
- Opportunistic behavior: A common pathogen in people with weakened immune systems, such as those with chronic lung disease, diabetes, or undergoing invasive medical procedures.

Enterococcus faecalis

- Typical infections: Urinary tract infections, endocarditis, wound infections, and bloodstream infections.
- Opportunistic behavior: Commonly found in the intestines, but can cause infections in immunocompromised individuals or those with medical devices (e.g., catheters).

Offer less common examples of pathogenic bacteria.

- Diphtheria
- Typhoid Fever
- Leprosy (Hansen's Disease)
- Anthrax

Name the three key concepts that are essential to understanding bacterial pathogenesis:

1. Adherence to Host Cells (Colonization)
   - Concept: For bacteria to cause infection, they must first attach to the host's cells, tissues, or surfaces.
   - Mechanism: Bacteria use specialized structures called adhesins (proteins or surface molecules) to bind to receptors on the host's cells. For example, E. coli uses fimbriae (hair-like projections) to adhere to the lining of the intestines.
   - Importance: Successful adhesion is the first step in colonization, allowing bacteria to establish a presence and resist being washed away by bodily fluids (like mucus or urine flow).
2. Invasion and Evasion of the Host Immune System
   - Concept: After adhering to the host's tissues, bacteria may invade deeper into the body or evade the host's immune defenses.
   - Mechanism: Some bacteria can invade host cells (like Salmonella entering intestinal cells), allowing them to hide from immune surveillance. Others produce virulence factors—such as toxins or enzymes—that damage tissues or suppress immune responses (e.g., Staphylococcus aureus secreting toxins that kill white blood cells).

When bacteria are exposed to antibiotics, they are pressured to evolve resistance, often by selecting for mutations or acquiring resistant genes from other bacteria.

- Impact on Treatment: Antibiotic-resistant bacteria complicate the treatment of infections. What used to be a simple infection, like a urinary tract infection, can now be much harder to treat if the bacteria are resistant to first-line antibiotics, requiring stronger and often more toxic medications.

Preventing and Combating Antibiotic Resistance

As a society, we need to combat antibiotic resistance through Antibiotic Stewardship – the proper use of antibiotics by prescribing them only when necessary and using the correct drug for the right infection. We can also work to prevent further antibiotic resistance through Infection Control – practices like hand hygiene, isolation precautions for infected patients, and sanitizing surfaces can reduce the spread of antibiotic-resistant bacteria.

Current Research Efforts to Combat Antibiotic Resistance

Science plays an important role in combating antibiotic resistance through the development of new antibiotics and new categories of antibiotics. An example is research into new antibiotics like Teixobactin which was discovered from soil bacteria using a new technique called the iChip, whole genome sequencing of bacteria, and alternative treatments, such as phage therapy, are ongoing to fight resistant bacteria.

Whole genome sequencing (WGS) of bacteria is a powerful method used to determine the complete DNA sequence of a bacterial genome, all at once. It gives a comprehensive view of a bacterium's genetic makeup, allowing scientists and healthcare professionals to understand how it behaves, survives, spreads, and resists treatment.

Whole genome sequencing is the process of: Extracting DNA from the bacterial cell; Breaking the DNA into smaller fragments; Reading the sequence of bases (A, T, G, C) in each fragment using sequencing machines (like Illumina, PacBio, or Oxford Nanopore); and Reassembling the genome with bioinformatics tools to create a full, detailed map of the bacterial DNA.Studies with important laboratory animals and in humans to study antibiotic resistance help scientists to understand resistance mechanisms and evaluate new antibiotics, and treatment strategies before they are used widely in public health.

New Research about Mono and Later Conditions

Mononucleosis ("mono"), primarily caused by the Epstein-Barr virus (EBV), is strongly linked to increased risks of long-term autoimmune and other chronic conditions. Research suggests EBV can trigger diseases like multiple sclerosis (MS), systemic lupus erythematosus, rheumatoid arthritis, and certain cancers by altering immune function. The virus can remain in the body, potentially contributing to chronic fatigue and other diseases.

Studies in Humans (Clinical and Observational) – are the gold standard for understanding real-world antibiotic resistance. Such studies test new antibiotics or new combinations in people with infections, especially those caused by drug-resistant bacteria. Humans are needed for surveillance studies where researchers track resistance patterns in hospitals, communities, and across countries. And in cohort studies, scientists observe antibiotic use and the development of resistance over time in populations.

Studies acquire participants in different ways depending on the "Phase" of the trial. Information about clinical trials are shared with doctors, hospitals, clinics, and other ways to attack and identify appropriate participants for each stage of the clinical trial.

Phase 1:

This initial phase focuses on safety and dosage. A small group of volunteers (usually 20–80 participants) are given the new treatment to determine the safest dosage, how it is absorbed, and how it affects the body.

Phase 2:

This phase expands to a larger group (usually 100–300 participants) of people who have the disease or condition being treated. The goal is to evaluate the treatment's efficacy and gather more information about its safety and side effects.

Phase 3:

This is the largest and most extensive phase, often involving hundreds or even thousands of participants. The primary goal is to compare the new treatment to the current standard of care, confirm its efficacy, and monitor its safety and side effects.

For example, scientists are conducting a clinical trial of colistin (an older antibiotic) to treat carbapenem-resistant infections in ICU patients. AND scientists are studying Fecal microbiota transplant (FMT) trials in humans to treat recurrent *Clostridioides difficile* and restore gut bacteria balance. Yes, this is what it sounds like, and it is proving to be an effective strategy!

Finally, vaccines are not only for viral disease - some vaccines, like the Pneumococcal and Meningitis vaccines can help prevent bacterial infections, reducing the need for antibiotics and consequently reducing the likelihood of resistance developing. There is even a **Plague Vaccine** - yes, we still do have cases of the plague (caused by the bacterium *Yersinia Pestis*).

Animals play a critical role in our search for therapies and new drugs to treat antibiotic resistant bacterial infections. Laboratory animals—like mice, rats, zebrafish, and even insects (like fruit flies)—are commonly used to model antibiotic resistance in controlled environments. Such studies help track how bacteria mutate or exchange resistance genes under antibiotic pressure; test the effectiveness of antibiotics on drug- resistant bacteria, and develop novel antibiotics, phage therapy, or immune-boosting treatments that can be tested for safety and efficacy.

- Mice infected with MRSA are used to test whether new drugs can clear infections resistant to methicillin.
- Gnotobiotic mice (raised in germ-free environments) are used to study how gut microbiota respond to antibiotics and how resistant strains take over.
- Zebrafish embryos are used to visually study bacterial behavior, biofilm formation, and drug effects in real time.

Conclusion

Understanding bacterial pathogenesis and antibiotic resistance is essential to addressing the challenges posed by infectious diseases. As bacteria evolve to become resistant to treatments, they can complicate infections, making them harder to treat and control Combining better infection prevention strategies with careful antibiotic use and the development of new treatments is crucial in fighting the growing threat of antibiotic resistance.

The 3 Rs of Biomedical Research

Researchers work to practice humane and ethical research and to take into consideration such issues. The 3 Rs is an example of how researchers practice humane and ethical pre-clinical research that include animal studies.

Researchers avoid the use of animals in research whenever possible and are constantly searching for alternative methods. They are required by federal law to present a "protocol" (a plan for their research to a committee (the Institutional Animal Care and Use Committee - IACUC) that is mandated by the federal law, "Animal Welfare Act".

They subscribe to "The 3 Rs" – (Reduction, Refinement, Replacement). They look for ways to reduce the number of animals necessary to obtain valid scientific results. This, in some studies, eliminates the use of animals. Researchers also refine experimental techniques and existing research methods. This includes new and more effective anesthetics and analgesics, species-appropriate housing, and enrichment activities. And researchers seek to replace animal models with alternative research methods whenever possible. Computer models or cell and tissue cultures are examples.

In fact, the development and validation of alternatives to animal models in research, and the refinement of existing research methods, is part of federal regulations governing the role of animals in medical research, and it is a high priority within the research community for scientific, humane, and economic reasons.

Some Questions for Discussion

- Why is it important to know about and apply this knowledge of bacterial infections?
- Why are antibiotic-resistant infections a 21st century societal challenge that we can no longer ignore?
- When do Infectious Diseases Become a Regional, National, or International Issue?
- What is society's role in addressing a disease?
- How does society decide which diseases to fully address regionally, nationally, and globally? Which diseases seem to attract the most attention?
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues. For example, sometimes the process of scientific research touches on issues that society finds controversial and uncomfortable. Stem Cell research, genetically modified organisms (GMOs), therapeutic cloning, human testing, and animals in medical research are examples of such "science-based societal issues". Discuss this.
- What other issues can impact the distribution of medications to fight or prevent infectious diseases?
- What has happened to introduce societal skepticism of some vaccines?
- What is herd immunity and why is it important?
- How do public health officials help to maintain herd immunity?