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Review Article

# Antibiotic Resistance: Mechanism and Prevention

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Antimicrobial resistance is a serious problem in global public health, and it affects our ability to prevent and control infections effectively. This occurs when bacteria and other microorganisms find a way to evade the effects of antimicrobial agents, such as those that would normally kill them or prevent them from reproducing. This means that the effectiveness of standard treatments is reduced, and infections become chronic, more likely to be transmitted, and associated with increased morbidity and mortality. Antimicrobial resistance (AMR) is a growing problem, and its main drivers are: Bacteria use a variety of different molecular mechanisms to evade antibiotics. This includes enzymatic degradation, target modifications, increased excretion of antibiotics from the cell, reduced permeability of the bacterial cell membrane, and biofilm development. Bacteria also use a process known as horizontal gene transfer, whereby bacteria can share resistance genes through a process known as conjugation, transformation, and transduction. Antibiotic resistance has critical and far-reaching effects, and its clinical effects include increased costs and length of stay in hospitals, increased mortality, and a great impact from an economic perspective, especially on healthcare and society in general. Antibiotic resistance also has a critical impact from a public health perspective, especially on the success of major medical procedures such as surgery, organ transplants, and chemotherapy.

**Keywords**
Antibiotic Resistance, Antimicrobial Resistance (AMR), Bacterial Mutation, Drug Resistance Mechanisms, Beta-lactamase, Efflux Pump, Biofilm Formation, Horizontal Gene Transfer, Multidrug Resistance (MDR).

## INTRODUCTION

One of the most alarming challenges facing the world in the near future is antibiotic resistance, which is regarded as one of the largest challenges facing modern medicine. Antibiotics are potent drugs that are administered in the treatment of bacterial infections, which are either bactericidal, killing the bacteria, or bacteriostatic, slowing down the growth of the bacteria. Since the isolation of penicillin in the early 20th century, antibiotics have completely transformed the field of healthcare, as bacterial infections, which were once deadly, are now curable in the most effortless ways. The development of resistance in the microbiota to antibiotics led to the need for antibiotics.[1-5]

Antibiotic resistance is the mechanism through which bacteria become immune to antibiotics, which are supposed to prevent or cure infections, rendering them completely useless in the process. While antibiotic resistance occurs naturally, the process has been accelerated by human activities, although some degree of natural antibiotic resistance occurs over time due to mutations in the bacterial flora's genetic code.[5-10]

Another factor that has contributed to the worry

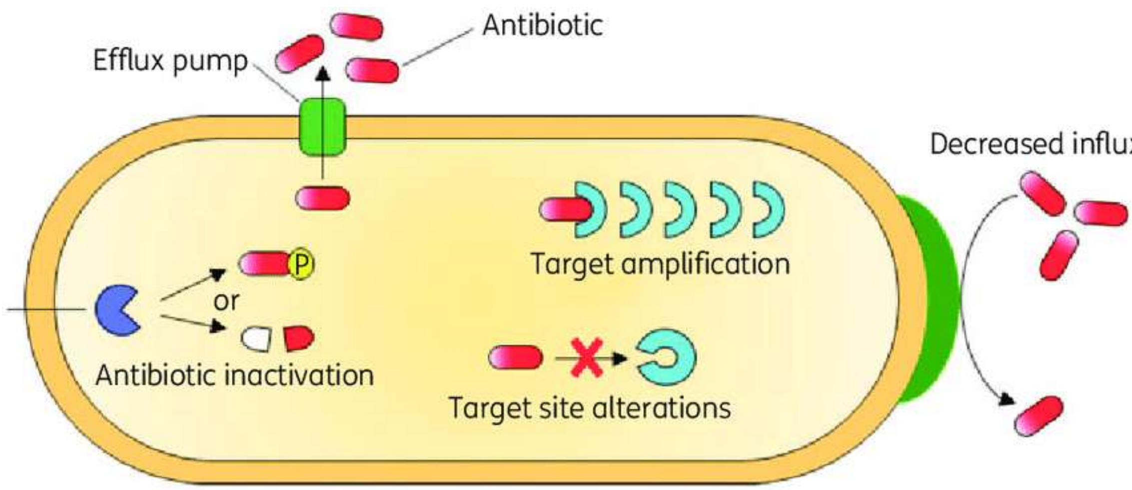


**Figure 1: Molecular Mechanisms of Antibiotic Resistance**

about antibiotic resistance is the misuse of antibiotics among the human population. The misuse of antibiotics includes taking antibiotics when one does not have a prescription, taking antibiotics when one is suffering from a virus

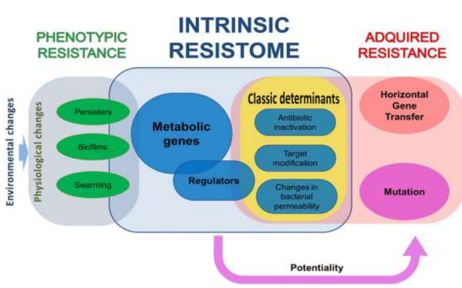


***Figure2: The Bacterial Resistome: Intrinsic, Phenotypic, and Acquired Resistance***

such as flu or common cold, and no one has been able to finish an antibiotic prescription. The bacteria that did not die will be able to develop resistance against antibiotics, and this allows resistant bacteria to flourish and multiply. Human beings, animals, and farming have all contributed to the consumption of a large

quantity of antibiotics. In farming, antibiotics are mixed with animal feed to encourage growth and prevent disease. Antibiotics are added to standard nutritional animal feeds. This is one of the major contributors to antibiotic-resistant bacteria, which will be passed on to human beings, and this bacteria will be spread to and through the land, soil, and water. The development of antibiotic resistance has been influenced by a considerable degree by the inherent capacity of the bacteria to be

adaptable and evolve. Bacteria have a reproductive rate where, on average, bacteria reproduce every 20 minutes. There will be a high turnover rate, even for the smallest genetic mutations. One genetic mutation, no matter how small, will allow a bacterium to be able to develop resistance against antibiotics.

Furthermore, Antibiotic Resistance in Bacteria is One of the most

**Types of Antibiotic Resistance**

Complex Phenomena Worldwide. Intrinsic, Acquired, Cross Resistance, Multidrug, Pan Drug Resistance, etc. are the Main Types of This Phenomenon, which Developed Naturally Through the Mechanisms Bacteria Use to Resist Antimicrobial Agents. Treatment Strategies and Infection Control Are Related Scientifically to These Mechanisms. Therefore Understanding the Biological Mechanism of Antibiotic Resistance Is Essentia l.

**Intrinsic Resistance**

Inherent resistance or intrinsic resistance is the innate, native ability of some bacterial species to be resistant to a given set of antibiotics. Inherently resistant bacteria have this characteristic as part of their nature; it is neither generated by a point mutation (in terms of genetics) nor gained from acquiring new genes. The inherent resistance is typically based on either structural properties of the bacteria or functional characteristics. The primary cause of intrinsic resistance is when the targeted receptor for the antibiotic does not exist on a particular bacteria. For instance, Gram negative bacteria are able to keep many antibiotics out with its outer membrane. Finally, there are bacteria that create enzymes that degrade a number of antibiotics. Antibiotic selection is significantly influenced by the fact that the level of resistance varies consistently across a single species of bacteria.[10-15]

**Acquired Resistance**

Bacteria have the capability to develop acquired resistance, which means they can begin to resist antibiotics which were once effective against them. This comes about as a result of changes in their genes, making them resistant to the drug. What makes this scary is that resistance can be transferred rapidly to other bacteria in the vicinity.

It looks like there are two main ways that bacteria get resistant. One is by mutations, which are basically random DNA changes. These changes can alter the way the antibiotic works with the bacteria, resulting in the drug becoming less effective. Another way is through gene transfer by which bacteria acquire resistance genes from bacteria around them, thereby enabling them to resist antibiotics.

From my side, I think gene transfer could be the more usual way through which bacteria become resistant and this might, to a great extent, contribute to the worsening of the situation. Bacteria have different ways of transferring genes. One of these ways is called conjugation, which is when bacteria physically connect with each other and exchange genetic material. This can happen between bacteria that are in close contact with each other, and it gives them the ability to share genes that can help them fight antibiotics. It is a bit of a scary thought that bacteria can so easily develop and spread resistance to antibiotics, and it is something that we presumably ought to be more vigilant about.

**Cross Resistance**

When you resist one type of antibiotic, you also become resistant to other antibiotics that are chemically similar or work in the same way. This is called cross-resistance. It happens because the resistance strategy targets a common feature of many drugs. If a bacterium can resist one antibiotic in a certain class, it might also be able to resist other antibiotics in that class. In this kind of situation, there are fewer drugs that can kill the bacteria, which makes treatment even harder. Cross resistance is a more complicated idea, especially when broad-spectrum antibiotics are used. This is because it can quickly make you resistant to other drugs.

**Multidrug Resistance (MDR)**

Multidrug resistance means that bacteria can resist the effects of more than one antibioticfrom different classes. This kind of resistance is very dangerous because it makes it much harder to find treatments and makes it morlikely that treatment will fail. Bacteria that are resistant to more than one drug often have more than one way to fight drugs at the same time. These are efflux pumps, enzymes that break down antibiotics, and changes to the target sites. You can often find these organisms in hospitals where antibiotics are used a lot and there is a lot of pressure to choose the right ones. Drug-resistant tuberculosis, methicillin-resistant Staphylococcus aureus, and resistant strains of Escherichia coli and Klebsiella pneumoniae are all examples of organisms that don't respond to more than one drug.[15-20]

**Extensive Drug Resistance (XDR) and Pan Drug Resistance (PDR)**

Extensive drug resistance refers to bacteria that are resistant to almost all available antibiotics except one or two classes. Pan drug resistance represents the most severe form, where bacteria are resistant to all known antibiotics. These

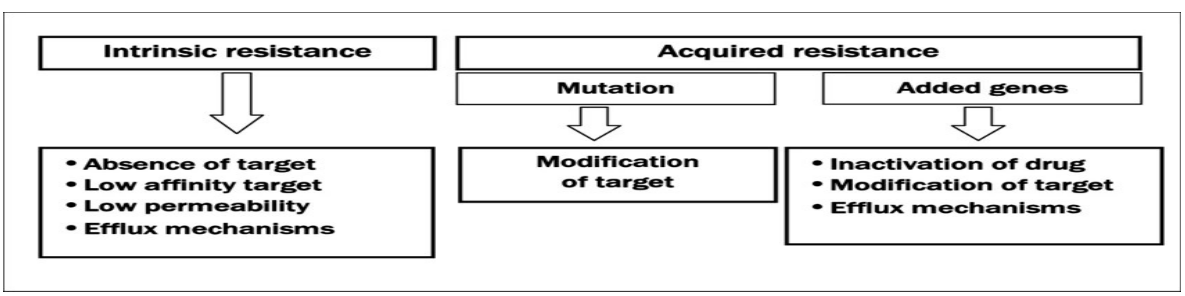


**Figure3: Overview of Intrinsic vs. Acquired Resistance Mechanisms**

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conditions make infections extremely difficult or even impossible to treat. Such advanced forms of resistance are increasingly reported and pose a serious threat to global health, emphasizing the urgent need for new treatment strategies and effective control measures.

**Causes of Antibiotic Resistance**

Antibiotic resistance is caused by a combination of natural processes and human actions that help bacteria survive and change when drugs are around. Microbes naturally become resistant to things over time, but this has been happening faster in recent years because of bad healthcare and the wrong use of antibiotics.

One of the main reasons is that people take too many antibiotics. People often take antibiotics when they don't need them, like when they have a cold or the flu. Antibiotics only kill bacteria, so if you take them when you don't need to, they can kill both good and bad bacteria. This allows resistant strains to survive and grow. Over time, these bacteria that are resistant become the most common. Another big reason is taking antibiotics the wrong way. Many people don't follow their doctor's instructions when they are on antibiotics. Some people stop taking their medicines before they finish the whole course, even though they feel better. Because this treatment isn't done yet, it doesn't kill all the bacteria. It doesn't kill the weaker ones; instead, it leaves behind the stronger ones that could become resistant. Taking leftover drugs without a prescription and treating yourself only makes things worse.

One big problem is that farmers and people who own pets give their animals antibiotics. Farmers give their animals antibiotics to help them grow and stay healthy, not just when they are sick. When animals are given these drugs all the time, the bacteria in their bodies can learn how to fight them off. People can get these bacteria that don't respond to antibiotics from dirty food, touching them directly, or from water and soil.

Infection control practices that aren't good make it easier for bacteria that don't respond to antibiotics to spread. Poor hygiene, dirty equipment, and too many people make it easy for infections to spread from one patient to another in hospitals. Bad sanitation, unsafe drinking water, and not enough places to throw away trash in the community make it easy for bacteria that don't respond to treatment to spread quickly.[20-25]

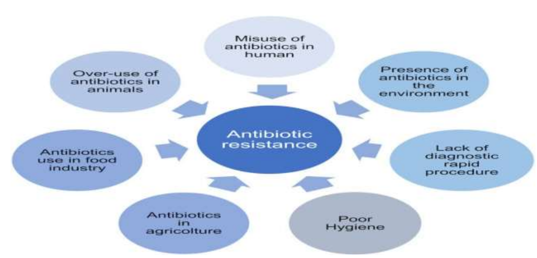


**Figure 4: Major Drivers and Causes of Antibiotic Resistance**

Another big reason is that people don't know enough about it. Many people believe that antibiotics can treat all infections, but this is incorrect. People take antibiotics when they don't need to because they don't know any better. If there aren't enough places to get tests done, doctors might give patients antibiotics without making a proper diagnosis. Things are getting worse because the rules aren't strict enough. A lot of places don't require a prescription to get antibiotics, which makes it easy for people to misuse them. Because there aren't strict rules about how drugs are sold, people can use them too much and become more resistant.

Resistance can also be caused by things in the environment. Waste from hospitals, drug companies, and farms may contain antibiotics and bacteria that are resistant to them. When this trash gets into the water and soil, it keeps bacteria exposed to low levels of antibiotics all the time, which makes them stronger.[25-30]

**Mechanism of Antibiotic Resistance**

The purpose of antibiotics is to kill bacteria or stop them from growing. But if bacteria learn how to live with them, they can become resistant to them. Bacteria can protect themselves in more than one way. These things happen when bacteria change their genes and adapt in ways that help them get rid of, avoid, or cancel out the effects of antibiotics. One of the most common ways that antibiotics break down is through enzymes. As part of this process, bacteria make enzymes that break down the antibiotic molecule so it can't do anything. Bacteria, for instance, make enzymes that break down beta-lactam antibiotics, which means they don't work. This means that the drug won't work and won't get to where it needs to go.

Changing the target site is also very important. Antibiotics work by attaching to certain parts of bacteria, like proteins or enzymes. Bacteria can

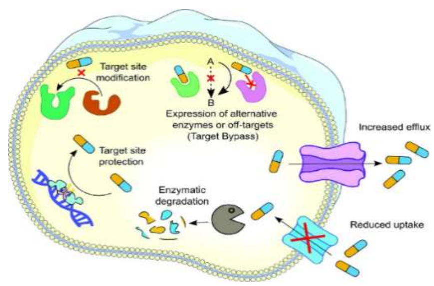


**Figure 5: Cellular Pathways of Bacterial Defense Against Antibiotics**

change these target sites by changing their DNA. This lets them antibiotic can no longer bind effectively. As a result, the drug loses its ability to interfere with bacterial functions, and the bacteria continue to survive and multiply.

Efflux pumps are also a significant mechanism of resistance. These are protein structures present in the bacterial cell membrane that actively pump antibiotics out of the cell. Even if the drug enters the bacterial cell, it is quickly removed before it can exert its effect. This reduces the concentration of the antibiotic inside the cell and allows the bacteria to survive.[30-35]

Reduced permeability is another way bacteria resist antibiotics. Some bacteria alter their cell wall or membrane structure to prevent antibiotics from entering the cell. This is especially common in certain types of bacteria that naturally have protective outer layers. By limiting drug entry, the bacteria avoid exposure to harmful concentrations of antibiotics.

Biofilm formation is a protective mechanism where bacteria form a thick, sticky layer on surfaces. This biofilm acts as a barrier that prevents antibiotics from penetrating and reaching the bacterial cells inside. Within a biofilm, bacteria can survive in a protected environment and become more resistant to treatment. Biofilms are commonly found on medical devices, tissues, and surfaces in hospital settings.

Genetic mutation plays a key role in the development of resistance. Random changes in bacterial DNA can result in new traits that help bacteria survive antibiotic exposure. These mutations can be passed on to future generations, making resistance a permanent feature of the bacterial population.

**Impact of Antibiotic Resistance**

Antibiotic resistance is an issue that transcends the realm of medicine. It has an effect on people, families, healthcare systems, and the economy of the whole world. As more bacteria become resistant to common drugs, its effects are spreading and getting worse. In the past, it was easy to get rid of, but now it's getting harder, more expensive, and sometimes even impossible.When people don't respond to antibiotics, they get sick for longer and with worse symptoms. When antibiotics don't work, infections stay in

*Figure 6 :Impact, Prevention, and Evolution of Antibiotic Resistance*

the body longer. This makes things worse, slows down healing, and makes problems more likely. There aren't many good ways to treat small infections, so they can sometimes kill you. Patients may need stronger drugs, which usually have more side effects and don't always work.

Things are even worse in hospitals. People who are having surgery, chemotherapy, or an organ transplant, for example, are very likely to get sick if their immune systems are weak. If these infections are caused by bacteria that can't be killed, it will be hard to treat them, and recovery is not guaranteed. This means that people have to stay in the hospital longer, get more intensive care, and have a better chance of dying. Infections that don't get better with treatment can also spread from one person to another, especially in places like hospitals where there are too many people or not enough staff.

The economy is greatly affected by antibiotic resistance. People who have infections that

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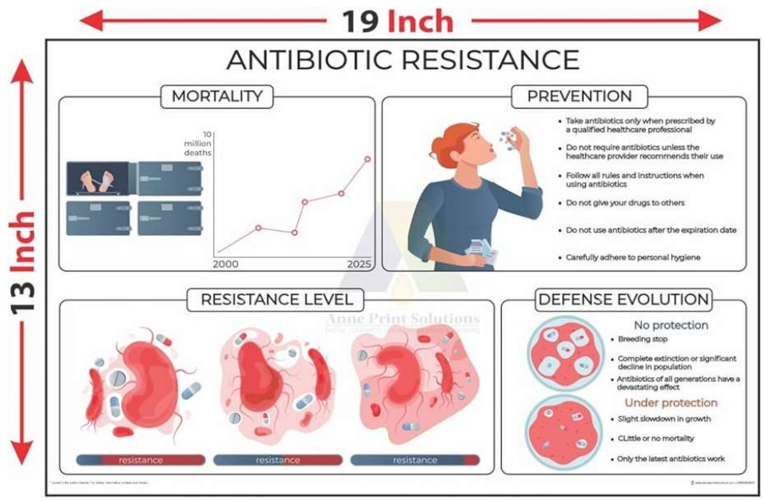


don't get better with treatment need more tests, more expensive drugs, and more time in the hospital. This makes it harder for patients and health care systems to pay for things. This can be very hard for people who live in countries with low or middle incomes because they don't have a lot of resources to begin with. Treatment may be too expensive for families, and hospitals may get too busy. Antibiotic resistance is bad for everyone, not just sick people. People who are sick for a long time can't go to school or work. This makes people less productive and slows down the growth of whole communities. When a lot of people don't want to get vaccinated, it can lead to outbreaks that are hard to stop. This raises the risk to public health. Another big worry is how it will change the way doctors do their jobs now. A lot of treatments use antibiotics that are very good at stopping or controlling infections. You need antibiotics that work for surgeries, childbirth, cancer treatment, and getting new organs. These procedures are much riskier if these drugs stop working, and in some cases, they might not even be able to be done. Bacteria that are resistant to drugs can travel from one country to another. People travel and trade more around the world, which makes it easier for infections that don't respond to treatment to spread quickly from one place to another. This means that antibiotic resistance is a problem that affects everyone in the world and needs everyone to work together to fix it. It's very hard to stop it from spreading if people don't work together. This problem is also bad for the environment. Waste from farms, factories, and hospitals can get into the ground and water and bring bacteria that antibiotics can't kill. This creates a cycle in which resistance keeps getting stronger and spreading in the environment, which eventually has an effect on human health again.[35-40]

**Diagnosis of Antibiotic Resistance**

It's important to find out if an infection is resistant to antibiotics so you can treat it correctly. If doctors don't get the diagnosis right, they might give antibiotics that don't work. This could make the condition worse and make it harder for the body to fight off infections. Finding the germ that caused the infection and figuring out which antibiotics will kill it is the goal of diagnosis. This method helps you pick the right medicine, cuts down on the need for antibiotics when they aren't needed, and makes patients feel better. The culture and sensitivity test is the most common and old-fashioned way to figure out what's wrong. This method takes a sample from the patient, such as blood, urine, sputum, or pus, depending on where the infection is. Then, the sample is put on a growth medium and kept warm so that bacteria can grow. When scientists find the bacteria, they put them in different antibiotics to see which ones can stop them from growing. Most of the time, the results show that there are clear areas around the antibiotic discs. This means that they can hurt the bacteria. This method is dependable and commonly employed, yet it may require 24 to 48 hours to yield results. Another important way to do this is through molecular diagnosis. The aim of this approach is to identify genes that confer antibiotic resistance in bacteria. PCR and other techniques are used to get resistance genes

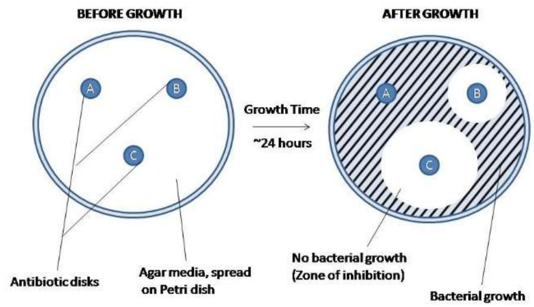


**Figure 7: Diagnostic Procedure: Culture and Sensitivity test**

straight from the sample. Molecular methods are faster than traditional culture methods and can give results in a few hours. They help you find strains that are hard to grow in a lab and that drugs can't kill. But not all health care facilities have the right tools and trained staff to use these methods.

More and more modern labs are also using computers to help them figure out what's wrong. At the same time, these systems can find bacteria and see if they are resistant to antibiotics. They give results faster and more reliably, which means people make fewer mistakes. Automated methods are very useful in hospitals where caring for patients means making quick decisions.

You need to do both clinical observation and lab tests to find out how resistant someone is. If a patient doesn't get better after taking antibiotics, it could mean that the bacteria they have are resistant to the drugs. After that, doctors may change the treatment based on what they know and what the tests show. It's not enough to just look at clinical signs; it's always better to have lab confirmation. People are working on quick tests that will help people find things faster and more accurately. The tests are meant to quickly find the microorganism and figure out how it fights treatment. A quicker diagnosis lets you start the right treatment sooner, which can stop problems and slow the spread of infections that don't respond to treatment.

There are still problems, even though there are a lot of ways to figure out what they are. In many places, especially in developing areas, it's hard to get to advanced lab facilities. If the diagnosis takes too long, doctors may give broad-spectrum antibiotics, which could make the problem worse. They are also used less often because they are expensive and people don't know how to use them correctly.[40-44]

## CONCLUSION

One of the biggest problems in healthcare right now is that antibiotics aren't working as well as they used to. The science behind this problem is scary, and so is how it affects our daily choices and actions. A big part of this problem is how people act, like how doctors give out drugs and how people use them. Taking too many antibiotics or taking them the wrong way has made bacteria stronger and better able to live. That's why a lot of treatments don't work as well as they used to. It's important to know that antibiotic resistance is already a problem and not something that will happen in the future. Some infections that used to be easy to treat now take longer to get better, and sometimes medicines that are common don't work at all. This hurts people's health and puts a lot of stress on families and the healthcare system. People and their families have to go to the hospital more often, which costs more money and makes them feel worse. You should also think about how it will slow down medical progress. Many surgeries, cancer treatments, and organ transplants that save lives need antibiotics to keep infections from happening. If antibiotics stop working, these procedures could be even more dangerous. This shows that antibiotic resistance affects more than just how infections are treated in the medical field. It's also good to know that this can be fixed. Doing little things well can make a big difference. You should only take antibiotics when your doctor tells you to, and you should always finish the whole course of treatment. Never take medicine on your own. It's very important to be aware. People are more likely to take antibiotics correctly if they know that they don't work against viruses and that taking them wrong can hurt everyone in the community.

Healthcare workers have a lot of work to do too. When doctors write prescriptions, they need to be very careful. They also need to tell

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their patients about antibiotics so that people don't take them when they don't need to. To keep bacteria that don't respond to antibiotics from spreading, hospitals have to follow strict rules about cleanliness and infection control. Health organizations and governments need to make sure that people follow the rules, make it easier for people to get tested, and give more money to find new treatments. Another important thing to think about is how people use antibiotics for things that aren't health-related. Limiting their use in farming and raising animals can help stop resistance from spreading through the environment and the food chain. We also need clean water, good sanitation, and good waste management to stop the cycle of resistance. Antibiotic resistance is a problem that affects everyone, and we all need to work together to fix it. People ought to assist scientists and physicians. Each person has a job to do. We can slow down the spread of resistance by making smart choices and taking antibiotics the right way. Antibiotics will still work in the future if we do the right things today. If we don't do something about this problem, we might not be able to treat even minor infections again. We can choose.

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**Conflict of Interest**

The authors declare that they have no conflict of interest