



# JOURNEY of an ANTIBIOTIC



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ReAct - Action on Antibiotic Resistance

**TOOLBOX**

*The ReAct Toolbox is a  
web-based knowledge repository  
for antibiotic resistance that collects:*

- Scientifically accurate information
- Practical advice
- Links to useful resources
- Examples from the field

Access  
the Toolbox:



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# **CHAPTER ONE**

**OF  
MAGIC BULLETS  
AND  
RESISTANCE**

Since the beginning of 2020, the COVID-19 pandemic has traumatised the entire planet.



Around the world scientists and doctors have taken time to understand the exact course of the disease caused by the SARS-CoV-2 virus and struggled to find suitable treatments.



SARS-CoV-2  
RT-qPCR KIT



COVID-19 is a grim reminder of the terrible toll taken by infectious diseases throughout human history.



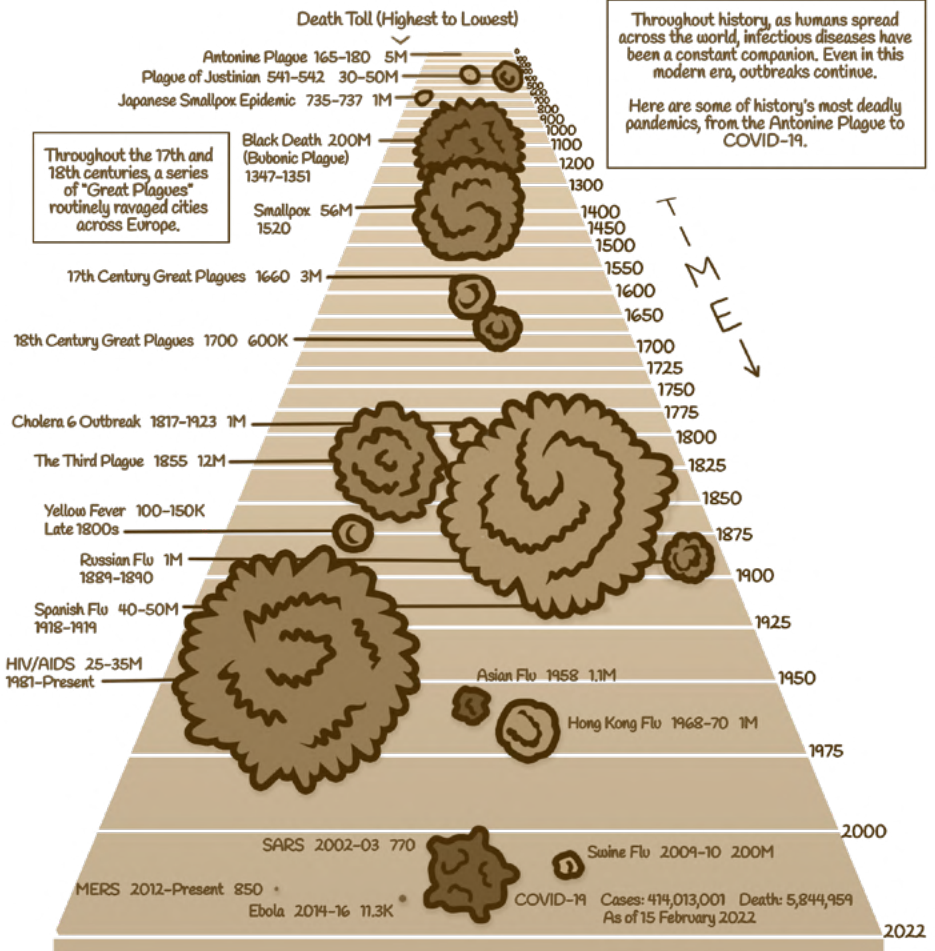
From smallpox and tuberculosis, to the plague and measles, a variety of diseases that are easily transmitted from person to person have killed innumerable people over the centuries.



In the past, there was no effective treatment at all for all these diseases **nor even an understanding** of their cause and how to prevent them.

# HISTORY OF PANDEMICS

Pan-dem-ic (of a disease) prevalent over a whole country or the world



Source: [www.worldometers.info/coronavirus/](http://www.worldometers.info/coronavirus/)

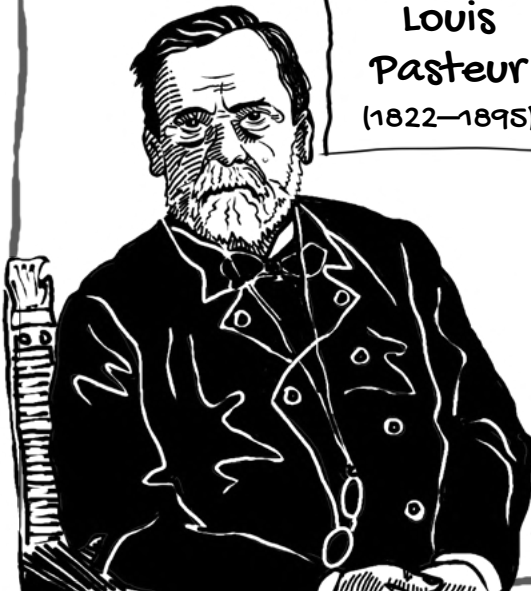
It was only in the late seventeenth century that bacteria and other very tiny living organisms were discovered by Antonie van Leeuwenhoek, a Dutch scientist and businessman using a **single-lensed microscope** of his own design.

Antonie van  
Leeuwenhoek  
(1632–1723)



Louis  
Pasteur  
(1822–1895)

It took another century though for the French scientist Louis Pasteur to confirm the link between bacteria and infectious diseases with his **'germ theory of disease'**.

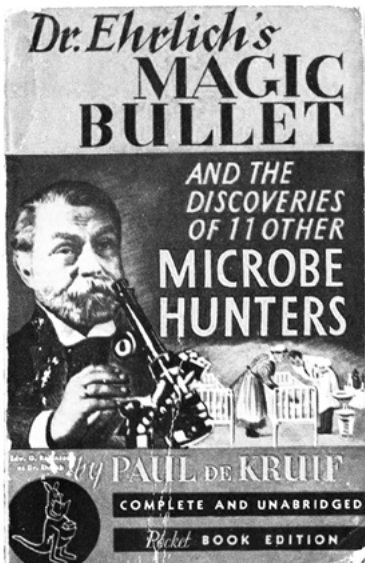




## Paul Ehrlich (1854–1915)

Once Pasteur's theory became established the search also began for a way to disable or kill all disease causing bacteria. Paul Ehrlich, the German chemist envisioned that

just like a bullet fired from a gun to hit a specific target, there could be a way to specifically target invading microbes, using special chemical compounds, which he called 'magic bullets'.



Salvarsan, an arsenic-based chemical discovered by Ehrlich and his team in 1909, proved an effective treatment for syphilis and was probably the first truly modern antimicrobial agent.





**Alexander Fleming**  
(1881–1955)

In 1928 Alexander Fleming discovered that certain fungi naturally produce an antibiotic to ward off bacteria.

The actual production of the antibiotic, called **Penicillin**, in a manner and scale suitable for wider use, was worked out by Howard Florey and Ernst Chain in 1942. Both of them shared the Nobel Prize in Physiology or Medicine with Fleming in 1945.

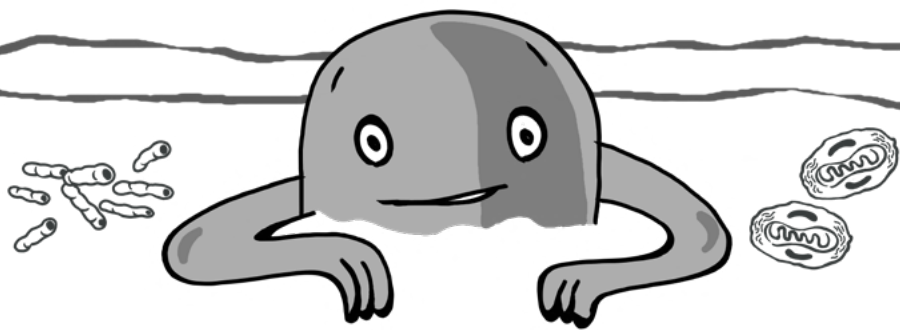
The discovery of Penicillin and many other antibiotics have saved millions of lives and for several decades it was believed by many health officials that infectious diseases had been conquered once and for all.



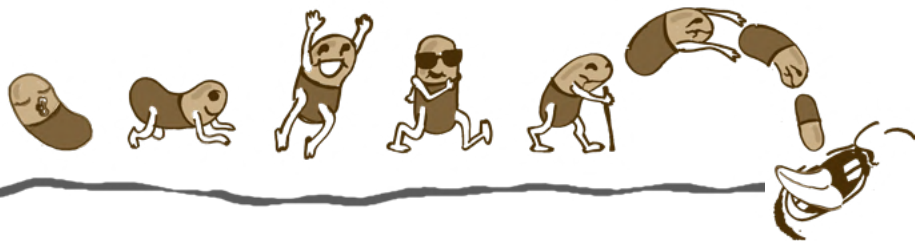
They had all spoken too soon and not accounted for the phenomenon of antibiotic resistance, which is when bacteria manage to escape the effect of antibiotics and continue to thrive, resulting in failure of treatment.



There are many complex factors that drive antibiotic resistance, ranging from industry incentives and competition, to lack of public awareness and inappropriate prescriptions.



In this illustrated book we follow the antibiotic on its long and adventurous journey, from the cradle of a research lab to its ultimate abode in the guts of a two or four legged animal, that includes us human beings.



It is only by understanding antibiotics in all their multiple dimensions that we can begin to start using them correctly and find solutions to the growing threat of antibiotic resistance.



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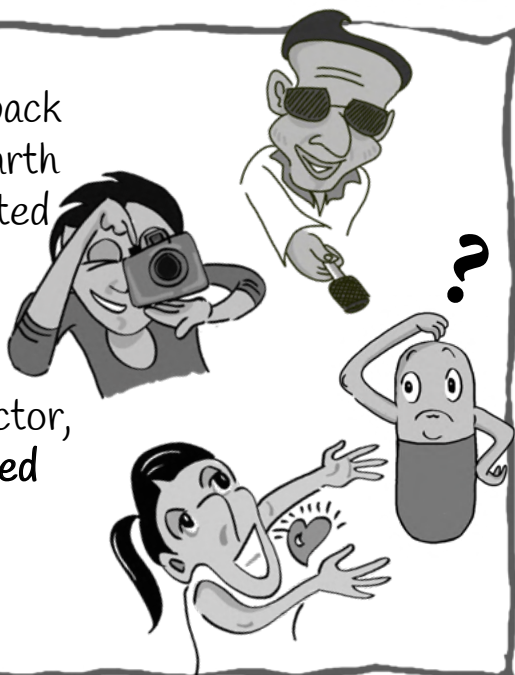
# CHAPTER TWO

ALL ABOUT  
ANTIBIOTICS



Let us take a few steps back now and ask – why on Earth should anyone be interested in antibiotics at all?

Especially if one is not a student of medicine, a doctor, or at least a patient in need of a cure for their bacterial disease?



Well the last bit in the above sentence gives  
**a big hint**

– like it or not, you or someone close to you is going to need an antibiotic desperately at one point in time.

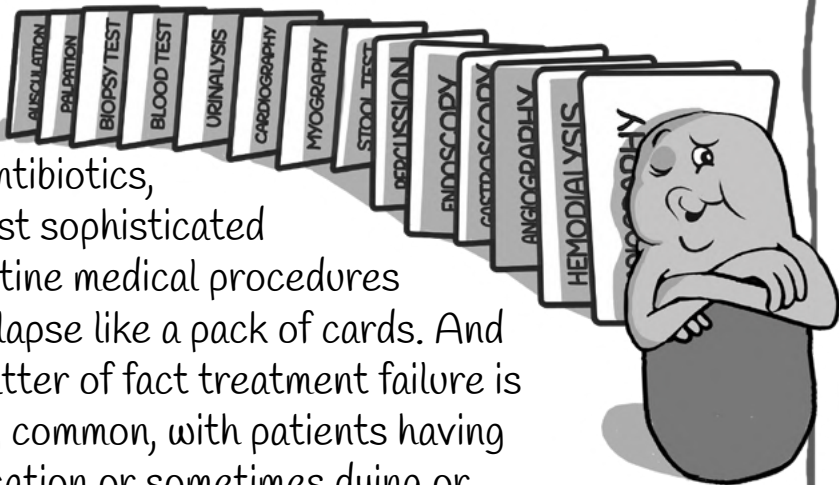


Besides...

...whether you need it or not,  
these drugs are used so widely, from human to  
animal health, that they have become the very  
foundation of all modern medicine.



Take away antibiotics, and most sophisticated but routine medical procedures will collapse like a pack of cards. And as a matter of fact treatment failure is already common, with patients having complication or sometimes dying or spending many extra days in hospitals due to lack of effective antibiotics.



All that is truly terrifying. However, the purpose of what we are trying to do in this book is not to try and scare you at all!

Fear and anxiety are not the best way forward while trying to find solutions – especially something as complex as

## Antibiotic Resistance.



A better way is to try and understand the world of antibiotics, as well as that of bacteria, is to get a good picture of how exactly the dynamic between the medicine and microbe works.



With some rich insights we may finally begin to figure out what is the best way to slow down antibiotic resistance and keep antibiotics working.

## What are antibiotics?

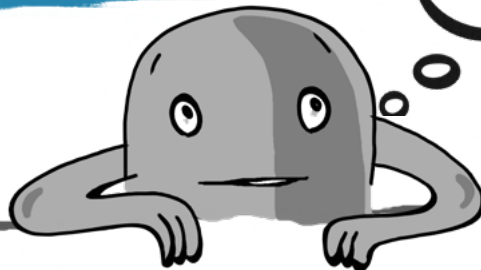
- Where do antibiotics come from?
- How do they work?
- Why are they important?
- How many kinds of antibiotics are there?
- How does antibiotic resistance lower their effectiveness?

And... if you are not already exhausted by that long list of questions – let us also ask how are they produced, distributed and consumed?

Ok. We will do this one at a time – step by step.

First, we will start with  
the meaning of the term :

# Antibiotics





What's in a name...

Antibiotics is a somewhat unfortunate label for a drug that has saved millions of human lives over the decades. The word comes from the Greek words '**anti**', meaning 'against', and '**biotikos**', meaning 'concerning life'.



Of course in this case, the reference is to



*The Merry Lives of Microbes*

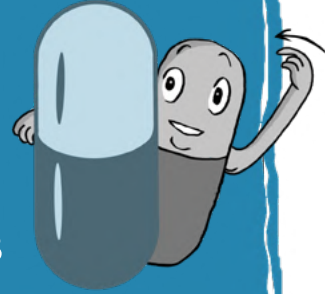
But taking the lives of even mere bacteria comes with a big  tag.



Bacteria are essential for the sustenance of many forms of life on Earth, including us human beings. Killing them without thought is bound to hurt all of us.

More on all this later though. For now let us clear up some confusion around terms such as:

Anti'iotics  
microbials  
bacterials  
virals  
fungals  
protozoals



While 'Antimicrobials', 'antibacterials' and 'antibiotics' are commonly used terms that can sometimes be used interchangeably, there are important differences between these words:

### Antimicrobials

#### Antibacterials

Against bacteria,  
e.g. drugs for  
bacterial  
pneumonia

#### Antivirals

Against viruses,  
e.g. drugs for  
herpes and  
HIV

#### Antiprotozoal Agents

Against parasites,  
e.g. drugs for  
malaria

#### Antifungals

Against fungi,  
e.g. drugs for  
tinea

## Antimicrobials

Antimicrobials is a wider term that includes all agents that act against microorganisms, namely bacteria, fungi, virus, and protozoa.

## Antibacterials

Antibacterials act only on bacteria. This term encompasses all compounds that act against bacteria, including antibiotics.

## Antibiotics

Antibiotics are produced naturally by microorganisms and kill or inhibit the growth of other microorganisms, mainly bacteria.

Strictly speaking, antibiotics do not include agents that are produced by chemical or biochemical synthesis. However for simplicity, synthetic or semi-synthetic variants (such as quinolones) are usually included under the term antibiotics.

## Antibiotics act on bacteria, not viruses

The key thing to remember is that antibiotics are mainly active against bacteria, but can also have activity against, for example, some protozoa.

**They do not cure infections caused by viruses.** Below are some examples of bacterial and viral infections:

BOX 1

Bacterial infection (Antibiotics work)	Viral infection (Antibiotics do not work)
Bacterial pneumonia	Colds
Sepsis (blood stream infections)	Most respiratory tract infections
Tuberculosis	Influenza (the flu)
Urinary tract infections	Viral gastroenteritis
Bacterial pneumonia	Measles

## Why are antibiotics important?

The discovery of antibiotics was one of the most significant medical achievements of the 20th century.

In the pre-antibiotic era of the early 1900s, people had no medicines against bacteria and as a result, human suffering was enormous. Even though the body's disease-fighting immune system can often successfully fight off bacterial infections, sometimes the microbes are too strong. For example,

- Before the advent of antibiotics, 90% of children with bacterial meningitis died. Among those children who lived, most had severe and lasting disabilities, from deafness to mental retardation.
- Throat infections due to a bacteria called streptococci was at times a fatal disease, and ear infections sometimes spread from the ear to the brain, causing severe problems.
- Tuberculosis, Typhoid fever, Gonorrhea are treated with antibiotics today. Imagine what would happen if they become untreatable.



## How do antibiotics really work?

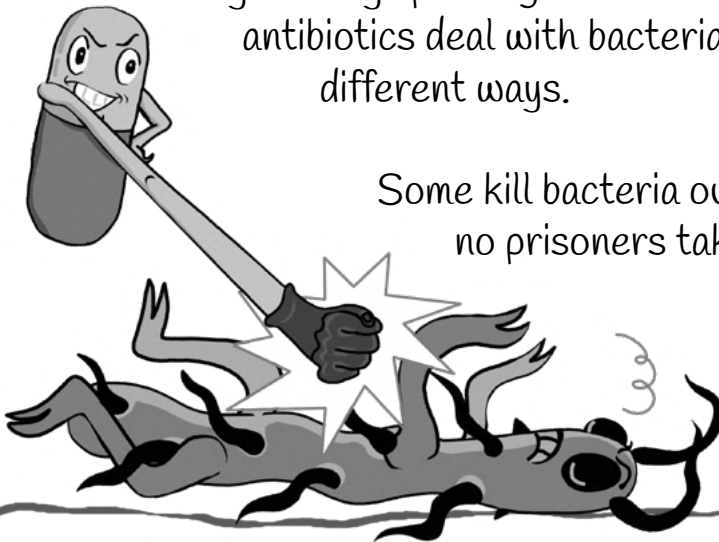
For most people, taking an antibiotic means popping a pill in the mouth and then completely forgetting about it once it is washed down the throat with a glass of water.



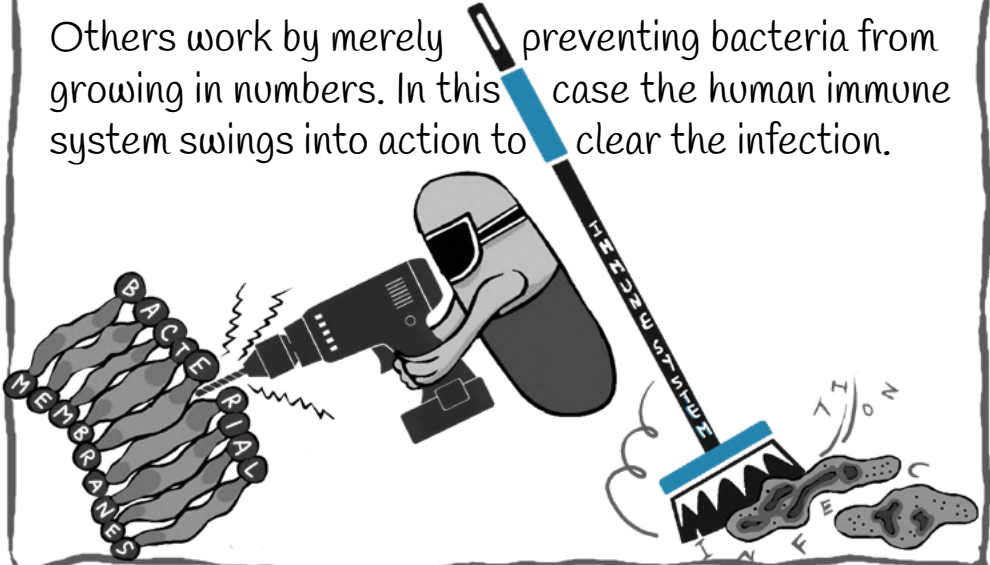
But what does an antibiotic really do inside the human body?

Very broadly speaking different classes of antibiotics deal with bacteria in different ways.

Some kill bacteria outright – no prisoners taken!



Others work by merely preventing bacteria from growing in numbers. In this case the human immune system swings into action to clear the infection.



While antibiotics usually do not harm human cells and target only bacteria, in some cases they can have unpleasant side effects for humans too.



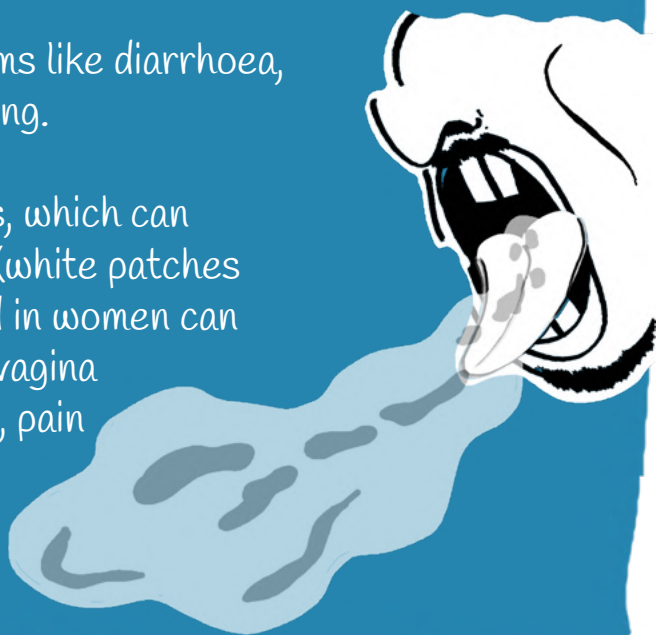
## Side-effects of antibiotics<sup>1</sup>

Like all medicines, antibiotics have the potential to cause side effects. When antibiotics are necessary, the benefits far outweigh the risks, but when they are not needed, you are taking an unnecessary risk.

Up to 10% of people taking an antibiotic may experience these common side effects:

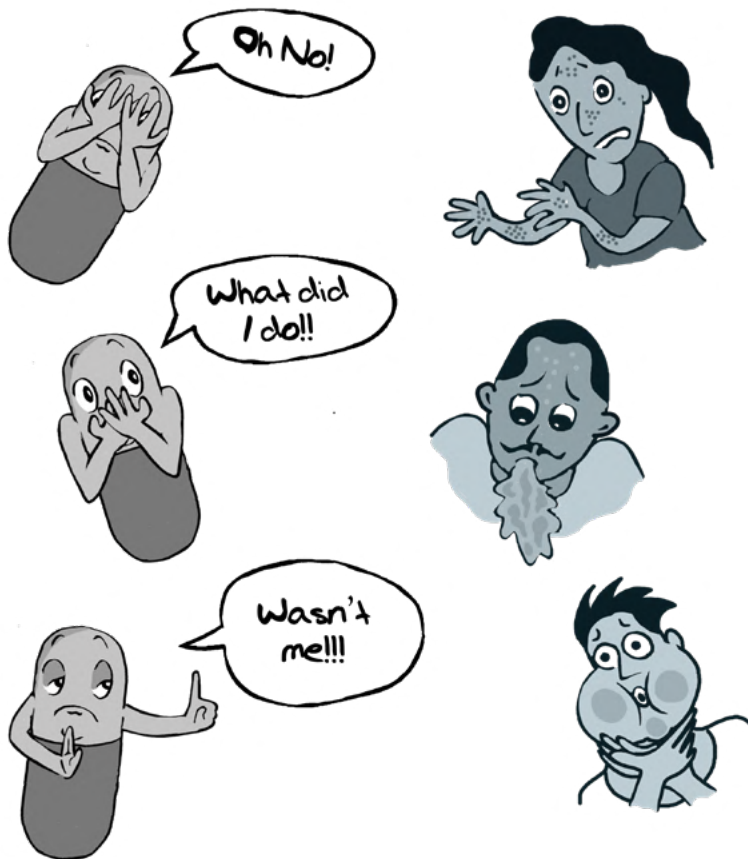
- stomach problems like diarrhoea, nausea and vomiting.
- fungal infections, which can affect the mouth (white patches will be visible) and in women can also occur in the vagina (causing itchiness, pain and discharge).

BOX 2



## Other less common side effects include:

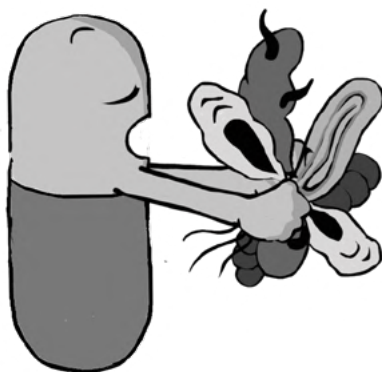
- diarrhoea caused by an intestinal infection, which may be serious and require further investigation and treatment
- allergic reactions, such as hives (large, red, raised areas on the skin), fever and breathing problems.



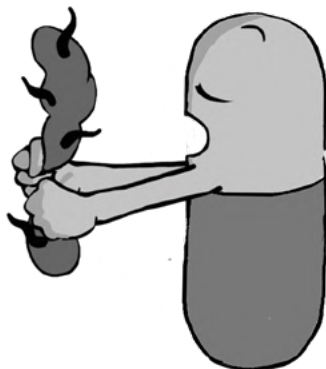
## Narrow-spectrum and broad-spectrum antibiotics

Antibiotics can either have a narrow or broad spectrum of action.

- Antibiotics that affect a wide range of bacteria are called **broad spectrum antibiotics** (e.g., tetracycline).



- Antibiotics that affect only a few types of bacteria are called **narrow spectrum antibiotics** (e.g., benzyl penicillin).



Narrow spectrum antibiotics are more specific and only active against certain groups or strains of bacteria. Broad spectrum antibiotics instead inhibit a wider range of bacteria. Narrow spectrum antibiotics are preferred since their impact on other, non-disease causing bacteria are more limited.

Unfortunately broad spectrum antibiotics are used more often as it can be difficult for doctors to diagnose the correct bacteria in time or the knowledge about how to correctly treat an infection may be lacking. This is one of the reasons for the emergence of antibiotic resistance. We will find out exactly why soon.





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# CHAPTER THREE

## THE BACTERIA-HUMAN EQUATION

Before we go any further to learn more about antibiotics, it is time to take a pause and ask some questions about their prime target – the bacteria.

Instead of assuming we know everything about them ('evil, disease-causing microbes') what if we started with a completely open mind and asked – **so what exactly are bacteria supposed to be?**



When they were discovered by Antonie van Leeuwenhoek in 1676, he thought of them as **animalcules**, meaning tiny animal in Latin.

For a long time bacteria were classified according to their basic shapes into five groups: spherical (cocci), rod (bacilli), corkscrew (spirochaetes), comma (vibrios) and spiral (spirilla).<sup>1</sup>

**Cocci****Bacilli****Spirochaetes****Vibrios****Spirilla**

## Gram-positive and Gram-negative bacteria

Bacteria are generally classified into two broad categories:  
Gram-positive and Gram-negative.

The term "Gram" here comes from Hans Christian Gram – the name of the person who developed the method for distinguishing between these two types of bacteria.

The differences between Gram positive and Gram negative bacteria are primarily related to their cell wall composition.

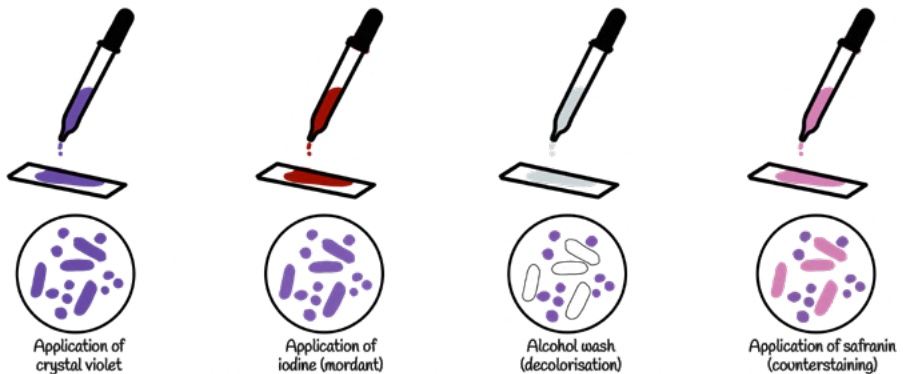
And none of it's got anything to do with Kilogram or Telegram, in case you're wondering!

BOX 3

Hans Christian  
Gram  
(1853–1938)



The staining method that Dr Gram introduced identifies bacteria based upon the reaction of their cell walls to certain dyes and chemicals. Gram-positive bacteria stain purple after Gram staining. Gram-negative bacteria stain red or pink.



Source: <https://ib.bioninja.com.au/options/untilted/b1-microbiology-organisms/gram-staining.html>

Some common  
**Gram-negative**  
bacteria that cause  
infections are:

- Klebsiella
- Acinetobacter
- Pseudomonas aeruginosa
- E. coli.

Some common  
**Gram-positive**  
bacteria that cause  
infections are:

- Staphylococcus aureus
- Streptococcus pyogenes
- Streptococcus pneumoniae

In the last couple of decades new methods of studying bacteria have emerged, such as polymerase chain reaction or PCR, also sometimes called **molecular photocopying**.



The process involves rapidly making billions of copies of a specific DNA sample and amplifying them to allow scientists to and study them in detail and understand their origins and characteristics. This has completely revolutionized our understanding of these invisible organisms.

First of all it turns out there are a vastly greater number of species of these invisible organisms than anyone imagined even a couple of decades ago.<sup>2</sup>



what's the big deal!  
we're invisible, right?

Secondly, they are found everywhere on the planet – from flaming hot volcanoes to the permafrost in Siberia.<sup>3,4</sup> They also exist in a very large number inside the human body and are critical to not just our survival but that of all life forms on earth.





Till not too long ago scientists believed there were about 30,000 formally named species that could be cultured in the laboratory and for which the physiology had been investigated.<sup>5</sup> Now they are not sure any more and thanks to newer diagnostic techniques, estimates for the number of bacterial species run from around half a million to a billion plus.<sup>6</sup>

There is also a continuous debate on whether bacteria, many of which constantly exchange genetic material between themselves, can even be classified in terms of many distinct species. Some have suggested bacterial cells are simply holding vessels for the genetic variation available in the bacterial gene pool, which change according to different environments.<sup>7</sup>



The point here is that the world of bacteria is quite complex, diverse and not reducible to simple black and white type of characterisation.



In the context of human or animal health too, scientists are finding that it is difficult to brand bacteria as permanently 'bad' or 'good'.



Yes, a small number of them do cause deadly diseases, under specific circumstances, but the vast majority form the very basis of all life and living processes on Planet Earth. The insight being expressed by a range of researchers – from microbiologists and chemists to ecologists and origin of life specialists – is very clear, that we live on a planet that is run by millions of bacterial species.

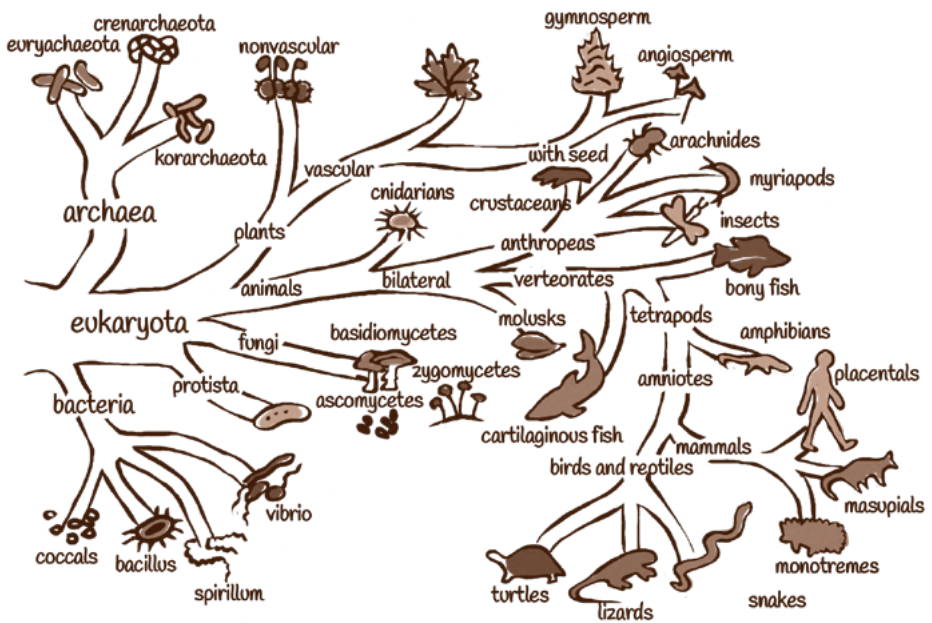


They were among the first forms of life on Earth, and are its most numerous living organisms.

## The facts and figures involved are stark!

a) Bacteria have been around for roughly 4 billion years on a planet that is 4.5 billion years old. They have not only survived the harshest weather, toxicity and abrupt shifts in environment, but have time and again contributed to mitigating these factors and making them conducive to the flourishing of life.

It is time we paid some respect to bacteria and stopped demonizing them!



b) Collectively bacteria account for around 70 gigatons of carbon in biomass distributed among all of the kingdoms of life. This is much greater the carbon in biomass of all the animals on the planet (including humans) put together, which constitute only 2 gigatons. (Plants still dominate the planet with 450 gigatons of carbon.<sup>8</sup>)

In other words, humans and other animals are essentially swimming in an ocean of bacteria – we have to learn to live with that reality.



c) The amount of microbes in the human microbiome is higher than the number of cells in the human body. The total microbial biomass in an average adult is approximately 0.2 kg.<sup>9</sup> The microbiome today is considered another organ of our bodies.

**So trying to destroy all the bacteria in your body is nothing less than trying to willingly injure yourself!**

d) More importantly, bacteria in the human microbiome contribute around 600,000 genes, way more than the human genome's 23,000.<sup>10</sup> We are yet to figure out how all this bacterial genetic material affects our health and lives. And while scientists are still trying to figure out this mystery it is best that the rest of us go a bit slow on popping those coloured pills whenever we feel like!

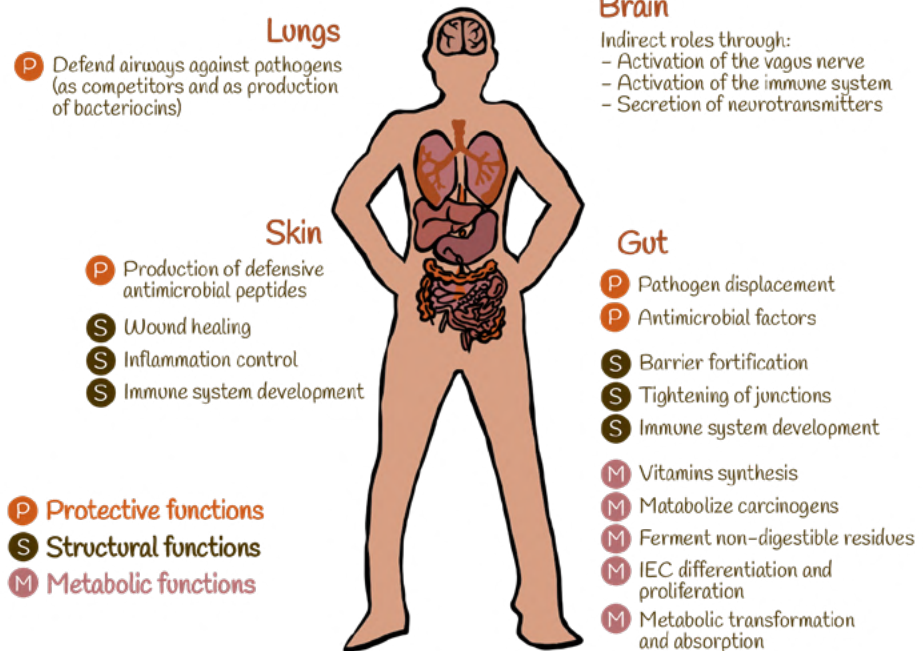


Human genome  
22,000 genes

Bacteria in  
human microbiome  
600,000 genes



To summarize, bacteria are phenomenally diverse, essential for survival of all life forms, and highly flexible and adaptable in the face of all challenges. These are all remarkable traits that we humans would do well to emulate.



Main functions of bacteria in the human body<sup>11</sup>

Our very survival may depend on it!







# CHAPTER FOUR

WHERE DO  
ANTIBIOTICS  
COME FROM?

We live in an age where products of modern medicine are all around us, in the form of pills, capsules, vials of injectable liquid and ointments. In fact,

given the way  
these products

are marketed  
it is raining  
medicines on us  
all the time.



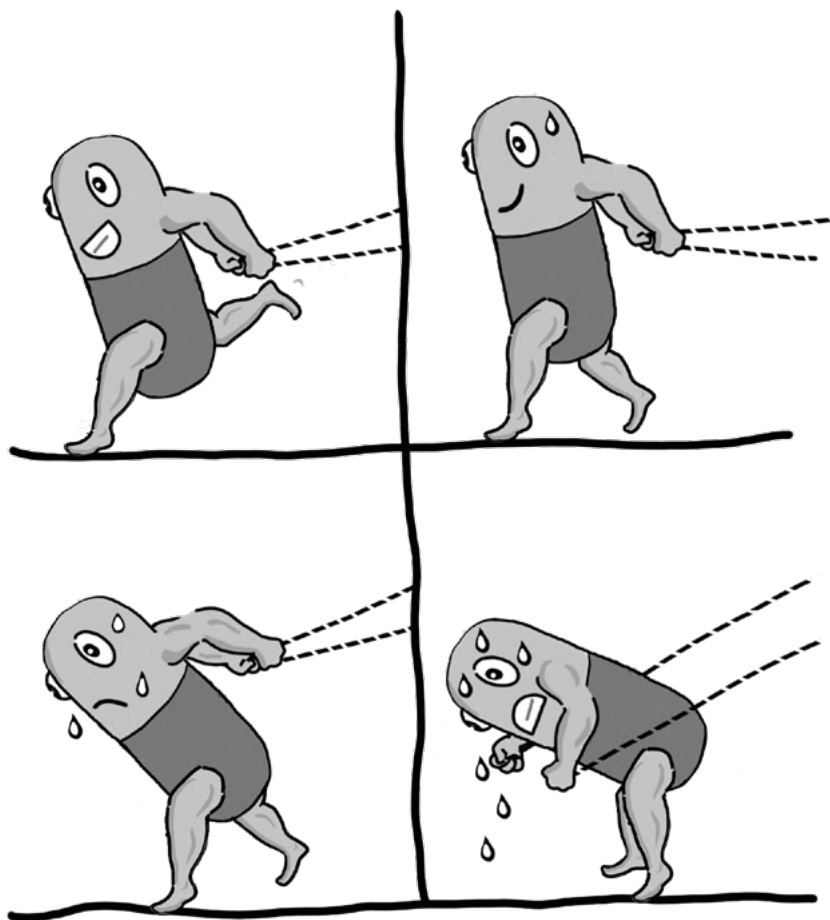
However, not many people are aware how these drugs are produced, distributed, prescribed or even how they actually work.

Most folks who are not trained as pharmacists or doctors (i.e. the majority of humans) just use these precious products without thinking twice about their origins . As long as these colourful pills work they are happy to keep using them.

What, Me Worry?



As we see in the case of antibiotics, this casual and almost blind faith in popping pills has resulted in the slow erosion of the very effectiveness of these medicines .



So, at least now, let us figure out the answer to the question – how exactly are antibiotics produced?

## Using microbes to fight microbes...

Surprising as it may sound, antibiotics have been produced in nature for millennia by microbes themselves, mostly for use against their fellow microbes!



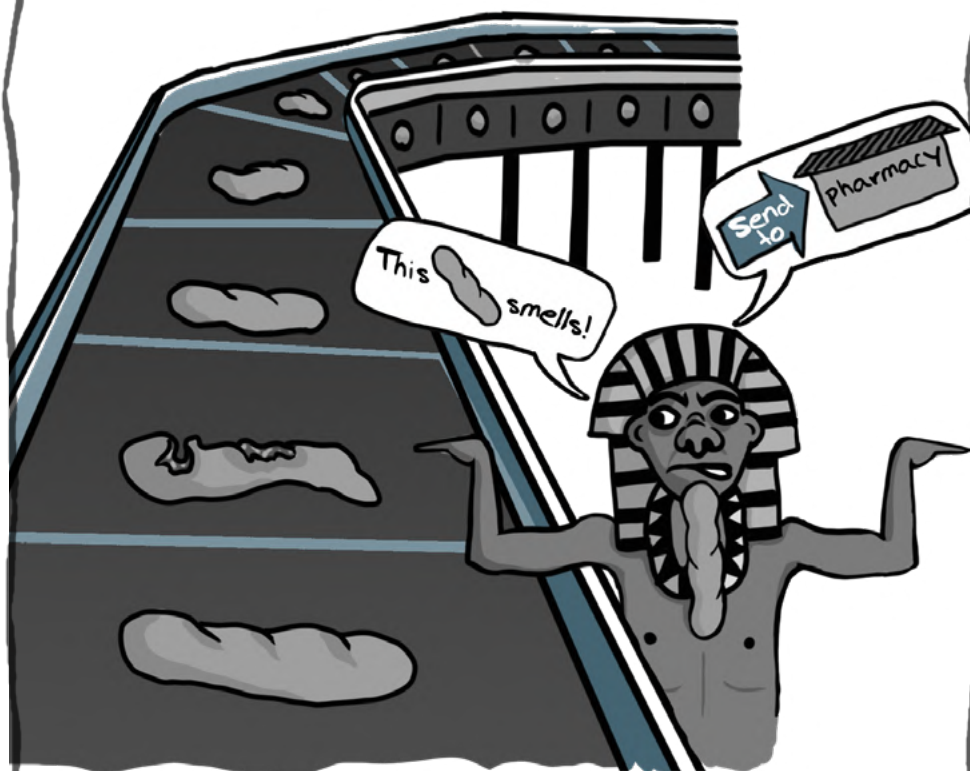
Analysis of the lineage of several antibiotic resistance genes in bacteria has revealed that some of them have been around for nearly two billion years!<sup>1</sup>

So show us some respect, will ya'?



And much before the modern era of antibiotics, there is evidence that ancient civilizations too had discovered a variety of such naturally available antibiotics for treating various infections.<sup>2</sup>

One such successful treatment was the topical application of mouldy bread, with many references to its beneficial effects from ancient Egypt, China, Serbia, Greece and Rome.





Much later, in 1928, this is exactly the phenomenon that Dr Alexander Fleming stumbled upon in his lab when he discovered that colonies of the common staphylococcus aureus bacteria were worn down or killed by the **mold (fungus)** growing on the same plate or petri dish. Fleming experimented further and determined that the mold made a substance that could dissolve the bacteria. He called this substance penicillin, named after the *Penicillium notatum* mold that made it.



The discovery of penicillin marked the beginning of the so-called **golden era of antibiotics**, which lasted till the early sixties, when many microorganisms were collected and studied for their potential antibiotic properties. Most of the antibiotic classes we use as

## PENICILLIN, New Wonder Drug from Mold

By JAMES JOHNSON

**A** FANTASTICALLY NEW drug that can cure the most common bacterial infections, penicillin, was discovered by Dr. Alexander Fleming in 1928. It is now being produced in large quantities and is being used to treat many types of infections.



medicines today were discovered and introduced to the market in this period.

**René Dubos**  
(1901–1982)



In 1939 for example the French microbiologist René Dubos isolated the substance **tyrothricin** from the microbe *Bacillus Brevis* and later showed that it was composed of two substances, gramicidin and tyrocidine.<sup>3</sup>

These were the first antibiotics from soil bacilli to be produced commercially<sup>4</sup>

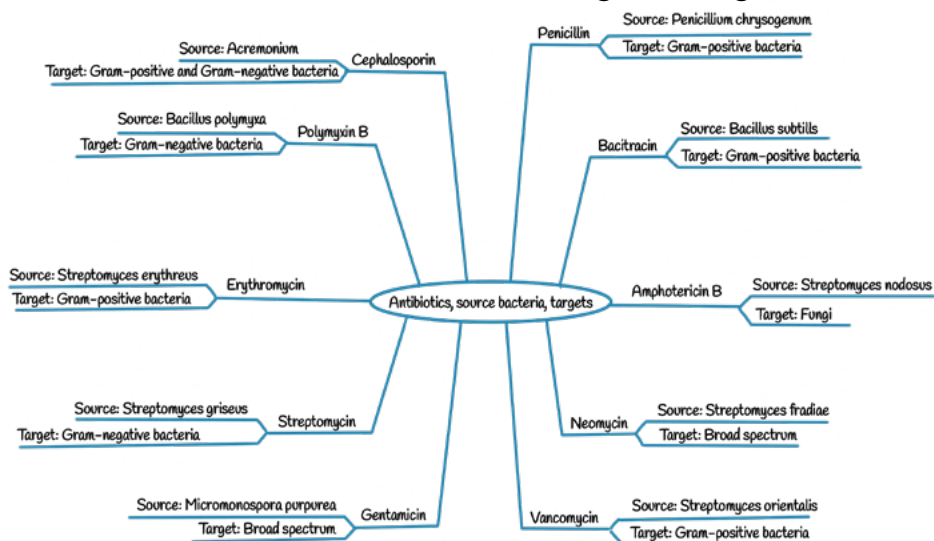
In 1944 Selman Waksman isolated the antibiotic **streptomycin** from *Streptomyces griseus*, an organism found in soil.<sup>5</sup> He received the Nobel prize in 1952 for discovery of the first antibiotic effective against tuberculosis. Similarly, in 1948 **cephalosporins**, one of the most important drugs for treatment of bacterial infectious diseases, were produced from *Acremonium chrysogenum*, a slow growing fungus.<sup>6</sup>

**Selman Waksman**  
(1888–1973)



A soil sample from Borneo in 1952 had the bacteria *Streptomyces orientalis*, from which vancomycin, another very important antibiotic, was eventually extracted and became available for patient use in 1958.<sup>7</sup> Streptomyces are the **largest antibiotic-producing family of bacteria**, producing over two-thirds of the clinically useful antibiotics of natural origin.<sup>8</sup>

The remarkable richness of microbial natural products as sources of antibiotics reflects the fact that they are products of evolution, selected over millennia for interaction with biological targets.

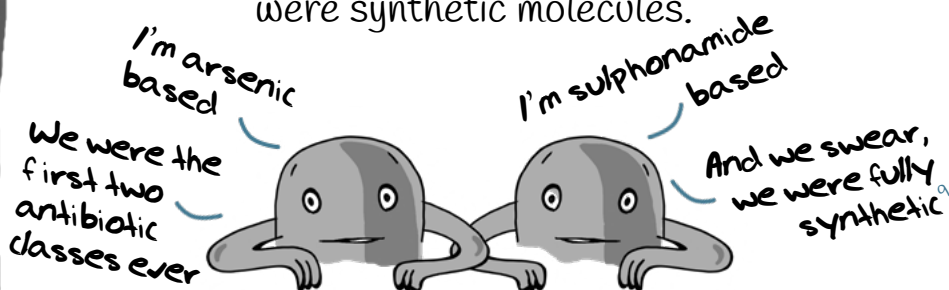


## Antibiotics from artificial sources

Strictly speaking:  
antibiotics are organic anti-infective agents  
that are derived from bacteria or molds  
that decrease multiplication  
or kill other bacteria.

However, the term antibiotic is now used loosely to  
include anti-infectives produced from manmade  
synthetic and semi-synthetic compounds.

In fact, the earliest two antimicrobials of clinical utility  
were synthetic molecules.

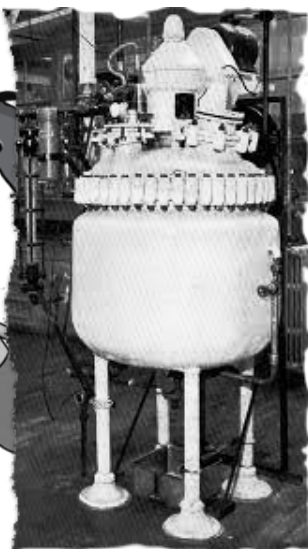


In synthetic or semi-synthetic antibacterials usually  
chemicals related to natural antibiotics are used to  
accomplish comparable tasks. Apart from sulphonamides  
other synthetic antibacterials include quinolones.

## Production of antibiotics

Typically, the production of antibiotics from natural sources is done through a fermentation process. The source microorganism is grown in large containers – with capacities of 100,000 to 150,000 litres – containing a liquid that facilitates their rapid growth.

The size of the bacterial population is controlled very carefully to ensure that maximum yield is obtained before the cells die. Then the antibiotic is extracted and purified into a crystalline product, for further processing before packaging into pills, capsules or vials for medical use.<sup>10</sup>



Container for growing the microorganism

Microorganisms used in fermentation are often not the same as their counterparts in the wild. They are genetically modified to yield the maximum amounts of antibiotics. The development of higher yielding strains over many generations can raise antibiotic yields by 20-fold or more.



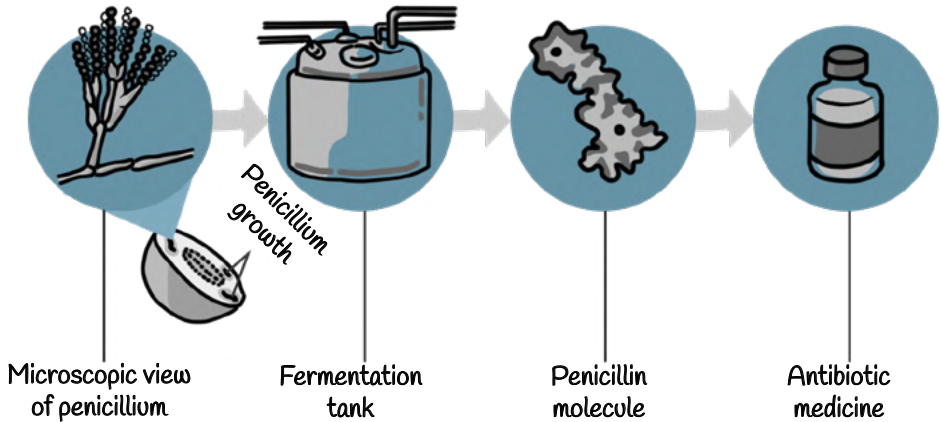
## How did they make penicillin?

(1) Penicillium mold naturally produces the antibiotic penicillin

(2) Scientists learned to grow the mold in deep fermentation tanks by adding a kind of sugar and other ingredients. This process increased the growth of penicillin.

(3) Then, scientists separated the penicillin product from the mold.

(4) Finally, penicillin is purified for use as an antibiotic medicine.



A large, stylized orange brushstroke graphic that serves as a background for the chapter title. It consists of several overlapping, diagonal strokes of varying lengths and thicknesses, creating a textured, hand-painted effect.

# **CHAPTER FIVE**

**DISCOVERING  
NEW  
ANTIBIOTICS**



Antibiotics present an interesting paradox :

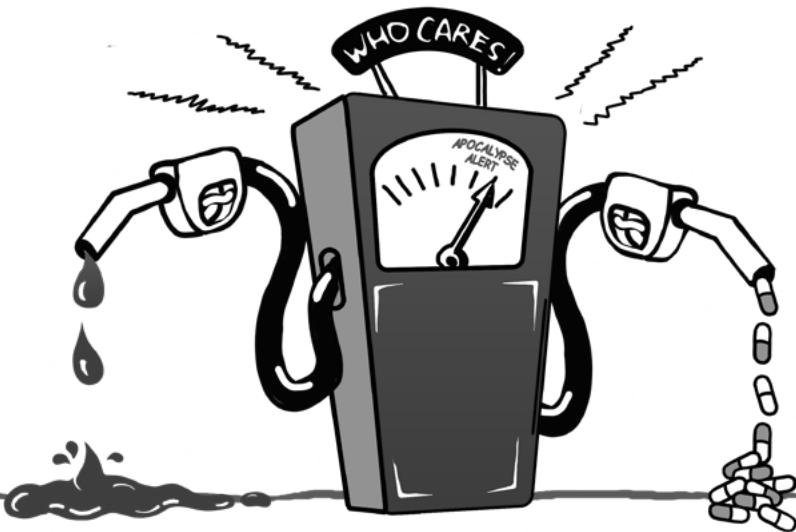
The more we use them, the less effective they become.  
And the less effective they become,  
higher the dosage in which we are forced to use them!

Antibiotics are just like fossil fuels – a non-renewable and finite resource. Just as the burning of these fuels has contributed to global warming and impending climate catastrophe – the use and abuse of antibiotics is spreading bacterial resistance...

...with all its

**DIRE CONSEQUENCES**

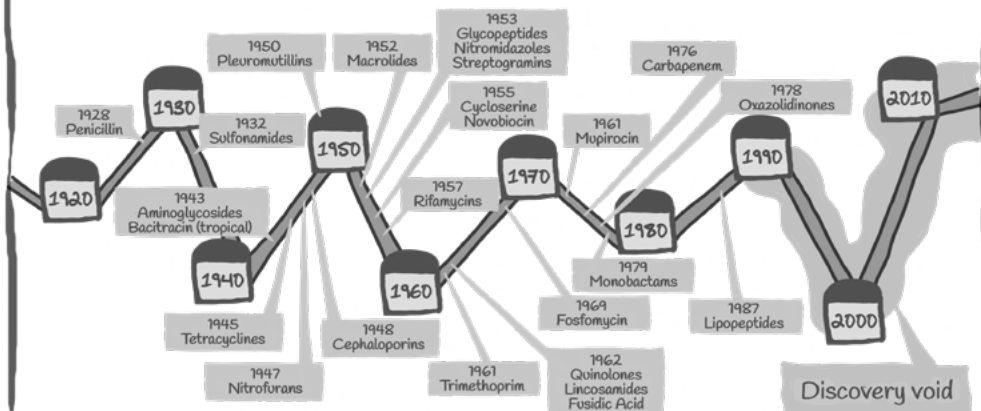
for human health!



Yes, it is essential to use antibiotics to save the lives of people affected by severe bacterial infection. It is important to keep in mind though, that sooner or later, bacteria will evolve to defeat the antibiotics we have. This means that we will always need to find new drugs to fight bacterial infections.

### Rising demand, dwindling supply

In the early years after antibiotics were introduced on a mass scale, bacterial resistance did emerge as a threat. However, this was also a time when many new classes of antibiotics were being discovered and existing ones modified to make them more powerful. So it was convenient to ignore antibiotic resistance.



However, today there are too few antibiotics being developed to meet the growing need. The last time scientists discovered a truly new class of antibiotics that made it to market was in 1987.<sup>1</sup>

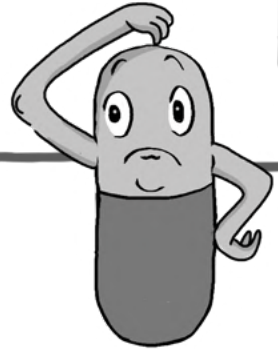
At the same time resistant bacteria that survive antibiotic treatment are becoming more and more common, making available antibiotics ineffective. We have reached a point where there are hardly any treatment alternatives left for some bacterial infections.

Especially worrisome is the lack of antibiotics against Gram-negative bacteria, which cause some deadly infections such as pneumonia and meningitis.



So...  
why can't we find new antibiotics?

Here are some of the



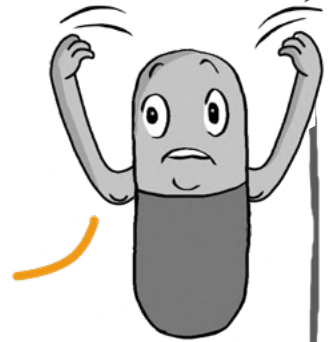
- Overcoming scientific barriers

It is extremely difficult to develop an antibiotic. First, like all drugs, it needs to get to the right place in the body at a high enough concentration without being toxic to the patient.

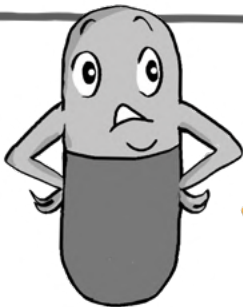
Then, it also has to enter and stay in the bacterial cell, which has proven very problematic. Efforts to screen large existing libraries of small molecules or use genomic sequencing have failed to find new antibiotics.<sup>2</sup>

Much of the problem seems to lie in the early stages of antibiotic development.

For example, we, the antibacterial drugs are estimated to have a ten-fold lower yield in the discovery stage of identifying promising new compounds when compared to all drug classes.<sup>3</sup>



These scientific difficulties have been compounded by several external factors. This includes the reality that most multinational pharmaceutical companies have exited the anti-infective field due to commercial returns being less than other therapeutic areas.



Over the last three decades, the number of multinational companies with active anti-infective programs has fallen from 18 to just 6 in 2020.<sup>4</sup>

## • The Pharma industry's priorities

There is a mismatch between the infectious diseases which most urgently need new antibiotics and the drugs that are currently being developed.

A recent analysis showed that of the 50 candidates in clinical development only two are targeting high priority multi-drug resistant Gram-negative bacteria, which are spreading at worrying speed and urgently require novel treatment options.

In other words, the pharma industry has a business model which ensures higher returns on investment. The collateral damage to this approach is the lack of R&D in newer antibiotics which is the real need of millions of patients who require effective antibiotics in a situation of rising bacterial resistance.





- The market-based model is not working

It is very expensive and often takes ten years or more to develop an antibiotic. The market-based model for financing late stage clinical development of pharmaceuticals relies on companies recouping their R&D costs through sales of the end-product.

This means the model relies on charging high prices and an incentive to sell as much as possible within 20 years before patent protection runs out.

Both features are undesirable for new antibiotics given that both affordable access and stewardship are required to preserve the drug's effectiveness. For these reasons, the "traditional" market model has not brought forward novel antibiotics for decades. Overcoming all these challenges is not going to be easy. A good beginning would be however for policy makers to encourage policies which prioritize public health and the needs of the population.







# CHAPTER SIX

DRUG MAKER  
HEAL THYSELF

One of the great ironies in the story of how antibiotic resistance emerges and spreads around the world involves the role of drug manufacturers themselves.

Yes, believe it or not, the same companies that produce life-saving antibiotics contribute towards polluting the environment with antibiotic residues from their manufacturing plants.

One reason for this is of course, that the manufacturing of antibiotics on an industrial scale, particularly through the fermentation process can be...



a very messy affair

...with  
discharge  
of waste into  
nearby water bodies.

The concentration of antibiotics in effluents from antibiotic-manufacturing sites can reach extremely high levels.



Apart from the toxic effects of such antibiotic concentrations on living organisms, such unchecked discharge of antibiotics also leads to an increase in bacterial resistance genes in the environment.

And in the end, it is these resistant bacteria that often return to haunt human populations in the form of untreatable infections.



The message here is simple:

**Polluting the Earth  
is the same as  
poisoning our own bodies!**

## What is the solution?

In response to growing worldwide concerns about antimicrobial resistance, in 2018, the AMR Industry Alliance, a global coalition of private pharma manufacturers, developed

### The Antibiotic Manufacturing Framework to ensure adequate control of manufacturing effluent emissions.<sup>1</sup>

It sets out minimum standards for companies to adhere to environmental compliance and appropriate antibiotic discharge management. The focus is on

- Setting up minimum requirements for water management,
- Solid waste management programs as well as conducting audits of antibiotic manufacturers.

Among the measures suggested was calculating API discharge amounts, called the **Predicted-No-Effect Concentration (PNEC)** or antibiotic concentrations at which, the Alliance believes, the selection pressure is minimal on microbes in the environment to mutate and develop drug resistance.

## Need for global rules

One way to tackle pollution at antibiotic manufacturing plants while ensuring access to low cost medicines is to tackle the problem through a global process instead of leaving it to individual countries or companies alone.

Global standards are needed that guide and regulate the production of antibiotics to discourage environmentally damaging practices. Such regulation can be accomplished through restrictions on procurement from polluting factories coupled with subsidies and incentives for implementing environmentally safe practices.

For example there could also be investments, in improving the supply chain or through preferential procurement of appropriate end products. For smaller manufacturers, which may have neither the financial capacity nor the technology to adjust to such requirements, an international system or Fund that would subsidize adjustments and provide access to technology should be considered. This is especially so, if such producers are committed to manufacturing good quality antibiotics needed in low and middle-income countries.





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# **CHAPTER SEVEN**

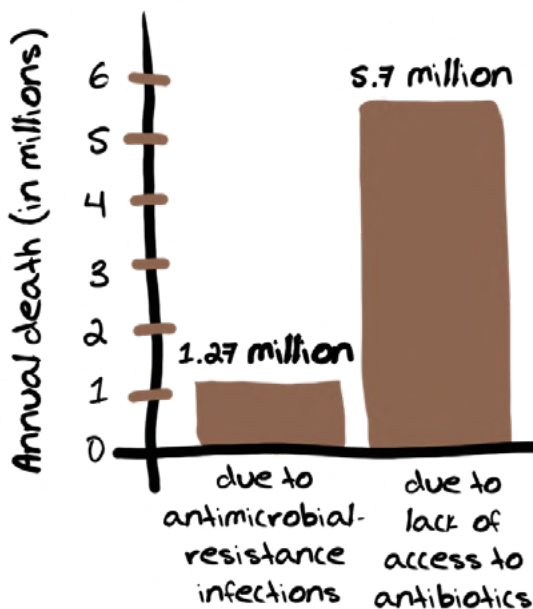
**ACCESS  
TO  
ANTIBIOTICS**

Reducing overuse of antibiotics is key to tackling antibiotic resistance worldwide. Lesser the amount of antibiotics used, the smaller the chance of bacteria becoming resistant to them.

However, this important goal has to be seen in the context of how even eight decades after their discovery, a vast number of people do not have access to these life-saving medicines.

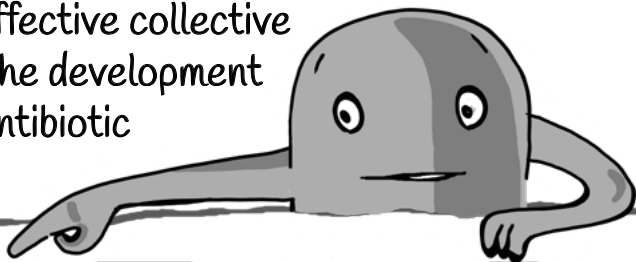
Every year there are over 5.7 million deaths that could be averted with access to antibiotics.

Yes, that is a huge number and one that is much bigger than the estimated 1.27 million lives lost annually due to antimicrobial-resistant infections.<sup>1,2</sup>



Not surprisingly, the majority of these deaths due to lack of access to antibiotics occur in low and middle-income countries.

Ensuring universal appropriate access to antimicrobials is not only a critical part of realizing the **RIGHT TO HEALTH**, but is necessary for mobilizing effective collective action against the development and spread of antibiotic resistance.



In other words the challenge of dealing with the growing problem of antibiotic resistance is not just about restricting inappropriate use of these valuable drugs. It is also about providing them to people who cannot get them when they really need them.

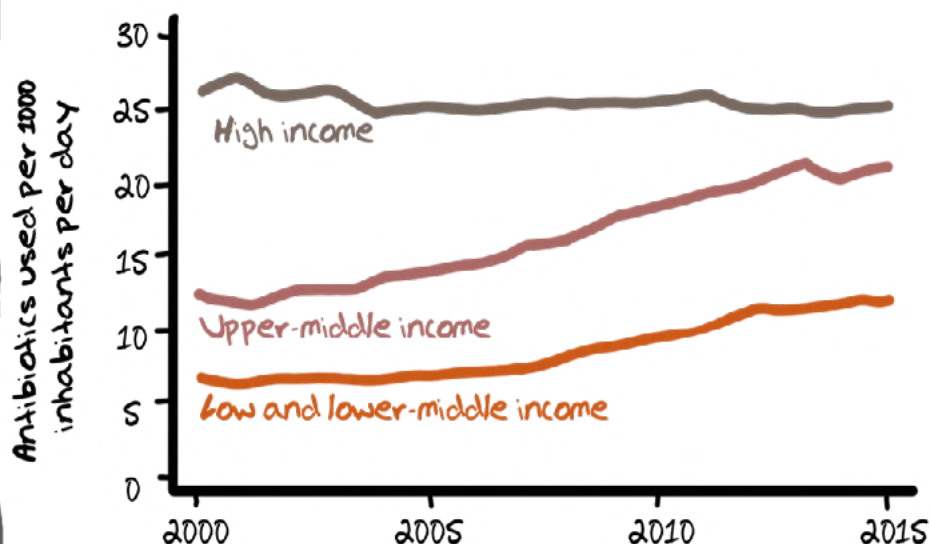
## Why is access a problem?

The COVID-19 pandemic has exposed many systemic and deeply unacceptable global health inequalities. The most glaring example is the way some rich countries get access to vaccines and other important medicines first, and poor countries are left depending on charity.



The situation is not very different in the context of antibiotics. Poorer countries, with a high burden of bacterial infections, are often the last to gain access to effective antibiotics.

According to the OECD, 50% of prescriptions for antibiotics in high income countries are unnecessary and antibiotic consumption in HICs, as depicted in the charts below, is more than double that in low-income countries measured in defined daily doses per 1000 inhabitants per day.<sup>3,4</sup>

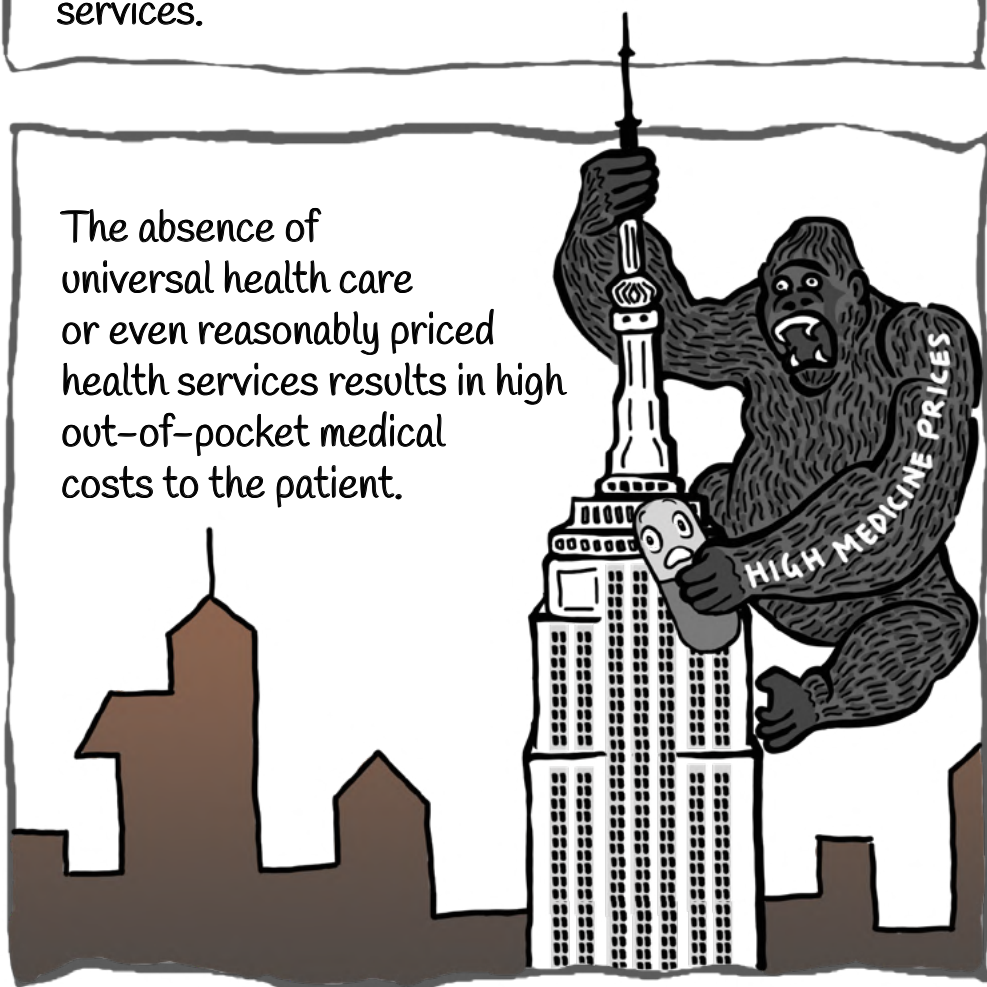


## High costs

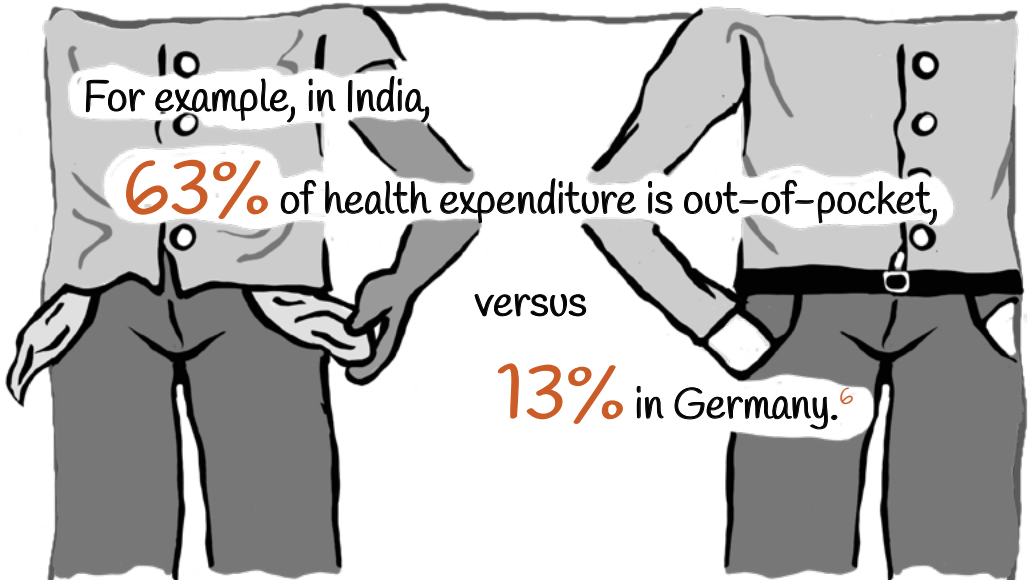
In many low and middle-income countries, even when antibiotics are available, patients are often unable to afford them.<sup>5</sup>

This could be due to high levels of poverty in general but also limited government spending for health services.

The absence of universal health care or even reasonably priced health services results in high out-of-pocket medical costs to the patient.







Such expenditures push some 38 million people into poverty each year in India alone.<sup>7</sup> A decade ago in India, the median overall additional cost to treat a resistant bacterial infection was US\$ 700, which equalled 442 days of work pay for the average rural male worker.<sup>8</sup> Currently, the burden may be worse.

Shortages in public health facilities force patients to go to private pharmacies to buy medicines that should have been provided free in the first place. Individuals may also self-medicate with antibiotics sold over-the-counter at the pharmacy or in the informal market. Others forego medication altogether, worsening the burden of bacterial infections in these countries.



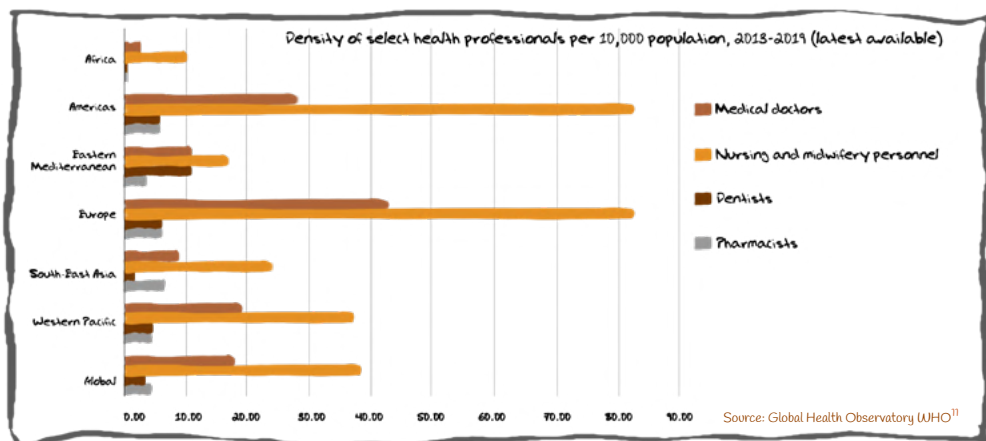
## Health systems

The responses sparked by the COVID-19 pandemic involved collaboration for rapid innovation of diagnostics and vaccines to implementation of preventive measures and equitable access to essential medicines and basic supplies. The same perspective needs to be applied to antibiotic resistance.

In other words, a more holistic health systems approach for sustainable access to antibiotics is required.<sup>9</sup> A fragmented approach is ineffective. This implies, among other things, concerted efforts towards human resources, universal health care, and optimal health-care infrastructure.

For example, a third of health-care facilities in low-resource settings have little access to running water and soap for handwashing.<sup>10</sup>

Health facilities in many low and middle-income countries are substandard and lack staff who are properly trained in administering antibiotics. Inadequate staffing makes it difficult to administer medicines and patients miss antibiotic doses, once again compounding the problem of resistance.



## Neglecting needs of low income countries

Just the mere existence of an effective antibiotic does not mean that they are available in countries where they are most needed. Most new antibiotics emerge from public or private labs in high income countries that have the skills and resources needed for the research and development required. **While these new antibiotics are registered for use in these countries, they often do not reach low and middle income countries.**<sup>12,13</sup> This could be because these markets are seen as not being lucrative enough or 'difficult' to operate in.

For example, among novel antibiotics entering the global pharmaceutical market between 1999 and 2014, registration was mostly concentrated in high income countries.<sup>14</sup>

**NO ENTRY****LOW INCOME  
COUNTRY ALERT**

Only 12 of 21 products were registered in more than ten countries.<sup>15</sup> For novel antibiotics introduced since 2014, registration has been filed in fewer than five countries per year, slowing down approval and use.<sup>16</sup>

Studies have also found that older off patent products are also unlikely to be widely available.<sup>17</sup> More than 10% of older antibiotics were not registered in even one of the 102 countries assessed. The so-called '**forgotten antibiotics**' – old, but still clinically useful antibiotics – were also found to be in short supply in LMICs.

Even where there is a commitment by a product developer to register and supply a country, significant resources from both the product developer and regulatory authority are still required before approval which can lead to lengthy delays.

...no country for  
old pills...



## Supply chain problems

The current global supply chain is fragile and relies on only a few producers of active pharmaceutical ingredients and manufacturers based in a few countries such as India and China. For some antibiotics, there are just one or two major producers and disruptions therefore lead to global stockouts and shortages.<sup>18</sup>

The entire chain of producers, suppliers and marketers are also not transparent making it difficult to get an accurate picture of specific ways to resolve problems.



In low and middle-income countries, weak drug supply chains make the consistent availability of antibiotics a problem. Maintaining quality of medicines is also a problem, with researchers finding that many products were stored and transported long distances without cold-chain temperature control.

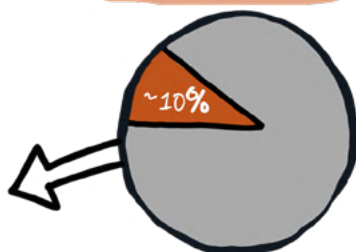
## Falsified medicines

Lack of oversight and regulation in the drug manufacturing and supply chain leads to poor drug quality and falsified medicines.<sup>19</sup>

According to a review of 100 scientific articles conducted by WHO:<sup>20</sup>

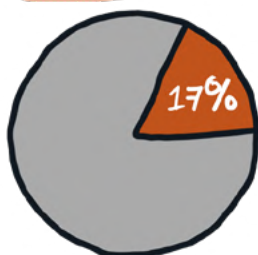
Medicines sold in low and middle-income countries

Up to 72,000 deaths from childhood pneumonia are attributable to poor quality antibiotics<sup>21</sup>



substandard or falsified

Substandard or falsified medicines reported to the WHO



Antibiotics  
Others

Many national drug regulatory authorities are also unable to assess the quality, safety, and efficacy of older antibiotics that are registered, and which may be substandard or falsified.

## Regulation

Limiting the sale of antibiotics to prescriptions seems like an easy solution and functions well in some countries. However, enforcing prescription-only laws may cut off access to antibiotics for parts of the population. This is particularly so in rural areas and in resource-limited settings that lack access to prescribers.<sup>22</sup>

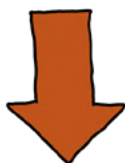
## What can be done?

As is evident from all that we have discussed so far the issue of access to antibiotics is a complex one, shaped by multiple factors.

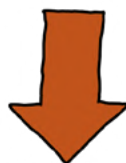
Improving access to antibiotics worldwide will require efforts from:



National governments, policymakers



Pharmaceutical companies



Public and private healthcare institutions



International public health bodies



This is not an exhaustive list of course, but...

**some of the steps needed to address key barriers to accessing antibiotics include:**

- Encouraging research and development of new or improved antibiotics, diagnostic tests, vaccines, and alternatives to antibiotics for bacterial infections;
- Supporting the registration of antibiotics in more countries according to clinical need;
- Developing and implementing national treatment guidelines for the use of antimicrobials;
- Exploring innovative funding for essential antibiotics;
- Ensuring the quality of antibiotics and strengthening pharmaceutical regulatory capacity;
- Encouraging local manufacturing for cost-effective antibiotics;
- Developing a system of global rules-based governance as a framework for solutions to all these challenges







# CHAPTER EIGHT

ANTIBIOTICS  
IN OUR  
FOOD!

For most people, the term 'antibiotics' usually evokes the idea of medicines used for treating human beings with bacterial infections. But many would be surprised to know that –

antibiotics are used in even larger quantities in the world of food animals – cows, chicken, pigs, sheep and aquaculture.

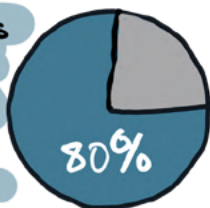


For example...



... according to the U.S. Food and Drug Administration:

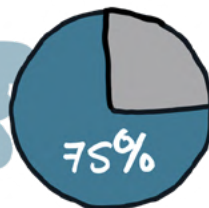
Antimicrobials in the USA, distributed or sold (by weight)



-  used for animals
-  used for humans

... and globally, some 131,000 tonnes of antibiotics are used annually in farming.<sup>1</sup>

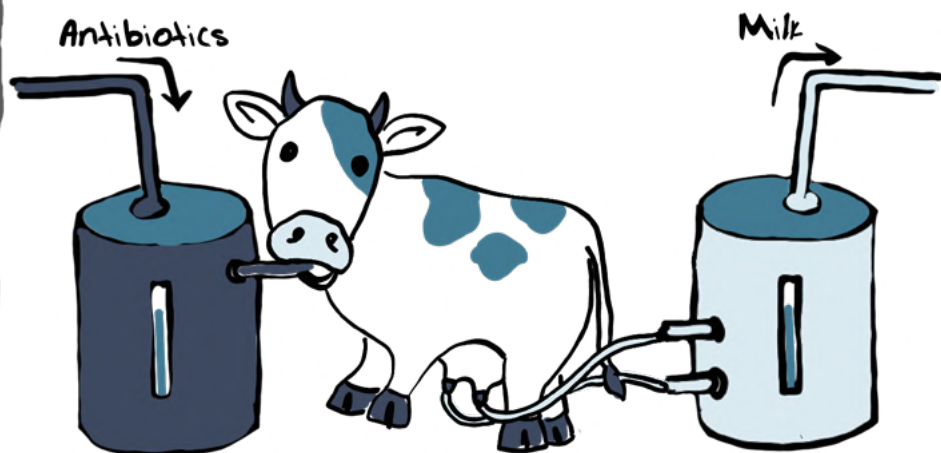
Antibiotics produced in the world annually



-  used for farming
-  used for humans

## Why is this significant at all?

The main reason is simply that the use of antibiotics in animals and the meat industry is also a major driver of antibiotic resistance, which then has consequences for both human and animal health.



Use of antimicrobials, in both human and non-human sectors, drives selection for resistance among bacterial pathogens. Repeated exposure to low doses of antibiotic agents, creates ideal conditions for the emergence and spread of resistant bacteria in animals. Many classes of antibiotics that are used for humans are also being used in food-animals.

Transmission of resistance from animals to humans can take place through a variety of routes. These include through direct contact, contamination of the environment and through food.

For example, farm and slaughterhouse workers, and veterinarians, who come in close contact with colonized or infected animals, are at risk of carrying resistant bacteria and passing them on to others.



Though the route of transmission is more complex, consumers may also be exposed to resistant bacteria via contact with or consumption of animal products.

The extensive use of antibiotics in farming of food animals on a routine basis produces antibiotic resistant bacteria that may lead to therapy failure for humans and animals.



## What are antibiotics used for in animals?

The broad purposes for which antimicrobials are used in food-animal production are:

- For therapeutic use i.e. treatment of disease;
- For non-therapeutic use, including prevention of disease;

- For 'growth promotion', as they are believed to "help growing animals digest their food more efficiently and allow them to develop into healthy individuals."

I'm sick of being prevented from being sick ...



Of all these, 'growth promotion' is the most problematic as lot of antibiotics are used for helping the food-animals gain weight. The logic is simple – bigger and heavier the food-animal, more the income for producers. This drive for profit ignores the larger health consequences to everyone due to increased bacterial resistance.

I feel the same...



Me too...



While such use for growth promotion has been banned or restricted in many countries, producers often find other ways of giving antibiotics to their animals, including in guise of 'prophylaxis' or preventive treatment.

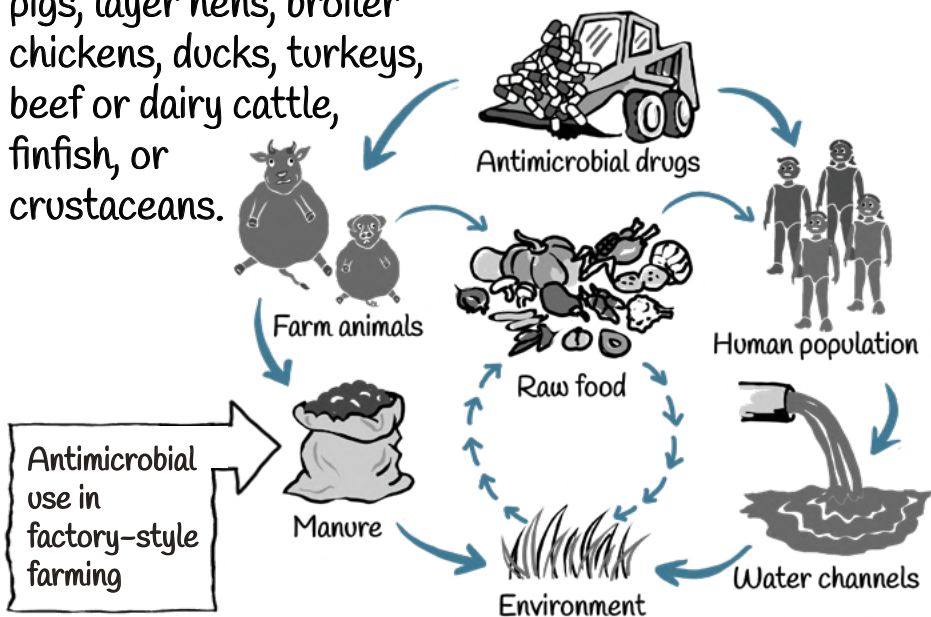
In the modern industrialized food-animal production, feed for growing animals often gets supplemented with antibiotics in various doses.



## Factory-style farming

This rising tide of antimicrobial use is propelled, in part, by the growing demand for animal protein and anticipated increases in industrial food-animal production. Such production involves factory-style farming, in which thousands of animals of one breed and for one purpose are raised under highly controlled conditions.

They are often kept in confined housing, given medicated feeds, and denied access to forage crops. Among the food-animals bred in this manner are pigs, layer hens, broiler chickens, ducks, turkeys, beef or dairy cattle, finfish, or crustaceans.

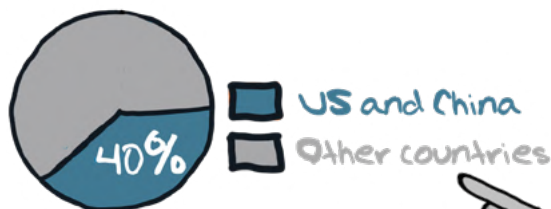




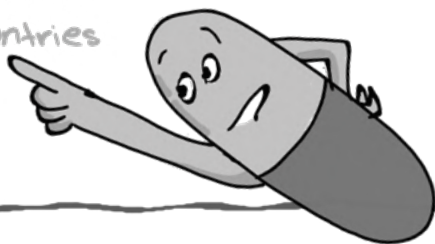
A study by the Organisation for Economic Co-operation and Development (OECD) attributes one-third of the global increase in antibiotic consumption to the shift towards intensive farming systems and two-thirds as a result of the larger number of food-animals in production.<sup>2</sup>

Rising meat consumption is a major driver of antibiotic use. Growth in global consumption of meat proteins over the next decade is projected to increase by 14% by 2030 compared to the base period average of 2018–2020, driven largely by income and population growth.<sup>3</sup>

The consumption of antimicrobial drugs in the food-animal sector is however not uniformly distributed throughout the world.<sup>4</sup>

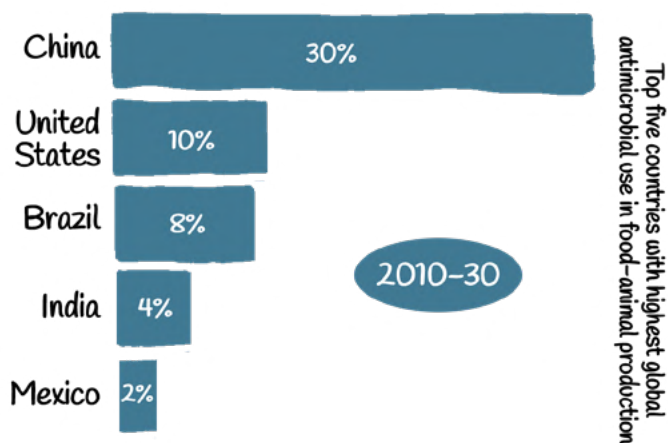


Country-wise consumption of antimicrobial drugs



Antibiotic consumption is also expected to rise significantly in several developing countries by 2030 due to increasing meat consumption.

By then, the BRICS countries – Brazil, Russia, India, China and South Africa – alone will witness a projected increase of antibiotic consumption by 99 percent.<sup>5</sup>



Total growth in use of antimicrobials in farming and food-animals between 2010 and 2030

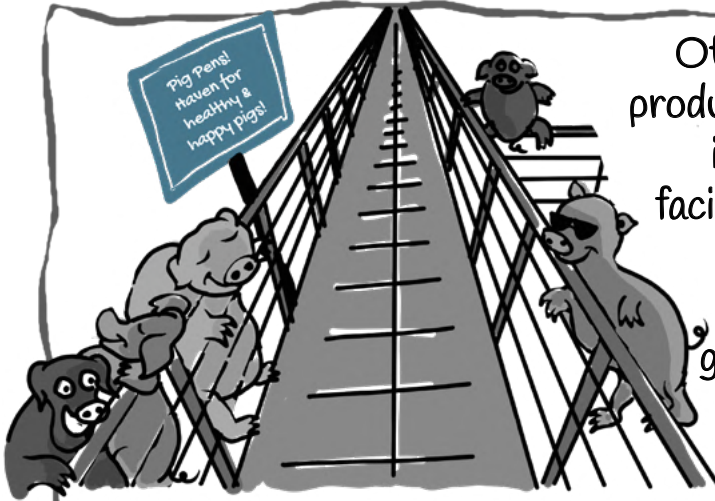
When it comes to antibiotic use, aquaculture, which is growing faster than any other food-animal sector, also seems to be a significant contributor to the spread of antimicrobial resistance.

## What are the alternatives?

While many producers and farmers justify antibiotic use in their food—animals as being 'unavoidable' there is considerable research that shows the production gains can be achieved by other means too.

Alternatives to non-therapeutic antimicrobial use range from changing production practices to using various substitutes. These include more environmentally sustainable systems, where a higher emphasis is placed on animal welfare and disease prevention through hygiene, vaccination and intelligent herd management.

Changes in production practices that reduce the need for non-therapeutic antimicrobials might include altering the weaning period, lengthening the feeding time, or improving sanitary and hygienic conditions. Substitutes for antibiotic therapies include vaccines, micronutrients, and other non-antimicrobial fortified feed such as for example, fish oils. One of the commonly considered strategies, drawing from the experience in Denmark, is improvement in hygiene and reduction in stress through changes to the production methods, density of animals in each farm and better sanitation.<sup>6</sup>



Other changes to production practices include cleaning facilities, improving ventilation and switching from gestation crates to pen system for swine.

By changing the environment and by decreasing the stocking density, producers can reduce the stress and disease transmission as well as improve control of temperature, humidity and hygiene in ways that benefit animal health. A combination of compulsory and voluntary actions with clear reduction goals resulted in a 56% reduction in antimicrobial use in farm animals in the Netherlands between 2007 and 2012.<sup>7</sup>

While such changes may require initial high capital investment costs and moderate resource inputs over time, they are among the most effective of the alternative strategies and help decrease the selective pressure to use antimicrobials for production or prophylactic purposes.

## Antimicrobial residues in food

Unregulated and excess use of antimicrobials in the animal sector often means that withdrawal times, i.e., the time between last antimicrobial treatment and marketing of food from the treated animal, are not respected. This can lead to higher than acceptable levels of antimicrobial residues in the food product.

For example, a study in Ghana showed that the prevalence of drug residues in animal source food was 20%.<sup>8</sup> In fish and shrimp bought at a regional market in Vietnam, antimicrobial residues were found in 25% of the screened samples.<sup>9</sup> In these cases, antimicrobial use is also a food safety issue.

However, while residues can be detected even in very small quantities, they are not inevitably toxic. The amount of residues needs to be related to evidence-based threshold limits to evaluate their potential impact on our health.



## One Health Approach

One of the consequences of the COVID-19 pandemic, that has devastated lives and economies throughout the world, is greater public awareness of the link between human interaction with animals and the transmission of dangerous new pathogens.

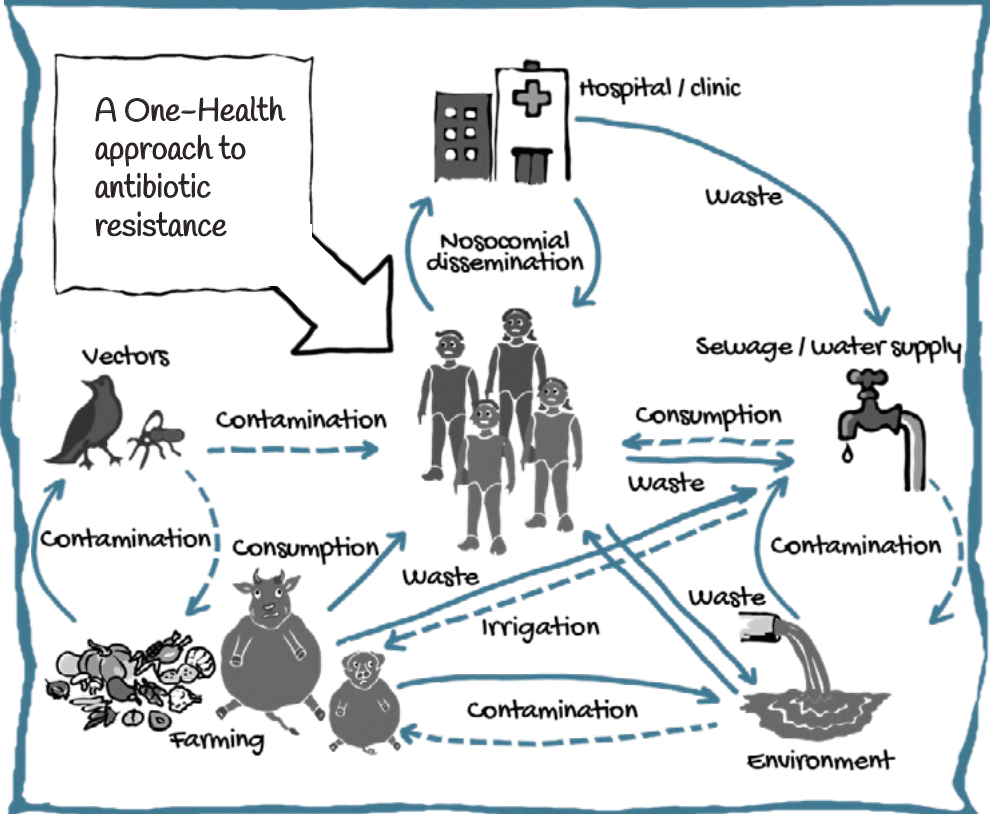
### BOX 4

While the emergence of a virus like COVID-19 is a relatively rare event, on a more routine basis the extensive use of antibiotics in farming of food animals produces antibiotic resistant bacteria that may lead to therapy failure with a negative effect on animal health and welfare.

The link between human, animal and environmental health is captured in the concept of One Health. This concept is now the basis of an important global movement that brings together human, veterinary and wildlife health communities to take a more coordinated approach to disease and epidemics in general.



The areas of work in which a One Health approach is particularly relevant include food safety, the control of animal diseases that can be transmitted to humans and combating antimicrobial resistance.





A large, stylized orange brushstroke graphic that serves as a background for the chapter title and subtitle. It consists of several overlapping, diagonal strokes of varying lengths and thicknesses, creating a textured, hand-painted effect.

# **CHAPTER NINE**

**A STITCH IN TIME  
SAVES NINE**

One of the key goals of global efforts to reduce antibiotic resistance is to lower the misuse and needless use of these life-saving medicines.

Lesser the amount of antibiotics consumed, among both humans and animals, lesser the chance of bacteria becoming resistant. Voila!

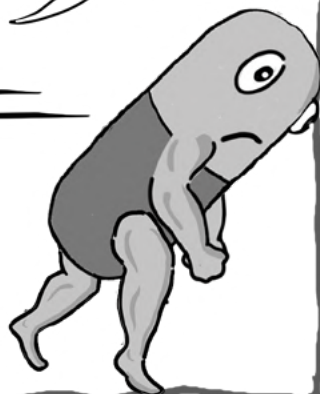
The argument is  
simple - right?



The argument is correct, except that it turns out, for all this focus on the medicines themselves, there is another important driver behind the spread and emergence of antibiotic resistance. And this is none other than the high number of bacterial infections itself.



United we stand!



It has been found that

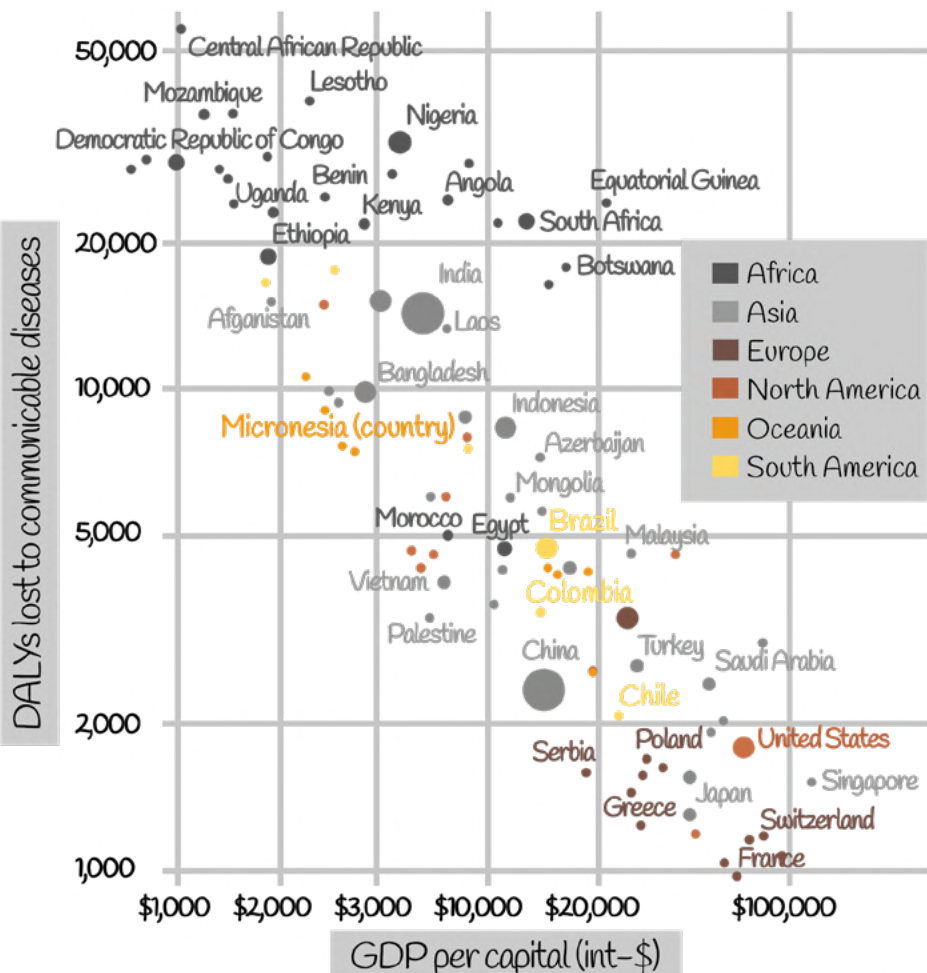
wherever there is more infectious diseases due to bacteria, there is also greater prevalence of resistant infections.<sup>1</sup>

Therefore, the prevention or reduction of bacterial infectious diseases is very important to lowering antibiotic resistance.



## Disease burden due to communicable diseases vs. GDP per capita, 2017

Disease burden due to communicable, maternal, neonatal and nutritional diseases, measured in DALYs (Disability-Adjusted Life Years) per 100,000 individuals versus gross domestic product (GDP) per capita, measured in constant international-\$.

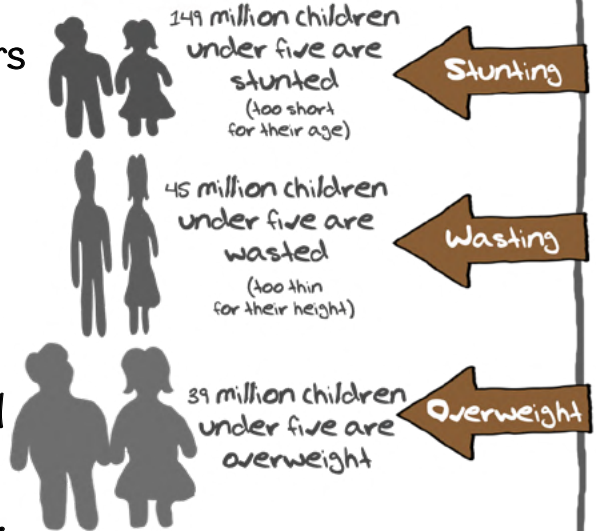


Source: Institute for Health Metrics and Evaluation, Data compiled from multiple sources by World Bank  
[OurWorldInData.org/burden-of-disease/](https://OurWorldInData.org/burden-of-disease/)

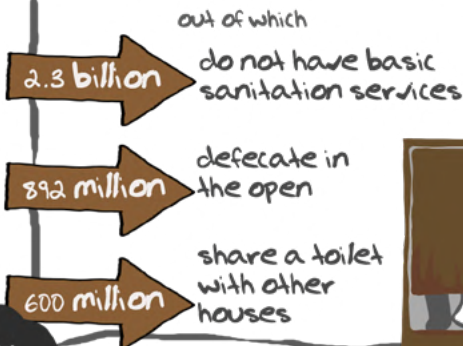
## Prevention and poverty

Prevention though is not as easy as it may sound. The drivers of infectious diseases are both diverse and numerous, including malnutrition, lack of safe drinking water, poor sanitation, pollution and lowered immunity of people due to other diseases.

### Three Faces of Malnutrition (2021)<sup>2</sup>



4.5 billion people globally have no toilets at home that safely manages excreta (2015)<sup>3</sup>



One-third of the world's population do not have a safe toilet; more than 660 million people do not have access to clean drinking water, and 1 in every 8 people currently defecates in the open.<sup>4</sup>

People living in poverty, due to their circumstances, often engage in practices that drive antibiotic resistance such as irrational use and self-medication for themselves or their family and children. In fact, it may not be a coincidence, but many poor countries around the world are more susceptible to the causes and consequences of antibiotic resistance.

So, one of the important strategies towards tackling antibiotic resistance globally could be for richer parts of the world to provide poorer parts, with the material and technical resources needed to provide their citizens with sufficient food, sanitation and clean habitats. This will require not only stepping up of worldwide efforts at poverty alleviation but also ensuring a greater role for LMICs in global institutions and decision making bodies.

How to handle antibiotic resistance?





## UHC and AMR

Given that tackling antibiotic resistance has been recognized as a challenge involving a wide range of sectors, attention in recent years has focused on implementing

### Universal Health Care (UHC).



The WHO defines UHC as:

"All individuals and communities receive the health services they need without suffering financial hardship".



In a good UHC system all citizens are provided the full spectrum of essential, quality health services, from health promotion to prevention, treatment, rehabilitation, and palliative care.

According to the WHO, **at least half of the world's population still does not have full coverage of essential health services**, most of them living in Low and Middle Income Countries (LMIC).

While a UHC system, to be truly successful has to address AMR and related issues, strengthening health systems can contribute to tackling bacterial resistance.

Some of the benefits of UHC include:<sup>5</sup>

- Greater breadth and depth in the population coverage of health services.
- Improved access to services like vaccination, preventative care and hygiene measures that lower the need for antimicrobials and thus slow the spread of AMR.
- More efficient and equitable financing to help close existing access gaps for treatable infections.

## Health literacy

Another key resource needed to prevent bacterial infections is knowledge of health systems, medicine and diseases.

Quite often, people think that the field of medicine is so specialised or complicated that there is no point in trying to learn much about it themselves. As long as they have a good doctor or hospital to go to, everything will be all right.

This attitude of blind faith adopted by many patients leads to a situation that puts a lot of pressure on doctors to solve all the patient's medical problems quickly. It becomes difficult for them to explain to patients that in reality, there are no easy solutions available.



If patients were more knowledgeable about the basics of health, medicine and disease, and less driven by anxiety and fear, this empowerment could enable patients to contribute to their own health in partnership with medical professionals.

Health literacy of the population is critical to ensure success of any health intervention, whether it be avoiding disease or using medicines appropriately. An alert and informed patient can help doctors do their job better and contribute to the overall health of the society by spreading the right message all around.

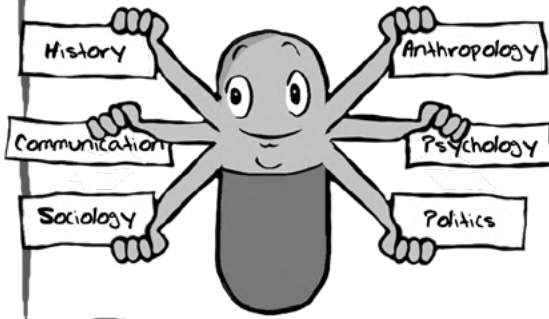


A large, expressive blue brushstroke that serves as a background for the chapter title. It consists of several overlapping, diagonal strokes that create a sense of movement and texture.

# **CHAPTER TEN**

**A NEED FOR  
HOLISTIC SOLUTIONS**

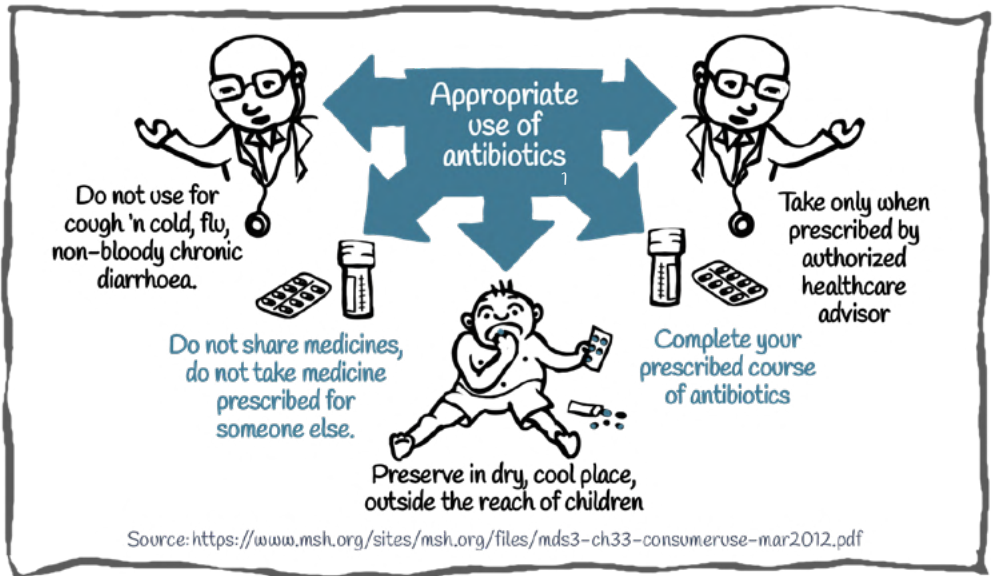
Dealing with patients or members of the public constantly brings in various other factors into the actual practice of medicine. In other words, the story of medicine is a combination of findings from various natural sciences along with



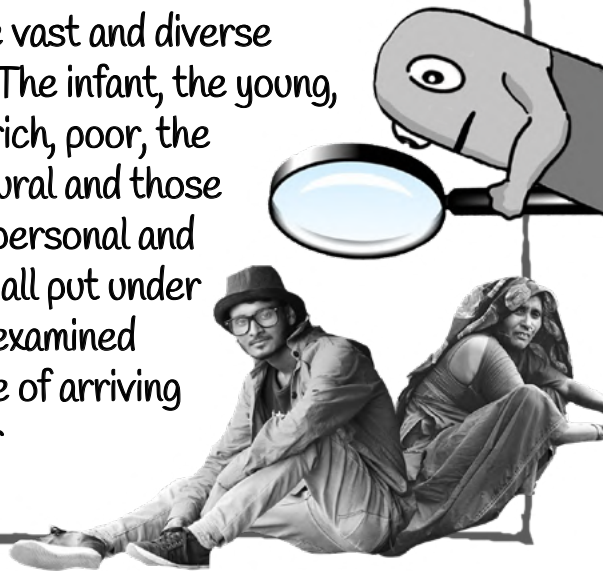
that of social sciences such as communication, psychology, sociology, anthropology and even political knowledge.

## The anthropological approach

Much of antibiotic resistance, whether in the human or health sector, is driven by the 'inappropriate' use of these critical medicines – which in turn is the outcome of various powerful factors shaping prescription or health seeking behaviour. Without a good understanding of these myriad factors, ranging from medical science to anthropology, it will be difficult to design effective policies or interventions to tackle the problem.



It cannot be assumed that a single conception of what 'health', 'disease' or 'medicine' mean – even if it is the most 'rational' and 'evidence based' – would be whole heartedly accepted by the vast and diverse populations of the world. The infant, the young, the elderly, men, women, rich, poor, the indigenous, the urban or rural and those who come from different personal and social histories cannot be all put under the same petri dish to be examined under a lens with the hope of arriving at one general formula for intervention.





This means that there cannot be one common standard set of criteria to define what constitutes 'good health' imposed on this diversity of worldviews. What people choose to do with their bodies and how they look after them is closely related to the context, culture and traditions they come from.

The only way to work on anything to do with health and medicine then is with the full participation of communities and individuals in a patient, respectful and organic process to arrive at common goals and objectives through consensus.

## A planetary perspective

While there has been recognition of the role of social, cultural and economic determinants that shape the health of all populations for quite some time now, there is also growing acknowledgment of planetary processes involved. As the Rockefeller Foundation–Lancet Commission on planetary health says in its 2015 report<sup>1</sup>:



"Changes to the structure and function of the Earth's natural systems are a growing threat to human health. Expect future substantial health effects from the degradation of Nature's life support systems." <sup>2</sup>

Drought

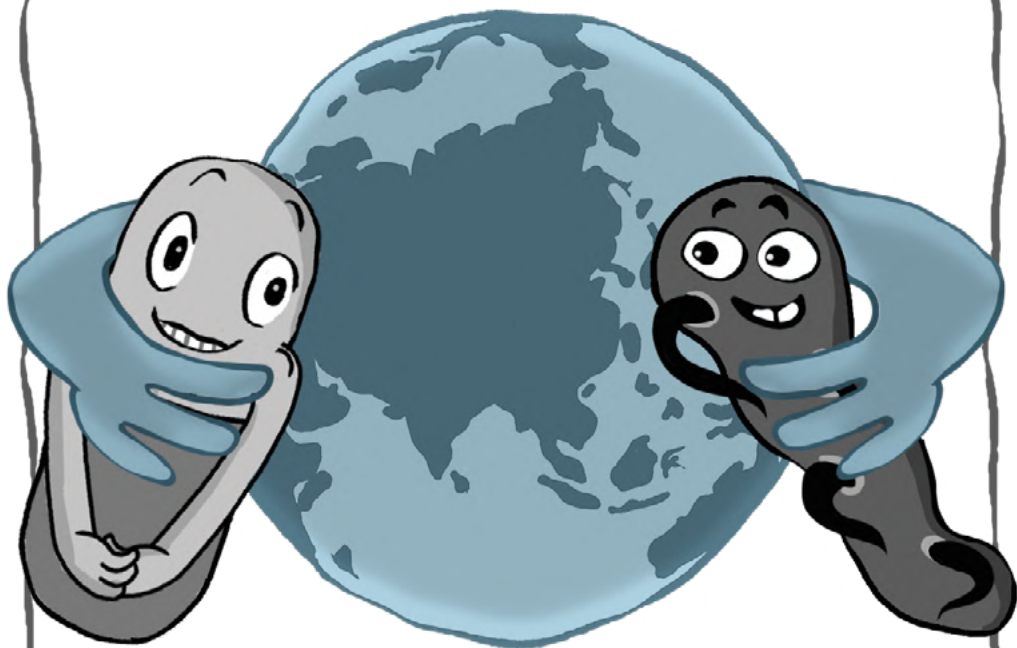
Flood

Heat  
Wave

Carbon  
Emission

Climate change is an obvious example of a phenomenon that, if not brought under control, can create conditions that bring the very existence of the human and other species itself into question. Mother Earth itself is sick today due to human actions over the last several centuries following the industrial revolution.

It is time to recognize that at the planetary level itself there is disease all around, all of which are intimately connected to the well-being of individual humans.



While there are numerous problems to be dealt with at the level of individual humans and their bio-medical needs no satisfactory outcomes can be expected without first understanding these problems in larger context of planetary or even social health. The fate of each one of us is connected intimately to the fate of rest of humanity as well as other forms of life and the planet.

There are countless ways how 'big picture' phenomenon impacts each of us as individuals. Air, water and soil pollution, declining nutrient content of available food, growing population density of cities, loss of biodiversity, lack of occupational safety, loss of income and jobs due to economic crisis, increased mortality and morbidity due to conflict – these are all planetary level diseases which need to be addressed as an integral part of any national or global policy on health and medicine.

The implication of this planetary approach is very straightforward. The primary medicines all humans truly need are good nutrition, clean air, clean water, safe environments, ability to live with dignity and a peaceful social milieu.

It is only on this sound foundation that the problem of antimicrobial resistance will ultimately become truly manageable.

It is therefore imperative that we imbibe the lessons that the past and the present have taught us, to ensure that the journey of the antibiotic continues into the future!



# Footnotes

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Goodbye fella's!  
See ya' in real life!



This illustrated book traces the journey of a typical antibiotic from birth to death. Through its childhood, teens, middle-age, all the way as it goes from conception in a lab to sale in a drug shop somewhere.

After which, it is either used to help cure a bacterial infection – as originally meant to – or becomes another wasted shot of a powerful medicine – destined for the graveyard of antibiotic resistance.

Surely you have heard of antibiotic resistance? Well, if you haven't then you are in the right place to learn all about this phenomenon that threatens, if unchecked, to damage the very foundations of modern medicine.

And if you have heard of it you there is even more reason for you to stay on. We will open your eyes to the secret working of many players – you may have never heard about – who determine the fate of antibiotics.

The world of research and development –that has been struggling for decades to produce new classes of antibiotics. Find out why this is a problem and what are the barriers involved.

Why is the manufacture of antibiotics globally today almost entirely concentrated in China and India? Turns out they are among the few countries willing to tolerate the hidden costs involved in making antibiotics. But is this really a good thing for everyone globally?

Once out in the marketplace how are antibiotics prescribed and consumed? This will determine the amount of antibiotic resistance they generate and how long the antibiotic itself will live as a useful medicine. And here we are not talking about antibiotics in human health alone but also in food –animal farming and agriculture – where the volumes involved are vastly greater.

Well, this story does not end with only the negatives but also shines light on the potential for change and improving the way the world handles antibiotics.

Just jump on board – we will take you for a ride you will never forget!

