soap *and* water

common sense

THE DEFINITIVE GUIDE TO VIRUSES, BACTERIA, PARASITES, AND DISEASE

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In memory of Dr. Sheela Basrur,
my mentor, friend, and partner in public health.
You are deeply missed.

And for Spencer

"...what we learn in times of pestilence: that there
are more things to admire in men than to despise."
—Albert Camus, *The Plague*

"If you can't explain it simply,
you don't understand it well enough."
—Albert Einstein

MICROBES INC.

ONE

GOOD BUGS, BAD BUGS

THE DOCTOR QUICKLY scanned the chart as she opened the door to the examining room. It was a busy day, and the patient had been squeezed into her schedule. The new mom with the crying infant on her lap looked harried and tired. The baby had developed a fever overnight, was clearly irritable, and looked unwell. His mother had tried some medication to relieve the fever but was certain the child had developed another ear infection and needed antibiotics. Feeling the pressure of the crowded waiting room and knowing she was already at least a half-hour behind schedule, the doctor hesitated. Her instincts told her the baby had probably caught a virus and the symptoms would resolve on their own in a day or two. But the child's mother was insistent; she couldn't take another sleepless night of worry.

This dilemma is faced every day by doctors around the world. With our overburdened health-care systems, taking the time to reassure patients and explain why antibiotics won't work is difficult for many health professionals to do. It is far easier and takes less precious time to succumb to the demand for antibiotics. These powerful medications have been available for only a few decades, and they have earned their reputation as "miracle drugs" by saving people from infections that used to kill. But the fact that they are effective only against bacteria — not viruses — has been lost in the excitement. We now know that the overuse and misuse of these miracle drugs are having long-term effects on our precious medical defences and are putting our health at risk. If only people knew the difference.

EVERY DAY, THE media inundate us with medical stories covering everything from miracle drugs to superbugs. In addition, we are bombarded with aggressive advertising campaigns from drug companies that tout medications promising to cure whatever ails us. It's nearly impossible to separate fact from fiction. Understanding how we get sick and what causes those nasty infections can help.

This book will navigate you through the complex world of bugs — those that cause illness and also those that play a role in keeping us healthy. We will cover the myths and misconceptions your doctor doesn't always have time to explain, and we will explore why the fundamental differences between viruses, bacteria, fungi, and parasites are important to our health. We will demystify the complex world of drugs, and we will look at the fascinating history of vaccines, antibiotics, and other measures that have been developed to protect us from some of the worst culprits in the ever-changing microbe world. We will explore the world of superbugs, and show how our actions can contribute to making these bugs so much more dangerous. We will lay naked the bug and expose its inner workings, and we will look at the three simple rules that can help us stay healthy: clean your hands, cover your mouth when you cough, and stay at home when you have a fever. Dr. William Osler's words ring as true today as they did more than a hundred years ago: "Soap and water and common sense are the best disinfectants."

MICROBES INCORPORATED

Thousands of people get sick from diseases caused by microorganisms that we inadvertently pick up from contaminated surfaces, ingest in our food, or inhale from the air. Countless hours of misery are caused by bugs called viruses, bacteria, fungi, and parasites — yet much of this suffering is preventable.

Welcome to the awe-inspiring world of Microbes Inc., a global corporation that has dominated our planet for three billion years. As in any global conglomerate, there are several divisions in the world of bugs, or microbes, and while they can all cause illness, some can be beneficial too. Let's take a tour through the halls of Microbes Inc. and explore the different divisions.

Viruses

The first group of bugs is the smallest and often the most lethal: the viruses. Viruses are small packets of genetic material that have evolved over billions of years to infect humans, animals, and even plants; no living organism can escape from the destructive touch of viruses. Viruses need to use another organism's cells in order to replicate and survive. They reproduce by inserting themselves into the cells of the body, where they hijack the programming mechanism that the cells use to replicate, making thousands and thousands of copies of themselves instead. The replicated viruses then burst out into the bloodstream, killing the initial infected cell and sending the legions of copies to find and infect more cells.

Viruses can cause illness by destroying human cells in a matter of hours or days, and they have been the cause of some of the most frightening and deadly diseases we know. And because viruses are made up of such small pieces of genetic material, they can change or mutate rapidly and have perfected this skill to evade our best efforts at containing them.

Human genetic material, or genes, consists of two strands of deoxyribonucleic acid, or DNA: the fascinating double helix that was first discovered by Nobel Prize–winning scientists James Watson and Francis Crick. This discovery revolutionized our understanding of how human genes replicate and how they determine everything from our hair and eye colour to whether we will develop diseases like cancer or Parkinson's. DNA is formed when two strands of ribonucleic acid (RNA) match in very specific ways. Each strand of RNA is composed of basic building blocks called bases, which are strung together in very specific patterns. There are four types of bases: adenine (A), cytosine (C), guanine (G), and thymine (T). Pairs of bases form a pattern that determines how the gene will be expressed in the person. So whether you will have blue eyes or brown eyes depends on how the RNA strands match up. If just one base is out of place or replaced, it can lead to very different outcomes.

It turns out that bugs have the same type of genetic material as humans, with the exception of a whole family of viruses, the RNA viruses, which have only a single strand of genetic material, or RNA. So while humans and DNA viruses have a double-checking mechanism for every time they replicate, the RNA viruses lack this biological trait. This means that the RNA viruses can reproduce much more quickly and are much more likely to introduce coding errors (like a base out of place) while they are replicating. We call this phenomenon "mutation."

Some mutations can affect the virus's ability to infect cells. These viruses die out quickly because they can no longer replicate their genetic material. But every now and then a mutation will come along that allows the virus to increase its rate of infection of new cells or hosts or to work around any defences we have developed (such as vaccines or antibodies). These mutations can open up whole new worlds to the virus's destructive power.

About five thousand viruses are known and have been characterized, but there are probably a hundred times more that we have not yet encountered. Let's look at a few viruses that have caused some of the most frightening illnesses known to humankind.

Smallpox

Throughout history the diseases caused by viruses have disrupted nations and destroyed everything from livestock to food supplies to entire communities. In the world of Microbes Inc. the senior VP of the virus department would have to be smallpox. Until the disease was eradicated in 1979, smallpox caused untold suffering for at least a thousand years in communities around the world. The smallpox virus invaded the cells of the skin, causing large, painful blisters that burst open, spewing highly contagious fluids and leaving the sufferer scarred for life. Tombs of ancient Egyptian kings are engraved with images of people marked by smallpox scars. The disease is also known to have decimated Native populations across North America. One of our greatest medical achievements has been the removal of this scourge from the planet.

SARS

The 2003 SARS (severe acute respiratory syndrome) outbreak is a perfect example of the havoc a virus can wreak around the globe. This ambitious upstart probably emerged from the untimely mixing of two or more rather tame viruses in wild animals, leading to mutations that enabled the new virus to infect humans. Scientists worldwide scrambled to track the origins of this deadly new bug, which spread suddenly and rapidly between people, causing severe influenza-like symptoms that could quickly lead to death. The bug was first detected in southern Guangdong Province in China in November 2002. But because the Chinese government for several months denied any outbreak of disease, this new and dangerous bug was given a timely head start. It managed to reach Hong Kong in February 2003, hitchhiking in the lungs of a doctor from Guangzhou, the province's capital, and within days had started its destructive journey to countries around the world. Over the next six months SARS spread from Hong Kong to Singapore to Vietnam to Taiwan to Beijing and Toronto.

This fascinating journey was carefully pieced together by epidemiologists, the microbe hunters of the medical world, who determined that the origin of the virus was in the "wet markets" of Guangdong Province. There a harmless coronavirus that caused mild sickness in some animals, but not humans, somehow managed to acquire a new piece of genetic material that allowed it to greatly expand its infecting universe. Testing of animals in the area where the SARS virus first emerged indicates that the bug probably got its start in wild civet cats that were raised in cages in the local wet markets and later served at restaurants. From the markets of Guangzhou the virus spread to Hong Kong, and with the help of travellers it continued to spread to cities around the world. The SARS story is truly a reflection of our modern mobile society.

Ebola

Ebola, another relatively new hire at Microbes Inc., is a virus that invades the blood, organs, and even layers of the skin, causing its victim to bleed everywhere, from the lining of their eyes to their intestines. The virus was named after the Ebola River in Zaire (now Democratic Republic of the Congo), where it first drew international attention in 1976 for decimating the village of Yambuku, affecting four hundred villagers and Belgian missionaries.

The Ebola virus was still very much an enigma in 1995, when another massive outbreak invaded Kikwit, Zaire. The people of Zaire had withstood decades of corruption and greed under the ruthless dictatorship of Mobutu Sese Seko, who had exploited the nation's vast mineral wealth and left the country with severe food shortages, a complete lack of infrastructure, a health system in tatters, and the highest child mortality rates in the world. In this tragic setting where people were used to seeing the young die of disease, starvation, or military assault, the gruesome nature of Ebola left even those who had seen so much suffering in despair.

Ebola is a virus that preys on acts of compassion, infecting those who nurse the sick or care for the bodies of the dead. The bug spread easily between patients and the few health-care workers in the rudimentary hospital, where basic infection-control measures such as handwashing were not in effect. The Kikwit outbreak was contained through the heroic efforts of the international medical community, particularly experts from the World Health Organization (WHO) and Médicins Sans Frontières, who worked with the traumatized local community. But it was not gone for long.

Despite intensive efforts to understand the workings of this devastating disease, the world was still unprepared when the next major outbreak hit the town of Gulu, Uganda, in 1999–2000. We still do not know where the virus lay dormant between these outbreaks, but many scientists suspect that local bats may have played a role. In addition, there is no effective treatment for the disease and no effective early warning system to detect the active virus and prevent its spread in high-risk areas. Like many of the top performers of Microbes Inc., Ebola has shown an uncanny ability to find the areas of the world most affected by poverty, war, starvation, and disease and to exploit an already vulnerable population barely clinging to life.

Influenza

Influenza, another senior manager at Microbes Inc., is a bug that has been credited as being the number-one killer of human populations. Circling the globe annually, this virus preys on the young and the elderly, leading to thousands of deaths worldwide every year. Because this virus has only one strand of nuclear material (RNA), it can change rapidly and takes on new bits of genetic material as quickly as it can. Every year the influenza virus changes just enough that the human immune system no longer recognizes it, and new immunization must be developed to combat the new form of flu. But the virus can also change in a major way at short notice, leading to major pandemics, or worldwide outbreaks of disease. In the past century and a half, a major global outbreak of influenza has occurred about every forty years.

A pandemic is a disease that circles the world, affecting people in many countries. This is in contrast to an epidemic or an outbreak, which are the terms used for diseases that cause illness in smaller areas. There have been three influenza pandemics in the past century, but the "Spanish flu" of 1918–19 still stands out as the most devastating pandemic in world history.

Recently the emergence in Southeast Asia and China of new variants of "avian" or "bird" influenza viruses has captured the attention of the world medical community. It has even led to the World Health Organization's urgent pleading for countries around the globe to plan for the next influenza pandemic — all this for a virus strain that has proven lethal to chickens but has yet to pass successfully between people. The unfortunate few who have contracted the disease have died at a much higher rate than those infected by the more common influenza strains that we have seen in the past forty years. In addition, the avian flu virus has made victims of the young and robust, those whose immune systems are not usually as vulnerable to infection. It may be only a matter of time before this adaptable bug manages to find a way to transmit efficiently between people through an innocent cough or sneeze and spread around the world.

While the world was watching Southeast Asia and the avian influenza bug, another virus quietly emerged in Mexico City in mid-April 2009. Hospital staff began reporting severe pneumonia in many young people, some of whom were rapidly dying. Samples were sent to the National Microbiology Laboratory in Canada, and within days a new influenza virus had been identified as the cause.

H1N1 influenza A virus had emerged again, but this time the bug had acquired new pieces of genetic material from swine in Europe and North America and mixed them with some human flu genes. By the time the bug was recognized, this virus had already adapted to the human system and was passing easily between people through coughing and sneezing. Within a week, hundreds of people in the United States and Canada and throughout Mexico had contracted this new form of influenza, and sporadic cases were showing up in Europe and South America. The WHO raised its pandemic alert level from three to five, the second-highest ranking on the scale used to indicate how close we are to a full-blown global pandemic. Outside of Mexico the cases seemed to be mild, more in keeping with seasonal influenza, but countries around the world stepped up their monitoring systems and continue to watch this bug closely. If we have learned one thing about the influenza virus, it is just how unpredictable this bug can be.

HIV

Another relative newcomer to Microbes Inc. that has had a spectacular long-term impact on the world's health is the human immunodeficiency virus or HIV. This RNA virus likely emerged in Africa sometime in the early 1980s, though scientists have since discovered the virus in human blood samples dating from at least three decades earlier.

HIV invades the cells of the human immune system, where it hides out patiently, sometimes for many years, before becoming active. The virus then attacks the cells in the human body that defend against infections, leaving the patient vulnerable to severe illnesses that those with healthy immune systems are able to fight off. AIDS, or acquired immune deficiency syndrome, is the medical term used to describe the stage of illness when HIV has compromised the immune system and these infections start to take hold. AIDS-defining illnesses include severe progressive tuberculosis, *Pneumocystis carinii* pneumonia, candida, cytomegalovirus infection, and a rare form of cancer called Kaposi's sarcoma. It can take many years before HIV leads to AIDS, because of the discovery of medications that suppress the virus. But there is still no cure for HIV, and once AIDS manifests its effects on the body, it will lead to certain death.

While HIV has undoubtedly devastated many families and communities, it has also been a major force in bringing together governments and health organizations to re-evaluate infection prevention and control measures. The disease has also spawned a whole specialization in medicine that deals only with the complexities of the virus. Beyond the medical system, HIV/AIDS has affected the economy, demographics, and social structure of families, communities, and entire countries, particularly in Africa, which has been disproportionately affected by this malignant bug.

THESE ARE JUST a few of the many bugs that make up the Virus Division of Microbes Inc. Many more viruses will appear in the following chapters, but for now let's take the stairs to the next floor and have a look at a group of bugs that is not all bad. In fact, we probably couldn't live without them.

Bacteria

The next floor up in the headquarters of Microbes Inc. contains the bugs in the Bacteria Division. Whereas viruses are made up of small packets of genetic material, bacteria are single-celled organisms shaped like rods, spheres, and spirals that have the capacity to reproduce indefinitely and independently, provided they have sufficient nutrients and a suitable environment — such as the human body. Some even have the capacity to change into a spore- or seed-like form, building a protective wall that is highly resistant to destruction. These bacterial spores, which are produced by bugs such as anthrax and *Clostridium*, can survive for decades in even the harshest environments. When conditions improve, they re-emerge, becoming active and causing disease. A classic example is the large outbreak of anthrax in cattle in Saskatchewan, Canada, in 2006, after record rainfall and flooding provided an ideal environment for the spores to emerge. Anthrax hadn't caused disease in that part of the Prairies for close to fifty years, but the spores had waited patiently in the soil until the conditions were just right. The bacteria then spread to the vulnerable cattle, crippling the Saskatchewan beef industry.

Bacteria, like humans, have DNA. Unlike viruses, bacteria are not dependent on the genetic apparatus of other cells to reproduce, and they can acquire new DNA in several ways. The first and most common way bacteria exchange bits of DNA is through merging, or microbe sex. Bacteria can reproduce at an astounding rate, producing millions of generations in a matter of hours (compare this to the human reproduction process, which takes somewhere around fifteen years to produce a generation). In addition, the new bacteria may pick up a piece of DNA that allow them to resist antibiotics, so the bug can live longer (survival of the fittest, at a micro level) and in many cases become stronger.

Bacteria can also acquire new DNA by swallowing up or ingesting bits of genetic material from the DNA of dead bacteria in their environment. This form of reproduction is completely foreign to humans, or any other multicellular organism, and gives the bacteria an incredible survival advantage. This ability to ingest the DNA of dead bacteria explains why a patient unfortunate enough to be infected with two bacteria at the same time can suddenly develop resistance to antibiotics.

The third way bacteria acquire new genetic matter hints at the complex interactions between the divisions at Microbes Inc. Viruses have the ability to infect bacteria by inserting a little piece of their own genetic material into the bacterial DNA. This process can lead to the evolution of the infected bacteria. But the virus can also take a chunk of the bacterium's DNA when it leaves the cell and transpose this genetic material to other bacteria, spreading the word, as it were, even farther.

In terms of sheer numbers, bacteria are the most successful organisms on the planet, and they have adapted to live in every environment imaginable. These bugs can live and thrive in everything from pools of sulphur to completely oxygen-free air to the boiling water of deep-sea volcanoes and everything in between. Bacteria are also one of our biggest natural energy sources, since they can process just about every type of substance in existence. Some species have even developed the ability to feed on and thereby break down plastics.

Bacteria are a natural part of the human condition: we live in a soup of bacteria both in and on our bodies and in our environment. Some estimates suggest that we have more than 100,000 individual bacteria per square centimetre on our skin! But unlike viruses, not all bacteria are bad bugs. We depend on bacteria for many things, from helping us digest milk to the production of yogurt, cheese, and other foods like fermented cabbage (sauerkraut and kimchee) and soy sauce. In addition, these "good bugs"— our "normal flora," as we affectionately call these bacteria in the medical world — help us to achieve a balance within our human systems, and they are tolerated by our immune systems without making us sick.

"Bad bugs," or infectious bacteria, on the other hand, replicate beyond the well-being of their host, causing illness and sometimes death. This can happen for a variety of reasons; for example, the bacteria on our skin may pick up a piece of DNA that allows them to resist antibiotics. This often happens in a hospital setting, where a patient who has been on antibiotics for a long time can pass on to other people a bacterial strain that has evolved to resist those medications. The antibiotic-resistant bacteria can be passed along by the contaminated hands of health-care workers or from innocently touching a washroom door in a hospital room shared by four patients. Either way, these new antibiotic-resistant bacteria have developed an evolutionary advantage, defying our usual antibiotic treatment and making the infection much more difficult to deal with. This process has led to the development of the so-called superbug, which we will review in the next chapter. For now, let's look more closely at some of the main bacterial players, particularly those that can cause illness and disease.

Staphylococcus and Streptococcus

Many of the offices in the Bacteria Division are occupied by *Staphylococcus* and *Streptococcus*. Strains of these two long-time leaders have made their homes on human skin and in our mouths and throats. Our skin acts as a waterproof barrier that protects us from getting infections. Having these normal bacteria on the skin's surface helps our bodies function and maintain a fine balance.

When the skin is broken, our immune system is tested, and that is when our normal flora can cause problems. Most commonly these take the form of skin infections, or cellulitis, and small pustules or abscesses. If our immune system is run down, say after receiving chemotherapy treatment for cancer or recovering from a bad viral infection, both *Staphylococcus* and *Streptococcus* can cause more severe, even deadly infections such as pneumonia (infection of the lungs) or sepsis (infection of the blood, or "blood poisoning").

Tuberculosis

Mycobacterium tuberculosis, or TB, is the senior VP of the Bacteria Division, having spent centuries infecting and killing people all over the world and from all walks of life. The disease has gone by many names over the centuries, including the White Death and consumption. From kings and queens to writers and painters, TB has led to the premature death of some of our most famous citizens.

This bacterium most often invades the lungs but can affect every part of the body from the bones to the lymph nodes to the brain. It can also remain dormant in the body for years before becoming active and unleashing its destructive force. The classic symptoms caused by this bug are blood-tinged cough from infection in the lungs, weight loss, and fatigue. In months, sometimes years, people are "consumed" by the bug until they no longer have the strength to breathe.

TB was temporarily thwarted in much of the Western world by improved sanitation and general nutrition, plus the development of antibiotics in the 1950s. But the bacterium has made a dramatic resurgence, and new strains of the disease have proven resistant to treatment. Couple this terrible bug with HIV, and even more severe illness develops more rapidly in the human host. This deadly duo is decimating families and destroying the way of life of entire communities and even countries. The effects of TB and HIV are particularly devastating in sub-Saharan Africa, where tuberculosis is the number-one cause of death by infectious disease and access to treatment may be several days' walk away or, in many places, non-existent.

Cholera

Another ancient disease that has made a comeback in recent decades is the scourge of cholera. Cholera is caused by a bacterium called *Vibrio cholerae*, which kills by essentially draining the body of water. The bug attaches to the lining of the intestines and hijacks the cells that regulate the amount of water we absorb and the amount we excrete as waste in the stool. When things are working well, we take in more water than we pass out. Water is essential for just about all our body functions and is the main component of most of our cells from blood to skin. Cholera bugs press the "excrete" button in every intestinal cell, stopping any absorption and causing a loss of 25 percent of body weight in mere hours. Death comes in as little as twenty-four hours unless the fluid is replaced rapidly and in large volumes.

Cholera is passed between people by what we call the "fecal-oral" route. The bug is most often transmitted from water or food contaminated with human excrement. Once in a new host, the bacterium settles in the intestines and rapidly reproduces until the body gives out. In some cases the immune system is able to rescue the patient from this terminal fate. The natural evolutionary pattern of all bugs is to weaken a person for long enough that the bug can reproduce and pass its legacy generation on to another host. It is in this way that the species survives.

Cholera outbreaks were documented in Sanskrit writings as far back as 500 B.C. For centuries the disease was confined largely to India and the Asian subcontinent, but by the mid 1800s cholera had found its nirvana in the densely populated cities of Europe and the United Kingdom, where the chances of finding a new host to infect were suddenly increased exponentially. Whether it was because of extreme overcrowding or inadequate — in some cases truly primitive — sewer systems that connected with drinking-water supplies, cholera no longer had to wait for victims; they were there for the taking. The bacteria could also make people deathly ill in a matter of hours because it was assured that the bug's progeny would inevitably find a new host to infect. Once improved sanitation and safe drinking-water systems were introduced into the city's infrastructure, cholera outbreaks became rare again, except in its ancient homes on the Asian subcontinent.

But the story doesn't end there. Ever seeking new ways to secure its survival, the cholera bug bided its time, causing small outbreaks in communities in India and Bangladesh while continually evolving to adapt to new conditions. Then when global travel and trade increased in the 1980s and 1990s, the bacterium found a chance to strike again. Hitchhiking in the bowels of ocean-going ships that carried goods from India to South America, cholera found a new home in Peru in 1991 when the vessels pumped their ballast into the harbour.

South America hadn't seen cholera for more than a hundred years (the last outbreak was in 1895) when this new strain, called El Tor, arrived on its shores. Through lack of hygiene the disease spread from street vendors selling contaminated seafood and beverages with contaminated ice. From Peru this new strain of cholera spread rapidly to Brazil, El Salvador, Nicaragua, Honduras, Guatemala, Mexico, Bolivia, Ecuador, and Colombia, leaving more than one million people sick and over ten thousand deaths in its wake in just five years. The economic loss to Peru alone cost the country US$495 billion.

The world of Microbes Inc. thus taught us another lesson: never be complacent. Complacency can be costly, and deadly.

Fungi: Moulds and Yeasts

The third major division of Microbes Inc. is a mixed group of single- and multi-celled bugs called fungi. The members of this division are varied and their effects on humans, animals, and plants are equally as different, though for the most part less severe than those of their bacteria and virus colleagues. In many ways they are the workhorses of Microbes Inc., adding all sorts of good things to the world and now and then causing some havoc. The most important types of fungi that can affect our health are the single-celled yeasts and the multi-celled moulds.

Moulds and yeasts have strong protective cell walls made of a protein substance called chitin, which allows these bugs to survive in some very unusual environments. More independent than their bacteria and virus co-workers, moulds and yeasts reproduce on their own, sometimes forming long filaments, or hyphae (think of an old piece of bread with furry green mould). Fungi have more complex DNA than viruses or bacteria and can grow to be quite large, large enough to be seen by the human eye. Mushrooms and truffles are examples of fungi that most of us are familiar with. They are by far the largest members of this group of more than 1.5 million species.

Fungi, especially moulds and yeasts, play many roles in our world, from decomposing organic matter (along with bacteria) to causing fermentation to providing valuable sources of medications. They can also produce toxins that are particularly lethal to humans. One potent toxin, called aflatoxin, is produced by a fungus that affects peanuts; even a minute amount of this substance can be lethal if ingested. Yet it is difficult to imagine our world without these bugs. Yeast is essential to the production of wine and beer and for baking bread, while a mould called *Aspergillus* yields tempeh and soy sauce. Another produces the "blue" in cheeses such as Stilton and Roquefort. In addition, these good bugs are the source of a number of bacteria-killing agents called antibiotics; from them we have developed drugs such as the penicillins and cephalosporins. Most human illnesses caused by fungi (mostly yeasts or moulds) tend to be relatively mild — conditions such as ringworm, skin infections, and athlete's foot — but some have more serious results and can even be deadly.

Cryptococcus Mystery

Cryptococcus gattii is a modern example of how lethal a fungus can be. This rare yeast lives in soil and the bark of certain trees, mostly eucalyptus, and has been present in areas of Africa, Australia, and southern California for decades. In 1999 it managed to get a toehold in the rainforests of central Vancouver Island in British Columbia, Canada, an area of the world where it had never been seen before. The bug may have been introduced to the region in ballast dumped by ships from Asia; we may never really know. Once on land, this fungus found a suitable home in local trees. Whether because of global warming or just plain luck, the bug was able to thrive and spread explosively over the next eight years, leading to infections in people who inhaled the yeast cells or spores. By 2007 *Cryptococcus gattii* had caused more than 216 people to fall ill with pneumonia, weight loss, night sweats, and fevers, and was responsible for at least eight deaths. Like many members of Microbes Inc., the bug preys on people with weakened immune systems. So while several thousand people may have been exposed to the fungus, only a relative few fell severely ill. This nasty bug is treatable with a potent antifungal medicine, but it took some time before public health disease trackers were able to identify the yeast and educate doctors, who were assessing patients with lung infections. For some it was too late.

The Great Potato Famine

Perhaps the most well-known fungus in history is a bug that doesn't make humans ill but in some ways changed the face of the world. This fungus goes by the grand Latin name *Phytophthora infestans* but is known the world over as potato blight. This bug was the cause of the great Irish potato famine from 1845 to 1849. The fungus was known in its time as potato cholera for the terrible smell it caused in the rotting spuds. The effects of this bug led to the death of 1.5 million people over five years and the exodus of millions of Irish peasants to the shores of North America.

The Irish potato blight is a cautionary tale that we need to heed even today. In 1533 potatoes were imported to Spain from Peru, and the crop had spread to the rest of Europe by early 1600. The original Andean species were hardy tubers that resisted pests such as potato blight. Over time its genetic diversity, which protected the plant in the wild, was bred out of the potato to offer consumers a more pleasing, uniform product. Unfortunately the potato was then no longer able to defend itself against disease.

When potato blight spread to Ireland in 1845, it found fields and fields of susceptible hosts ripe for attack. The population was dependent upon the plant for their diet, and potato cholera led to the starvation of millions of people. This same issue of overbreeding has also resulted in ruined banana crops in Ecuador and widespread disease in vineyards in France. While a single uniform plant product may be beneficial to markets and trade, it creates a weakened species susceptible to the destructive forces of many bad bugs and can have a far-reaching effect on the health of our societies.

Parasites

Members of the final division of Microbes Inc. are the largest in size but have roles as diverse as many of their colleagues. Parasites are bugs that derive nourishment and protection from other living organisms, known as hosts. Many of them find the human body to be the perfect host for some or all of their life cycle. They range in size from microscopic single-cell bugs that are ten times larger than bacteria to multicellular creatures that can be seen with the naked eye. Tapeworms are a good example of larger parasites; some can even grow to be six metres long.

Parasites can be transmitted from animals to humans, from humans to humans, and even from humans to animals.

These bugs live and reproduce in the tissue and organs of infected hosts and are often excreted as hardy spores or eggs in the feces. They are known to be the cause of food- and water-borne illness around the world, and some of the smaller and more devastating members use vectors such as mosquitoes to find their next victim.

About 70 percent of parasites are one-celled bugs. *Giardia* is a common parasite that lives in rivers and streams and forms a hardy cyst that can easily survive the body's digestive juices. When ingested, the bug infects the intestines, causing nasty stomach cramps and diarrhea. Another one-celled parasite is *Toxoplasma gondii*, a unique bug that carries out its reproductive cycle in members of the cat family. In its infective phase the bug forms a strong cyst called an oocyst, which is shed into the environment in cat feces. In its quest to find a new cat to invade, it can sometimes be ingested by humans. While toxoplasmosis rarely makes cats ill, the parasite can cause fevers, swollen lymph nodes, and muscle aches in humans, and those with weakened immune systems can experience permanent eye and brain damage.

The other 30 percent of workers in the Parasite Division are large multicellular bugs we can see with the naked eye. They include roundworms, pinworms, hookworms, tapeworms, and flukes. The preferred hosts for most of these bugs are the animals we rely on for food. They are especially adept at spreading between domesticated cattle and swine that are bred in large, crowded farms. While improved animal husbandry practices in much of the Western world have limited the range of these bugs, their influence is still great in many countries and has had an impact on everything from our food sources to religious practices.

Malaria

The most famous member of the Parasite Division is the one-celled bug called *Plasmodium*, which causes the deadly disease malaria. This remarkable bug has survived for centuries, adapting to just about every place on earth and resisting attempts to contain the disease. Malaria is one of the most influential diseases in human history, and while its impact is no longer felt in much of northern Europe and North America it is still prevalent in Southeast Asia and is responsible for killing as many as a million children a year in Africa.

The history of malaria is the history of man's interface with nature. When humans began farming some six thousand years ago, contact was made with insect species that were previously isolated in the forests. One of the key new contacts was mosquitoes. There are several thousand species of mosquitoes, and about 10 percent transmit diseases to humans. Mosquitoes are amazingly opportunistic, and several species have adapted to survive in specific temperatures, altitudes, and breeding conditions. Some have even adapted to become fully urbanized city dwellers and are able to exist only in the man-made world.

Initially malaria was caused by *Plasmodium ovale*, a species of the bug that produced relatively mild disease in humans. But as we moved farther into mosquito habitat, more virulent strains of the disease emerged. Today the most serious and often deadly infections are caused by *Plasmodium falciparum*, a bug that is now responsible for 95 percent of deaths caused by malaria. This parasite has had such a devastating effect on populations in Africa that people in the area have developed a genetic adaptation called sickle-cell trait, which protects them against the disease. Yet despite our best defences, this pesky parasite continues to have a devastating impact on communities around the world.

DIVISION	SIZE/CHARACTER	PICTURE
Viruses	100 nanometres (100 billionth of an inch) Uses other organism's cells to reproduce	
Bacteria	10 times larger than viruses (at least 1 micron or 4 millionths of an inch) Single-celled microbes that reproduce independently	
Single-celled parasites, yeast, and fungi	10 times larger than bacteria or 0.01 mm Have hard cell walls or form cysts to survive	
Multicellular parasites	Can be seen with the naked eye Can be up to 6 m (20 ft) long	

HOW DO WE GET SICK?

Microbes have designed many evolutionary strategies to spread to new hosts. They can be inhaled into our lungs, ingested in food and water, exchanged through infected body fluids or absorbed through our skin by direct contact or touch, and finally they can spread through insect and animal bites. It is this innate will to survive that has allowed them to maintain their reign as the dominant species on the planet.

A common way for bugs to spread between humans is through the air. These particular bugs infect a host's respiratory system, forcing the person to cough or sneeze, thus dispelling a moist cloud of microbe mist into the environment that others can easily, and unknowingly, breathe in. These stealthy bugs cause some of the world's most deadly diseases and are the reason why covering your mouth when you cough or sneeze is essential to sparing others from infectious disease.

Other bugs pass through the fecal-oral route, when a host unknowingly ingests the microbes that live in human waste. These microbes spread into the environment by causing diarrhea. Millions of bugs hide out in an infected person's loose, watery stool, and then contaminate food or water that others unknowingly ingest. While this sounds pretty gross, we have to remember that most bugs are microscopic in size; millions and millions of infectious bugs can be living in what appears to be a perfectly clear glass of water. If sanitary conditions are poor or if people do not adequately wash their hands after using the toilet, these bugs can remain active, sometimes for hours, on our hands. And if an infected person handles food for others to consume, the cycle starts again in a new digestive system. This is one of the many reasons why washing your hands or using an alcohol-based hand rub is critical to maintaining good health and stopping the spread of disease.

But disease can also be transmitted through other means such as direct contact or touch. Skin-to-skin contact can spread illness when, for example, an infected pustule on one person touches a small tear in another person's skin. Sexual contact is another common way to transmit disease through direct touch. We can also pass diseases through blood, as we saw so tragically in the 1990s when patients around the world contracted HIV through blood transfusions (this was before policies were instituted that required all blood donations to be tested for the virus). In hospitals and other health-care settings, diseases such as hepatitis B and HIV can be passed on from an accidental needle-stick injury. Bugs are also spread between injection drug users who share tainted equipment. Some can even be transmitted through breast milk or other body secretions such as urine, saliva, or even tears.

Finally there is a whole class of diseases that can be passed on to people by what are known as vectors, the term used for insect, tick, and animal bites. The main culprits in this class are mosquitoes, which are responsible for infecting humans with a nasty range of diseases including malaria, yellow fever, and dengue. With increasing global temperatures these vectors have expanded their reach and now make their homes in areas of the world where the species was previously unknown. The virus that causes dengue, for example, is making a huge comeback in parts of the world that had been free of the bug for decades. Another fearsome bug, passed mainly through bats but also through foxes, raccoons, and dogs, is rabies, a disease that is almost always fatal in humans.

The respiratory and fecal-oral routes are the two most common ways for bugs to infect new human hosts. Interestingly, most microbes have adapted to perfect only one method of transmission. For example, if you happen to eat food contaminated with an influenza virus, it is unlikely to make you sick, because influenza doesn't have the ability to survive the acid environment of your stomach. On the other hand, if you somehow inhale *Salmonella*, a common bacteria in food, the bug probably will have no effect on your health because it has not developed the ability to attach to the lining of your nose or lungs.

With so many ways of contracting disease and so many dangerous, adaptable bugs, the path to protecting ourselves has been complex. But there have been some major medical advances in the past two hundred years. We will examine the battle between bugs and humans in the next chapter.