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Chapter 1

Focusing on Vaccine Fundamentals

Infections that once haunted childhood are now seen only in textbooks. These were the true bogeymen of childhood, the real monsters under the bed. They were common and potentially life-threatening. We now have vaccines for these infections that were so tricky to treat and easy to spread. Most children around the world are vaccinated against these bogeymen, including, among others, measles, polio, diphtheria, tetanus, and smallpox. Vaccines have helped send these diseases packing, even though we still don't always have good treatments for the diseases themselves.

There's a lot of information — and misinformation — out there about vaccines. When large groups lose trust in the benefits of vaccination, many people, not just those who don't want to be vaccinated, can suffer. Diseases like COVID-19 can continue to spread. Those who have weakened immune systems that don't respond well to vaccines can be infected by others. It's important that we keep our eyes on the common enemy — infectious diseases.

Realizing the Crucial Role of Vaccines

Vaccinations provide a valuable tool. You can give your immune system a heads-up about infections before you ever see them. You can stop diseases before you ever get sick by giving your immune system a cheat sheet on what to look for. Unlike medications that reduce the symptoms once the illness has begun, vaccines can stop infections before they ever happen. Childhood — and adulthood — have become a lot safer in the process.

Vaccines give your immune system a superpower. Through vaccines, your immune system learns how to stop bad guys it's never seen before. These bad guys cause infectious diseases. They're the *pathogens,* also called germs, which are so tiny that we can see them only with a microscope. These pathogens include bacteria, viruses, fungi, and parasites. Chapter 2 describes different viruses and the vaccines that combat them, while bacteria and their vaccines are discussed in Chapter 4.

REMEMBER

Vaccines provide you with personal protection against these pathogens and the diseases they cause, but what works even better is if everyone is vaccinated. The superpower of a vaccine increases as more people jump on the bandwagon. With infectious diseases, we're all in this together. If everyone is vaccinated, a pathogen spreading person to person is stymied.

Vaccines may not provide 100 percent protection. Some people may not be able to take or benefit from a vaccine; they may be too young or have a weakened immune system. But if enough of us are vaccinated, odds are the pathogen just can't spread. It can't jump from person to person. It may infect one person and maybe another, but if most people are vaccinated, it won't keep finding new people to spread to and will fade away.

This is what *herd immunity* is all about — when enough people are vaccinated, we can push back the spread of some terrible and deadly diseases. Chapter 11 details the benefits of herd immunity and debunks the myths often perpetuated about vaccines. Diseases can bounce back if fewer people are vaccinated.

We can save many lives if we had more vaccines. Scientific challenges and the lack of funding and motivation have kept some vaccines from being developed. (See Chapter 13 for more information.) New diseases yet to emerge will need vaccines, as we have seen as COVID-19 has spread around the world. (See Chapter 3 for info on COVID-19 and the vaccine.)

It may not seem so exciting now, but we have had reliable and effective vaccines only since the end of the 1700s. At that time, it was found that one mild virus, cowpox, can train our immune system to protect us from a terrible virus, smallpox. (If vaccine history interests you, check out Chapter 12, which discusses the people instrumental in creating a number of vaccines. Chapter 14 describes major pandemics throughout history.)

Many vaccines work on the same principle as this first vaccine did: Show the immune system something harmless but similar to what causes the disease, and the immune system will learn to protect us against the dangerous one too. However, scientists continue working on vaccines to develop new, possibly more effective approaches to train our immune system. Different pathogens require different sorts of vaccines, and for some diseases, vaccines still elude us.

We do have vaccines for a wide range of infections, though. Vaccines can prevent some types of liver disease (hepatitis A and B) and some types of cancer (human papillomavirus). We also have vaccines for adults, such as for pneumonias and shingles, diseases we're more prone to as we get older. But we still don't have vaccines for the infections that year after year take the most lives. We don't have an HIV vaccine, and we need better vaccines for tuberculosis and malaria. We also don't have a vaccine for the common cold, which would be hard to make. Chapter 6 provides information on all current vaccines, while Chapter 13 looks at diseases that still aren't preventable.

REMEMBER

As is often said about vaccines, it's not vaccines that save lives; it's vaccinations. For communities to be protected, vaccines need to be given. The tough part is often ensuring that vaccines are accessible for all and vaccination rates are high enough to protect the entire community.

Explaining How a Vaccine Works

Vaccines hold up a "Wanted" photo of the bad guy — the pathogen or germ. Each vaccine is a little different, but they all show our immune system something super recognizable about the pathogen. That way, if we are ever exposed to this pathogen, our immune systems will respond to it.

The "Wanted" photo can be some bit from the outside of the pathogen, like a specific protein or sugar. These bits act as a way to identify the pathogen, similar to the way a tattoo or birthmark helps you identify a person. The vaccine version may attach this "Wanted" photo to a warning, like a blinking red light, such as a protein that will create a stronger immune response.

Other vaccines may be the equivalent of a head-to-foot photo; some vaccines use the whole pathogen (in a killed vaccine, explained more in Chapter 5) or in a live, but safe, similar version. Chapter 7 discusses the ingredients that typically make up vaccines.

REMEMBER

Vaccines let you bypass the delay it would take to develop natural immunity if you were first exposed to the pathogen without this head start. Normally, it can take a couple of weeks for your immune system to figure out how to fight a new disease; with a vaccine, your body is ready and able to fight from the first time you see the actual pathogen.

Find out more about the basics of how a vaccine works in the following sections.

Distinguishing between antigens and antibodies

Antigens are what is memorable in the "Wanted" photo. An antigen is something very specific — like that birthmark or tattoo — that can't be missed. Your immune system uses that very specific marking to create an immune response and memory. This marking is usually a protein or sometimes a sugar on the outside of the pathogen.

Antibodies are what your body makes in response to antigens. After your body has been shown the antigen or "Wanted" photo, you keep a supply of memory immune cells that can make a whole lot more antibodies if the pathogen ever arrives. Specific antibodies go after just one specific antigen. Once that antigen is found again, your body floods it with copies of this antibody from those memory immune cells. The antibodies then attach themselves to their antigens, which are on the outside of the pathogen. The antibodies then stop this specific pathogen, like a virus particle or bacterium cell, from causing any more problems.

It typically takes a few weeks after exposure for the body to produce this response. Vaccination gives you a head start so you already have the ability to make all these antibodies if you need to. With a natural infection, you can get quite sick before you were able to scramble and create an effective immune response.

Breaking down other vaccine ingredients

Vaccines contain more than just the "Wanted" photos, called antigens, that help your immune system identify pathogens (see the preceding section). Other ingredients are needed to make sure the vaccine works as it should:

- Some of these "Wanted" photos don't create much of an immune response. The immune system needs to be alerted to the fact that this "Wanted" photo is important to remember. Vaccines may include an alert, which acts like a red blinking light, saying "pay attention here." This ingredient may even be directly attached to the "Wanted" photo. Such alerts when added to the vaccine mix are called *adjuvants.* A common adjuvant includes aluminum, also found in drinking water, antacids, and antiperspirants. We discuss the ingredients that go into vaccines more in Chapter 7.

- Vaccines also may contain stabilizers, much like some of our food does. These include sugars and gelatin (also found in Jell-O) that keep the vaccine ingredients well mixed, so they don't separate or deteriorate.
- Vaccines can sometimes include preservatives to keep mold or bacteria from growing in the vaccine, much like we would have in a bottle of jam at home. Just as many foods are advertised as preservative-free, many vaccines are too. Preservatives are particularly used in multi-use vaccine bottles, especially for the flu, as these are kept open longer to vaccinate multiple people. In some cases, this can include thimerosal, which contains mercury, but it's a type of mercury that doesn't have the same worrisome risk as the mercury found in fish. Children's vaccines do not include mercury, except in rare cases with multi-use flu vaccine vials and some specific brands of tetanus shots for adolescents.
- Vaccines may also include trace amounts of chemicals used in their production. These substances are removed, but sometimes a very small amount remains. In order to include a whole virus or bacteria but make sure it's dead and won't make copies of itself, formaldehyde is used. The amount used in a vaccine is much, much less than we naturally have in our bodies.
- Sometimes antibiotics, usually not the sorts we are allergic to, are used to keep bacteria from growing during production. These antibiotics are removed at the end, so at most only a tiny amount remains. Eggs are used to grow some viruses used to make vaccines, and so egg proteins, in very tiny amounts, may be present in some specific vaccines.

Comparing Viruses, Bacteria, and Toxins

REMEMBER

Scientists have studied and created different vaccines for a whole range of different pathogens. Pathogens are the germs, so small that you need a microscope to see them, that cause infectious diseases. The two main types of pathogens we vaccinate against are viruses and bacteria:

- **Viruses** are super tiny particles, made of genetic material surrounded by a protein shell. They can make copies of themselves only inside of other cells.
- **Bacteria** are more complicated; they are single-celled, living organisms that can usually make copies of themselves on their own.

Viruses, the smallest of the common pathogens, are protein shells with a bit of genetic instructions tucked away inside. Viruses use these instructions inside another cell, such as our own, to make copies of themselves; in the process our cells may be damaged by the virus or our immune system's response. Because viruses can't make copies of themselves on their own and need to be inside a cell, they aren't considered fully alive. We go more in-depth about viruses in Chapter 2.

Pathogens also include bacteria, as we talk about in Chapter 4. These are made up of a single cell that can reproduce on its own. Some bacteria invade your cells; others remain outside; some may do either. You have lots of bacteria inside your body at any time. In fact, we have more bacterial cells than human cells in our bodies. Our skin and gut and immune systems keep these bacteria where they should be, but sometimes these bacteria or new invading bacteria can make you sick. Antibiotics can work against these worrisome bacteria, but antibiotics don't work as quickly as vaccines. Vaccines prevent you from ever getting sick, while antibiotics only reduce the symptoms once you do get sick.

Other types of pathogens include the following:

- **Parasites:** These can be single-celled like malaria, which is a lot larger and more complicated than bacteria are. Parasites can also include worms that infect you or even tiny insects like bed bugs or scabies. We haven't been successful at making vaccines for many of these but are now having some success with making vaccines for malaria.
- **Fungi:** These are effectively the mini cousins of mushrooms. They include molds and yeasts. Infections may be from the environment, say from a dust storm in Arizona that can spread Valley Fever, a fungal infection, from the sand and dust. There haven't been any approved fungal vaccines.
- **Prions:** Like viruses, prions also aren't really alive, and they're even smaller. They're just crumped proteins that can cause other proteins of the same type to crumple up in the same way. This type of infection causes Mad Cow Disease and a few other diseases, but they're incredibly rare. We don't yet have any vaccines for prion diseases in humans (but there is some promising work for animal diseases).

Vaccines for viruses and bacteria can include many different types (see Chapter 5 for details):

- The oldest type is a similar but alive (or replicating) bacteria or virus that shows our immune system what the danger is without causing us any harm.

- Another tried-and-true method is to take killed, whole bacteria or viruses. These won't be able to infect us but will show our immune system what to watch for.
- Other vaccines use small proteins or sugars, found on the outside of bacteria or viruses, that can be used to recognize pathogens.

IS THIS INGREDIENT SAFE?

Vaccines go through rigorous multi-stage testing to ensure they prevent disease and are safe without worrisome side effects. Once vaccines are approved, they continue to be watched for any signs of any problems. Chapter 5 looks more closely at the vaccine testing and manufacturing processes.

The ingredients in vaccines are carefully monitored to ensure they don't have worrisome side effects. The ingredients are clearly listed in the insert that comes with the vaccine. If you ever have any questions about any ingredients and whether you might be allergic to one, you can discuss this with your doctor or healthcare provider.

After vaccines are approved by government agencies, including the Food and Drug Administration (FDA) in the United States, they are still monitored for any signs of problems. Anyone who is vaccinated in the United States can report any side effects to a national database that watches for and tracks patterns and serious events.

The manufacturing of vaccines is also watched closely. There are ongoing inspections and monitoring of vaccine production facilities by the FDA in the United States and by other independent government organizations in other countries. Around the world, the World Health Organization (WHO) also assesses factories before they begin production for quality, safety, and efficacy. Only factories that are continually inspected and approved for production can make the vaccines.

Once vaccines are produced, they undergo testing again. Vaccines are made in batches called *lots.* Samples from every single lot must be tested to ensure they have the pure, potent, and safe ingredients they are intended to have. No vaccine lot can be distributed until it is released by the FDA. Other countries have similar regulations. If a problem was found in a vaccine from one lot, the entire lot can be recalled.

Once vaccines are released, they have to be packaged and stored in certain conditions to keep the vaccine from deteriorating. Many vaccines require what is called *cold chain,* meaning they have to be kept within a very specific range of cold temperatures all the way from factory to delivery for vaccination. That way, you can feel assured that the vaccine you receive is still potent when you receive it.

- Some vaccines are made against the toxins that bacteria release to make us sick. The vaccine includes something similar and benign, called *toxoids,* which don't make us sick, in order to teach our bodies to recognize toxins.
- Two new types of vaccines have been used so far for viruses — viral vector vaccines and vaccines made from genetic material, like mRNA. These vaccines carry the genetic instructions into our cells in order to build a protein that our immune systems can use to recognize a pathogen.

Studying COVID-19 Vaccine Development

Infectious diseases have not been completely tamed. COVID-19 reminds us there are many viruses and bacteria out there that we've never dealt with before. It goes without saying that COVID-19 changed the world abruptly for us all. In the first full year of the pandemic (2020), it led to at least 350,000 deaths in the United States and at least 1.8 million deaths reported worldwide. Vaccines have been an important part of the solution.

No vaccines have been watched as closely as the COVID-19 vaccines as they passed through phase I, then II, then III, and onto use in the general population. The world watched as controlled trials studied the use of the vaccines versus a placebo. These trials — as well as post-rollout monitoring — looked closely for any side effects.

As we discuss in more detail in Chapter 3, many different types of vaccine methods are used today. A lot of advances in vaccine science led to the COVID-19 vaccines. The first vaccines came from science that was only a couple of decades old. The COVID-19 vaccines currently in use are messenger RNA (mRNA) or viral vector vaccines.

REMEMBER

Vaccines were also shown to provide better protection than natural infection, especially when facing new variants of COVID-19. As COVID-19 has spread around the globe, it has collected many new mutations creating new variants, so your immune system may not recognize new variants after getting sick with a prior one. It may become necessary to have booster COVID-19 vaccinations to remain immune, just like you need to remain protected against the flu.

WHY LAST YEAR'S FLU VACCINE WON'T WORK THIS YEAR

Most vaccines work well year after year. Some, particularly for influenza, need an update. That's because some pathogens change their looks. It's the pathogen equivalent of a wig or a fake moustache that fools our immune systems. What the pathogen looked like last year may not be what it looks like this year, at least to our immune systems.

Pathogens may change their looks by collecting mutations that each make small changes generation after generation. Over time, in a pathogen's family tree, the great-grandparents may look just a bit different than future generations. There may be different proteins (or sugars) on their surfaces, making them unrecognizable.

The flu does even more to dodge your immune system's attention. Mutations build up as the flu copies itself again and again. But it does something more. It also mixes and matches the proteins on the outside. It takes a fake moustache and a hat one year, a wig and a mask another year. This means a vaccine that works this year may not work next year. Some types may persist for a few years. Others need to be updated. As we discuss in Chapter 6, a lot of thought goes into the flu vaccine each year, trying to guess six months ahead which fake moustaches and wigs will be en vogue for the flu this year. The vaccine is updated every year in both the Northern and Southern hemispheres in time to vaccinate everyone who wants it in preparation for the wintertime flu season.

Understanding the Importance of Vaccine Schedules

Unfortunately, vaccines don't always fall into the "one and done" category. In many cases, a series of vaccines, given on a specific schedule, are necessary to provide you or your children with protection against diseases. While no one wants to get an injection more than once, skipping doses or spreading them out can decrease the effectiveness of the vaccine and increase your chance of becoming ill.

REMEMBER

Vaccine schedules are particularly important for infants and children because the diseases that the vaccines prevent are especially deadly for them. While the number of vaccines given to babies today has increased, worrying some parents, science has shown that the total number of vaccines given today isn't harmful. Spreading out vaccines on a delayed schedule can be harmful rather than helpful to infants, increasing their risk of becoming sick. To help you make the best decisions about vaccinations, Chapter 11 discusses the myths that surround vaccination and vaccine schedules, especially for young children.

Trying to keep track of vaccination schedules can be complicated. We make it easier by describing which vaccines are required for infants and children at which ages in Chapter 8. We include the same information for adults in Chapter 9. Chapter 10 explains when you or your child should *not* get vaccinated, due to certain health conditions. Thankfully, these conditions are rare.

Preparing for Potential Vaccine Side Effects

Any substance you put inside the human body has the potential to cause side effects. In most cases, side effects don't affect everyone, and most side effects aren't serious or long lasting. But it's always nice to be prepared for typical side effects, and it's important to be aware of more serious side effects that necessitate a visit to your healthcare provider. We spell out side effects and what to watch for in Chapter 7.

WARNING

Rarely, around one in a million or so cases, a vaccine can cause an anaphylactic reaction. This type of reaction can affect many body systems and be life-threatening. Anaphylactic reactions can occur if you have an allergy to one of the ingredients found in the vaccine. If you have known allergies to a vaccine or a possible vaccine component, always check the ingredients on a vaccine's label before being vaccinated. Anaphylactic reactions can include difficulty breathing, facial swelling, a drop in blood pressure, or loss of consciousness. Most, but not all, anaphylactic reactions occur within a few minutes after receiving a vaccine.

WARNING

Anaphylactic reactions are a medical emergency and require immediate medical attention. If you've had this type of reaction in the past, your healthcare provider may recommend carrying an epinephrine (epi) pen.

Optimizing Your Immune Response

REMEMBER

While you can't prevent all illnesses, you can do your part to keep your immune system as healthy and effective as possible. Getting vaccinated is the number one thing you can do to boost your immune system. Certain lifestyle changes can also help keep your immune system humming.

No, there are no magic bullets, pills, or other easy ways to do this. But Chapter 15 includes information that you may not have realized on ways to keep your immune system healthy, from the effects of smoking and alcohol on your immune system to the benefits of getting enough sleep. We also include info on supplements often taken for good health.