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The Independent Scientific Advisory Group for Emergencies (SAGE)

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Preventable Diseases, Preventable Tragedies: Why Vaccines Are Essential

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Preventable Diseases, Preventable Tragedies: Why Vaccines Are Essential

Introduction

The first vaccine was given by Edward Jenner in 1796. Since then, vaccination has dramatically reduced serious disease and deaths from a host of infectious agents. Smallpox, the target of Jenner's pioneering inoculation 229 years ago, was declared eradicated – i.e. no longer existing in nature - in 1980. Eradication through vaccination is also within reach for some other diseases, such as polio. Elimination, meaning no sustained community transmission, has been achieved for multiple infections in the USA, UK and other countries through vaccination. However, reduced vaccine uptake in recent years now threatens these achievements.

In some ways, vaccination has become a victim of its own success. Diseases that were common killers in the 19th and early 20th centuries are now so rare that most people—including many doctors—have never seen a case. Stories about adverse effects of vaccines, whether true or false, are ubiquitously amplified on social media[1] and even some mainstream media.

Small wonder that many people are wondering whether the benefits of vaccines outweigh their risks. It is important that we all understand the potential harms of *not* vaccinating (or delaying vaccination). The death in February 2025 of an unvaccinated American child from measles is a sobering reminder that the diseases we vaccinate against in early childhood can kill.[2] Another death (in an adult) in the same outbreak[3] reminds us that not being vaccinated as a child leaves us with lifelong vulnerability.

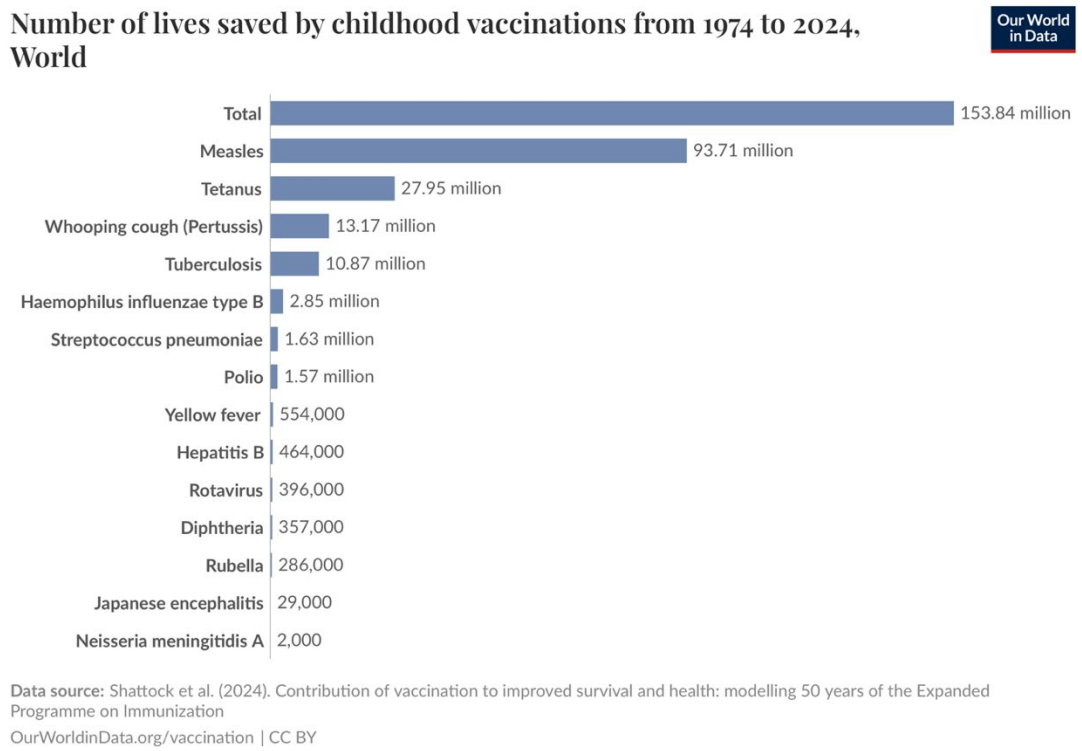
In this report, we cover four topics.

1. Once-common diseases that have been controlled by vaccines;
2. What vaccination is and how it works, both at individual and population levels;
3. Balancing the benefits of vaccines against the risks;
4. Why vaccine uptake is falling in some countries.

Some diseases that have been controlled by vaccines

Overview

The graph below shows that an estimated 154 million lives have been saved worldwide by childhood vaccines between 1974 and 2024.



In this section, we discuss diseases whose frequency has fallen dramatically in the last few decades as a direct result of childhood vaccination programmes. We describe what the diseases are, their effects on people (both typically and in severe cases), and how vaccination has reduced their impact. For describing impact, we primarily use statistics from the USA.

In this report, we cover: Measles, Tetanus, Whooping Cough, Diphtheria, Chickenpox, Hepatitis B, Polio, Mumps, Meningococcal Disease, Rubella (German Measles), Haemophilus Influenza B (Hib), and Human Papilloma Virus (HPV). We also briefly mention two diseases (influenza and COVID-19) whose severity has been changed by regular vaccination of adults.[1]

[1] We have not covered tuberculosis (TB) because this remains a challenging infection to eradicate due in part to many people having latent infection without active disease. Whilst the current vaccine is 70-80% effective at preventing the most severe forms of disease, it is not very effective against preventing pulmonary TB. As such there is still debate about vaccine efficacy and about who should be vaccinated, in what circumstances and for what purpose (individual or population protection). Vaccination against TB is not currently part of routine immunisations in either the UK or the USA.

Measles

Measles is the most infectious viral illness known. The first symptoms appear about 10-12 days after exposure to someone with the illness and include high fever, cough, runny or blocked nose, sneezing and red, sore eyes. These are followed a few days later by a rash that starts on the face and behind the ears before spreading to the rest of the body. Spots may also appear in the mouth, inside the cheeks and lips. Most patients improve after 7-10 days although about one in four unvaccinated people will require hospitalisation.

Common serious complications include diarrhoea, ear infections and pneumonia; some of these are directly caused by the measles virus and some are due to a bacterial infection developing on top of the virus. More rarely, measles causes meningitis (inflammation of the membranes surrounding the brain), encephalitis (inflammation of the brain itself), seizures (fits) and blindness; one or more of these complications occur in about 1 in 1000 people overall. Whilst they are most likely to affect babies and people who are immunosuppressed, they can occur at any age in unvaccinated people: the 7-year-old daughter of the author Roald Dahl tragically succumbed to measles encephalitis in 1962, just before vaccines were available. Measles during pregnancy can cause miscarriage, stillbirth or premature delivery.

The measles virus can weaken the immune system both during the acute infection and for the longer term. The virus actively targets the "memory" white blood cells that produce antibodies, making the person vulnerable to other infections, including some to which they were previously immune, for the rest of their life.

Very rarely, (in about 1 in 10,000 cases) the measles virus can linger in the brain and recur, usually around seven years after the original infection. This is known as subacute sclerosing panencephalitis (SSPE), a progressive neurological disorder which gets inexorably worse and is invariably fatal.

Measles vaccine was first introduced in the USA in 1963 and first combined with the mumps and rubella vaccines (as MMR) in 1971. Before the introduction of the vaccine, there were approximately 3 million reported measles cases in US children every year, 48,000 hospitalisations and 400-500 deaths.[5] Vaccination efforts led to a more than 95% reduction in measles cases between 1965 and 1968. Measles was declared eliminated in the USA in 2000, but several outbreaks have occurred since, linked to travel outside the USA and to unvaccinated people.[6] Across the world, measles kills more than 100 000 people annually, almost all unvaccinated or partially vaccinated children.[7] The current outbreak in the US, centred in Texas but now spreading to other

states, has exclusively affected unvaccinated children and adults, and has already led to the most tragic consequences.

Tetanus

Tetanus is caused by the *Clostridium tetani* bacterium which is widespread in soil and manure. Patients are infected when the skin is broken by a contaminated object, for example by treading barefoot on a dirty nail. The bacterium produces a toxin which interferes with nerve transmission resulting in muscle spasms. The most common form of tetanus starts between 3 and 21 days after the injury and the first signs are spasms in the jaw – the old name for tetanus is "lockjaw". These spasms then spread to the rest of the body and each one lasts a few minutes. They can be strong enough to tear muscles and break bones. Other symptoms include fever, headache, high blood pressure, a fast heart rate and difficulty swallowing. The illness usually lasts 3-4 weeks, although recovery may take many months, and about 10% of patients die.

Babies of mothers who have not been immunised can die from tetanus when the umbilical cord is cut with dirty instruments or when the stump is not kept clean. However, if the mother has been vaccinated her immunity will be passed to her baby and offer effective protection for the first few months of life. Neonatal tetanus was common until the late 20th century but has now been eliminated in many countries.

Tetanus is not passed from person to person. Vaccination is the only way to prevent it because the bacterium which causes it so widespread in the environment. The first vaccines were developed in 1924. Pre-vaccination there were about 500-600 cases a year in the US. Thanks to vaccination, in the United States there are now about 30 cases a year, nearly all in unvaccinated or only partially vaccinated people.[8]

Whooping cough (pertussis)

Whooping cough is caused by the *Bordetella pertussis* bacterium, which is spread through the air easily by coughing and sneezing. The infected person typically gets a mild fever, runny nose and cough, about one to two weeks after exposure. These symptoms are followed a week later by severe coughing fits and this phase lasts up to three months, which is why it is sometimes called the 100 days cough. In about half of patients at the end of a coughing fit there is a characteristic 'whooping' sound as the patient takes a deep breath in. Often the coughing is violent enough to cause vomiting, bleeding in the eye (subconjunctival haemorrhages) or rib fractures. Young babies may not cough but instead may have periods of difficulty breathing.

Antibiotics can be useful if started early in the infection and are sometimes given to vulnerable contacts of infected people. Although most older children and adults make a full recovery, babies under one year of age are particularly at risk of severe disease. Half of young babies with whooping cough will need treatment in hospital and one in 200 will die.

The pertussis vaccination does not completely prevent the infection in all cases but, if infected after vaccination, the symptoms are much milder. As well as being included in the early childhood vaccine schedule, it is also offered to all pregnant women as they will pass on protective antibodies to their babies which last until the baby can receive its first vaccination. Routine vaccination started in the 1940s, when there were about 175,000 annual cases[9] and 9,000 deaths[10] in the US. There are now about 10,000-40,000 cases a year in the US, and 10-20 deaths.

Diphtheria

Diphtheria is a serious infection caused by a bacterium called *Corynebacterium diphtheriae* and spread mostly by coughing and sneezing. Most commonly, it causes a sore (and very swollen) throat, fever, weakness and lethargy. A characteristic sign is the formation of a thick, greyish-white membrane that sticks to the tonsils, back of the throat and inside the nose. This membrane can obstruct the airway and lead to death by suffocation. Diphtheria can also cause myocarditis (inflammation of the heart muscle), leading to heart failure and abnormal rhythms (including, occasionally, cardiac arrest); neuritis (inflammation of the nerves), causing paralysis; a nasty rash (with ulceration) of the skin; and toxaemia (blood poisoning from potent toxins produced by the diphtheria bacterium), leading to multiple organ failure.

In the 1920s, the USA saw 100,000 to 200,000 cases of diphtheria every year, with 13,000 to 15,000 deaths (mostly in children under 5, but also in older adults).[10] Vaccines were introduced in the 1930s and 1940s (depending on the state) and led to a dramatic fall in cases and deaths from diphtheria. From 1996 through 2018, 14 total cases of diphtheria were reported in the United States, an average of less than 1 per year.[10] They were likely imported from a country where vaccines weren't widely available.

Chickenpox

Chickenpox is caused by the highly infectious varicella zoster virus. Symptoms usually appear 10-21 days after being exposed to a person with the illness, In adults and teenagers the disease typically begins with a few days of feeling unwell (low grade fever loss of appetite and headache) before the rash appears. In children, the rash may be the first sign of illness. It consists of small blisters which first appear on the trunk and face and then spread to the limbs, before eventually crusting over. The spots can be very itchy and bacterial infection of the skin after scratching is common. Chickenpox is often a more severe illness in adults, especially men, and can affect internal organs such as the brain (encephalitis), liver (hepatitis) or lungs (pneumonia). Chickenpox pneumonia can be particularly severe in smokers. Deaths from chickenpox are rare, occurring in approximately 1 in 60,000 cases. In 2015 chickenpox resulted in 6,400 deaths globally, down from 8,900 in 1990.

If a pregnant woman who has not previously had chickenpox or been vaccinated is infected in the first six months of pregnancy, the virus can cause severe malformations of the developing baby. Infections later in pregnancy may cause severe illness in the mother, preterm birth and infection of the newborn.

The virus that causes chicken pox is not always eliminated from the body by the immune system but may linger in nerve roots. In later life, it can be reactivated and show as shingles, also called herpes zoster, a painful blistering rash that appears in the area of skin supplied by one nerve root. Shingles usually affects older adults. It can be triggered by anything that reduces the function of your immune system. Recent research has identified shingles as contributing to the development of dementia in some people and modern shingles vaccines as reducing that risk.

In the UK, vaccines against chickenpox are not yet included in the childhood immunisation schedule, although they have been recommended at 12 and 18 months, but in many parts of the world including the USA children are routinely vaccinated.

In the US, where the vaccine was introduced in 1995, annual numbers went from over 4 million cases and over 10,000 hospitalisations down to fewer than 150,000 cases and 1,400 hospitalisations now.[11]

There is a programme of vaccination of older adults against shingles in the UK.

Hepatitis B

Hepatitis B is a blood borne virus that affects the liver. The virus can be passed on from an infected mother to her baby at childbirth (vertical transmission). It can also be passed on through saliva (e.g. human bites), through sex (especially if one partner has an open sore), and in blood, for example from contaminated blood transfusions or sharing of needles for intravenous drug use.

The acute (short-term) phase of hepatitis B happens about one or two months after infection and typically manifests with nausea, loss of appetite, fever and jaundice. This illness usually lasts a few weeks. Some patients have no symptoms and are unaware of the infection.

The chronic (long-term) phase of hepatitis B may also be asymptomatic. However, it may cause ongoing inflammation of the liver which in turn may lead to cirrhosis (in which the liver progressively shrivels up and stops working), liver cancer and liver failure.

Hepatitis B is very widely present in the world, affecting about 3.8% of the world's population in 2019, and causing 820,000 deaths, mostly from cirrhosis and liver cancer.

Vaccines for hepatitis B were first used in the USA in 1991 and are part of the routine childhood immunisation schedule there. They are 95% effective when given in

childhood. Since vaccination, the rate of acute Hepatitis B decreased by 80% in children under 10 years old and by 95% in healthcare workers.[12]

In many other countries, hepatitis B vaccine is given only to people considered at high risk of exposure to blood borne infections, including intravenous drug users and healthcare staff.

Polio

Polio is short for poliomyelitis, a viral infection that is passed on by eating or drinking something contaminated with the virus. Many people have no symptoms at all. One in four will have mild gastro-intestinal symptoms (e.g. diarrhoea) or flu-like symptoms (fever, sore throat and lassitude). In approximately one in 100 people, the virus also infects the nervous system where it causes headache, neck stiffness and pins and needles. In severely affected patients the nervous system involvement results in muscle weakness and paralysis—most commonly of the legs but sometimes of the muscles of the head, neck and diaphragm (an internal muscle which is needed for breathing). This paralysis can cause permanent disability. Deaths from polio are mostly the result of respiratory failure (because the person is unable to breathe because their rib and diaphragm muscles have stopped working). People may remember images of hospitals filled with so-called "iron lungs", which breathed for patients until they hopefully recovered, which sadly was not always the case. Many people also lived with long term physical disabilities caused by polio induced paralysis, including Franklin D. Roosevelt, the 32nd President of the USA from 1933 – 1945, who was left dependent upon a wheelchair by the illness in 1921.

The polio vaccine was introduced in the USA in 1955. Before that time, periodic epidemics occurred. In a typical year, there would be 25,000-50,000 reported cases of polio, 8,000-16,000 cases of paralytic polio and 2000 deaths from polio.[13] Since the introduction of vaccines, polio has become almost unknown in the USA and most of the world. The last case of polio was in 1979 and in 1994 polio was declared eliminated from the Americas.[14] Older vaccines used a live attenuated vaccine (the oral vaccine) which, although safe, could circulate in areas with low vaccine coverage. If this happens for a long enough the virus can revert to the original form that again causes the symptoms of polio. This does not happen if a population has been well-vaccinated as people will be resistant to any poliovirus infection. Current polio vaccines use a killed virus and are very safe and cannot transmit in under-vaccinated populations.

Mumps

Mumps is a highly contagious infection caused by the mumps virus. It typically affects children, but people of any age can become infected, and it can be more severe in unvaccinated adults. It begins with a fever, headache, fatigue and muscle aches (a phase known as the 'prodrome'). Then, the parotid salivary glands at the side of the face

(on either one or both sides) become swollen and painful ('parotitis'). There is pain on chewing and swallowing, and it can be difficult to swallow food and fluids. The person also often has dry mouth, earache and jaw pain.

Complications are common. Between 20 and 40 percent of adult males who get mumps will develop orchitis (inflammation of the testes); around half of these will notice some shrinkage of their testicles and an estimated 1 in 10 men experience a drop in their sperm count (the amount of healthy sperm their body can produce). Viral meningitis can occur if the mumps virus spreads into the outer protective layer of the brain (the meninges); this occurs in up to 1 in 4 cases of mumps. About 1 in 25 cases of mumps lead to short-term inflammation of the pancreas (acute pancreatitis), 1 in 100 develop encephalitis and 1 in 25 temporary or permanent hearing loss. Miscarriage can occur if mumps infection happens in pregnancy. Death is very rare in mumps but can occur from encephalitis.

Mumps vaccine was introduced in the USA in 1967 and incorporated into the triple (MMR) vaccine in 1971. Before the vaccine was introduced, hundreds of thousands of cases occurred in the USA annually. Since vaccination became widespread, the incidence of mumps has fallen by 99% in the US, and the US currently sees about 400-600 cases of mumps per year.[15]

Meningococcal disease (including meningitis)

Meningitis means inflammation of the meninges, the delicate membrane that encases the brain. It can be caused by many different infections (and also, occasionally, for other, non-infection related, reasons). *Meningococcal* meningitis is a particularly severe form of meningitis caused by the meningococcal bacterium, *Neisseria meningitidis*. In infected people, the disease progresses rapidly, beginning with high fever, severe headache, nausea and vomiting, and cold hands and feet (a sign of circulatory shock). A stiff neck, sensitivity to bright light, and confusion are all indications that the meninges are severely inflamed. A characteristic rash can appear. It is often said that the rash of meningococcal disease is flat and purple (known as purpura, which means "little bruises") and does not blanche when pressed (for example, with the base of a glass). In reality, a meningococcal rash may take many forms. While a rash is a bad sign (indicating severe infection), the absence of any rash does not exclude meningococcal disease. In babies, instead of the classical signs, the infant may just appear unwell and have a bulging fontanelle (the soft spot on the top of the head).

Approximately one in 10 people who develop meningococcal meningitis will die, usually because the disease was not promptly diagnosed and treated. In those who survive, the complications can be horrific. Septicaemia (blood poisoning) can lead to blood clotting problems in the arms and legs, requiring (in some cases) amputation of the fingers and toes, and even whole limbs, to save the person's life. Approximately one in 100 adults

and up to one in 12 children who survive meningococcal infection undergo amputation. Kidney failure is common in the acute illness and may lead to lifelong dependence on dialysis. Infection of the brain can cause permanent brain damage, and damage to the nerves of hearing can cause permanent deafness.

An early form of meningococcal vaccine was introduced in the USA in the 1970s. A more effective form, the conjugate vaccine, became available in 2005, and a further improved version appeared in 2016. Annual cases in the US have declined from a few thousand to a few hundred.[16] [17]

Rubella (German measles)

Rubella is a viral illness which causes a rash and swollen glands at the back of the neck and behind the ears. The rash appears on the face about two weeks after exposure to someone with the disease and then spreads to the rest of the body. It usually only lasts 3 days although the swollen glands may last several weeks. Most people have mild symptoms; some do not even know they have had the infection. Others experience fever, sore throat, fatigue and joint pains and in severe cases complications may include bleeding problems, swelling of the testicles and inflammation of the brain (encephalitis) and nerves.

If someone is infected with rubella in the first 20 weeks of pregnancy, there is an 80-90% chance of miscarriage or still birth. Babies who do survive are likely to suffer from congenital rubella syndrome which is characterised by heart defects, deafness and congenital cataracts. The virus may also affect the development of other of the baby's organs.

Vaccination against rubella is given as part of the MMR vaccine. Women who are planning a pregnancy are offered rubella antibody testing and a vaccine if they are not immune. Women who have already conceived and are found to not to be immune are offered the vaccine as soon as they have had their baby.

There was a rubella epidemic in the USA in 1964-1965 which caused 12.5 million cases and led to 20,000 babies born with congenital rubella syndrome.[18] Of these, 2,100 died shortly after birth, 12,000 were deaf, 3,580 were blind, and 1,800 were intellectually disabled.

Since vaccination was introduced, rubella has been eliminated in the Americas but is still widespread in some other parts of the world.[19] From 2016-2019, there were about 5 cases of rubella a year in the US, all in people who caught it abroad.

Haemophilus influenzae B (Hib)

Haemophilus influenzae type b (Hib) is a bacterial infection that can cause very serious illness in unvaccinated children. Its effects include meningitis (a similar picture to meningococcal meningitis described above, but less rapidly progressive and without

the rash), pneumonia (a serious infection of the lungs, causing breathing difficulties), infections of the bones and joints, and septicaemia (blood poisoning, manifest as a severely unwell child with fever, chills, confusion, low blood pressure and progressive organ failure). Between 1 in 50 to 1 in 20 unvaccinated children under 5 with Hib die.[20]

In addition, Hib can cause a characteristic *epiglottitis*—swelling of the epiglottis (the little flap of cartilage that covers the windpipe). A child with epiglottitis is severely unwell and at risk of death. The swollen flap obstructs the passage of air into the lungs, leading to noisy and laboured breathing (stridor) and a distressed and panicking child.

Before the introduction of a vaccine in 1985, there were about 12,000 cases per year.[20] Hib was a leading cause of bacterial meningitis in children under 5 in the USA. Modern vaccines are highly effective at preventing Hib (for example, the incidence of haemophilus meningitis has fallen by over 90% since their introduction). From 2009-2018, there were only 36 reported cases of Hib in children under 5.[21] However, unvaccinated children are at high risk of infection as Hib remains widespread in the USA.

Human Papilloma Virus (HPV)

There are many different strains of Human Papilloma Virus (HPV), one group of which ('low-risk HPV') causes common warts (e.g. on the hands) and genital warts, and another group ('high-risk HPV') that causes changes in various organs that can, over years, develop into cancer. These organs include the throat, cervix (neck of the womb), vagina, vulva, anus and penis. Cancers of these organs are thus a form of sexually transmitted disease. Vaccination against HPV is highly effective at preventing these cancers. For example, in Scotland, HPV vaccination was introduced for girls aged 12-13 in 2008. Long-term follow-up in 2024 showed that not a single case of cervical cancer has occurred in a woman who was vaccinated against HPV at age 12-13.

Cervical cancer is a common cancer in USA, with around 13,500 new cases and 4500 deaths annually. The rates used to be much higher but have been gradually falling since the introduction of 'Pap' smears in the 1970s (which detect pre-cancers and curable early cancers) and the introduction of HPV vaccine in 2006. But coverage in the USA is relatively low (around 60% of eligible teenage girls, and only 16% of those aged 27-45 are fully vaccinated). As the Scottish experience illustrates, wider uptake could save lives. Vaccinating boys will help prevent the spread of HPV and also protect them directly against cancer of the throat, anus and penis.

Influenza and COVID-19: repeat vaccines needed

The diseases discussed above are the ones for which childhood vaccinations are recommended in many countries, and against which a person, once they have completed a full course of vaccination, is generally protected for life. Additionally, there are diseases for which repeated vaccination is needed. Examples include:

Influenza (flu) is a contagious respiratory illness that can lead to serious complications, especially for vulnerable populations such as elderly people or those with pre-existing illnesses. The viruses that cause this are able to mutate and evade the responses we have developed from previous infections or vaccinations meaning that we need different vaccines each year to target the latest variant. Annual vaccination is the most effective way to protect yourself and others. While vaccine effectiveness varies from year to year, depending on how well the vaccine strains match circulating viruses, it consistently reduces the risk of severe illness, hospitalization, and death.[22] Studies show that flu vaccination can significantly lower your chances of getting sick, and if you do contract the flu, it tends to be a milder case. Therefore, getting vaccinated is a crucial step in safeguarding your health and the health of those around you.

COVID-19 remains a significant public health concern, and vaccination is a critical tool in mitigating its impact (see this article with key graphs[23]). While the virus continues to evolve, necessitating updated vaccines, all licensed vaccines to date have consistently demonstrated effectiveness in reducing the risk of severe illness, hospitalization, and death.[24] Current data indicates that updated COVID-19 vaccines provide significant protection against circulating variants, though this protection is not lifelong. While breakthrough infections can occur, vaccinated individuals typically experience milder symptoms in the acute phase and are less likely to develop the prolonged form of COVID-19 known as long COVID. Staying up to date with recommended COVID-19 vaccinations will help protect yourself and contribute to community-wide immunity.

What is vaccination and how does it work?

Individual immunity

The outcome of any infection is like a race between the pathogen (e.g. virus, bacterium) and our immune system. The first time we experience an infection, it can take time for the body to generate the appropriate white blood cells and antibodies that are tailored to fight that particular pathogen. While your immune system is gearing up, the pathogen can take advantage and for some people this can making them very sick indeed or even be fatal. One of the major outcomes of the response to an infection is that our immunity lays down a “memory”. This means the next time we’re exposed to that particular pathogen, the immune system is primed and ready, and responds more rapidly and aggressively. The second “race” is more easily won: a second infection may not occur at all or may be milder than the first.

The idea of a vaccine is to prepare your immune system’s memory without having to run that risky first race. This is much safer than having to experience the often harmful, and sometimes deadly consequences of becoming infected without any protection. Vaccines are usually a safe (‘attenuated’) or killed form of a specific pathogen, or one part of the pathogen in isolation that can be delivered in a variety of ways. Some

vaccines require several doses initially to ensure you get the best possible immune response. In those cases, the protection they confer will not be optimal unless the full course of vaccines is taken. Some vaccines, such as flu, require annual boosters. There are two main reasons for needing boosters. One is that our immunity wanes. The other reason we need new vaccines is that viruses like influenza keep evolving and changing make the original vaccines less effective, as this article from 2023 on COVID boosters explains.[25]

We need tailored vaccines for each pathogen as our immune cells are super-precise and targeted. Young babies are amongst the most vulnerable to infection risks, so many vaccines are given at an early age. Some vaccines will make you immune to ever contracting an infection, i.e. they evoke "sterilising immunity", but for those (such as COVID and flu) that don't, they still partially prevent infection and dramatically reduce the chance of you becoming very ill or dying compared to being exposed and infected without a vaccine.

Population immunity

Vaccines benefit the community as a whole. The more people that are vaccinated, the better. This is because fewer people are likely to become hosts for an infection and then spread it to others, leaving the pathogen with nowhere to go. At that point, its numbers start to decline – a state we call "population immunity". Population immunity has been transformational in reducing many formerly common diseases to very low levels in many countries (e.g. polio or measles).

How a disease spreads is determined by both how infectious it is, as well as how many people in the population are susceptible to infection. A person who has never met the pathogen is susceptible. One who has had the disease or been vaccinated will often (but not always) be immune. A highly contagious disease that a population has never experienced or been vaccinated against before will spread rapidly because everyone in the population is susceptible. This happened, for example, when the SARS-CoV-2 virus (which causes COVID-19) emerged in 2019.

For a disease to spread, each infected person must, on average, give the disease to more than one other susceptible person. But if an infected person passes the pathogen to *fewer* than one other person on average, then the number of infections in the population starts to decline. The "basic reproduction number", or "R_0", is an estimate of how many people, on average, an infected person passes the pathogen to. The higher the R_0, the higher the percentage of the population will need to be vaccinated to prevent the outbreak spreading. The R_0 of measles, for example, is around 18, so 92-95% of the population must be protected to prevent (or curtail) an outbreak. This article explains how R_0 is calculated.[26]

Logically, the way to make an outbreak slow down, or even disappear completely, is to ensure that as few people as possible in the population are susceptible to the pathogen, so there's little or no chance that an infected person will pass it on. Whilst this can be achieved through various methods that physically interrupt transmission such as masking, isolating and ventilation, the only way to eliminate the pathogen is to ensure that as many people are immune as possible. Historically, this level of population immunity has only ever been achieved through concerted vaccination programmes.

To vaccinate or not to vaccinate?

Side effects—real and oversold

Vaccines have been an enormous success story but, as with all medicines, side effects may occur. Vaccines are designed to engage our immune response to achieve their protective effects, and our immune system is very powerful. Typical mild side effects include a sore arm, some redness over the jab site, and perhaps a mild fever for a day or two after many vaccines. But humans are diverse, a very small proportion of us will mount an unfavourable, severe response that can have serious and even fatal consequences. Such events are exceptionally rare. They generally become evident only after vaccines have been given to millions of people.

One example is the rare, yet tragic brain blood clots that occurred in a small number of people (primarily young women) who received the AstraZeneca COVID vaccines.[27] This extremely rare phenomenon occurred in 15 cases of deep vein thrombosis and 22 events of pulmonary embolism out of 17 million vaccines in UK and EU.[28] It was not picked up in clinical trials, even though tens of thousands of participants took part, but became apparent after millions had received the injection. Analysis of these individual cases led to revised protocols on who could receive the vaccines, based on the balance between the risk of harm from COVID-19 (relatively low in healthy young women) and the rare but not zero risk of thrombosis with this particular vaccine. It should not be forgotten, however, that the AstraZeneca vaccine saved millions of lives worldwide.[29]

This example illustrates why it is important to collect data on serious side effects, however rare. Vaccine manufacturers, and clinicians who prescribe and administer vaccines, are required to maintain "pharmacovigilance" as a vaccine is rolled out across a population. In addition, there are public reporting systems for vaccine side effects, though data from these systems need to be interpreted with care. The majority of side-effects reported to the US VAERS or UK Yellow Card systems, for example, are later found to be coincidental following detailed investigations, rather than being caused by the vaccine.

Sadly, these sorts of associative data have been used by people (sometimes in bad faith) to artificially inflate the incidence and severity of adverse reactions. This has been particularly the case recently with respect to the mRNA COVID vaccines. For instance, myo- and pericarditis (heart inflammation) are known side-effects of these vaccines (with a combined incidence of less than 1 per 100,000 individuals).[30] These complications occur most commonly in teenage boys and young men, but both their incidence and their severity are far lower than the same complications caused directly by SARS-CoV-2 infection, where incidence is approximately 20 per 100,000 individuals.[31] Moreover, the reduced dose of COVID vaccines for children has effectively eliminated such concerns in under 12s. Claims regarding other cardiovascular complications for these vaccines are similarly over-inflated.

Why is vaccine uptake falling?

Childhood immunisation rates have been falling for several years.[32 33] One reason for this is a rise in vaccine hesitancy across the world which has led the WHO to declare it as one of the ten biggest risks to human health.[34]

Vaccine hesitancy refers to a delay in acceptance or refusal of vaccination despite availability of vaccination services.[35] This phenomenon is complex and varies across time, place and the type of vaccine. Hesitancy does not fully account for the reduction in vaccine uptake and this is important when considering strategies to enhance vaccine uptake. Many individual factors influence the likelihood of taking up vaccines including accessibility of vaccines or information about vaccines, prior negative health-care experiences and mistrust of organisations or advocacy of alternative healthcare and vaccine hesitancy

The reasons for these diverse factors reducing vaccine uptake are multi-faceted and are often summarised by the '5 Cs'—Confidence, Complacency, Convenience, Communication and Context.[36]

'**Confidence'** considers fears around the safety and efficacy of vaccination and the possibility of side effects versus the risk of the actual diseases. This can be fuelled by suspicions about pharma, government organisations and healthcare practices or more modern vaccines such as mRNA vaccines.

'**Complacency'** about the severity of eliminated or seasonal diseases has become common as few people now have experience of these diseases. It stems from a misunderstanding of the risks of a disease versus the risk of being vaccinated against that disease.

'**Convenience'** covers factors such as accessibility and availability of vaccines or vaccine centres, ability to take time off work to attend for vaccination, quality of service and affordability of vaccines.

‘**Communication’** considers how accessible and clear the information is regarding vaccines, including where and when it is available locally. Good communication can have a positive influence on confidence.

‘Context’ considers cultural sensitivities and needs—for example, informing people if vaccines are halal or suitable for vegans.

Uptake of vaccines is strongly influenced by social factors such as poverty, racial and ethnic background, practicalities such as proximity to vaccine centres.[37] Some scholars have criticised the term ‘Convenience’ in the ‘5Cs’ taxonomy, for example, because it has connotations of individual preference and downplays the role of societal factors such as health insurance coverage, workers’ rights (e.g. to time off to attend vaccination) or the limited availability of vaccine clinics in deprived localities.[38] Vaccine uptake globally is strongly influenced by global supply chains, which may be compromised by national or commercial vested interests.[37 39]

Misinformation (that is, information that is incorrect, whether intentional or not) and disinformation (information deliberately put out to mislead), especially on social media, can sow confusion, fuel uncertainty and breed vaccine hesitancy.[40] For example, an alleged link between the combined measles, mumps and rubella (MMR) vaccine and autism spectrum disorder has been widely circulated, leading to falling uptake rates, but this alleged link has long ago been thoroughly debunked in studies that included millions of individuals.[41] The recent announcement of a new programme of US research into this settled issue has no scientific basis.[42]

Work is needed to improve public trust in vaccines, to communicate clearly, and to make vaccines easy and convenient to access. Different population groups may need specifically tailored approaches especially groups with historically low vaccine uptake. Factors known to be relevant include certain demographics for example some Black and South Asian ethnic groups, religious orthodoxy, socio-economic deprivation, disability, language proficiency and education.[29] Tailoring immunisation programmes (TIP) are designed to provide insights into the barriers that specific populations face, formulate interventions, and evaluate results, leading to equitable vaccination uptake regardless of income, age, ethnicity or religion.[30]

Conclusion

We are facing a crisis of public confidence in the efficacy and safety of vaccines. It is critical that the public receive the correct messaging. We must be honest that severe reactions can occur rarely for individuals, and that these numbers accrue over time. But we also need to convey the message that populations have been spared literally millions of fatalities through the use of vaccines, especially those given to children in routine vaccination schedules. When weighing the risks of vaccinations against their

benefits, people need to compare not simply avoiding side effects of vaccines but also not being protected from the disease in question.

As a recent UNICEF publication ('For Every Child, Vaccination') pointed out, "Now is a time for determination. Now is a time for political will. Now is the time to protect the health of every child."

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