A Comparison of Bacterial/Animal/Plant Viruses and Their Effects on Humans

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Abstract:
Viruses are small intracellular parasites with either a DNA or RNA genome surrounded by a protein coat. Despite the fact that they are usually considered non-living and not as complex as cells, viruses have the ability to infect and affect numerous hosts. This review paper highlights the similarities and differences between bacterial, plant, and animal viruses. Although viruses are generally thought of as pathological, they also contribute to treatments for diseases like cancer. Beyond providing basic information on viruses in general, the harmful and helpful aspects of each major type, as grouped by their main hosts are also discussed. Understanding the differences between viruses can introduce new avenues for humans to exploit for safety and therapeutic benefit.

Introduction:

The term “virus” has become a well-known term following the numerous pandemics that have occurred recently. A virus is defined as “an infective agent that typically consists of a nucleic acid molecule in a protein coat, is too small to be seen by a light microscope, and can multiply only within the living cells of a host” (Oxford English Dictionary). Even though new viruses are identified every year, they were first discovered over 200 hundred years ago. In the late 1800s, Dutch scientist Martinus Beijerinck conducted experiments on the tobacco mosaic plant to discern the possible agents that cause the tobacco mosaic disease. By extracting the sap of plants with the disease and passing it through a porcelain filter, he confirmed that no bacteria would be left in the filtered sap. The filtered sap was then rubbed on healthy tobacco plants, resulting in the spread of the disease (Campbell Biology Tenth Edition, 393). The infection persisted even in the lack of bacteria. Additionally, Beijerinck learned that the agent of the tobacco mosaic disease could not be grown in test tubes or Petri dishes. He became the first scientist to bring forth the concept of a virus when he concluded that the pathogen must be simpler and smaller than a bacterium. The development of the electron microscope in the 1930s allowed researchers to eventually visualize the infectious particle. Shortly thereafter in 1935, Wendell Stanley, an American scientist, crystallized the disease-causing agent, now known as the tobacco mosaic virus (TMV). These infectious microbes residing in a variety of organisms have led to epidemics and pandemics worldwide. By covering a few different hosts that viruses attack and their impact on the world, humans can better take care of themselves and prevent problems on a global scale.

Similarities:

Physical Structure

The basic structure of viruses don’t greatly vary. Viruses are tiny packages of protein and nucleic acid (Figure 1). Their bodies are made of a protein shell, known as a capsid (rod-shaped, polyhedral, or more complex), and contain genetic material with single/double stranded RNA/DNA inside. Each type of virus is categorized into the Baltimore classifying system based on their nucleic acid, strands, replication sense, and mechanism (Chakraborty, 2018). Animal viruses can sometimes have an envelope, which is a spherical membrane made of lipids. Viruses can evolve to have membranes as an additional defense and entrance mechanism that resulted from interactions with host cells. All viruses are nonliving parasites, and they cannot reproduce on their own and must replicate through the host cells they infect.

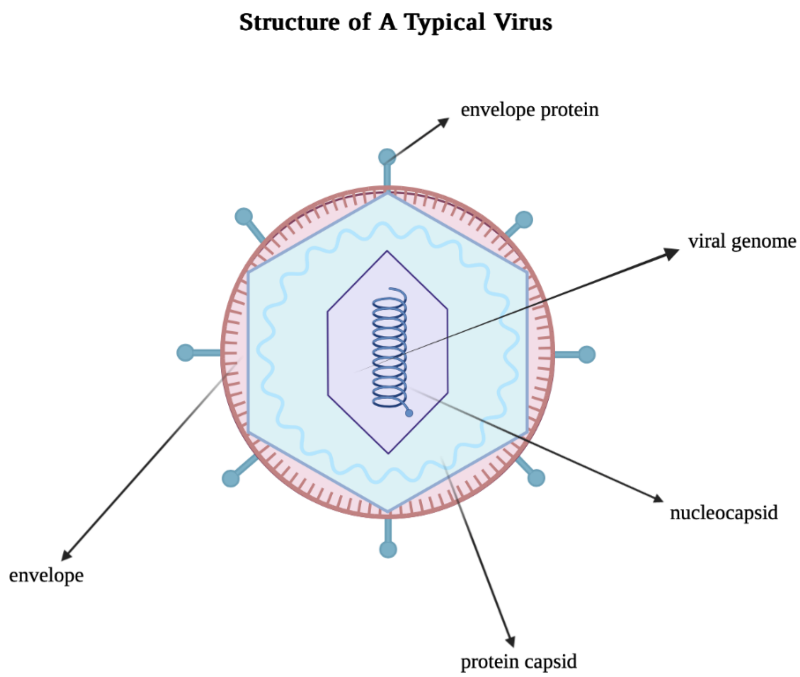

Figure 1. Structure of a virus. The figure above shows the typical structure that viruses have. While not all viruses have envelopes, they have a capsid and a viral genome made of RNA or DNA. Created with BioRender.com.

Mutations in Viruses

Because viruses have error-prone replication systems that are sensitive to their environment, they have the tendency to undergo mutations (Sanjuán and Domingo-Calap, 2016). Mutations occur when viruses undergo copying errors leading to changes in its proteins, leading to several consequences. Since the immune system of the impacted animal cannot recognize the mutated virus, prior vaccines may have little to no value. For these types of viruses, new vaccines must be developed regularly. Assuringly, most mutations result in incomplete viruses. These incomplete viruses are easily exterminated by the white blood cells in the immune system or other antiviral systems (in the case of organisms without a complete immune system), raising no further concern (Sanjuan and Domingo-Calap, 2016). In fact, sometimes, vaccines are made out of viruses that have mutations introduced to them by scientists so that they can't cause disease. Mutations also play a role in viral evolution. The theory of evolution states that species change over time, give rise to new species, and share a common ancestor (Influences on Darwin, 2016). Some mutations that occur in viruses may be its way of adapting to the environment and becoming stronger to survive.

Research on Viruses

Scientists conduct experiments on multiple types of viruses to gain a better understanding and prevent the consequences they cause. Depending on the virus, there are different safety facilities that are used for researching them. In fact, the US government doesn't allow people to perform studies on certain animal viruses unless it is in Manhattan, Kansas. The testing sites comply with numerous safety restrictions put in by government officials (KSVDL, n.r.). This is to prevent the experimental virus from escaping and affecting all the domestic animals nearby and causing food and economic burden. Similar restrictions are also placed on plant virus experiments to prevent problems in the economy related to agriculture and farming. Some laboratory-modified viruses created by scientists can be used to kill cancer cells, treat multiple genetic diseases with gene and cell therapy tools, or serve as vaccines (Mietzsch and Agbandje-McKenna, n.r.). Information in later sections will expand on this topic.

Bacterial Viruses:

Bacterial viruses, or bacteriophages, are viruses that only infect bacteria. Since viruses don't have the organelles needed to replicate their genes, they reproduce within the host cells they infect. There are two ways that bacteriophages can reproduce within the host bacteria: the lytic cycle and the lysogenic cycle.

The Lytic Cycle

The lytic cycle, also referred to as the "reproductive cycle", is a six-stage process in which bacteriophages replicate inside a host cell (Figure 1). The process of reproduction occurs as follows: the bacteriophage uses its tail fibers to latch on the surface proteins located on the outside of a bacterial cell. It then contracts its tail, injecting the phage DNA/RNA into the host cell and leaving the empty capsid that remains outside. By making use of the organelles in the cell, the phage DNA/RNA takes command and arranges the production of proteins and copies of the genome using the host and viral enzymes. Since each phage copy is made up of head, tail, and tail fibers, three separate types of proteins assemble to create each separate component. During the formation of the head, the genome is placed inside the capsid. Lastly, the phage produces genes to make an enzyme, endolysin, that damages the cell wall of the host cell, allowing fluid from the outside (Kurzgesagt - In a Nutshell, 2018). The entry of excessive amounts of fluid leads to the swelling of the cell. Eventually, the cell lyses and releases all the phage particles that were constructed to further infect new hosts.

The Lysogenic Cycle

The lysogenic cycle is the other form of reproduction used by bacteriophages (Figure 2). The main component that makes the lysogenic cycle different from other forms of replication is that it doesn't necessarily end with the lysis of the host cell. The process first starts with the bacteriophage latching onto the surface of the host cell and inserting its DNA/RNA inside. Instead of commandeering the production of more viruses, the DNA/RNA of the phage is combined with a particular section of the bacterial genome. This leads to the integration of phage DNA/RNA into the genome of the bacterium, also known as the prophage. As the bacterium reproduces normally, the prophage is replicated as well and is transmitted to bacterial daughter cells. As time passes, a large population of bacteria infected with the prophage is produced. Occasionally, the prophage exits the chromosome of the bacterium and allows the initiation of the lytic cycle (Abedon, 2016). The process of using both the lysogenic and lytic cycles allows the replication of more viruses in a shorter amount of time.

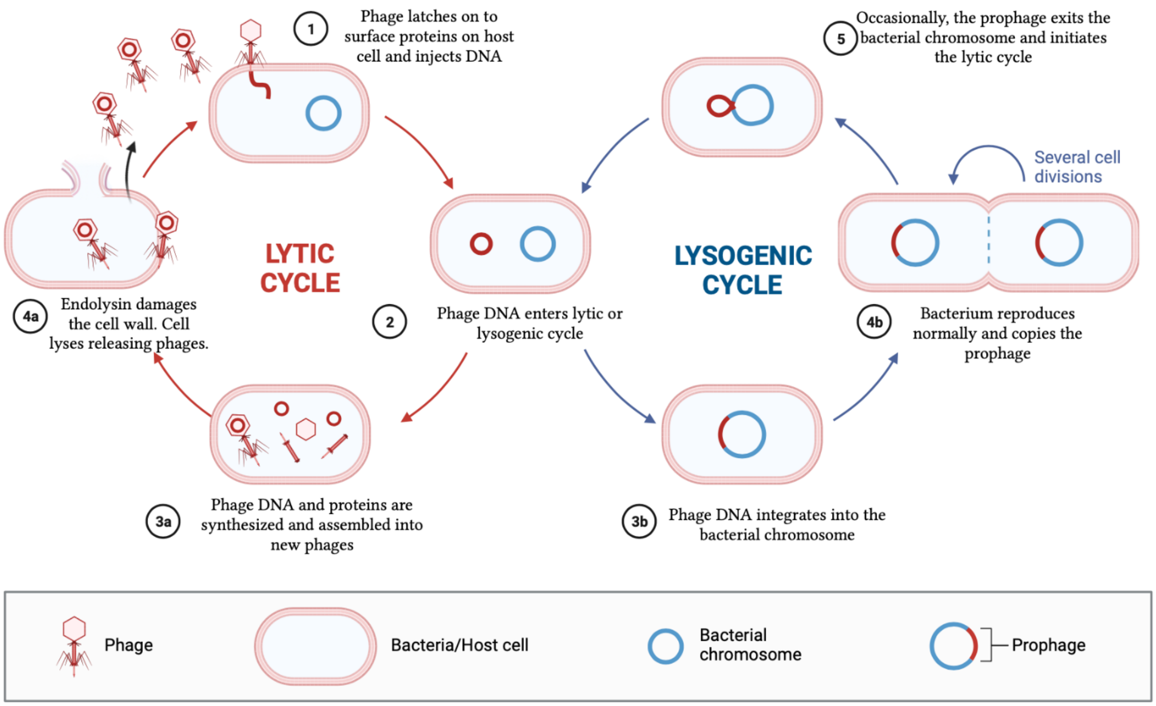

Figure 2. Lytic and lysogenic cycles. The figure above shows the reproduction process of a bacteriophage. The left side, bolded in red, is the lytic cycle. The right side, bolded in blue, is the lysogenic cycle. Adapted from (Alsobhi, 2021). Adapted from "Lytic and Lysogenic Cycle", by BioRender.com (2023).

Bacterial Defenses

In response to the virus's attacks, bacteria have their ways of fighting back. Most bacteria make use of a system known as CRISPR/Cas to provide defense against phages. A bacterial cell takes a short part of the phage genome, called a 'spacer', and inserts it into its own genome. Upon reinfection of the bacterium, the cell recognizes and destroys the virus due to the phage genomic segment that it saved in its genome. This stops the virus from destroying the cell's DNA. By passing on this trait to its progeny, the bacterium can create a population resistant to the virus. Mutations that occur in the phage can allow the virus to still infect bacteria with a 'spacer' (Schelling and Sashital, 2020). A virus can still combat this by having multiple 'spacers' in its genome, but experiments conducted by scientists have found this very uncommon (Heler et al., 2015).

Bacteriophages: Interactions with Humans

As phages attack bacteria, the metabolic process is disrupted and large populations of bacteria can be lost. Bacteriophages can greatly impact bacteria but are known to be helpful to humans most of the time (Principi et al., 2019). Bacteriophages only target a specific type of bacteria and sometimes its close family. Phages can help humans by treating diseases originating from bacteria instead of using medications like antibiotics (Volkers, 2022). Scientists are also considering injecting bacteriophages into people with bacterial infections. Since phages only attack certain types of bacteria, human cells are immune to them, decreasing the side effects of treating the infection. This would be preferable to using antibiotics that kill every bacteria in the human body, even the good bacteria in the intestines that help with digestion. Using phages to treat diseases and infections would prevent the loss of essential bacteria. Unlike antibiotics, phages mutate at the same rate as the bacteria do, so bacteria immune to the original variant are destroyed by the new variants of the phage. To become immune to multiple types of viruses, bacteria lose their defense mechanisms against antibiotics (Kurzgesagt - In a Nutshell, 2018). Using both antibiotics and phages to treat disease can increase survival rates from bacterial infections. This treatment method has been used before the discovery of antibiotics and has continued to be performed in many countries today. However, some bacteriophages do cause harm to humans by specifically targeting good bacteria (Sulakvelidze et al., 2001). For instance, the bacteria that are major boosters of the immune system. Some phages can also carry toxic substances in their genes that transfer to the bacteria they infect. This can cause health problems like cholera, flesh-eating disease, and dysentery in humans (Guerin and Hill, 2020). Even though they are viruses, bacteriophages have both helpful and harmful aspects to them. The complexities of these microbes just make them more interesting. Humans should be careful of phages, but they may open up a new pathway in research to better understand bacteria by helping maintain a healthy microbiome while removing dangerous ones.

Examples of Bacteriophages Discovered

There are thousands of species of bacteriophages in the world. Each one affects a specific type of bacteria. The biggest known bacteriophage discovered is the bacillus megaterium phage G. It infects bacillus bacteria and has the largest genome (with dsDNA) in bacteriophages from the Myoviridae family. Another bacteriophage, the lambda phage (escherichia virus lambda), infects the bacteria *Escherichia coli*, commonly known as that *E. coli*. This is one type of bacteriophage that resides within the genome of the bacteria and reproduces through the lysogenic cycle. Instead of causing harm to humans, the lambda phage can treat many health problems by serving as an anti-cancer vaccine and providing valuable nutrients in the form of enzymes (Fuller et al., 2013).

Plant Viruses:

There are two ways that viruses can transfer to plants: horizontal transmission and vertical transmission.

Horizontal Transmission

Horizontal transmission is when a plant is infected from an external source of the virus. Damage from wind, injury, or herbivores can make the outer protective layer of cells, the epidermis, of the plant weaker and more susceptible to viral infections (Boundless, 2023). Insects not only injure plants by eating them, but can also serve as the main carriers of viruses. They transfer the virus from one plant to another as they interact with them (Dietzgen, 2016). Farmers also play a part in the transmission of viruses when using the same pruning shears and tools for multiple plants. Viruses from the infected plant pass onto the farming tools and then to healthy plants when they aren’t sanitized.

Vertical Transmission

Vertical transmission is when a plant inherits the viral infection from a parent. In plants, vertical transmission is also referred to as “seed transmission” showing the passage of the pathogen through seeds to seedlings to plants in the next generation (Matsushita et al., 2018). Instead of sexual reproduction, the virus can also spread through asexual propagation which involves taking a part of a parent plant and allowing it to regenerate into a new plant (Sorenson, 2018).

Plant Defenses Against Viruses

To counteract attacks from viruses, plants have developed two different approaches: gene-mediated resistance and RNA interference-based defenses. Furthermore, plants resist viral infections through recessive gene-mediated resistance utilizing mutations of essential genes in viral infections (Liu et al., 2017). Gene-mediated resistance is triggered when dominant plant disease resistance (R) genes recognize the entry of viruses and respond by encoding corresponding dominant virulence (Avr) genes (Moffett, 2010). RNA interference (RNAi) or post transcriptional gene silencing (PTGS) is a biological response to double-stranded RNA (dsRNA) which mediates resistance to viruses and expresses protein-coding genes. This complex method of defense has many benefits including functional genomics, therapeutic intervention, and agriculture (National Library of Medicine, n.r.).

Plant Viruses and Humans

Plant viruses can cause considerable harm to plants, but reassuringly, they rarely directly affect humans. In fact, thousands of viruses are present in the vegetables and fruits consumed by humans daily (Jonghe, 2020). As with bacteriophages, plant viruses only attack specific plants and their close relatives. This is because plant viruses don’t have the same surface receptors for recognition and entry into the host cell that is needed for animals and bacteria (Liu et al., 2013). While plant viruses are not known to affect humans directly, they can cause major problems in the economy due to mass killing of many agricultural crops. Plant viruses are responsible for thirty billion dollars lost annually and account for 50% of plant diseases worldwide (Hilaire et al., 2022).

Through biotechnology, plant viruses can be used in numerous applications. This table is replicated from a 2019 review by Pasin and others authors (Pasin et al., 2019).

Use	Description	References
Enhanced plant aesthetics	Increase beauty and commercial value of ornamental plants	Valverde *et al*. (2012)
Cross-protection	Delivery of mild virus strains to prevent infections by their severe relatives	Ziebell and Carr (2010)
Weed biocontrol	Viruses triggering lethal systemic necrosis as bioherbicides	Harding and Raizada (2015)

Pest biocontrol	Enhanced toxin and pesticide delivery for insect and nematode control	Bonning *et al*. (2014); Cao *et al*. (2015)
Nanoparticle scaffolds	Virion surfaces are functionalized and used to assemble nanoparticles	Schoonen *et al*. (2015); Steele *et al*. (2017); Wen and Steinmetz (2016)
Nanocarriers	Virions are used to transport cargo compounds	Aumiller *et al*. (2018)
Nanoreactors	Enzymes are encapsulated into virions to engineer cascade reactions	Brasch *et al*. (2017); Comellas-Aragonès *et al*. (2007)
Bioimaging	Virions are functionalized with dyes or contrast agents to enhance cell imaging	Shukla *et al*. (2013)
Recombinant protein/peptide expression	Fast, transient overproduction of recombinant peptide, polypeptide libraries and protein complexes	Dugdale *et al*. (2013); Gleba *et al*. (2014); Julve Parreño *et al*. (2018)
Functional genomic studies	Targeted gene silencing using VIGS and miRNA viral vectors	Dommes *et al*. (2018); Tang *et al*. (2010)
Genome editing	Targeted genome editing *via* transient delivery of sequence-specific nucleases	Zaidi and Mansoor (2017)
Metabolic pathway engineering	Biosynthetic pathway rewiring to improve production of native and foreign metabolites	Bedoya *et al*. (2012); Kumagai *et al*. (1995); Majer *et al*. (2017); Mozes-Koch *et al*. (2012); Zhang *et al*. (2013)
Flowering induction	Viral expression of *FLOWERING LOCUS T* to accelerate flowering induction and crop breeding	McGarry *et al*. (2017)
Crop gene therapy	Open-field use of viral vectors for transient reprogramming of crop traits within a single growing season	Gleba *et al*. (2014)

Biomolecule evolution	Libraries of target sequences are cloned into viral vectors; directed *in vivo* evolution selects improved or new functions	Aiming and Zhou (2016)

Table 1. Applications of plant viruses in biotechnology.

As of now, no cures have been developed to fight plant viruses. The only solution we currently have is to prevent the spread of viruses between the plants themselves. Since sexual reproduction is necessary in some plants, farmers can try to prevent viral spread by avoiding the involvement of organisms like infected insect vectors while also maintaining good hygienic and cleaning farming tools before using it on multiple plants (UC IPM, 2017). Common signs of the viral infection are bleached and dark spots on leaves and fruits, stunted growth, or damaged flowers and roots (Campbell Biology Tenth Edition, 405).

Examples of Plant Viruses Discovered

The most well-known plant virus discovered is the tobacco mosaic virus (TMV). As mentioned in the introduction, the TMV was the first virus discovered in the world. It is a single-stranded RNA virus which causes “mosaic” like prints and discoloration on the leaves of many plants, including tobacco. Through engineered modifications, the plant virus TMV has also been used in many applications to treat cancer (Venkataraman, 2021). Another virus, the tomato yellow leaf curl virus (TYLCV), causes great harm to the farming industry. It has single-stranded DNA and creates a deadly disease in tomato plants. The single-stranded positive RNA virus, potato virus Y (PVY), causes similar mosaic symptoms as the TMV does in solanaceous plants like potato, tomato, pepper, tobacco, and eggplant (Scholthof et al., 2011).

Animal Viruses:

The third main host discussed in this research paper are animals and humans. These organisms are mainly affected by animal viruses.

Process of Reproduction

The animal virus reproduction process starts with the virus binding to the receptors on the host cell membrane using its surface molecules. Enveloped animal viruses can use one of two possible ways of entry: endocytosis or fusing with the membrane and releasing the capsid inside the cell (Figure 3). Nonenveloped viruses cannot undergo fusion, since they don’t contain envelopes to fuse with the cell membrane. Endocytosis is when the cell brings the virus inside and fusion is when the virus merges with the cell. After entering into the cell, the virus uses the host cell’s resources to make new viral proteins and genetic material. Lastly, viral particles assemble to form new viruses: enveloped or non-enveloped viruses. Enveloped viruses may take pieces from the plasma membrane or other membranes of the host cell as they form. On the other hand, non-enveloped viruses build up in the infected cell until the cell bursts or dies, resulting in the release of viruses (Cooper, 2000).

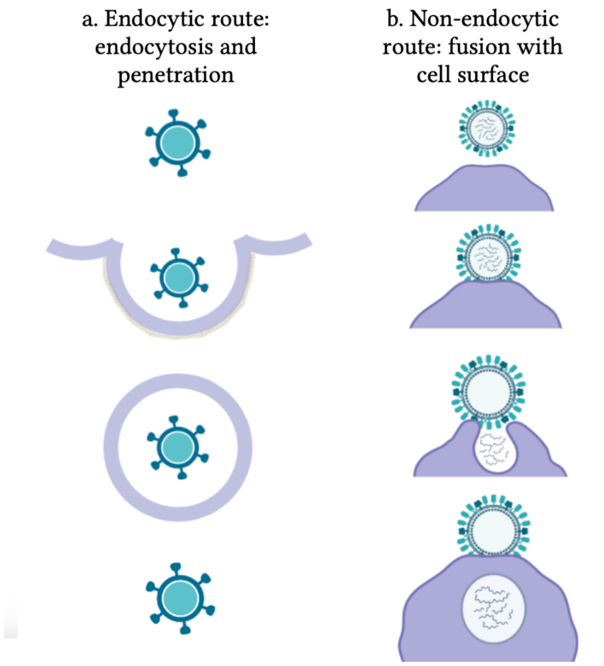

Figure 3. Endocytosis and fusion. The figure above shows the endocytic (left) and the non-endocytic (right) route, the two different ways animal viruses with envelopes can enter a cell. Adapted from (Dimitrov, 2004). Created with BioRender.com.

Host Defenses

Animal viruses lead to many direct and indirect consequences in humans and animals. Pathogenic viruses can cause damage to the cells by disrupting cell function or killing them. The immune system inside humans and other organisms helps combat these viruses by fever, secretion of chemicals, and antibodies, amongst other defense mechanisms. Raising body temperature through fever inactivates the viruses from the excess heat (Balli et al., 2022). Through secretion of interferons that help cells respond to infections, viruses are prevented from reproducing. The antibodies present in the immune system combined with other cells can physically target the invader (Klimpel, 1996).

Means of Spread

Generally, animal viruses have one or more animal hosts they infect. For example, some viruses may only infect humans while others can affect other animals as well. Diseases that spread from animals to humans are called zoonotic diseases which can be caused by viruses, bacteria, parasites, and fungi. Zoonotic diseases that transfer between humans and other animals can lead to major problems like worldwide pandemics. Viruses can spread between organisms through direct/indirect contact, vectors, food, and water. Direct contact includes contact with saliva, blood, urine, mucous, feces, or other bodily fluids of an infected animal. Indirect contact involves exposure to areas where infected animals live/roam or objects and other surfaces that have been contaminated by germs. Vector-borne diseases involve being bitten by a tick or insects like mosquitoes and fleas. Consuming contaminated food and water, including the meat of animals with the virus or water containing the feces of infected animals, can cause illness in humans and their pets (Hart et al., 2022).

Examples of Animal Viruses
A few well-known animal viruses that affect both humans and animals are rabies, ebola, and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Rabies can spread from one animal to another through the saliva of infected organisms. Most common symptoms include fever, headache, excess salivations, muscle spasms, paralysis, mental confusion. No specific treatment is available to cure rabies, but contraction may result in immediate fatalities (WHO, 2023). Ebola causes severe bleeding, organ failure, and sometimes death in humans and other primates. The virus can spread through touching contaminated surfaces or contact with saliva or bodily fluids like blood. Symptoms begin with fever, headache, muscle pain, and chills and can later escalate into internal bleeding resulting in the vomiting or coughing of blood (Garibaldi, n.r.). Around 35,000 people contract this virus annually, resulting in the deaths of approximately 11,000 people (Barbiero, 2020). SARS-CoV-2, which causes COVID-19, causes multi organ effects leading to damage in the lungs, heart, kidneys, skin, and brain. COVID-19 usually spreads through close contact with bodily fluids or touching contaminated surfaces. General symptoms include fever, chills, cough, body aches, headache, shortness of breath, fatigue, nausea, vomiting, diarrhea, congestion or runny nose, sore throat, and loss of taste or smell. Out of the hundreds of millions of people who contracted the virus, almost 3 million people died from it at the height of the pandemic. As the years pass, cases and deaths have been gradually decreasing (WHO, 2021).

Conclusions and Discussion:
Viruses, non-living microscopic organisms, affect multiple types of hosts causing both harm and help to bacteria, plants, and animals. Viruses can bring about severe (sometimes lethal) diseases in multiple organisms, but they also provide crucial aid in curing other illnesses, including ones that aren't affected by antibiotics. Research being done by scientists around the world to help us understand these pathogens better everyday. Still, there are many questions that remain unanswered: Will there ever be a cure to all viral infections instead of vaccines? Will humanity be able to combat every mutated virus with a new vaccine? Do humans have enough resources to continue making antiviral medicines in the future? Can we get rid of antibiotics by using other types of viruses instead? As humanity continues to explore the capabilities of viruses, we will find the answers to many of our queries. As of now, the general population can prevent pandemics and take care of their health with simple actions. They can use proper personal hygiene by washing their hands frequently, covering their nose and mouth while coughing or sneezing, avoiding contact with infected people, wearing a face mask when contracted with the virus, sanitizing regularly touched surfaces, and isolating from high risk patients. Humans can also lessen interactions with animals in the wild and domesticated. The spread of many future zoonotic diseases can be prevented in this way. These actions can help prevent both the contraction and spread of a virus. People can also donate money to influence research on viruses and prevent any future epidemics.

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