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DOCTORATE IN PUBLIC HEALTH

PHE674: Public Health Biology

ATLANTIC INTERNATIONAL UNIVERSITY
FEBRUARY 2022

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1 Disease Ecology

1.1 Defining Disease Ecology

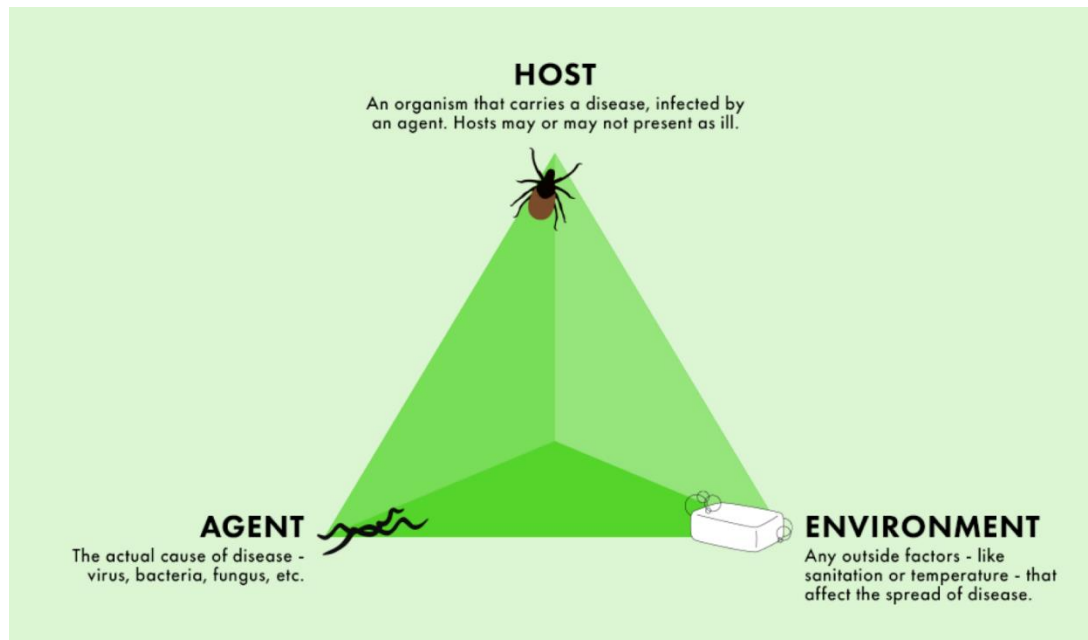
Ecology is defined by Merriam-Webster as “a branch of science concerned with the interrelationship of organisms and their environments” (Merriam-webster, 2019). Infectious diseases can cause harm to individuals, the population at large and the environment or ecosystems they inhabit. Most infectious diseases are caused by pathogens or parasites which can negatively affect or kill their host, though it could be argued that this is rare given these pathogens or parasites require a living host to survive. Pathogens and parasites are also common and healthy in many environments thus not causing disease but rather contributing to the health of that environment. When they do cause disease, pathogens and parasites can be severely detrimental, as is evident with the current and ongoing COVID-19 pandemic.

Disease ecology is concerned with interactions rather than individual pathology or epidemiology. For example, disease ecology considers how parasites might spread through an animal population and affect not only that population but the environment which they inhabit. In considering this impact, disease ecology helps to understand interactions between the two, impact on both, and how rising epidemics can impact public health and the environment. With epidemiology, the focus is on what causes the disease, how incidence of disease is identified, and mechanisms used to prevent or treat the disease. Disease ecology seeks to understand why patterns of disease occur and the variables that affect these patterns (Serc.si.edu, n.d.).

1.2 The Epidemiological Triangle

The Epidemiologic Triangle (CDC, n.d.) consists of three vertices. The “agent” is that which causes the disease, such as a pathogen or parasite. The “host” is the organism that harbors the disease” The “environment” are those factors not related to the host or agent that cause or allow transmission. An aim in epidemiology is to sever one of these vertices and stop progression of disease, thereby preventing or ending epi- or pandemics.

Figure 1 The Epidemiological Triangle (New Hampshire Public Radio, 2020)



Disease ecology applies to Public Health in the following way. Incidence of disease, where this occurs, the timing of this occurrence and how it interacts with a specific population and the environment is the foundation of this model. As populations interact with the environment these result in emergent properties.

1.3 Emergent Properties

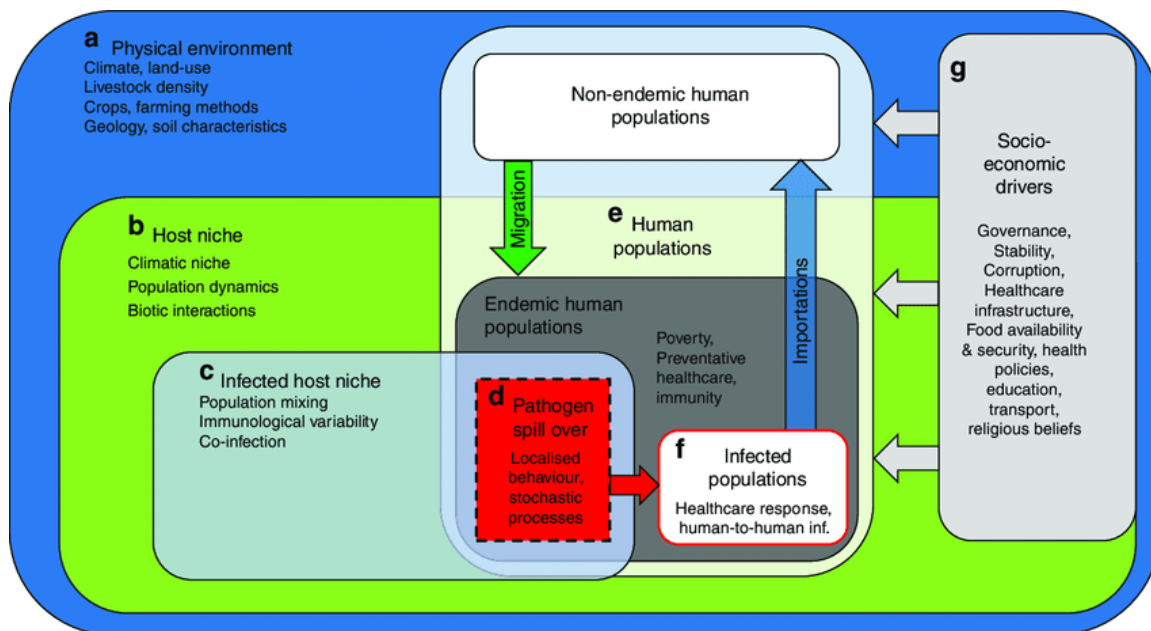
Emergent properties are typically not expected and include properties in materials as well as behavior in organisms. These emergent properties are observed because of interactions among components of a system which could not be anticipated when considering each of those components alone. Examples of these are found in ant colonies. When related to the current COVID-19 pandemic, a consideration would be whether the use of a new, effective, vaccine could result in making the pandemic worse? (Mercer, 2018).

1.4 The Niche

In understanding infectious disease, the role of the “niche” is important when considering how these diseases occur and must be handled. The niche are those conditions within the environment that define the limits of the disease parasite or pathogen’s ability to survive. These

conditions determine whether that disease-causing factor is required to grow when there are numerous available resources or adapt to conserve energy when there are few. (*Wikipedia*). The occurrence of disease is directly related to the overlap in time and space between these populations. An example of this can be seen in Figure 2 (Redding et al., 2019) which illustrates how various niches, when overlapping in time and space, can result in changes in behavior and adaptation that contributes to the start of disease that becomes endemic.

Figure 2 Model of niche interactions causing spread of zoonotic disease (Redding et al., 2019)



These kinds of population interactions involve the following:

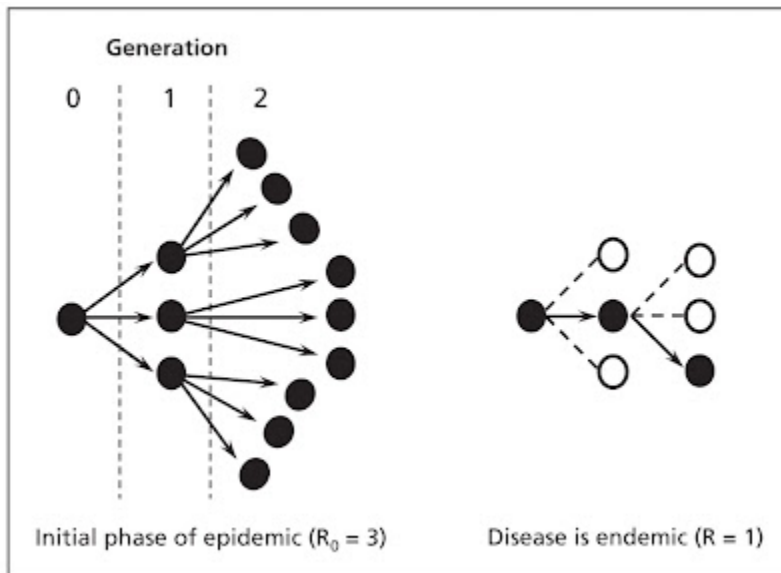
- Environmental diseases caused by toxins such as lead, cancers, and famine.
- Directly transmissible infectious diseases such as influenza and measles.
- Zoonotic diseases that transmit to humans from animal species like COVID-19.
- Vector-borne diseases that transmit to humans via the action of another species like Lyme disease spread by ticks.

2 Disease Dynamics

2.1 Net Reproductive Ratio

There are many examples of emergent properties in disease ecology that are associated with the needs of Public Health and contribute to Public Health biology. It is important to understand the concept of the net reproductive ratio and effective reproductive ratio. To do this it is best to draw from examples of how vaccine programs are related to net reproductive ratio and describe the relationship between this and herd immunity to examine implications for patterns of future diseases.

Figure 3 Net Reproductive Ratio (*infectionlandscapes, 2011*)



The net reproductive ratio, or R_0 defined the rate at which a pathogen will reproduce in a population when the number of hosts are not limited. The number of secondary cases caused by an infected host (primary case) in spreading a pathogen is equal to R . In the diagram above, the picture on the left shows the initial phase of an epidemic, one host can infect three (3) individuals thereby resulting in a net reproductive ratio of $R_0 = 3$. Because there are several available hosts, each person can infect another three (3) and so an epidemic starts when $R_0 > 1$. In the picture on the right, the host was only able to infect one (1) other individual at any time, $R_0 = 1$ as it persists endemically, and the disease is likely to remain endemic as long as it replaces itself. If $R_0 < 1$

then each primary case does not produce enough secondary cases to replace or replicate itself, and the disease will die out.

Net reproductive ratio may be calculated using the following equation:

$R_0 = B * N * d$, where:

R_0 is the number of secondary infections

B is a parameter used to indicate the mode of transmission

N is the size of the population susceptible to infection, and

D indicates the length of time the pathogen is infectious.

Once a pathogen establishes itself within a population, those individuals infected either die or become immune to new infections, unless that pathogen mutates to escape the natural immunity. There are therefore less susceptible hosts and rate of transmission should be lower than R_0 . Once a pathogen has established itself within a population, the average number of secondary cases caused by each primary case is calculated as the Effective Reproductive Ratio (R_e). This is calculated using the following equation:

$R_e = B * X * d$, where:

R_e is the number of secondary cases caused by each primary case

B is the parameter used to indicate the mode of transmission

X is the size of the population susceptible to infection, and

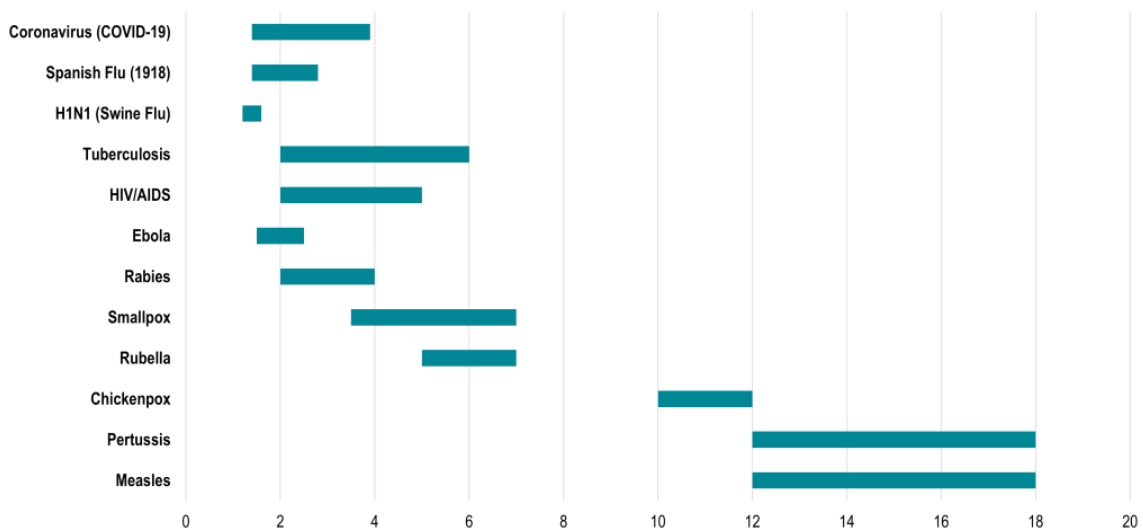
D indicates the length of time the pathogen is infectious.

Some diseases show temporal stability in incidence and are thus endemic. These include persistent infections, poor natural immunity, and low rates of mortality. Other diseases are characterized by repeated outbreaks on a regular basis and are thus epidemics. These include acute infection, long-lasting immunity and/or high rates of mortality. If hosts susceptible to infection are readily available within the infected population the disease tends to be endemic

opposed to when they are less available (epidemic) or not available at all (pathogen/disease dies out).

Figure 4 illustrates the R_0 of major known infectious diseases. The higher the value of R_0 , the more likely the risk of an epidemic or pandemic because of the infectiousness of the disease. It might be important to note that the ability of a pathogen to infect within a population does not necessarily correlate with the lethality of the disease. For example, influenza has an R_0 of 2 to 4 with lower rates of mortality than Ebola which has an R_0 of between 1.5 and 2.5. SARS-CoV-2 has naturally changed this as the new variants of concern (VOC) change R_0 over time from between 1.4 and 3.9, depending on the VOC (The Geography of Transport Systems, 2022).

Figure 4 Basic Reproduction Number of Major Infectious Diseases (The Geography of Transport Systems, 2022)



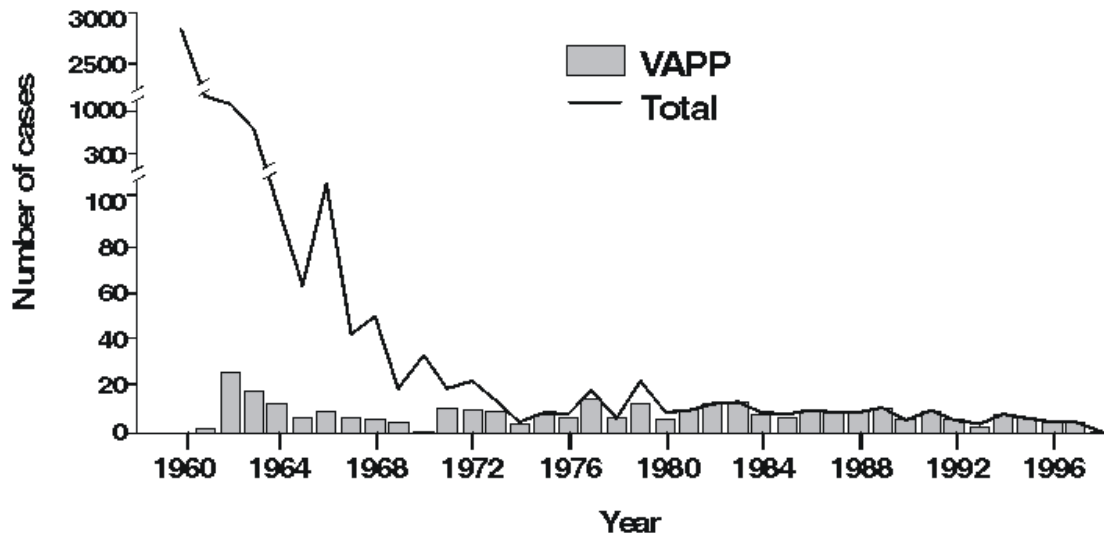
2.2 Net Reproductive Ratio and Disease Control

Controlling epidemics and ridding the population of disease has historically been via vaccination however has not required all members of the population to be vaccinated to be successful. To date, vaccinated members of the community have provided protection to those unvaccinated by preventing the spread of disease between infectious and unprotected members of the community. As immunity grows within a population, thereby protecting those not vaccinated, herd immunity is achieved. In terms of R_0 , a disease pathogen would not continue to spread within an unprotected or unvaccinated population if $R_0 < 1$. It has been established that the

more infectious a pathogen, the higher the number of population that must be vaccinated to control disease. Small increases in infectiousness can lead to large increases in the proportion of individuals that must be vaccinated.

Figure 5(CDC, 2019)

FIGURE. Total number of reported paralytic poliomyelitis cases and total number of reported vaccine-associated paralytic polio (VAPP) cases — United States, 1960–1998*



*Updated June 16, 1999.

In summary, R_0 and R_e are measures of how a pathogen acts within a population that can act as a suitable host. How the infection acts depend on the availability of susceptible hosts and the infectiousness of the disease. R_0 can be used to determine the number of population that must be protected to get rid of the disease as a failure to do so can affect how long and how extensive an infection, and therefore an epidemic or pandemic, can be.

3 Emerging Infectious Disease

Emerging Infectious Diseases (EID) are those whose incidence in the human population has increased within the past 20 years or threaten to increase in the future. These often occur as outbreaks in relatively large numbers and result in impacting Public Health, health care and economic infrastructure. There are typically two types of EID namely, apparent EID where an increase in incidence of disease is due to changes in our ability to ascertain the etiology and its

contribution to that disease, and real EID where an increase in incidence of disease is due to adaptation of interactions between humans and their environment.

3.1 Apparent EID

An example of apparent EID lies in changes in technology where the advent of polymerase chain reaction (PCR) technology and identification of subtypes of human papillomavirus (HPV) has been associated with Cancer. Before the use of PCR technology, doctors used epidemiology to associate sexually transmitted infections as a possible cause of Cancer.

3.2 Changing Patterns of Disease and Disease X

In 2015, the World Health Organisation (WHO) designated Disease X, of unknown origin but likely to occur sometime in the future, and of pandemic proportion. In 2020, Disease X, was named COVID-19. COVID-19 was therefore not a surprise to many who study epidemiology but to the public this was somewhat shocking. Earlier outbreaks of Middle East Respiratory Syndrome Coronavirus (MERS), and severe acute respiratory syndrome (SARS) did not result in pandemics but were nevertheless indicative of the changing patterns of disease (Iserson, K.V., 2020).

It is difficult to identify a specific disease or know when these diseases will appear in the general population. Public Health and epidemiology aim to identify the emergent properties and niches that might overlap, which are more likely to occur, and what the result of possible interactions might be, in identifying a future disease. Disease patterns change over time due to changes to the pathogen, the environment, the population and hosts, and the reservoir (the source of the pathogen, often animals). Pathogens also adapt over time via mutations as they seek out the most appropriate hosts and these changes might be due to the host actions themselves, e.g., development of drug resistant forms of pathogens as a result of the use of antibiotics.

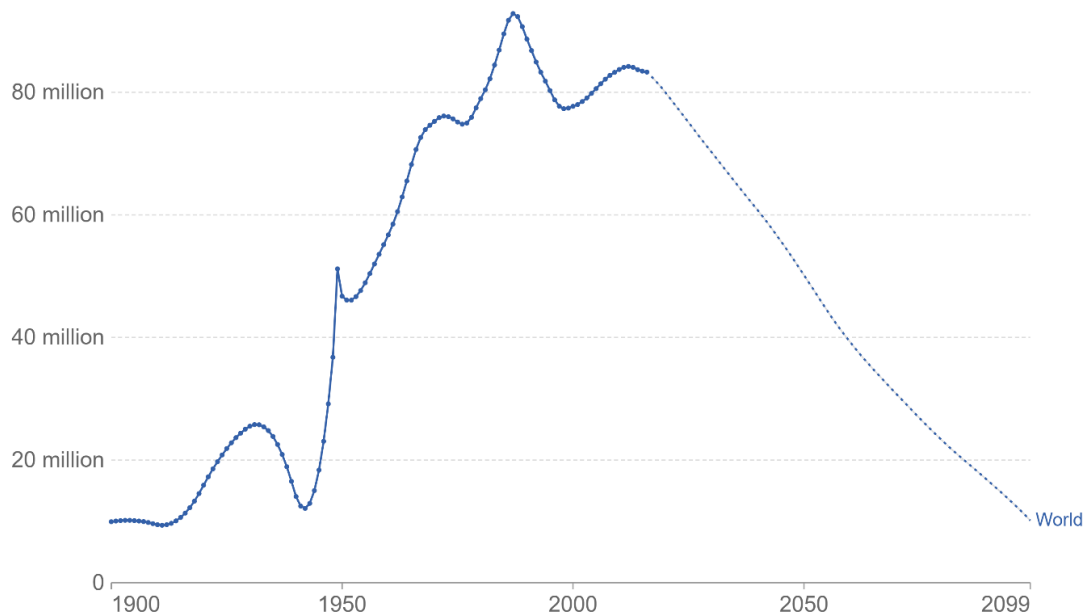
3.3 Changes in the Human Population

The world population has increased from one (1) billion people in 1800 to over 7.7 billion people in 2022 (Roser et al., 2019).

Figure 6 (Roser et al., 2019)

Absolute increase in global population per year

Absolute population change measures the net increase in total population in any given year e.g. data for 1950 represents the net change in total population from 1950 to 1951. Data projections to 2100 are based on the UN Population Division's 'medium variant' projection.



Source: Absolute population change - OWID based on HYDE & UN

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As the human population has changed over time, moved from rural farmlands to towns and cities, and encroached on the environment, they have made the handling of disease more difficult and allowed for spread and crossover of disease between the natural habitat, animals, and humans. In addition, travel has made it possible for pathogens to spread to environments they would not previously have reached. Developments in technology and medicine have made it possible for highly susceptible hosts to live longer thereby contributing to the spread and mutability of disease.

4 Pathogens

In biology, infectious disease is caused by pathogens that have the capacity to replicate and are transmitted either from human to human, from animal to human, or from the environment to human. High rates of mortality have been attributed to infectious diseases that cause respiratory diseases, Acquired Immune Deficiency Syndrome (AIDS), Tuberculosis (TB), Malaria, and more recently, COVID-19. Similarly, leading infectious causes of Cancer have been

attributed to pathogens such as Human papilloma virus (HPV) (Communicable Diseases 2021, WHO 2022). While tools such as the Polio Vaccine and Public Health measures such as water sanitation have led to a reduction in mortality, many infectious diseases have continued to add to the Public Health burden when treatments fail, or the pathogens adapt via mutation to evade eradication. Also, new emerging diseases such as COVID-19 clearly show that measurement, monitoring, and awareness is paramount to Public Health and its measures. This includes using available tools and measures against diseases to control infection, development of new tools to handle changes in diseases, and prediction of diseases that may occur in the future. Accomplishing these requires consistent and ongoing knowledge of the biology of these pathogens and the impact on host immunity.

5 Innate Immunity

Immunity is of vital importance to living beings to protect against infection and ensure survival. Immunity is also of vital important to Public Health when it can be boosted or used to protect individuals and larger populations from disease using methods such as vaccination. To achieve this, a complete understanding of how the immune system works is important. Humans are born with innate immunity that can fight off infectious agents as a “first-line” defense. These include the following:

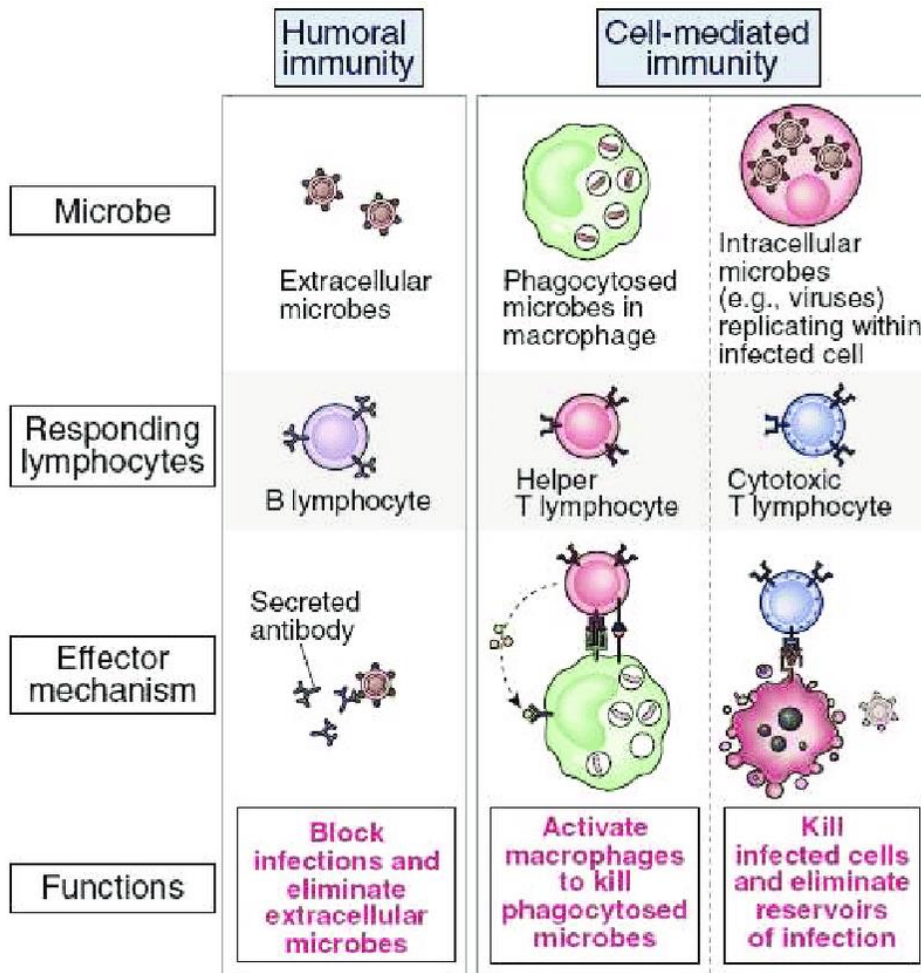
- Physical barriers such as skin, cornea, mucus layers and excreted fluids like urine,
- Chemical barriers such as stomach acid and,
- Active mechanisms that are either intracellular such as apoptosis or organismal such as phagocytosis.

Phagocytosis is an active process used by innate immunity to destroy pathogens that invade the host. This process is mediated by specialized cells (phagocytes) such as macrophages and neutrophils which engulf pathogens thereby killing and digesting them. However, the ability to engulf these pathogens is highly dependent on available and recognizable receptors on the pathogen and some pathogens are resistant to this process, like TB. Phagocytes are in strategic places such as skin, blood, and in the digestive system, are attracted to sites of injury and can be taught to become better at the process of engulfing and destroying pathogens (Günther, J., & Seyfert, H. M., 2018).

6 Adaptive Immunity

The immune system of the host can adapt by learning from exposure to a specific pathogen. This memory is typically evident a few days after exposure and leads to a larger response following subsequent re-exposure to the same pathogen. Adaptive immunity is divided into two parts namely Humoral or Cell-mediated Immunity (CMI).

Figure 7 Illustration of Humoral and Cell-mediated Immunity (Mareai, S., 2018)



6.1 Humoral Immunity

Humoral immunity is achieved by the presence of protein molecules call antibodies (Ab) and immunoglobulin (Ig). Ab can be found in fluids such as blood and mucus and are able to

recognize and destroy viruses, toxins, and bacterial infections which have an extracellular phase. Ab are less effective against that that do not.

6.1.1 Antigen Binding

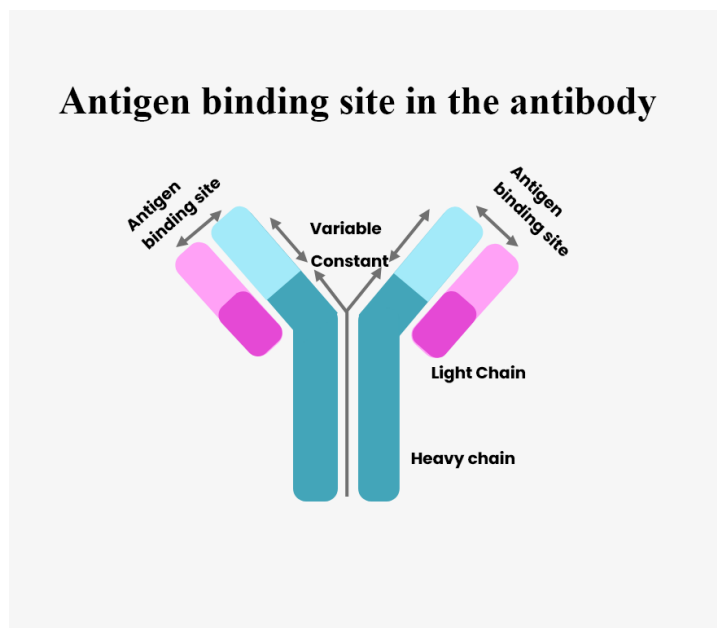
Ab physically bind to targets called antigens (Ag). They can do this, much like puzzle pieces fit together, because of an exact fit between the Ab and Ag, known as the epitope. This binding is specific in that an Ab can only bind to its matching epitope which causes destruction of that antigen (pathogen).

6.1.2 Antibody Structure and Neutralization

The Ab structure is such that there are variable regions which different from Ab to Ab, thereby allowing in different responses by Ab to invading Ag. It is estimated that an individual holds approximately 10^9 Ab within their immune system at any time. There are many types of Ab, examples of which are IgM and IgA found on mucosal surfaces, and IgG found in serum and currently of importance in the fight against COVID-19.

Neutralization occurs when an Ab binds to the Ag thereby causing pathogen destruction or inactivation.

Figure 8 Antibody Structure and Binding (CBSE., n.d.)



6.2 Cell-mediated Immunity

CMI is created by the presence of cytotoxic T cells (killer T cells, CD8⁺ cells) which kill other cells, usually those infected by a pathogen or helper T cells (CD4⁺) which build future immune responses by helping to prime killer T cells.

6.2.1 T-cell Receptor Structure and Neutralization

Like humoral immunity, CMI also requires a specific puzzle-piece type of fit through recognition of an Ag by a T-cell receptor. T-cell receptors are much like Ab however recognize Ag by their shape. This shape is determined by the presence of Ag fragments bound to another protein known as the MHC I antigen, found on the surface of almost all cells. By a process of “presentation”, T-cell receptors recognize the bound structure. CMI tends to target pathogen-infected cells thereby killing the cells and the pathogen within. Unlike humoral immunity that uses Ab in extracellular spaces, CMI mediated by T-cells is effective against intracellular pathogens but also destroys the infected host cells.

7 Vaccination

The immune system is of vital importance in allowing for survival of the host following infection with a disease-causing pathogen. Measure to protect and promote immunity within the population have become central to the responsibility of Public Health where immunity can be affected to protect both individuals and larger populations. One such measure used by Public Health is vaccination. The choice of vaccine depends on knowledge of the pathogen and how boosting immunity might create protection which requires a full understanding of the disease-causing pathogen, immunity mechanisms, target antigens, and choice of vaccine. The COVID-19 pandemic has largely been controlled via the development of various types of vaccine, most notable the messenger ribonucleic acid (mRNA) vaccines, which have been administered more than 10.2 billion times since the start of the COVID-19 pandemic (Bloomberg, 2021).

8 Conclusion

The understanding of biology within the realm of Public Health requires in depth understanding of disease, the immune system, and large-scale protective measures required to protect the individual and the general population. While vaccination has become central to the topic of protection against disease, this does not discount the requirements for effective treatments and necessary advancement in science, current thinking, and public perceptions. This is no more evidence than today, where disinformation pervades Public Health and society. Continued understanding, development, and research will ensure that Disease X, and the next pandemic are well prepared for, in the continued effort to maintain good Public Health and longevity.

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