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Vaccination Protects the Human Body from Certain Diseases

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Abstract: Vaccination is a procedure by which certain antigenic material is introduced into the body. The goal of vaccination is to create immunity to a certain disease. Vaccinations are considered to be the most effective and cheapest method of preventing the appearance and spread of infectious diseases. The vaccine may contain live but attenuated pathogens of bacteria or viruses, dead or inactivated pathogens, or only isolated specific proteins of the given pathogens. Smallpox was the first disease that people tried to prevent by vaccination.

Keywords: Vaccine, Pathogens, COVID-19, Public Health.

INTRODUCTION

Vaccination relies on the generation of acquired immunity [Williams, A. E. 2012]. More specifically, vaccination induces an immune response to the antigenic products contained in the vaccine, which results in the development of memory immune cells. When a live pathogen is then encountered the memory cells recognize the same antigenic components (or close variants of) and generate an immune response against that pathogen. The memory response is more rapid and ardent than the primary response to the vaccine; hence the pathogen is contained and destroyed effectively with the minimum amount of damage to the host.

The ideal vaccine needs to fulfil a number of criteria to be effective. Historically vaccinologists endeavoured to develop live-attenuated vaccines derived from either the disease-causing microorganism or from a closely related form of the pathogen. The vaccinia virus used to eradicate smallpox is an example of a liveattenuated vaccine, which is a tissue culture adapted strain of cowpox. Attenuated vaccine strains should cause no or little disease but induce an effective immune response to the intended pathogen. Inactivated vaccines employ whole bacteria or viruses that are rendered nonpathogenic by inactivating them, usually by chemical, UV or heat treatment. The pathogen can no longer replicate inside its host and therefore cannot cause disease but still induce an immune response. The inactivated cholera vaccine is an example of a killed-bacterial vaccine. Acellular vaccines consist of fractions of bacteria (with the toxic components inactivated) or empty virions (virus capsules) that retain their immunogenic components. For example, the diptheria vaccine contains an inactivated toxin that has been treated with formaldehyde to form a toxoid. The formaldehyde cross-links the amino acids in the diptheria toxin rendering it non-toxic and safe for use as a vaccine.

Throughout the past century, vaccination programs have been formulated to protect individuals and populations primarily by protecting people from infection [Ewald, P. W, 2004]. It is increasingly being recognized that the focus on protection from infection is misplaced, for two related reasons. The first is that vaccines, even successful ones, often are imperfect; that is, they may protect people from disease but not from infection. If so, measurements of infection are not as relevant as measures of morbidity and mortality. The second reason is that vaccination programs may influence the evolution of the pathogen's virulence, that is, the inherent harmfulness of the disease organism. When a pathogen is eradicated globally, distinction between the incidence and the harmfulness of infection is a moot point – when no pathogens remain to be transmitted, it does not matter whether the pathogen was more harmful or less harmful prior to eradication. When the target organism is not eradicated, however, the distinction is important, because the vaccination program itself may cause an evolutionary change in the target organism, making it more or less harmful than it was at the inception of the vaccine program. When an antigen is used in a vaccine, any variant that is immunologically distinct from the antigen or that does not express the antigen at all will be controlled less well by the vaccination program than those pathogens that express that vaccine antigen. This process can lead to vaccine escape, whereby the variant that is less well controlled by the vaccine increases in frequency during the course of the vaccine program.

Pathogen

Successful vaccines must take into account the type of pathogen, the tissue which it infections and

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its mode of cell entry [Williams, A. E. 2012]. Pathogens that reside in the extracellular environment are more susceptible to antibody-mediated immune responses than those that reside inside cells. Therefore, in order to eradicate extracellular pathogens, or prevent intracellular pathogens invading cells, an antibody-mediated immune response is desirable. Inactivated bacteria or viruses that do not invade or replicate in host cells are ideal vaccines to induce strong B cell-mediated antibody responses. On the other hand, pathogens that replicate in host cells are more susceptible to cytotoxic T cell responses that kill infected cells and prevent the pathogen from spreading. Live-attenuated vaccines that retain a low level of replication potential, or DNA vaccines, are more effective at inducing cellmediated immune responses. The location of pathogen entry and replication is also an important consideration for vaccine design. Most pathogens enter the body across mucosal surfaces such as the lung or intestine so an effective mucosal immune response is desirable. The ideal vaccine would induce both antibody and cellmediated immune responses at the appropriate site of pathogen entry.

Host

For any infectious process to occur, the pathogen and the host must first encounter each other [Madoff, L. C. *et al*., 2005]. Factors such as geography, environment, and behavior thus influence the likelihood of infection. Although the initial encounter between a susceptible host and a virulent organism frequently results in disease, some organisms can be harbored in the host for years before disease becomes clinically evident. For a complete view, individual patients must be considered in the context of the population to which they belong. Infectious diseases do not often occur in isolation; rather, they spread through a group exposed from a point source (e.g., a contaminated water supply) or from individual to individual (e.g., via respiratory droplets). Thus, the clinician must be alert to infections prevalent in the community as a whole. A detailed history, including information on travel, behavioral factors, exposures to animals or potentially contaminated environments, and living and occupational conditions, must be elicited. For example, the likelihood of infection by Plasmodium falciparum can be significantly affected by altitude, climate, terrain, season, and even time of day. Antibiotic-resistant strains are localized to specific geographic regions, and a seemingly minor alteration in a travel itinerary can dramatically influence the likelihood of acquiring chloroquineresistant malaria. If such important details in the history are overlooked, inappropriate treatment may result in the death of the patient. Likewise, the chance of acquiring a sexually transmitted disease can be greatly affected by a relatively minor variation in sexual practices, such as the method used for birth control. Knowledge of the relationship between specific risk factors and disease allows the physician to influence a patient's health even before the development of infection by modification of these risk factors and—when a vaccine is available— by immunization.

Many specific host factors influence the likelihood of acquiring an infectious disease. Age, immunization history, prior illnesses, level of nutrition, pregnancy, coexisting illness, and perhaps emotional state all have some impact on the risk of infection after exposure to a potential pathogen. The importance of individual host defense mechanisms, either specific or nonspecific, becomes apparent in their absence, and our understanding of these immune mechanisms is enhanced by studies of clinical syndromes developing in immunodeficient patients. For example, the higher attack rate of meningococcal disease in people with deficiencies in specific complement proteins of the so-called membrane attack complex than in the general population underscores the importance of an intact complement system in the prevention of meningococcal infection.

Vulnerability

World has rapidly become much more vulnerable to the eruption, and most critically, to the widespread and even global spread of both new and old infectious diseases. This new and heightened vulnerability is not mysterious [Draine, Y. *et al*., 2011]. The dramatic increase in worldwide movement of people, goods, and ideas is the driving force behind the globalization of disease. For not only do people travel increasingly, but they travel much more rapidly, and go to many more places than ever before. A person harboring a life-threatening microbe can easily board a jet plane and be on another continent when the symptoms of illness strike. The jet plane itself and its cargo can carry insects bringing infectious agents into new ecologic settings. Few habitats on the globe remain truly isolated or untouched, as tourists and other travelers penetrate into the most remote and previously inaccessible areas in their search for new vistas, business, or recreation.

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Such a devastating disease would clearly have profound implications for international relations and the global economy. With death tolls rising, vaccines and drugs in short supply, and the potential for the virus to spread further, governments would feel obliged to take drastic measures that could inhibit travel, limit worldwide trade, and alienate their neighbors. It is even doubtful that any of the world's wealthy nations would be able to meet the needs of their own citizenry, much less those of other countries. Domestic vaccine purchasing and distribution schemes currently primarily assume that only the very young, the elderly, and the immunocompromised are at serious risk of dying from the flu. Every year the United States plans for 185 million vaccine doses, trusting that the flu will kill only the usual risk groups. If that guess were wrong, if all Americans were at risk, the nation would need at least 300 million doses. That is what the entire world typically produces each year. There would thus be a global scramble for vaccine.

SARS

The first new infectious disease of the 21st century was identified as severe acute respiratory syndrome (SARS), and the first case of SARS was reported in the Guangdong province of China in November 2002 [Glick, B. R. *et al*., 2014]. In 2003, there were simultaneous outbreaks of SARS in several major cities, including Hong Kong, Singapore, and Toronto, Canada. Given the high frequency of air travel, the disease rapidly spread to 29 countries on five continents. With the assistance of the WHO, authorities in affected regions immediately implemented strict infection control procedures, so that by 23 September 2003, the outbreak was effectively contained. However, this was not before a total of 8,096 SARS cases and 774 associated deaths were reported. Within a very short time, scientists had identified a novel coronavirus, SARS coronavirus (SARS-CoV), as the causative agent of the disease.

SARS-CoV is enveloped and contains a single-stranded plus-sense RNA genome of about 30 kilobases (kb). The viral spike (S) protein, which is inserted into the viral membrane, binds to a receptor protein that is present on the surfaces of mammalian host cells. After binding of the virus to the receptor, the viral and cell membranes can fuse and facilitate entry of the virus into the cell.

The spikes of SARS-CoV are composed of trimers of S protein, which belongs to a group of class I viral fusion glycoproteins that also includes HIV glycoprotein 160 (Env), influenza virus hemagglutinin (HA), paramyxovirus F, and Ebola virus glycoprotein. The SARS-CoV S protein encodes a surface glycoprotein precursor predicted to be 1,255 amino acids in length, and the amino terminus and most of the protein are predicted to be on the outside of the cell surface or the virus particles. The predicted S protein consists of a signal peptide (amino acids 1 to 12) located at the N terminus, an extracellular domain (amino acids 13 to 1195), a transmembrane domain (amino acids 1196 to 1215), and an intracellular domain (amino acids 1216 to 1255). The S protein is composed of two subunits; the S1 subunit contains a receptor-binding domain that engages with the host cell receptor angiotensin-converting enzyme 2, and the S2 subunit mediates fusion between the viral and host cell membranes. The S protein is essential to induce neutralizing antibody and T-cell responses, as well as protective immunity, during infection with SARS-CoV. Because the S protein mediates receptor recognition as well as virus attachment and entry, it is an important target for the development of SARS vaccines and therapeutics.

Vaccines

Vaccines function by stimulating the immune system and prompting a primary immune response to an infecting pathogen or to molecules derived from a particular pathogen [Stratton, K. *et al*., 2012]. The immune response elicited by this primary exposure to vaccine pathogen creates immunological memory, which involves the generation of a pool of immune cells that will recognize the pathogen and mount a more robust or secondary response upon subsequent exposure to the virus or bacterium. In successful immunization, the secondary immune response is sufficient to prevent disease in the infected individual, as well as prevent the transmission of the pathogen to others. For communicable diseases, immunizations protect not only the individual who receives the immunization, but also others with whom he or she has contact. High levels of vaccination in a community increase the number of people who are less susceptible or resistant to illness and propagation of the infectious agent. Unvaccinated individuals or those who have not developed immunity to this pathogen are afforded an indirect measure of protection because those with immunity reduce the spread of the pathogen throughout the entire population. The larger the proportion of people with immunity, the

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greater the protection of those without immunity. This effect is called "herd immunity." Herd immunity is an important phenomenon as immunization programs rarely achieve 100 percent immunization in a population; and in some cases, previously vaccinated persons may not exhibit effective immunity and disease may result from exposure to the pathogen. For protection, immunization of not only ourselves but also our neighbors is important.

The overwhelming safety and effectiveness of vaccines in current use in preventing serious disease has allowed them to gain their preeminent role in the routine protection of health. Before an immunization is introduced for population-wide use, it is tested for efficacy and safety. However, immunization is not without risks. For example, it is well established that the oral polio vaccine on rare occasion causes paralytic polio and that vaccines sometimes lead to anaphylactic shock. Given the widespread use of vaccines; state mandates requiring vaccination of children for entry into school, college, or day care; and the importance of ensuring that trust in immunization programs is justified, it is essential that safety concerns receive assiduous attention.

The biological basis of successful vaccination is our own complex immune system and its response to pathogens [Halloran, M.E. *et al*., 2010]. Vaccination can induce an immune response that mimics natural infection or tries to do even better than our response to a pathogen. Vaccination induces an immune response in the individual vaccinated. A population of hosts has a collective level of immunity that results from the level of immunity in the individuals that compose it. The collective immunological status of a population of hosts, as opposed to an individual host, with respect to a given pathogen is called herd immunity. Maintenance of individual immunity can depend on repeated boosting by natural infection. The level of transmission may be diminished by high levels of immunization or natural immunity in a population to the point that natural boosting of immunity does not occur. Thus for some infections, a complex interplay between individual and population level immunity is maintained through the dependent happenings.

The immune response is also the source of many safety considerations of vaccination. Before a vaccine can be shown efficacious against infection or disease in a large-scale field study, it must be shown to elicit an immune response and to be safe in smaller studies.

Vaccines are most commonly administered using a needle and syringe; however, their use is associated with numerous drawbacks such as needlestick injuries to health care workers and the costs and logistical challenges associated with the safe disposal of sharps in the medical waste stream [Flyer, D.C. *et al*., 2012]. The seriousness of these issues, the need to simplify global immunization programs, and the development of needle-free vaccine delivery have become a global priority. One needle-free vaccine approach being developed is the use of a vaccine patch which delivers the vaccine through the skin. Referred to as transcutaneous immunization (TCI), the topical application of a vaccine formulation on the skin targets the skin as an immunologically active site.

Normally, up-to-date vaccines induce adaptive immune responses and provide the body with immune memory for a long-term period in human life to those pathogens against which they have been directed [Klimov, V. V, 2019]. One type of vaccine manufactured of antigens from extracellularly located pathogens can induce an advanced B-cell-mediated response, formation of specific antibodies and long-term memory B cells, and the preventive effect of immune clearance. Another type of vaccines is manufactured of antigens from intracellularly parasitized pathogens. It can trigger CD4+ and CD8+ T-cell-mediated responses, the formation of effector CD4+ T cells, CD8+ T cells, and long-lasting memory CD4+ and CD8+ T cells and achieve preventive effects of immune clearance.

However, there is a third type of vaccines made of antigens from opportunistic pathogens that may result in the establishment of immune containment only and shortterm immune memory. Unfortunately, artificial immunity after all types of vaccines is not entirely identical as compared to natural immunity, which is always lifelong against absolutely pathogenic microbes.

Furthermore, there are questions related to the immunological safety of vaccines and their capacity to trigger non-antigen-specific responses possibly leading to conditions such as allergies, autoimmunity including pathology of the CNS, or even premature death. Additionally, some parents choose not to vaccinate their children because of fear of autism or other disorders. Nowadays, groups of activists, antivaccinationists, object to

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the scientific basis, medical safety, religious ground, ethical aspect, and legislative right of any vaccination. It leads to a decrease in herd immunity (community immunity, population immunity, or social immunity), which is a form of indirect protection from infectious disease that occurs when a large percentage of a population has become immune to infectious agents, thereby providing a measure of protection for individuals who are not immune.

Nowadays, three million deaths per year are prevented worldwide by vaccinations. To date, the eradication of smallpox is one of the most significant achievements of modern medicine. It became possible due to an effective vaccine and global vaccination programs, which led to herd immunity to the infection.

There are two goals of any vaccination, tactical and strategic. The tactical goal is the generation of long-lived memory T cells and B cells to a particular infectious pathogen at the individual level, whereas the strategic goal is the achievement of herd immunity to this pathogen at the population level. Herd immunity is a form of indirect defense against infection in non-vaccinated individuals that occurs when most of the population has become immune to the infection due to the vaccination.

Government authorities usually rely on expert advisory committees to make recommendations for the use of vaccines, such as the Advisory Committee on Immunization Practices (ACIP) in the United States [Salmon, D.A. *et al*., 2016]. European countries make recommendations at the national level rather than across the European Union. WHO provides guidance for use of vaccines in developing countries. These advisory committee recommendations provide guidance on vaccine use in different ages and risk groups as well as information on what is known about the safety of the vaccine. Recommendations include guidance on groups or individuals who should not receive the vaccine due to safety concerns. For example, guidance is given for individuals with underlying conditions that might predispose to serious adverse events in order to prevent possible vaccine-associated injuries. Generally live vaccines are not given to persons with serious immune deficiency disorders, but some live vaccines are safe in those with less serious immunological conditions. Vaccine recommendations may include guidance for use in populations not studied in clinical trials, such as pregnant women. There is wide variability in vaccine recommendations globally as there are many differences in the burden of disease, and considerations of risks and benefits from vaccines.

COVID-19

The way the global vaccine research and development system is currently constructed and operated is not optimized to develop, manufacture, and equitably distribute vaccines [Nickerson, J. W. *et al*., 2020]. Given these conflicting realities, a new approach to health innovation is required.

Specifically, we argue that any COVID-19 vaccines must be re-conceptualized as global public goods rather than publicly subsidized, privately controlled commodities. By "public good" we mean that COVID-19 vaccines—while material in form—are, at bottom, information-based products. That is, once knowledge about a given vaccine's safety and effectiveness against SARS-CoV-2 is in hand, only resources (for example, manufacturing facilities) and law (for example, patent law) can limit its consumption; the underlying knowledge about how to make and use them, absent these limitations, is both non-rivalrous and non-exclusive. Because of the demand for such vaccines, and their central importance to securing adequate public health within and across countries, no one nation, or private manufacturer, alone can guarantee their provision; rather, their development and production will, of necessity, be a global endeavour, thus the term "global" public goods. We argue that this conceptualization of COVID-19 vaccines as global public goods must be carried through the entire process of producing, testing, manufacturing, and distributing any resulting COVID-19 vaccines. To make it concrete, we outline how this global public goods approach might be achieved in the Canadian setting, while also recognizing that the approach must be adopted elsewhere as well if global needs are to be met.

Like many other knowledge-based goods in the health domain, vaccines are not usually treated as public goods, on the strength of the argument that without the promise of exclusivity, private companies would not undertake the lengthy, costly process of developing them for human use. Patent rights and other legal protections from potential competitors are used to motivate, coordinate, and sustain vaccine R&D, from discovery and preclinical stages of research (often performed by publicly funded institutions) through to clinical trials involving human participants,

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manufacturing, and regulatory approval (usually run by the private sector). Most vaccines and drug therapies that reach the market follow this pattern.

There are several limitations associated with this publicly subsidized, privately appropriated approach. Principal among them are that health conditions or diseases which afflict the world's poor or carry less predictable financial returns typically command very little interest. Prior to COVID-19, coronaviruses were an example of this lack of interest: only six interventions reached the clinical trial phase of development, all of which relied heavily on public funding.

Public Health

Understanding public health requires a keen understanding of the points where individuals have compatible or conflicting interests and needs [Reich, J. A. 2016]. One such point is "herd immunity" against infectious disease. When a person receives a vaccination, she has a far greater chance of being protected from that illness—receiving individual benefit—but also helps to protect others in the community who are vulnerable to infection. Some vaccines benefit only the individual, like that for tetanus, which is a disease that is not contagious but results from exposure to a toxin in the environment that causes neurological damage and death and is difficult to treat. However, the majority of required vaccines do not just protect the child who receives inoculation, but also prevents exposure of life-threatening illnesses in the disabled, the aged, the immune-compromised, the infants too young to be vaccinated, and the pregnant women whose fetuses could be devastated by these illnesses, as well as those few individuals who did not gain immunity from a vaccine they received.

If a community-level immunity rate, known as herd immunity, of approximately 85–95 percent (depending on the disease) is maintained, virtually all members of the community are protected from infection. It is impossible to create immunity in 100 percent of a population. With herd immunity, diseases are blocked from reaching those who would be at risk by those who are vaccinated.

By taking advantage of the adaptive immune response, vaccines can be administered to immunise against infections and toxins [Fulford, M.R. *et al*., 2020]. Vaccines capitalise on the immune response targeting specific antigens and forming a memory for these antigens. If an antigen can be presented to our immune system stripped of the accompanying threat of a pathogen, then the adaptive response will be able to make memory (T and B) cells that will be quickly activated should the pathogen that antigen is associated with be encountered.

Vaccines have been developed that use live bacteria or viruses that have been weakened (attenuated), inactivated and parts of bacteria and viruses (fractions). Researchers are currently exploring methods of directly changing host immune cells via DNA and recombinant vector vaccines. Whilst the principal of tricking our immune system with antigens is straightforward, the reality is far more complex. Unfortunately, making vaccines is not a simple affair. This is because many pathogens mutate (e.g. the common cold); invade and damage immune cells thereby evading detection or destroying our defences (e.g. HIV); or have a complex life cycle (e.g. malaria) to name but a few barriers. The route of administration and the site of injection can also influence the efficacy of a vaccine; this is why some are injected, and others are inhaled or swallowed.

Regulatory Challenges

The fundamental goals in developing new vaccine technologies are to improve current vaccines for existing clinical indications and to develop new immunogens for both pediatric and adult use [Gruber, M. F. *et al*., 2001]. Recent progress in the field of recombinant DNA technology and advances in basic immunology have accelerated the development of novel vaccine approaches to modulate the immune response. Examples include non-replicating antigen delivery systems, genetically modified vectors expressing foreign antigens, DNA vaccines, as well as the use of novel adjuvants and different modes of vaccine administration.

The diversity and complexity of these products present new regulatory challenges, because specific standards for the criteria of safety, purity and potency for these products may not exist and current experience largely relies on animal models. The problem is further complicated by the variety of regulatory submissions for prevention of viral, bacterial and parasitic diseases. Therefore, the safety, purity and potency of these products are evaluated using a case-by-case approach that is product-specific and indication-based. Consideration is also given to potential risks versus the benefits of using the product in the target population. It is important to realize that

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regulatory policy evolves in response to advances in technologies.

CONCLUSION

When it comes to vaccination, it should be said that it is actually an artificial creation of immunity in order to protect against a certain infectious disease, and this is achieved by initiating an immune reaction by ingesting a certain immunogen. Vaccination can be performed by injecting one or more immunogens in a number of different ways. Vaccination is one of the most effective public health measures in the history of medicine that has independently extended human lifespan by at least 20 years. Since the whole world is facing the COVID-19 pandemic from the end of 2019, it should certainly be emphasized that vaccination against COVID-19 introduces a substance into the body that stimulates the human immune system to independently create resistance to coronavirus. Covid-19 is a contagious disease. The vaccine is the most effective way for people to avoid getting seriously ill from this disease. Vaccination also helps reduce the spread of covid-19 in society. That is why it is important that as many people as possible decide to get vaccinated.

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