Routes of Transmission and the Introduction of Foreign Animal Diseases

overview 2
part 1

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Portals of Entry of a Foreign Animal Disease

A number of diseases on OIE lists, as well as emerging infectious diseases, constantly threaten to expand their geographic range and become established in new regions. Diseases such as heartwater, now found mainly in Africa, could become endemic in any country where suitable host populations and tick vectors exist. Where OIE diseases have been eradicated from parts of the world, countries also face the ongoing threat of re–introduction. In 2001, for example, foot and mouth disease was reintroduced to the United Kingdom as well as to other FMD-free countries like Argentina and Uruguay. To prevent foreign animal diseases from entering the U.S., authorities must monitor all of the routes by which pathogens could cross our borders. This job is made more difficult by the existence of many diverse portals of entry, including livestock and pets, wildlife, animal products, arthropod vectors, inanimate objects, and humans.

Entry in animals

Each year, the U.S. imports livestock and poultry from many countries (1.5 million cattle and 5.8 million pigs were imported in 2002). People also return to the country with pets, either following a vacation or after living abroad. These animals must be screened to ensure that diseases are not entering the U.S. as hitchhikers on a flock of sheep or the family dog. Although the system works well, occasionally a potential disease problem is missed. In one recent incident, screwworms were found in a group of horses imported from Argentina, after they had left the U.S. quarantine facility. Animals that do not pass through inspection stations, such as smuggled animals or migratory animals, pose an even greater risk of introducing an exotic disease. During the last 20 years, many outbreaks of Newcastle disease have been caused by psittacine birds that were illegally imported into the U.S., bringing exotic Newcastle disease virus with them. And obviously, migratory animals and birds do not stop at border inspection stations. A migratory bird carrying a bit of rabbit feces on its feet could easily stop in the U.S., depositing rabbit hemorrhagic disease in the vicinity of susceptible lagomorphs. Similarly, migratory birds with exotic poultry diseases fly freely across national borders.

Vectors and fomites

Pathogens can also enter the country on **fomites** (contaminated inanimate objects) and **vectors** (living organisms that transmit diseases from one animal to another). Vectors capable of carrying some very serious diseases of livestock have been imported on reptiles, which previously were

not subject to screening by agriculture officials. *Amblyomma variegatum*, a tick vector of heartwater, has been discovered on tortoises imported into Florida. Fomites can also carry pathogens into the country: for instance, a livestock virus could be carried across international borders on the shoe from a traveler who had walked through an infected farm.

Animal products

Each year the U.S. imports millions of tons of edible animal products. Although these shipments are screened for infectious agents, it is foolhardy to assume that the system is flawless. In addition, imported biologics such as vaccines, embryos and ova for embryo transfer, and semen for artificial insemination must be screened to ensure freedom from harmful infectious agents.

People

Humans can act as fomites or incubators to bring livestock diseases into the U.S. The foot and mouth disease virus, for example, may survive on clothing or shoes under cool damp conditions for days. Failure to adequately disinfect outerwear contaminated by this virus could result in an epizootic within the U.S. Another human–as–fomite possibility would be carrying pork products from a country in which classical swine fever is endemic. This systemic disease of pigs, present in both the Dominican Republic and Cuba, could enter the U.S. through a discarded sausage or ham sandwich brought in by a traveler. Additionally, there are some diseases that infect both people and animals. Rift Valley fever, for instance, is a mosquito–borne viral disease that causes illness in both humans and ruminants. A human returning from a visit in an infected part of the world could be incubating Rift Valley fever on return to the U.S. and, once within our borders, develop a full–blown viremia that mosquitoes could then pick up and carry to ruminant livestock nearby.

Besides all of these unintentional means of introduction, consider the possibilities of a nefarious introduction: for instance, a bioterrorist using a foreign animal disease agent to decimate our susceptible livestock species. Any of the routes mentioned above could be used by a bioterrorist. The economic consequences would be the same as those of an unintentional introduction and our only defense is to respond rapidly and effectively.

Definitions for Understanding the Transmission of Exotic Diseases

While many portals of entry exist for exotic diseases, each specific pathogen can use only some of these routes. To understand the characteristics of a given agent that contribute to the likelihood for introduction, we must first review some general concepts in animal disease transmission.

A **disease** is defined as any deviation from normal structure or function. Diseases may be described according to their transmission characteristics. An **infectious disease** is a disease caused by the invasion and multiplication of a living agent in or on a host. Infectious diseases can be described as viral, bacterial, mycotic, or parasitic according to the type of etiologic agent responsible. Infections may or may not result in disease. In contrast, an **infestation** is the invasion, but not multiplication, of an organism in or on a host. Because they multiply in the host, bacterial and viral diseases are considered to be infections. However, parasitic diseases can be either infestations or infections depending on the life cycle of the parasite in question. Many metazoan parasites do not multiply within the same host; the presence of these agents is most appropriately referred to as an infestation. These two terms are also commonly used to contrast the presence of organisms inside a host body (infection) with the presence of organisms on the hair, fur, feathers, or skin of the host (infestation). In Lyme disease, for example, the tick vector *Ixodes scapularis* infests a host while the bacterial pathogen *Borrelia burgdorferi* is transmitted by the tick and infects the host.

A **contagious disease** is a disease that is transmissible from one human or animal to another via direct or airborne means. Agents that cause contagious diseases can be spread from animal to animal in excretions and secretions, respiratory aerosols, scabs, and other body fluids or tissues. One example of a directly contagious disease is peste des petits ruminants, a serious viral disease of small ruminants in Africa, the Middle East, India, and the Arabian peninsula. Sheep and goats with peste des petits ruminants excrete infectious virus in their ocular, nasal, and oral secretions. Coughing and sneezing animals readily spread the virus to nearby animals in aerosols.

Infectious diseases can also be communicable without being contagious. A **communicable disease** is caused by an agent capable of transmission by direct, airborne, or indirect routes from an infected person, animal, or plant, or from a contaminated inanimate reservoir such as the soil. Indirect routes include transmission by insects or on vehicles such as food, water, clothing, and equipment. Many important communicable diseases are not directly contagious, but are transmitted between animals by arthropod vectors. African horse sickness is one example. This disease, a severe cardiac and pulmonary disease of horses and other Equidae, is caused by an orbivirus transmitted by biting midges in the genus *Culicoides*. Infected horses can transmit the African horse sickness virus to new *Culicoides* vectors but do not spread it directly to other horses.

Understanding these terms is crucial to understanding how exotic diseases are introduced into a country. For example, if a disease is highly contagious, we know that we have to prevent close contact between pos-

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Communicable disease—a disease caused by an agent capable of transmission by direct, airborne, or indirect routes from an infected person, animal, or plant, or from a contaminated inanimate reservoir

sibly infected animals and those that are immunologically naïve. Such prevention may take the form of quarantining animals, possibly slaughtering infected or exposed animals, and increasing surveillance to prevent the future spread of the disease. In some cases, care must also be taken to prevent contact with inanimate objects that may harbor viable infectious organisms to prevent the spread of communicable diseases.

Routes of Transmission of Infectious Disease Agents

The most likely route of introduction of an exotic disease depends on its mode of transmission. A pathogen transmitted by mosquitoes can be spread between regions in an infected insect, while a virus that persists on fomites can enter a country on a contaminated shoe. Other, more fragile, pathogens may be able to enter new areas only in the infected host animal. A number of factors can influence the mode of introduction of a given pathogen: whether it is transmitted between unrelated animals or from parent to offspring, if an intermediate host or vector is required for transmission, how persistent the pathogen is in the environment, and whether the disease agent is immediately infectious or requires time in the environment to develop to the infectious stage. Disease agents that are more easily transmitted and spread are considered to pose a greater threat of introduction.

Vertical transmission

Vertical transmission is the transfer of a pathogen from a parent, usually the dam, to the offspring through reproduction. Infectious diseases are usually transferred from the mother to the embryo, fetus, or newborn prior to, during, or shortly after parturition. Types of vertical transmission in veterinary species include transplacental passage of pathogens to the offspring and the transmission of infectious agents through the colostrum or milk. Classical swine fever virus is an example of a disease agent that can be transferred vertically. If a sow becomes infected with CSFV while she is pregnant, the virus can cross the placenta, resulting in infection of the fetus and potentially the newborn. *Toxoplasma gondii*, the causative agent of toxoplasmosis, can also be transmitted vertically through the placenta. Transplacental transmission of *T. gondii* can cause abortion in sheep and severe congenital abnormalities in humans. *Strongyloides stercoralis*, a small intestinal nematode of dogs, cats, and humans, can be transmitted via the milk from a dam to her nursing offspring.

Horizontal transmission

Horizontal transmission is the transfer of a pathogen from an infected animal to a naïve animal, independent of the parental relationship of those individuals. Horizontal transmission can occur by either direct or indirect contact. Pathogens spread by **direct contact** are transmitted

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Vertical transmission—the transfer of a pathogen from a parent, usually the dam, to the offspring through reproduction.

Horizontal transmission—the transfer of a pathogen from an infected animal to a naïve animal, independent of the parental relationship of those individuals

directly from animal to animal; pathogens spread by **indirect contact** are transmitted through an intermediary such as a physical object or insect.

Disease agents transferred by direct contact may be spread by actions such as licking, rubbing, biting, and coitus. The classical swine fever virus, the causative agent of classical swine fever, is an example of an agent that can be transmitted horizontally by direct contact. This virus is spread from pig to pig primarily by oral contact with blood, tissues, secretions, and fomites. Classical swine fever is most often introduced when infected pigs are mixed with uninfected pigs; thus livestock shows and auction sales are two high–risk places for infection. **Airborne transmission** is also considered to be a form of direct horizontal transmission because pathogenic agents don't usually survive extended periods of time within aerosolized particles. Close proximity of infected and non–infected susceptible individuals is thus required for airborne transmission. Foot and mouth disease is a classic example of a disease that uses airborne transmission. The direct and indirect routes are not mutually exclusive; some agents can be spread by both routes.

Indirect contact through fomites and vectors

Pathogens transmitted by indirect contact are spread by fomites or vectors. **Fomites** are inanimate objects that can carry infectious agents from one animal to another. Examples of fomites include used needles, dirty clippers, contaminated clothing or vehicles, and contaminated food and water supplies. **Iatrogenic transmission** is a specific form of horizontal transmission by fomites in which the veterinarian or physician accidentally furthers the spread of a disease agent via routes such as contaminated instruments or vaccines. Routine procedures such as bleeding, tagging, dehorning, and vaccinating can create an opportunity for iatrogenic transmission by contaminating pieces of medical equipment, which serve as fomites for the pathogen.

The term **vector** is sometimes used in a broad sense to signify anything that allows the transport and/or transmission of a pathogen. Some sources consider fomites to be vectors. However, according to a strict, ecological definition, vector–borne transmission occurs when a living creature, because of its ecological relationship to others, acquires a pathogen from one living host and transmits it to another. Thus vector–borne transmission is a form of indirect horizontal transmission in which a biological intermediary, often an arthropod, carries a disease agent between animals. Vectors may be either biological or mechanical. A **biological vector** is a vector that supports replication of the pathogen. The disease agent and the biological vector have a long–standing ecological relationship. Biological vectors are usually persistently infected with the disease agent

Indirect contact— pathogens transmitted through an intermediary such as a physical object or insect

Airborne transmission—the transfer of a pathogen via particles in the air, usually aerosolized

Fomites—inanimate objects that can carry infectious agents from one animal to another

Iatrogenic transmission—a specific form of horizontal transmission by fomites in which the veterinarian or physician accidentally furthers the spread of a disease agent via routes such as contaminated instruments or vaccines

Vector—used in a broad sense to signify anything that allows the transport and/or transmission of a pathogen

Biological vector—a vector that supports replication of the pathogen

and may even be a required part of that organism's life cycle. A **mechanical vector**, on the other hand, is a vector that carries the pathogen but the pathogen is not altered while on the vector. Infection in mechanical vectors tends to be short–lived and a mechanical vector is considered to be little more than a flying fomite.

Bovine anaplasmosis, caused by *Anaplasma marginale,* is an example of an agent that can be transmitted by both vectors and fomites. In the western United States, *A. marginale* is transmitted by members of the hard tick genera *Dermacentor* and *Boophilus* and thus is a vector–borne disease. However, in the southeastern and midwestern U.S., mechanical transmission by biting flies and iatrogenic transmission with contaminated equipment and needles appears to be more important in maintaining this disease.

Transmission dynamics within biological vector populations

The two major forms of transmission within vector populations, transstadial and transovarial, can be very important in maintaining a source of infection for animals. In **transstadial transmission**, infection with a pathogen is maintained in the vector as it develops between life stages. A tick vector infected as a larva with *Borrelia burgdorferi*, the causative agent of Lyme disease, will maintain the infection when it next molts to the nymph and then the adult stage. **Transovarial transmission** is a form of vertical transmission in which the female vector passes the infectious agent through her eggs to the next generation. Eggs passed by an adult female *Boophilus* tick infected with *Babesia bigemina* will hatch infected larvae.

Transovarial transmission can be very important in maintaining a source of infection for animals. In particular, it allows pathogens to survive conditions that kill the adult vectors but allow the eggs to survive. This can be illustrated by an outbreak of vesicular stomatitis in the 1980s. Vesicular stomatitis, a livestock disease found in the Americas, causes vesicles and ulcers on the mouth and hooves of swine, cattle, and horses. The agent, the vesicular stomatitis virus, is spread by black flies and sand flies. In 1982, an outbreak of vesicular stomatitis occurred in the southwestern United States. Authorities expected this outbreak to subside upon the death of adult flies following the first winter frost. Unexpectedly, the outbreak continued throughout the winter. At the time, this continuance was attributed to the movement of infected animals and the exposure of uninfected animals to contaminated objects. However, it is now known that the vesicular stomatitis virus is transmitted transovarially in its vectors and this may have contributed to the overwintering ability of the virus.

Mechanical vector— a vector that carries the pathogen but the pathogen is not altered while on the vector

Transstadial transmission— infection with a pathogen is maintained in the vector as it develops between life stages

Transovarial transmission—a form of vertical transmission in which the female vector passes the infectious agent through her eggs to the next generation