• PRRS virus is highly infectious (a pig can become infected by exposure to just a few viral particles) but not highly contagious (is not transmitted from one pig or contaminated surface to another pig very easily).

• PRRS virus can be transmitted vertically (from a mother to her offspring) during gestation. This is known as in utero or “transplacental” infection. The virus can be transmitted through milk but the significance of this is not known.

• Horizontal infection (from an infected pig to an uninfected pig) is also possible. This may result from exposure to body fluids (semen, blood, oral and nasal secretions), feces, contaminated surfaces or vectors, and possibly through the air.

• Vectors that may contribute to transmission of PRRS virus include, needles and syringes, insects, clothing and outerwear, and birds although their significance is unknown.

• Feral pigs can become infected with PRRS virus but their importance in transmission or maintenance of the infection in an area is unknown.

• PRRS virus can be found under specific conditions in pork meat. However, the ingestion of pork meat is not thought to be important in transmission of the virus.

• PRRS virus is found in nearly all areas of the world where pigs are located.
Epidemiology and Ecology
J Zimmerman

Introduction

The section summarizes current knowledge regarding the distribution of PRRS virus in populations and describes what we know about how PRRS virus is maintained in populations and how it interacts with the environment. This information is the key to PRRS prevention and/or control. Under the best circumstances, the basic sciences are able to develop effective tools to use against infectious diseases, especially efficacious vaccines and good diagnostic assays. Ultimately, however, the effective application of even the best tools science can develop must be grounded in population medicine.

Transmission

Transmission requires that the pathogen successfully exits an infected host, escape potential threats to its existence in the environment, avoid the host defense system, and reach the site of replication in a new, susceptible host. Transmission is a process with an associated probability of success. Intuitively, it can be recognized that this probability is not fixed, but varies depending on the stage of infection and the specific circumstances. For example, the probability of transmitting PRRS virus from a pig is greater during the acute phase of the infection, when virus is being shed in great amounts, than during the chronic stage of infection. Specific circumstances are important, as well. For example, infected sows in gestation crates are less likely to transmit virus than pen-housed sows. We do not currently have good estimates of the probability of transmission for various circumstances and stages of disease, but some probability of transmission exists as long as infectious PRRS virus is present in the pig.

PRRS virus is highly infectious, but not highly contagious. This may sound like a contradiction, but it is not. To be highly “infectious” means that exposure of the animal to relatively few virus particles results in transmission. Thus, Yoon et al. (1999) estimated that intranasal or intramuscular exposure to 10 or fewer virus particles were sufficient to produce infection. By comparison, many other diseases of swine considered to be highly infectious (such as pseudorabies) require several thousand virus particles to produce infection. "Contagious" means that transmission occurs by contact with infected animals or virus-contaminated surfaces. A highly contagious pathogen transmits readily from infected to susceptible individuals. In contrast, producers often comment that it is difficult to intentionally transmit PRRS virus by housing negative animals with infected animals and that it is common to find negative animals within infected groups. In 1992, Potter (1994) investigated nine herds that had received infected breeding stock from a single PRRS virus-positive herd and found no serological evidence of transmission. For PRRS virus, the “highly infectious, but not highly contagious” viral strategy has been effective because infectious virus is present in carrier animals for months and because the population density in swine herds essentially guarantees that a circumstance will eventually occur that brings a carrier together with a susceptible animal.

Vertical Transmission

Vertical transmission is defined as transmission from one generation to the next by infection of the embryo or fetus in utero (within the uterus). Some experts include transmission of infectious agents to offspring in milk as vertical transmission, as well. Transplacental transmission (transmission of fetus occurring through passage of the virus across the placenta) was first reported by Christianson et al. (1992). To date, the cumulative evidence indicates that transplacental transmission occurs most readily during the third trimester of pregnancy (Benfield et al., 1997, Christianson et al., 1993, Kranker et al., 1998, Lager et al., 1997a, Mengeling et al., 1994), but Molitor et al. (2001) discovered that some isolates are capable of transplacental transmission as early as 30 days of gestation. Further, Prieto et al. (1996b, 1997a, 1997b) found that inoculation or insemination of gilts with semen contaminated with Spanish PRRS virus strain 5710 did not interfere with conception and fertilization, but virus was recovered from 20 day-old embryos in 3 of 5 litters, indicating early infection and death of embryos. Once infected, immunity against transplacental transmission upon subsequent challenge with the same strain of the virus appears to be long term. However, for reasons unknown at this time, immunity is incomplete against different strains of the virus. That is, re-challenge of previously infected sows with viruses other than the original virus isolate may result in transplacental transmission (Benson et al., 2000, Lager et al., 1999).
Vertical transmission has been shown to be a potential means of biosecurity breach. Dewey et al. (2000) reported the case of 350 pigs imported into Canada from the Netherlands in May 1999. The pigs were caesarian-derived, raised in isolation until they were 2 to 3 weeks of age, then shipped to Canada. Upon arrival, they were quarantined in a federally controlled facility for 3 months, then moved to a farm isolation facility. In August, tonsil biopsies were collected from 26 animals, of which 13 were positive for PRRS virus. Eleven of the samples showed greater than 99 percent homology to Lelystad virus (the European strain of the virus, not found in Canada at that time). The only possible conclusion is that these animals were infected in utero.

It is suspected that neonatal pigs may become infected after birth by exposure to infected dams, but the mechanism(s) of transmission has not been demonstrated. PRRS virus has been detected in milk under experimental conditions (Wagstrom et al., 2000) and transmission to neonates is assumed possible, but unproven. Transmission by contact of neonates with virus-contaminated oronasal secretions from the dam may occur, but is also unproven.

**Horizontal Transmission**

**Direct transmission**

Direct transmission involves the immediate transfer of an infectious agent by physical contact with the infected individual or by contact with virus-contaminated material from an infected individual. PRRS virus transmission most commonly occurs by direct transmission, i.e., close contact between animals (nose-to-nose) or by exposure to contaminated body fluids (semen, virus-tainted blood, or perhaps mammary secretions). Social behavior and the character of pig-to-pig interactions are important in direct transmission, particularly the aggressive behavior associated with establishing a social order within a group. Typically, fighting involves slashes or bites in the shoulders, neck, and head and results in the exchange of blood and saliva. Bierk et al. (2001) associated transmission with aggressive behavior between carrier sows and naive contacts. Non-aggressive behavior that results in exchange of blood and saliva, i.e., tail-biting and ear-biting, may also function in transmission. The frequency of these behaviors is related to facilities, management system, group sizes, group stability, mixing, and other population factors (Hafez and Signoret, 1969, Whittemore, 1998).

**Indirect transmission (fomites, arthropods, aerosols)**

By definition, indirect transmission means transmission by an intermediate vehicle, such as inanimate objects or substances (e.g., water, food), living carriers (insect, bird, wildlife vectors), or aerosols.

**Fomites** - As previously discussed, PRRS virus is shed at low levels in a variety of secretions and excretions and is inactivated in the environment at a rate that depends on the ambient temperature and moisture conditions. Under warm dry conditions, inactivation is relatively rapid (Pirtle and Beran, 1996). Otake et al. (2002a) showed that PRRS virus was present on workers' coveralls, boots, and hands following 60 minutes of contact with acutely infected pigs. However, elementary sanitation procedures, such as changing coveralls, changing boots, and washing hands, was sufficient to stop transmission. Under experimental conditions, Dee et al. (2002a, 2002b) showed that PRRS virus could be moved easily on fomites in the field under winter conditions, but to a much lesser degree during warm weather.

Contamination of instruments and medications with body fluids from PRRS virus-infected animals can result in transmission. This includes instruments used for ear notching, tail docking, teeth clipping, or tattooing, as well as and needles, syringes, medications, and biologics. Recently, Otake et al. 2002b confirmed needle-borne transmission of PRRS virus under experimental conditions. Preventing the transmission of PRRS virus via commonly used instruments will require awareness of the risk and strict adherence to procedures that prevent transmission.

**Insects** - Insects are well recognized for their role in the transmission of a variety of infectious agents. Insects may serve as mechanical vectors, in which the infectious agent is carried either internally or externally (body surface) to the next susceptible individual, or biological vectors, meaning that the pathogen replicates in the insect prior to transmission to the host. Research in insect-borne infections is challenging because the interactions between vertebrate host, insect, pathogen, and environment are often highly complex.

The role of insects in the transmission of PRRS virus has recently become an active area of investigation. Otake et al. (2002c) reported detection of PRRS virus in mosquitoes captured on a farm undergoing a PRRS outbreak. Subsequently, they demonstrated...
mechanical transmission under experimental conditions in 2 of 4 attempts by allowing mosquitoes to feed on viremic pigs (pigs that had PRRS virus circulating in their blood). Otake et al. (2002d) also examined the transmission of PRRS virus by houseflies. By abrading the skin of infected and recipient pigs so as to provide access to blood, houseflies that fed on infected pigs were able to mechanically transmit virus to recipient pigs. In a separate study, house flies were allowed to feed on a viremic pig, then were held at 27°C (81°F) and tested for the presence of PRRS virus over time. PRRS virus could be detected in the flies zero and 6 hours after feeding but later samples (12, 24, 48, 72, and 96 hours) were negative.

Overall, the current data indicate that flies and mosquitoes are mechanical vectors of PRRS virus under experimental conditions. Whether PRRS virus is actually an insect-borne disease will require additional experimental and field studies. If it is proven that certain insect species participate in the transmission of PRRS virus in any one region, it will need to be established that the appropriate vector/host/environment relationships are in place elsewhere in the world where pigs are raised.

**Aerosol transmission** - Airborne virus was once considered the primary route of PRRS virus transmission, with aerosol transmission suspected to occur over distances of up to 20 kilometers (Anon, 1991). Since PRRS virus is present in the upper respiratory tract and oropharyngeal area of infected pigs for an extended period, this was not an unreasonable hypothesis. Wills et al. (1997b), however, found that transmission by direct contact occurred much more readily than transmission across a space of up to one meter. Other workers reported similar results. Torremorell et al. (1997) demonstrated transmission over a distance of one meter in one of two attempts. Likewise, Lager and Mengeling (2000) successfully transmitted PRRS virus in one of two attempts from infected pigs to susceptible pigs via a tube 8-cm in diameter and 50 cm in length. Otake et al. (2002e) reported transmission over a distance of 2.5 meters from infected animals to susceptible pigs sharing the same air space, but aerosols emitted from exhaust fans over distances of one to 30 meters did not transmit PRRS virus to sentinel pigs. The one exception to this pattern of poor transmissibility via aerosols is a report by Kristensen et al. (2002). In three trials, approximately 50 acutely infected pigs transmitted PRRS virus over a distance of one meter to approximately 50 negative pigs when 1, 10 or 70 percent of air was exchanged.

Available data suggest that the minimum infectious dose via aerosol exposure is probably low (Yoon et al., 1999). If the threshold exposure dose is low, however, then the experiments described above suggest either that infected pigs aerosolized very little virus or that aerosolized virus was rapidly inactivated under the environmental conditions under which most of the experiments were conducted.

**Factors of undetermined significance in transmission**

Differences among virus isolates, age of pig at time of infection, stress, bacterial or viral co-infections, diet, and host genetic factors, should be included on the list of factors of undetermined significance in transmission. In addition, the following are factors with a possible, but uncertain, role in PRRS virus transmission.

**Alternate hosts** – It is possible that a wildlife species was the original source of the virus, therefore, one or more alternate host species may exist. The identification of alternate hosts is important because of their potential role in transmitting PRRS virus between herds (area spread) and the possibility that an unrecognized species might serve as a source of new strains of PRRS virus.

Feral swine are susceptible to PRRS virus infection, but the occurrence of infection in free-ranging animals is relatively rare. Overall, the data suggest that PRRS virus did not originate in feral swine, but moved from domestic swine into the feral population. Feral swine generally live in small groups of fewer than 20 individuals (Hafez and Signoret, 1969), a population probably not sufficiently large to maintain the infection indefinitely. Nevertheless, in areas where feral swine interact with domestic swine, feral swine might serve as a source of PRRS virus.

A number of species have been examined and found not to be susceptible to PRRS virus, including mice, rats (Hooper et al., 1994), and guinea pigs (J. Zimmerman, unpublished data). Likewise, Wills et al. (2000b) found no evidence of PRRS virus replication in cats, dogs, mice, opossums, raccoons, rats, skunks, house sparrows, or starlings. In addition, 30 dogs and 5 deer captured in suburban areas in Kanagawa Prefecture (Japan) were negative for PRRS virus antibodies (Neagari et al., 1998). Zimmerman et al. (1997) reported that some avian species, mallard ducks in particular, were susceptible to PRRS virus. Mallards exposed to PRRS virus in drinking water shed virus in feces and virus was
recovered from fecal samples collected from 8 of 20 ducks 39 days after exposure. In a second experiment, mallard-to-mallard transmission was demonstrated by infecting ducks with feces from ducks shedding PRRS virus. Swine were shown to be susceptible to the mallard-derived virus. However, subsequent workers have been unable to replicate these experiments (F. Osorio, personal communication). At this juncture, the issue of non-swine host species is unresolved.

**PRRS virus in pig meat (cannibalism)** - Questions regarding the ability of infectious PRRS virus to persist in pork or pork products quickly surfaced among international trading partners in the early 1990s. Understandably, PRRS virus-free countries had no wish to introduce the virus through the importation of virus-contaminated pork products if it was determined that ingestion of pork meat was an important route of transmission.

Several studies have evaluated the presence of PRRS virus in meat. Bloemraad et al. (1994) reported that virus was present, although at low titer, in muscle tissue collected from viremic pigs and that the quantity of virus was only slightly affected by storage for up to 48 hours at 4º C (39º F). In a research setting, Magar et al. (1995b), inoculated 6-month-old pigs with PRRS virus and muscle tissue samples were collected at 7 and 14 days post inoculation. Virus was isolated from samples collected 7 days post inoculation but samples collected 14 days after inoculations were negative. In a slaughterhouse study, muscle tissue samples were collected from 44 carcasses from herds known to be PRRS virus positive but no virus could be isolated. The investigators concluded that meat does not retain detectable amounts of PRRS virus and that transmission of virus through pork is unlikely. Overall, the data suggest that virus is present at low levels, or not at all, in the meat of market-aged swine and that the risk of transmission to swine by the consumption of pig meat is low.

**Transmission Within Herds**

Once infected, PRRS virus tends to circulate within a herd indefinitely. Investigators have reported isolation of virus from nursery pigs up to 2.5 years after the initial PRRS outbreak (Joo and Dee, 1993, Stevenson et al., 1993). However, spontaneous elimination of PRRS virus from commercial herds has been reported, but the circumstances under which this occurs are not well defined (Freese et al., 1993). The key components appear to be persistent PRRS virus infection in clinically normal carrier animals and the continual introduction of susceptible animals either through birth or purchase (Wills et al., 1997c). In a typical scenario, the virus is perpetuated by a cycle of transmission from dams to pigs either in utero or post partum, or by commingling susceptible animals with infected animals in later stages of production. In neonatal pigs, maternal antibodies may provide some protection from infection. However, the degree of protection is not very well characterized and appears to be of short duration. Under conditions in which susceptible and infectious pigs are mixed, e.g. at weaning, a large proportion of the population may quickly become infected. Dee and Joo (1994) reported 80 to 100 percent of pigs in three swine herds were infected by 8 to 9 weeks of age and Maes (1997) found 96 percent of market hogs sampled from 50 herds to be positive. However, the pattern of infection in PRRS virus-endemic herds often deviates from this description of rapid, uniform spread. Within infected herds, marked differences in infection rates between groups, pens, or rooms of animals are often observed. Houben et al. (1995) found transmission to vary even within litters, with some littermates becoming positive as early as 6 to 8 weeks and other individuals as late as 10 to 12 weeks of age. In some cases, litters of pigs reached 12 weeks of age, the end of the monitoring period, and still remained free of PRRS virus infection. Thus, it is possible for animals in endemically infected herds to escape infection for an extended period of time. Dee et al. (1996) concluded that the presence of susceptible animals in breeding herds provided a mechanism to maintain persistent viral transmission in chronically infected farms.

Albina et al. (1994) described the mechanisms that allow PRRS virus to persist in infected farms as,

1. Incomplete infection of the susceptible population during the acute phase.
2. Introduction of new susceptible pigs in the form of replacement breeders.
3. A persistent viral infection in individual pigs with the potential to excrete virus under certain conditions, such as animal grouping, farrowing or weaning.
4. A rapid decrease in maternal immunity, with young pigs becoming susceptible to infection or re-infection several months later.
5. Lack of protective immunity, or variable periods of active immunity, in infected pigs.
Transmission Between Herds

Frequently, elimination of PRRS virus from herds in swine dense areas is commonly followed by re-introduction of the virus weeks or months later. The introduction of virus into a herd in the absence of any apparent animal or human contact is termed “area spread.” Under most circumstances, the source of the virus is unproven. Possible sources for consideration include the introduction of infected animals or contaminated fomites onto the premises, or spread via insects, aerosols, water, or non-porcine hosts.

Dee (1992) was the first to recognize the primary role of infected animals in herd-to-herd transmission. Following outbreaks of PRRS in late 1990, Dee (1992) reported that, of 10 farms surveyed, 8 had purchased breeding stock from the same source. The interval from arrival of the stock to appearance of clinical signs ranged from 3 to 24 days. In a regional PRRS virus control program in France, Le Potier et al. (1997) estimated that 56 percent (66 of 118) of herds acquired the infection through infected pigs, 20 percent (23 of 118) through infected semen, 21 percent (25 of 118) through fomites/slurry, and 3 percent (4 of 118) through unidentified sources. In Illinois, Weigel et al. (2000) noted that the purchase of semen or boars was associated with increased risk, whereas isolation of gilts after purchase was associated with decreased risk of infection. Other investigators have also noted that proximity to infected herds increased the risk of acquiring PRRS virus. For example, in Denmark, it was observed that the risk of a herd becoming PRRS virus-positive increased with the density of PRRS virus-positive neighboring herds, but decreased with distance from them (Zhuang et al., 2002). In France, Le Potier et al. (1997) found that 45% of herds suspected to have become infected through area spread were located within 500 meters (0.3 miles) of the suspected source herd and only 2% were more than one kilometer from the initial outbreak.

Using a molecular approach to the problem of area spread, Goldberg et al. (2000) evaluated the gene sequences from 55 field isolates collected in Illinois and eastern Iowa with the objective of determining whether the genetic similarity of PRRS virus isolates reflected their geographical proximity. Somewhat surprisingly, they found that the genetic similarity of isolates did not correlate with their geographical distance and, on that basis, concluded that PRRS virus was most commonly introduced into herds through animals or semen, as opposed to mechanisms associated with spread from neighboring herds.

Recent publications by Dee et al. (2002a, 2002b) have demonstrated the ease with which PRRS virus can be moved between farms on commonplace equipment and objects common to swine farms, e.g., styrofoam semen coolers, metal toolboxes, plastic lunch pails, and cardboard boxes, especially when wet and cold. It is highly unlikely that clean-appearing and ordinary objects would be recognized as the source of the introduction days or weeks later, when the infection became apparent.

Overall, the cumulative information suggests that the risk of introducing PRRS virus can be reduced by carefully monitoring the PRRS virus status of replacement livestock and boar studs that supply semen for artificial insemination and by implementing procedures to avoid the introduction of PRRS virus on contaminated fomites.

Summary

PRRS virus is found in most areas of the world. Within infected countries, 60 to 80 percent of herds are typically infected, with in-herd prevalence highly variable. Estimates of prevalence are complicated by the use of MLV vaccines in most parts of the world. MLV vaccines have been available since 1994 and antibodies against vaccine virus are not easily differentiated from antibodies against PRRS virus field strains. Population density has a marked effect on the prevalence of PRRS within herds and regions. Even within the same area, larger herds tend to have higher in-herd prevalence than smaller herds.

Swine are susceptible to PRRS virus by several routes of exposure, including intranasal, intramuscular, intraperitoneal, oral, and vaginal. Exposure to 10 or fewer PRRS virus particles by intranasal, intramuscular, and probably intraperitoneal routes results in infection (Yoon et al., 1999).

Infection of susceptible animals results in the shedding of virus in saliva, nasal secretions, urine, semen, and perhaps feces, with shedding occurring simultaneously from many sites at low levels or perhaps intermittently. Pregnant susceptible females inoculated in late gestation have been shown to shed virus in mammary secretions (Wagstrom et al. 2001). The infection is a chronic, persistent infection whereby virus replicates in susceptible cells of infected individuals for several months. Shedding of PRRS virus in secretions and excretions results in environmental contamination and creates the potential for transmission via fomites. The virus is generally short-lived in the environment and is
quickly inactivated by drying, but it can remain infectious for an extended time under specific conditions of temperature, moisture, and pH. Dee et al. (2002a, 2002b) illustrated that PRRS virus could be moved easily on fomites in the field under winter conditions but to a much lesser degree during warm weather. Standard disinfection and sanitation procedures are effective against the virus, but they must be studiously applied.

PRRS virus transmission most commonly occurs by direct transmission, i.e., close contact between animals or by exposure to contaminated body fluids (semen, virus-tainted blood, or perhaps mammary secretions). The aggressive behavior associated with establishing a social order within a group that involves slashes or bites in the shoulders, neck, and head and results in the exchange of blood and saliva and transmission of PRRS virus. Indirect transmission by fomites, vectors, or aerosols may also occur. Of these, transmission via instruments and medications contaminated with body fluids from PRRS virus-infected animals is the most important. This includes instruments used for ear notching, tail docking, teeth clipping, or tattooing, as well as and needles, syringes, medications, and biologics. Recent research has shown that flies and mosquitoes are capable of mechanical transmission of PRRS virus under experimental conditions (Otake et al., 2002c, 2002d). Establishing whether PRRS virus is an insect-borne disease will require additional experimental and field studies. Aerosol transmission is also still an open question. Results of pig-to-pig aerosol transmission experiments have been mixed and essential information (the quantity of virus excreted by pigs and the rate of inactivation of aerosolized virus) is missing.

The ability of PRRS virus to establish persistent infections in animals is the primary challenge to successful prevention and control programs. Establishing and maintaining herd immunity in the face of persistent infection is problematic because vaccines that induce long-term protective immunity against heterologous isolates and eliminate or reduce virus shedding are not yet available. Finally, if elimination is achieved, herds are vulnerable to re-infection with PRRS virus through the introduction of subclinically-infected animals or by area spread. This scenario is reminiscent of other infectious agents, i.e., classical swine fever virus (hog cholera) or African swine fever, which have been successfully controlled and/or eliminated in the past through coordinated regional efforts.

References


