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Airborne transmission of swine pathogens

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Introduction

The primary mode of transmission of most swine pathogens is by direct contact between individuals. Some pathogens (mainly viral diseases) may also spread by contaminated semen or other body fluids, transported from one individual to the next.

Other modes of transmission include release of the pathogen to the environment. If the pathogen is capable of surviving in the environment, there is a risk of the pathogen travelling to a susceptible animal. When evaluating the probability of aerosol transmission of a swine pathogen between farms, the key issues are:

- the quantities of pathogens released in aerosols,
- the survival of the pathogen in aerosols, and
- the minimum infection dose in susceptible individuals in recipient herds.

Infectious aerosol may be generated by sneezing and coughing of diseased animals. It has been observed that a sneeze in humans produces 1,940,000 particles (droplets) with 75% being smaller than 2(m^1. For particles below this size—which is the case for most swine pathogens—gravity has little effect. The particle can thus float in the air for hours. For airborne transfer of a pathogen over short distances (<3 kilometers), the time of travel can be very short: In a light breeze (e.g., wind speed 6 m/sec) a particle would travel 360m in just one minute and 1,080m in 3 minutes.

For some of the pathogens that have been studied, survival in aerosols decays logarithmically. This implies, that the number of viable pathogens is halved in each fixed period of time (e.g., 10 minutes). With, for example, 100 pathogen particles per volume of air released, 50 particles would still be viable 10 minutes later. Meteorological factors such as relative humidity, temperature, UV-light and the so-called open-air-factor affect the half-life of the airborne pathogen. But even if these factors in the above example would reduce the half-life to 5 minutes, 25 particles would still be viable 10 minutes later. A study into the environment of a farrow-to-finish farm of 1,500 sows consistently shows a concentration of potential pathogens (strep. and *E. coli*) of 30–70 CFU/m^3 up to 500m from the farm buildings[2].

If only one or few pathogen particles are required to infect an animal (or, e.g., one animal out of 1,000 animals in a herd), then airborne transmission is not such a remote possibility. Whether infection takes place or not is closely related to the size of the pathogen and the susceptibility of the pig. With decreasing size of a pathogen in an aerosol, the dose (number of pathogens) required dramatically decreases[3]. For airborne bacteria it has been estimated that only approximately 20% are solitary pathogens, whereas 80% are bigger particles consisting of agglomerates of pathogens or pathogens linked to dust particles[4]. The susceptibility of pigs exposed to aerosols of viable pathogens depends on the clearance capacity of the respiratory system. The specific immunity of the animal and the level of air contaminants (e.g., dust and gasses) affect the clearance capacity[5].

In the following we will investigate the possibility of airborne transmission of swine diseases through a review of experimental as well epidemiological studies on airborne survival, aerosol transmission (within-farm) and between-farm transmission. As examples we have elected to focus on some of the most relevant pathogens: *Pasteurella multocida* (P.m), *Actinobacillus pleuropneumoniae* (A.p), *Mycoplasma hyopneumoniae* (M.hyo), *Pseudorabies/ Aujeszky* virus (PRV), and *Porcine Respiratory and Reproduction Syndrome* virus (PRRSV).

Pasteurella multocida (P.m)

Survival of P.m in the environment

Experimental viability studies of P.m (subspecies multocida) aerosols show half-lives for different strains of 12–28 minutes at 23°C and 75% relative humidity (mean: 21 minutes)[6]. Another study shows a reduction in half-life with increasing temperature and a very short half-life at low relative humidity (3 minutes at 44%)[7].

From the environment P.m can be isolated from other animals such as calves, rats, cats, dogs, rabbits, goats, and humans[8,9,10]. In an experimental model toxigenic P.m. isolated from humans has been shown to be able to cause atrophic rhinitis in pigs[9].

Studies of P.m. aerosol transmission

Only few studies have been conducted on P.m. aerosols under farm conditions. In one study airborne P.m. was recovered in 29 out of 44 finishing herds (66%) with a mean and maximum concentration of 32 CFU/m^3 and 144 CFU/m^3, respectively[11]. The same study showed a significant ($P<.01$) correlation between occurrences of clinical atrophic rhinitis and recovery of toxigenic P.m. In another field study carried out on a large farm, P.m. consistently was isolated from the air in two-thirds of all samplings (48 samplings in total)[2].

Based on these data within-farm airborne transmission of P.m seems possible.

Transmission of P.m. between farms

It is difficult to find data in the literature that document airborne transmission of P.m. between farms. Experience from the Danish SPF production herds, which are freeform infections with toxigenic P.m., shows a very low re-infection rate of less that 1% of the herds per year. Denmark has a dense pig population, typically 10–30 herds in a 3km zone (radius=3km); approximately 65% of the conventional herds have clinical atrophic rhinitis[12]. Amongst SPF nucleus and multiplying herds (approximately 300 herds), which are scattered all over the country, the re-infection rate is 1.1% as a mean for a 12-year period. These herds are monitored by monthly clinical inspections and by nasal swabs twice a year. Most, if not all, of the re-infections in these herds are due to infected replacement stock and throughout the years airborne transmission has never been suspected in any case.

Actinobacillus pleuropneumoniae (A.p)

Survival of A.p. in the environment

Survival of A.p. in aerosols has been estimated in a few experimental studies. One study found a mean half-life of 30 minutes at 27°C and 41–46 minutes at 21°C[13]. In an experimental inoculation study using A.p. aerosols, the bacteria could be detected for at least 11 minutes[14]. The same study showed that a dose of as few as 6 CFU of viable A.p. was enough to cause pleuropneumonic lesions in fully susceptible pigs. This dose of A.p. should be compared to the data in a case report from one herd, where A.p.was isolated in one-third of all samplings (48 in total) with a mean concentration of 1100 CFU/m^3[2].

Studies of A.p aerosol transmission

Airborne A.p has been demonstrated by PCR in the finishing units in 7 of 12 herds known to be infected by A.p. type 2[15]. Two experimental studies have demonstrated airborne transmission over short distances. These studies showed that A.p could be transmitted over a distance of 1 meter[16] and at least 2.5 meters[17], respectively. None of the studies were designed to demonstrate spread over longer distances that they did. Even though these studies documented airborne spread of A.p, direct isolation of A.p from the air during the experiments only succeeded in 1 of 18 attempts and 2 of 12 attempts, respectively.

The conclusion from these studies—that at least short distance spread is possible—is in accordance with our own experience that pleuropneumonia has been seen jumping from compartment to compartment down the line of a corridor in newly A.p-infected finishing herds.

Transmission of A.p between farms

Few studies have dealt with between-farm spread of A.p. One case report points to airborne transmission as the most probable cause of infection in one farm and a possible way of transmission in another 3 farms[18].

An epidemiological study in Denmark gave a clear indication of airborne spread[19]. The study was performed by ribotyping A.p. isolates from 12 re-infected Danish SPF herds and the surrounding pig herds in a distance of 1km from the SPF herd. In one case there was a strong indication of airborne transmission and in another 4 cases the possibility existed.

Experiences from the health control of the Danish SPF nucleus and multiplying herds (approximately 300 herds), which are free from A.p. infections, are suggestive of airborne transmission as the only possibility in some out of the 3% of the herds re-infected every year. The SPF nucleus and multiplying herds are monitored by monthly clinical inspections and monthly blood testing of 20 animals for antibodies against A.p. Some of the re-infected herds have been closed for years with a very high level of biosecurity and, in some cases, the re-infection coincided with acute A.p outbreaks in chronically infected neighbour farms. Based on these cases it is estimated that airborne transmission can take place up to a distance of approximately 500m under the right circumstances: a high release from a large farm with acute outbreak in cool and humid weather and with a highly susceptible population of pigs in an SPF herd.

Mycoplasma hyopneumoniae (M.hyo)

Survival of M.hyo in the environment

Mycoplasma hyopneumoniae seems able to survive for a relative long period in the environment. Experimental studies with M.hyo in water show survival times of 2–4 weeks at room temperature and indicate survival times of more than 12 weeks at low temperatures (0–3°C)[20]. When M.hyo is permitted to dry out—for example, on clothes, the survival time is reduced to 1–7 days[20,21].

Studies of H.hyo aerosol transmission

Under experimental conditions M.hyo can easily be transmitted to susceptible pigs exposed to an aerosol of M.hyo.

In one study all pigs seroconverted 2–3 week after the exposure and 32 of 37 exposed pigs (86%) had pneumonic lesions at slaughter[22]. In another study 200 pigs were exposed to an aerosol[23]. All pigs seroconverted between 8 days and 6 weeks after the exposure and 76% of the pigs had pneumonic lesions at autopsy.

Detection of M.hyo by air sampling in M.hyo-infected herds using specific growth media has never been reported. Even direct sampling from the nostrils of infected pigs, from which high amounts of M.hyo were isolated from pneumonic lesions the subsequent day, was unsuccessful[24].

So far only one study has succeeded in the detection of airborne M.hyo under field conditions[25]. Using a nested PCR, airborne M.hyo was detected in 80% of farms with acute respiratory symptoms, whereas detection was not possible in infected farms without acute cases of pneumonia.

Based on field experiences it is generally accepted that M.hyo can be spread by the airborne route from compartment to compartment of a farm.

Transmission of M.hyo between farms

Several retrospective epidemiological studies in countries with minimal disease herds without M.hyo have pointed to airborne transmission as one of the main causes for reinfections with M.hyo.

In the UK a case control study showed that the distance to other pigs as well as the density of pigs in the area were significant factors for the breakdown of M.hyo-free herds[20]. The same study calculated a safe distance to avoid airborne transmission to be 3.2km.

A similar study was performed in Denmark based on 204 former or present SPF nucleus and multiplying herds[26]. Using a Cox regression model distance to the nearest non-SPF herd, distance to the nearest large non-SPF herd and the purchase of replacement stock from more than one herd per year were significant risk factors for reinfection with M.hyo. Based on the regression model a so-called normogram was established. In the normogram one can estimate the possibility of avoiding infection with H.hyo for one more year as a function of the three risk factors. As an example: If an SPF herd buys replacement stock from only one herd and the nearest farm is 2km away the probability of maintaining its SPF status for one year more is 0.97. Today this normogram is implemented in a geographical information system (GIS), a database with information about all swineherds in Denmark. This system identifies a farm by two coordinates, which can be interpreted as (x,y)-coordinates[27]. The database contains information of the PRRS status of each herd, the herd size, and the health status of each herd with respect to Danish SPF diseases (M.hyo, tox. P.m., A.p together with *Barchyspira hyodysenteriae*, mange, and lice). The GIS can be used to print maps of herds in an area and the herd-specific 1-year probability of survival as an SPF herd is automatically calculated for the herd in question.

A study in Swiss minimal disease herds demonstrated the following risk factors for infection with M.hyo: Distance to the nearest non-SPF pig herd, the size of that herd, the density of the pig population in the area, the distance to the next road regularly carrying pig loads, and the difference in topography[28].

Pseudorabies virus (PRV)

Survival of PRV in the environment

Experimental data suggests that PRV is a fairly resistant pathogen. The virus remains infective for 1–14 days at 25°C in contact with substances commonly found in pig farms:

- swine urine: 14 days;
- saliva: 4 days;
- lagoon water: 4 days;
- saliva on steel: 4 days;
- in swine feces: 2 days;
- on denim: 1 day[29].

PRV can be readily recovered from within the body of houseflies that had ingested the virus[30]. There was no evidence of virus replication in the flies. The half-life of the virus in flies ranged from 1.7–13 hours depending on the age of the flies (3–13 days old) and ambient temperature (10–30°C).

The survival of PRV in aerosols has been studied, showing a logarithmic decay, with a mean half-life of 27 minutes at 4°C and 85% relative humidity and a mean half-life of 17 minutes at 22°C and 85% relative humidity[31].

Studies of PRV aerosol transmission

Several researchers have isolated and quantified the PRV load in the air space surrounding infected animals and demonstrated aerosol transmission. Donaldson et al. recovered PRV from the air of boxes containing groups of infected pigs from days 1 to 7 after infection[32]. On a 24-hour basis the maximum amount of virus excreted per pig was 5.3 $\log_{10}TCID_{50}$. Air from the boxes was drawn into a separate box containing sentinel pigs and subclinical infection was transmitted from the infected pigs to the sentinel pigs. Bourgueil et al. recovered PRV days 1 to 6 from the air in rooms containing challenged or vaccinated-challenged groups of pigs[33].

Gillespie et al. exposed pigs to aerosols of PRV for 15 minutes on 3 consecutive days[34]. All the pigs became in-

fected at a total estimated dose of 4.5 $\log_{10}$ $TCID_{50}$. Baskerville reported that the minimum infective dose was 1.0 $\log_{10}$ $TCID_{50}$ by intranasal challenge[35].

All of the above studies were performed in experimental settings. Isolation of PRV from stable air has also been successful. Mack et al. isolated PRV from 33 of 47 air samples collected in 40 PRV-infected herds[36].

Transmission of PRV between herds

In the 1980s, it was hypothesized that airborne transmission was an important mode of disease spread between herds. Spread of PRV between premises located in the same area of the UK had taken place without any history of obvious physical contact between them[37]. Based on an analysis of meteorological data, it was concluded that airborne transmission could be responsible for 7 of 11 outbreaks. Similar conclusions were reached in a study of 10 herds in Indiana: on the basis of lack of other modes of transmission and meteorological data, aerosol transmission of PRV between the herds was probable[38].

Further evidence that has strengthened the hypothesis of aerosol transmission has been collected from the border area between Germany (an endemically PRV-infected area) and Denmark (an area with PRV-negative and fully susceptible herds) without any physical contacts across the border. On multiple occasions PR outbreaks in Denmark coincided with wind blowing from the German area and the virus strains were clearly of non-Danish origin[39, 40]. In some cases, airborne transmission of the virus over distances of 15–40km constituted the most likely mode of introduction.

In 1989–1990, introduction of PRV in a fully susceptible Danish population of 422 herds resulted in outbreaks in 102 herds[41]. In 64 herds (63%) no physical contacts could be established with other infected herds but "area spread" was suspected owing to short distances to other infected herds.

Porcine respiratory and reproduction syndrome virus (PRRSV)

Survival of PRRSV in the environment

PRRSV has been characterized as an unstable virus, which cannot be recovered from contaminated samples of straw, plastic, boot rubber, stainless steel, swine saliva, swine urine, or faecal slurry after day 0. PRRSV has been isolated from fresh water up to day 11[42].

The stability of PRRS virus in aerosols has not been investigated. The related Equine Arthritis Virus (EAV) in aerosols showed moderately good stability when the aerosol was sampled 5 minutes after aerosol generation at low relative humidity (<40%), but the virus was not viable at a higher relative humidity after 5 minutes[43].

In a study performed to assess people handling pigs as mechanical vectors for PRRSV, the RNA of PRRSV was detected on 2 (in a finger nail rinse sample and in saliva) out of 10 persons immediately after close contact with clinically affected pigs[44]. On a third person, PRRSV RNA was detected 5 hours after exposure (fingernail) and on a fourth person PRRSV RNA was detected in a nasal swab 48 hours after exposure. People could not transfer the pathogen to sentinel pigs in this experiment.

The only animal species other than swine known to replicate the virus are mallard ducks and a few other avian species. Many other species commonly found around farms have been shown not to be likely hosts or reservoirs of PRRSV: Mice, rats, guinea pigs, dogs, cats, racoons, opossums, skunks, sparrows, starlings, or muscory ducks[45, 46, 47, 48].

Studies of PRRSV aerosol transmission

Within-herd aerosol transmission of the PRRS virus has been suspected[49]. An experimental study with a US-PRRS field isolate demonstrated airborne transmission of the PRRSV (in one of two experiments), although only over a distance of 1m[16]. In experimental studies, aerosol transmission has been difficult to reproduce consistently. Aerosol transmission was detected at a distance of 42cm in one of three experiments and 102cm in one of two experiments[46]. In another study aerosol transmission was established in one of two experiments[50].

Torremorell et al. attempted to isolate the PRRS virus in air samples during the experiment without success[16]. We are not aware of other studies that have attempted to detect and quantify PRRS virus in the air space around infected animals.

A study by Yoon et al. has shown that fewer than 20 virions were enough to induce infection via the intra-nasal route[51].

Transmission of PRRSV between herds

Live PRRS vaccine virus has been detected in semen after vaccination of boars in experimental studies[52,53] and in semen samples from AI boars at AI stations up to 6 weeks after vaccination[54]. The PRRS field virus can be transmitted to naïve breeding animals through the use of AI semen[55]. This implies that field studies of PRRSV transmission must be designed so to avoid bias on the results by this transmission mode.

In Denmark 2,500 PRRS-negative herds are monitored for PRRSV by monthly or annual blood samples. Each year, 6–7% of the herds become infected. Introduction of animals subclinically infected with PRRS accounts for 15–20% of the outbreaks. Danish boar stations are PRRS-negative. We believe that the remaining outbreaks are caused by area spread. There is no obvious seasonal pattern in the outbreaks.

Evidence from field diagnostic investigation of seven outbreaks occurring in the same area of Iowa showed an exceptional homology of the virus isolates from the farms[50]. There was no common link between the farms suggesting that area spread had occurred. The authors assumed that the outbreaks were attributed to aerosol transmission.

In a study of risk factors for introduction of PRRSV in sow herds in Denmark during a 15-month period in 1996–1997, exposure from infected neighbour herds within a 3km radius was the single most important risk factor for introduction of PRRSV[56]. The exposure from neighbour herds was calculated based on the size of the infected neighbour herd and the distance to the infected neighbour herd. The relative risk (RR) of having an infected 500-sow-herd as a neighbour at a distance of 1,000m was 1.5 (compared to not having an infected neighbour herd within 3km). If the neighbour infected 500-sow-herd was located 500m away, then RR=4. If the neighbour infected 500-sow-herd was located 300m away, then RR=45. From this it is obvious that distance is the single most important factor for area spread.

Conclusion

This review demonstrates that there is solid circumstantial evidence for within-farm as well as between-farm transmission by the airborne route for all the pathogens mentioned, except for P.m where between-farm airborne transmission seems unlikely.

Most data presented here are of a qualitative nature, merely suggesting that there is a possibility of airborne transmission without estimating the magnitude of that possibility. One exception is the Danish study on risk factors for infection of uninfected herds with M.hyo[26] in which the risk of becoming infected is estimated in relation to the distance to infected herds in the surroundings.

The definitive and ultimate proof of airborne between-farm transmission remains to be found, i.e. when an "ear tagged" and uniquely identified pathogen is isolated from diseased pigs in a farm, from the outgoing air of that farm, possibly from the outdoor air between that farm and another farm, from the incoming air of the second farm, and from pigs at that farm with clinical symptoms and pathological findings typical for the pathogen in question.

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