FOOT-AND-MOUTH DISEASE

Swine Health Information Center

The Swine Health Information Center, launched in 2015 with Pork Checkoff funding, protects and enhances the health of the United States swine herd by minimizing the impact of emerging disease threats through preparedness, coordinated communications, global disease monitoring, analysis of swine health data, and targeted research investments.

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SUMMARY

IMPORTANCE

- Foot-and-mouth disease (FMD) is a highly contagious vesicular disease of cloven-hoofed animals, including cattle and swine. It has been eradicated in the United States, but in endemic areas and during outbreaks, FMD causes production losses and impacts international trade.
- FMD is clinically indistinguishable from other vesicular diseases, such as Senecavirus A.

PUBLIC HEALTH

FMD is not a public health risk.

INFECTION IN SWINE

- Initial signs of FMD in pigs include fever and blanching of the coronary bands, followed by the development of severe foot lesions in the interdigital spaces and along pressure points, severe lameness, and reluctance to move. Vesicular lesions also develop on the snout, muzzle, and gums.
- Abortion may occur in pregnant sows.
- Myocarditis can lead to acute death in piglets.

TREATMENT

- There is no treatment for FMD virus (FMDV) infection other than supportive care.

CLEANING AND DISINFECTION

- FMDV concentration in the muscle is low. Meat must be heated to 158°F (70°C) for 30 minutes to inactivate FMDV.
- FMDV can survive for months in the environment, particularly in cold temperatures.
- Products approved for disinfection in an outbreak include sodium carbonate (4%), sodium carbonate and sodium silicate (0.1%), sodium hydroxide (2%), and sodium hypochlorite (up to 12.5%). Citric acid has also been approved.

PREVENTION AND CONTROL

- Standard biosecurity practices should be in place on swine farms.
- In an outbreak situation, a combination of stamping-out and vaccination may be used to control the spread of FMDV.

TRANSMISSION

- FMDV is found in vesicular fluid and secretions and excretions from infected animals, including saliva, nasal secretions, milk, urine, feces, and semen.
- Pigs generate a large quantity of infectious aerosols that can be inhaled by other animals or become windborne, travelling long distances.
- In pigs, the virus is transmitted by direct contact with infected animals and by contact with contaminated fomites, such as dirty hands, clothing, and footwear, as well as objects like vehicles and equipment.
- Pigs can also acquire FMDV through ingestion of contaminated meat, meat byproducts, or uncooked garbage containing food waste. Where garbage feeding is legal, waste must be cooked to 212°F (100°C) for 30 minutes and cooled before feeding it to pigs
- Cattle can become carriers of FMDV, but pigs do not become persistently infected.

PATHOGENESIS

- In pigs, the main site of FMDV entry and replication is the oropharynx, especially the dorsal surface of the soft palate and the oropharyngeal tonsils.

DIAGNOSIS

- FMD testing must be conducted at the National Veterinary Services Laboratories. Additional laboratories are approved to conduct testing in an outbreak situation.
- Reverse transcription polymerase chain reaction (RT-PCR) is the most commonly used diagnostic test for FMDV.
- The preferred tissue for FMD diagnosis is epithelium from unruptured or freshly ruptured vesicles or vesicular fluid. Blood (serum) or throat swabs can also be submitted from pigs, as well as myocardium from dead piglets.

EPIDEMIOLOGY

- Infection with FMDV occurs in cloven-hoofed animals, including livestock and wildlife. Cattle, pigs, sheep, and goats are the most significant hosts in Western countries, while the water buffalo and the African buffalo are important in Asia and Africa.
- FMD is endemic in many parts of Africa, Asia, and the Middle East. Serotypes O and A circulate widely. South African Territories (SAT) serotypes have mainly occurred in sub-Saharan Africa and the Middle East until their recent emergence in North Africa and Western Asia.
- Morbidity can reach 100%. Mortality is generally low in adult pigs, but secondary bacterial infections in vesicular lesions can lead to chronic lameness, wasting, or death. Death can occur in up to 20% of piglets due to heart failure.

ETIOLOGY

- FMDV is a non-enveloped, positive-sense, single-stranded RNA virus that belongs to the family *Picornaviridae*. Seven serotypes of FMDV (A, O, C, SAT 1, SAT 2, SAT 3, Asia 1) have been described.

HISTORY IN SWINE

- The last reported case of FMD in the United States occurred in 1929. In 2025, an outbreak occurred in water buffalo in Germany, which had been FMD-free for 37 years.

IMMUNITY

- Circulating antibodies are detectable 3–5 days after the onset of clinical signs. Viremia and nasal/oral shedding usually subside within 14 days post-infection.
- Inactivated FMD vaccines may be used in endemic countries and during outbreaks. Vaccination is far less common in pigs than in cattle in many regions, and vaccines effective in cattle may fail to confer sufficient immunity in pigs.
- Immunity to one FMDV serotype does not protect against infection with other serotypes.

GAPS IN PREPAREDNESS

- FMD epidemiology remains poorly understood. More information is needed on virus biology (including different serotypes), geographic distribution, pathogenesis (including carrier and species differences), and host range (including the potential role of feral swine).
- Quick and simple diagnostic tests are needed, particularly those that can be used pen-side. Additional research is needed to address cross-protection and simplify vaccine strain matching. The expanding range of SAT serotypes demonstrates the increasing likelihood of transboundary spread.
- Many FMD studies have focused on cattle rather than pigs. Importantly, there are differences between species regarding FMD transmission, pathogenesis, clinical signs, immunity, and vaccination. More studies are needed that include or focus on pigs to identify species differences.

LITERATURE REVIEW: FOOT-AND-MOUTH DISEASE

IMPORTANCE

Foot-and-mouth disease (FMD) is a highly contagious vesicular disease of cloven-hoofed animals, including cattle and swine. It has been eradicated in the United States, but in endemic areas and during outbreaks, FMD causes production losses and impacts international trade. FMD is clinically indistinguishable from other vesicular diseases, such as Senecavirus A. The reintroduction of FMD remains a concern in many free areas, including the United States.

PUBLIC HEALTH

FMD is not considered a public health risk. Only around 40 cases of FMD in humans have been described in the literature despite the high prevalence of FMD in animals worldwide.[1] The last known human case occurred in 1966 in Britain.[2]

Infections have occurred primarily in people who worked closely with infected animals,[3] although at least one report describes infection caused by ingestion of raw milk.[4] FMD is not associated with eating meat, including pork. Signs include fever and blisters on the skin or in the mouth.[5] Infections are generally mild, and patients usually fully recover. People who work with livestock can temporarily carry FMD virus (FMDV) in their nasal passages.[6-9] However, transmission to animals is rare.

Historical accounts of FMD in humans should be interpreted with caution, given the limited laboratory capabilities at the time of diagnosis. Some cases may have been caused by other animal pathogens, such as vesicular stomatitis, or by human viruses such as coxsackievirus A16, which causes hand, foot, and mouth disease (a human disease unrelated to FMD). For information on FMDV in pork, see *Survival*.

INFECTION IN SWINE

Clinical Signs

According to the World Organization for Animal Health (WOAH), clinical signs vary with the strain of virus, exposure dose, animal age and breed, host species, and degree of host immunity. Initial signs of FMD

in pigs include fever and blanching of the coronary bands, followed by the development of severe foot lesions in the interdigital spaces and along pressure points, severe lameness, reluctance to move, and dog-sitting. Pigs may huddle together and stop eating. Lesions also develop on the snout, muzzle, and gums, but drooling is not common as in cattle. Abortion may occur in pregnant sows.[10,11]

Recovery in adult pigs usually occurs in 7–14 days post-infection. However, secondary bacterial infections may lead to complications, and severe foot lesions can result in long-term lameness and debilitation.[12]

Postmortem Lesions

In pigs, oral lesions are most often found on the tongue, at the back, or on the tip. Vesicles on the feet occur in the interdigital space, at the bulb of the heel, and along the coronary band. Severe foot lesions may lead to claw shedding. Vesicles also develop on the snout, teats, mammary glands, prepuce, vulva, and other sites. Lesions can be staged according to their development/healing status (as described in Alexandersen).[10]

- Days 0–2: development of vesicles
- Days 1–3: rupture of vesicles (initially with fragments of epithelia attached)
- Days 2–3: sharply marginated erosion, with the sharpness lost around day 3
- Days 4–6: serofibrinous exudation
- Day 7+: beginning of repair with a marked fibrous tissue margin

In piglets that die acutely, no gross lesions may be seen. In those less than 8 weeks old, myocarditis can lead to the development of "tiger heart," a condition characterized by soft, flaccid heart muscle with white or grayish stripes.[10]

TREATMENT

There is no treatment for FMDV infection other than supportive care. Various antivirals have been tested against FMDV[13] but none are approved for commercial use.

CLEANING AND DISINFECTION

Survival in Meat and Meat Products

FMDV survival in meat can be affected by multiple factors, including processing and storage temperatures, pH, storage time, water activity, salinity, and the presence of additives.[14] Generally, high FMDV concentrations are found in blood, bone marrow, lymph nodes, and epithelium, where the virus can survive for weeks to months. In contrast, virus concentration in the muscle is low. FMDV can survive processes such as chilling, curing, and steaming. According to the USDA, meat must be heated to 158°F (70°C) for 30 minutes to inactivate FMDV.[11] Natural casings must be treated with either sodium chloride or a phosphate salt/sodium chloride mixture at 68°F (20°C) for 30 days to ensure FMDV is inactivated.[15]

Survival in the Environment

FMDV is inactivated by pH extremes (<6.0 and >9.0). The survival of FMDV in most infected or contaminated materials in hot and temperate climates is three months or less. However, the virus can persist for much longer at subzero temperatures.[16] FMDV may survive for 10 to 15 weeks in cattle and swine slurry under cool laboratory conditions.[17] The virus can also persist in wool, hair, skin, and bristles for long periods.[11] Inactivation procedures are described in the *WOAH Terrestrial Code*.

Disinfection

FMDV is readily inactivated by acids, alkalis, and sodium hypochlorite (bleach).[18] Products approved for APHIS's use in an outbreak include sodium carbonate (4%), sodium carbonate and sodium silicate (0.1%), sodium hydroxide (2%), and sodium hypochlorite (up to 12.5%).[19] Citric acid has also been approved. A list of *EPA-registered disinfectants for FMDV in farm settings* is available from the USDA.

PREVENTION AND CONTROL

FMDV spreads through movement of infected animals, feeding of contaminated animal products, and carriage on fomites or mechanical vectors. Standard biosecurity practices should be in place on swine farms. These include thorough cleaning and disinfection of animal areas, vehicles, and equipment; frequent handwashing; and wearing clean boots and clothing when working with pigs.

The last FMD case in the United States was reported in 1929. The detection of FMDV in U.S. livestock or wildlife would constitute an animal disease emergency. Response strategies outlined in the *Foot-and-Mouth Disease Response Plan: The Red Book* for control and eradication of FMD in domestic livestock include:

- **Stamping-out:** depopulation of clinically affected and in-contact susceptible animals.
- **Stamping-out modified with emergency vaccination-to-kill:**
  Stamping-out, plus vaccination of at-risk animals, with subsequent *depopulation and disposal of vaccinated animals*.
- **Stamping-out modified with emergency vaccination-to-slaughter:**
  Stamping-out, plus vaccination of at-risk animals, with subsequent *slaughter and processing of vaccinated animals*.
- **Stamping-out modified with emergency vaccination-to-live:**
  Stamping-out and vaccination of at-risk animals, *without subsequent depopulation of vaccinated animals*. Vaccinated animals intended for breeding, slaughter, milking, or other purposes live out their useful lives.
- **Emergency vaccination to-live without stamping-out:**
  Vaccination *without depopulation* of infected animals or subsequent slaughter or depopulation of vaccinated animals.

TRANSMISSION

FMDV is found in vesicular fluid and all secretions and excretions from infected animals, including saliva, nasal secretions, milk, urine, feces, and semen.[10] Viral shedding usually begins several days before clinical signs are apparent.[20] Pigs generate large amounts of infectious aerosols that can be inhaled by other animals or become windborne, traveling long distances and surviving for up to 5.5 days.[21] However, pigs are relatively resistant to airborne FMDV infection.[22,23] Weather conditions, such as relative humidity, wind, and cloud cover, as well as topography, significantly impact airborne spread.

Additionally, FMDV is transmitted by direct contact with infected animals and by contact with contaminated fomites, such as dirty hands, clothing, and footwear, as well as objects like vehicles and equipment. The virus can enter the skin directly through abrasions/wounds caused by fighting or other trauma.[10] Wild boars and feral domestic pigs can be infected with FMDV, and like other pigs, shed the virus before the appearance of clinical signs.[24] Other animals, including rodents and dogs, may act as mechanical vectors.

Pigs can also be infected after eating meat, meat byproducts, or garbage containing uncooked food waste (also known as swill) that is contaminated with FMDV. Garbage feeding is prohibited in 25 states.[25] In states where garbage feeding is legal, producers must obtain a license from the USDA. Garbage/food waste must be cooked to 212°F (100°C) for 30 minutes and cooled before feeding it to pigs.[26] Illegal importation of meat and meat byproducts is considered a high-risk activity.[27] Imported feed and feed ingredients are also potential sources of virus, with FMDV survival documented for up to 37 days.[28]

Some species can become carriers of FMDV, defined as animals from which infectious virus can be recovered more than 28 days post-infection. In particular, up to 85% of cattle can remain infected for months to years.[29] Carrier animals are not visibly ill, although the state is associated with suppressed immunity.[21,30] FMDV does not persist in cells from the porcine dorsal soft palate[31] or in pigs.[32] A "pseudopersistent" state has been described in which infectious virus can be isolated from swine lymphoid tissue 17 days post-infection.[33] FMD RNA may be recoverable from lymphoid tissues for up to 60 days post-infection. However, infectious FMDV in porcine tissues cannot be detected beyond 28 days post-infection.[32]

PATHOGENESIS

In pigs, the main site of FMDV entry and replication is the oropharynx, especially the dorsal surface of the soft palate and the oropharyngeal tonsils. The virus can also enter the body through cuts or abrasions in the skin.[10] During the viremic period, which lasts 4–5 days, FMDV spreads to secondary sites. However, the virus remains highly concentrated in the epithelia of the pharynx, mouth, and skin.[10] The pathogenesis of abortion in pregnant sows has not been established.[10] Stenfeldt[12] has summarized the current knowledge of FMD pathogenesis in pigs, and Kabir et al.[34] has reviewed FMDV infection and mechanisms of immune evasion.

DIAGNOSIS

It is not possible to clinically distinguish FMD from other causes of vesicular disease in swine, including Senecavirus A, swine vesicular disease, vesicular stomatitis, and vesicular exanthema of swine. In the United States, diagnostic testing for FMDV must be conducted at the National Veterinary Services Laboratories (located in Ames, Iowa, and Plum Island, New York). Additional laboratories are approved to conduct FMDV testing in an outbreak situation.[35]

Tests to Detect Nucleic Acids, Virus, or Antigens

FMDV can be propagated in many continuous cell cultures as well as porcine, bovine, ovine, and caprine primary cells (as described in Alexandersen).[10] Viral antigen can be detected using an indirect sandwich ELISA.[36,37] Lateral flow devices have been described[38-40] but are not validated by WOAH. Complement fixation is not preferred, but it may be used if ELISA reagents are unavailable.

Reverse transcription polymerase chain reaction (RT-PCR) is the most commonly used diagnostic test for FMDV. It is serotype-specific and works with a wide range of sample types, including epithelium, milk, serum, and esophageal-pharyngeal fluids. Standard[41,42] and real-time RT-PCR (rRT-PCR)[43,44] methods have been described. The VP1 region is a common target for RT-PCR and is used for genetic sequencing. See Wong et al. for an in-depth discussion of FMD diagnostic testing.[45]

In areas where FMD is endemic and vaccination is used, diagnostic tests must be able to differentiate infected animals from vaccinated animals (DIVA). A detailed review of FMD diagnostic tests for endemic countries, including DIVA tests, has been written by Tewari, Jain, and Bhatia.[46]

Tests to Detect Antibody

Enzyme-linked immunosorbent assays (ELISAs) are used to detect antibodies to FMDV. Tests based on structural proteins are serotype-specific, and in non-vaccinated animals, a positive test indicates prior infection.[47] As described by the *WOAH Terrestrial Manual*, examples include the solid-phase competition ELISA[48-50] and the liquid-phase blocking ELISA.[51,52] Tests that detect antibodies to non-structural proteins, which are highly conserved, are not serotype restricted.[47] Virus neutralization can also be used to detect antibodies to structural proteins. According to WOAH, it is considered the gold standard test for FMD testing, but it requires tissue culture, is slower than ELISA, and is subject to contamination.[47]

Samples

According to the *WOAH Terrestrial Manual*,[47] the preferred tissue for FMD diagnosis is epithelium from unruptured or freshly ruptured vesicles or vesicular fluid. Blood (serum) or throat swabs can also be submitted from pigs, as well as myocardium from dead piglets. Experimentally, oral fluids have been successfully used for qRT-PCR[53-55] plus antigen and IgA detection.[54]

EPIDEMIOLOGY

Species Affected

Infection with FMDV occurs in cloven-hoofed animals, including livestock and wildlife. Cattle, pigs, sheep, and goats are the most significant hosts in Western countries, while the water buffalo and the African buffalo are important in Asia and Africa. Species that are susceptible but low risk in North America include bison, elk, deer, llamas, and alpacas. Animals that have been infected experimentally include rodents, guinea pigs, rabbits, cats, dogs, mink, monkeys, snakes, birds, and chickens. Many other species are susceptible to FMDV but do not appear to be involved in natural transmission (as described by Alexandersen).[10]

Geographic Distribution

FMD is endemic in many parts of Africa, Asia, and the Middle East. In these countries, poor or no FMD control poses a threat to neighboring countries where FMD is controlled.[29]

According to WOAH, as of 2026, FMD-free regions *without vaccination* include North America, Central America, most of South America, Australia, New Zealand, and most of Europe. A few Asian countries are included in this list, such as Japan, Singapore, and the Philippines. Areas that are FMD-free *with vaccination* include Colombia, Ecuador, Paraguay, Uruguay, parts of Argentina, and parts of Russia.[56]

Serotypes O and A circulate widely. Asia 1 occurs only in Asia. South African Territories (SAT) serotypes have been confined to sub-Saharan Africa and the Middle East until recently. Since 2025, two SAT1 subtypes have been cocirculating in North Africa and Western Asia. See Humphreys et al.[29] for more details on the global spread of FMDV serotypes since 2015.

Morbidity and Mortality

Morbidity can reach 100%. Mortality is generally low in adult pigs, but secondary bacterial infections in vesicular lesions can lead to chronic lameness, wasting, or death.[10] Most animals recover within 2 to 3 weeks. Death can occur in up to 20% of piglets due to heart failure. Vaccination may prevent the development of severe clinical disease, but it does not stop FMDV transmission.[10]

ETIOLOGY

FMDV is a non-enveloped, positive-sense, single-stranded RNA virus that belongs to the family *Picornaviridae*. It is assigned to the genus *Apthovirus*, which also contains equine rhinitis A virus, and bovine rhinitis A and B. Other picornavirus genera that infect pigs include *Cardiovirus*, *Enterovirus*, *Kobuvirus*, *Pasivirus*, *Sapelovirus*, *Senecavirus*, and *Teschovirus*.[10]

FMDV is small (~30 nm) and has a genome of about 8 kb, containing a 5′ UTR, a large polyprotein-coding region, and a 3′ UTR. There are four structural (VP1–4) and eight non-structural proteins (Lpro, 2A, 2B, 2C, 3A, 3B, 3Cpro, and 3Dpol).[10] VP1 is important for phylogenetic analysis.

Seven serotypes of FMDV (A, O, C, SAT 1, SAT 2, SAT 3, Asia 1) have been described.[57] However, serotype C has not been reported since 2004 and is considered extinct.[58] Each serotype contains multiple subtypes (also known as topotypes). Recombination between picornaviruses, including FMDV, has been

documented in the laboratory[59] and in nature.[60,61] Mixed infections involving serotypes O and A, as well as Asia 1 and O, have been reported. Co-circulation of multiple FMD strains also occurs.[62]

HISTORY IN SWINE

Vesicular disease in cattle has been recognized since the 1500s. A viral cause for FMD was first suggested in the late 1800s. By the 1860s, the virus spread from Europe to Argentina and then throughout the Americas. Serotypes O, A, and C were described in the 1920s, while SAT 1, 2, and 3 and Asia 1 were reported in the 1940s and 50s, respectively. In Europe, FMD outbreaks—with periodic epidemics—were very common until the 1970s when vaccination began. Early vaccine programs focused on cattle, but swine vaccination for types C and O was also implemented in the 1960s (as described by Alexandersen).[10] FMD was the first disease for which WOAH established an official list of disease-free Members.

The last reported case of FMD in the United States occurred in 1929. However, FMD outbreaks in free areas remain a concern. During the 2001 epidemic in the United Kingdom, more than 6 million cattle, sheep, and pigs were culled for disease control and welfare reasons on over 2000 premises. The epidemic cost more than $5 billion USD in direct costs and an additional $10 billion due to trade restrictions and tourism losses.[63,64] Periodic outbreaks in Japan, South Korea, and Taiwan have proven difficult to control despite efforts including mass vaccination.

In 2025, an outbreak occurred in water buffalo in Germany,[65] which had been FMD-free for 37 years. A list of other FMD incursions since 2022 has been compiled by the *Swine Health Information Center* (SHIC).

IMMUNITY

Post-exposure

Circulating antibodies are detectable 3–5 days after the onset of clinical signs. Viremia and nasal/oral shedding usually subside within 14 days post-infection.[12] At least one study concluded that FMD RNA is detectable in serum for nearly a year, but this result has not been replicated.[66] Natural infection induces a strong IgA response, while inactivated vaccines do not.[10] The innate response is not well understood and may not play a major role in FMDV infection.[10]

Vaccines

Inactivated FMD vaccines are effective, but their use comes with limitations. FMD vaccine strains must be matched to outbreak strains to be effective, and vaccine formulations must be updated frequently to provide protection against emerging variants. Vaccine programs may require two or more doses, since herd-level protection lasts only six months. These issues, combined with the large number of animals that would be affected, make vaccination an unlikely response strategy for a widespread or catastrophic outbreak in the United States or North America.[67] Novel vaccine platforms, including virus-like particles, peptide-based vaccines, and recombinant vaccines, are being explored for their potential to provide broader and longer-lasting immunity (reviewed by Mohamadin et al.[13] and Elrashedy et al.[68]).

Specific to pigs, vaccination is far less common than in cattle in many regions, and vaccines effective in cattle may fail to confer sufficient immunity in pigs.[12]

Cross-protection

Immunity to one FMDV serotype does not protect against infection with other serotypes. Additionally, each serotype contains multiple subtypes (topotypes), which can affect vaccine efficacy.[10]

GAPS IN PREPAREDNESS

The re-emergence of FMD in the United States and other FMD-free countries remains a concern, as outbreaks would cause devastating losses to the swine industry through culling and disruption of international trade. As evidenced by the 2025 outbreak in Germany,[65] surveillance and rapid response are critical for controlling FMD.

As described by Humphreys et al.,[29] FMD epidemiology remains poorly understood. More information is needed on virus biology (including different serotypes), geographic distribution, pathogenesis (including carrier and species differences), and host range (including the potential role of feral swine). Quick and simple diagnostic tests are needed, particularly those that can be used pen-side. Additional research is needed to address cross-protection and simplify vaccine strain matching. The expanding range of SAT serotypes demonstrates the increasing likelihood of transboundary spread.

Many FMD studies have focused on cattle rather than pigs. Importantly, there are differences between species regarding FMD transmission, pathogenesis, clinical signs, immunity, and vaccination (as described by Stenfeldt).[12] More studies are needed that include or focus on pigs to identify species differences.

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