PORCINE CIRCOVIRUS 3

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.

March 2022 | Updated January 2026

SUMMARY

IMPORTANCE

- Porcine circovirus 3 (PCV3) is an emerging swine pathogen with potential economic importance.
- It has been associated with signs similar to those caused by porcine circovirus 2 (PCV2), a major swine pathogen. However, many infections are subclinical, co-infections are common (including with PCV2), and PCV3 pathogenicity studies have yielded mixed results.

PUBLIC HEALTH

- Porcine circoviruses (PCVs), including PCV3, are not considered to be zoonotic.

INFECTION IN SWINE

- PCV3 has been associated with respiratory disease, reproductive failure, neurological disease, enteric disease, and porcine dermatitis and nephropathy syndrome (PDNS).
- In pathogenicity studies, PCV3 inoculation does not consistently lead to the development of clinical disease.

TREATMENT

- There is no treatment for pigs infected with PCV3.

CLEANING AND DISINFECTION

- Circoviruses are stable in the environment. In the laboratory, potassium peroxymonosulfate, sodium chloride, sodium hypochlorite, and sodium hydroxide are the most effective for PCV2. No specific information on disinfectants for PCV3 was found.

PREVENTION AND CONTROL

- PCV2 prevention is based on factors that can influence susceptibility. These include good nutrition, biosecurity, and vaccination. No specific control measures have been described for PCV3.

TRANSMISSION

- Both PCV2 and PCV3 spread through vertical and horizontal transmission. The virus is shed in most secretions/excretions. Direct contact is the route of most significance, but PCVs also spread via fomites and ingestion.

PATHOGENESIS

- Little is known about PCV3 pathogenesis. In the field, PCV3 is linked to lymphoid depletion, vasculitis, and fetal mummification.

DIAGNOSIS

- Many polymerase chain reaction (PCR) assays have been developed for PCV3 in the research setting. Most are based on the Cap protein.
- PCV3 has only recently been isolated in cell culture. The virus can be demonstrated in lesions by immunohistochemistry (IHC) or in situ hybridization (ISH).
- Although antibodies are not diagnostic for PCV3, a few enzyme-linked immunosorbent assays (ELISAs) have been described to detect recombinant Cap protein.
- PCV3 can be detected in many tissues and organs. Heart, lung, and lymphoid tissue are important for histology and IHC or ISH. When PDNS is suspected, skin lesions should be submitted, and in cases of reproductive failure, fetal tissues should be submitted. Oral fluids and processing fluids can be used for prevalence studies.

EPIDEMIOLOGY

- PCV3 is found in wild and domestic pigs in many swine-producing regions of the world.
- Globally, PCV3 prevalence ranges from about 6.5% to 84%. The virus has been detected in pigs of all ages, but prevalence appears to be lower in piglets and higher in adults, including sows.
- Death is uncommon in young pigs, but perinatal mortality in sows is a feature of reproductive disease.

ETIOLOGY

- PCV3 belongs to the family *Circoviridae*. Circoviruses are very small, non-enveloped viruses with a circular, single-stranded DNA genome.
- Currently, there are four recognized circoviruses of swine, designated PCV1–4. A novel PCV, tentatively named PCV5, has recently been detected in China.
- The PCV3 genome is distinctly different from other PCVs and is related to canine and bat circoviruses.

HISTORY IN SWINE

- PCV1 was identified in 1974 as a contaminant in a pig kidney cell line. In 1997, PCV2 was recognized as the cause of a novel wasting disease affecting Canadian pigs.
- In 2016, PCV3 was detected in tissues from sows from North Carolina that aborted and died acutely with PDNS-like clinical signs. PCV4 and PCV5 were identified in samples from pigs with respiratory, enteric, and reproductive disease in 2019 and 2025, respectively.
- Evidence suggests that PCVs have been circulating in swine long before they were first detected.

IMMUNITY

- The PCV3 antibody response is mainly due to IgG, which can be detected experimentally at seven days post-infection. The duration of immunity is unknown.
- There is no cross-protection between PCV3 and other PCVs, including PCV2. There are no commercially available PCV3 vaccines, but vaccination is available through a veterinary prescription.

GAPS IN PREPAREDNESS

- PCV3 has been associated with many PCVAD-like clinical signs. It remains unclear whether PCV3 is a primary pathogen. The strongest evidence of causality involves PCV3-systemic and PCV3-reproductive disease. As with PCV2, many PCV3 infections are subclinical, and co-infection with other swine pathogens is common.
- To better understand the impact of PCV3 on the swine industry, more evidence is needed on pathogenesis, host genomics, viral genomics, and immunology. New diagnostic tools are needed for surveillance and detection of new PCV strains.

LITERATURE REVIEW

IMPORTANCE

Porcine circovirus 3 (PCV3) is an emerging swine pathogen with potential economic importance.[1] It has been associated with signs similar to those caused by porcine circovirus 2 (PCV2), a major swine pathogen. However, many infections appear subclinical, co-infections are common (including with PCV2), and PCV3 pathogenicity studies have yielded mixed results.

PUBLIC HEALTH

PCVs are not considered to be zoonotic. PCV3 transmission has occurred in baboons receiving heart transplants from PCV3-positive pigs. However, experimental infection of human embryonic kidney cells has been unsuccessful.[2] Anti-PCV antibodies detected in humans, mice, and cattle are most likely due to a similar virus, not PCV.[3] Although PCV nucleic acids have been detected in vaccines produced for humans and pigs, this is thought to be due to poor quality control.[4]

INFECTION IN SWINE

PCV 1 and PCV2

Porcine circovirus 1 (PCV1) is nonpathogenic in swine.[4] In the 1990s, PCV2 was associated with postweaning multisystemic wasting syndrome (PMWS) in pigs 2-4 months of age. Clinical signs of PMWS include enlarged subcutaneous lymph nodes, wasting, diarrhea, respiratory distress, pallor, and occasionally icterus.[4] Lymphoid depletion and lymphohistiocytic or granulocytic inflammation are components of the diagnosis.[4] Although PCV2 is a primary pathogen, many infections are subclinical.[4,5] Co-infection with other swine pathogens is common.[6] Collectively, PCV2 infections are now known as porcine circovirus-associated disease (PCVAD).[5] Clinical manifestations include systemic disease (PCV2-SD, formerly PMWS), porcine dermatitis and nephropathy syndrome (PDNS), lung disease (PCV2-LD), reproductive disease (PCV2-RD), enteric disease (PCV2-ED), and subclinical infection (PCV2-SI).[5]

PCV3

In general, signs of PCV3 are very similar to signs of PCV2. The virus mostly causes respiratory disease in young pigs[7-14] and reproductive failure in sows.[13,15-28] PCV3 nucleic acids have also been detected in pigs with neurological disease,[11,18,29] enteric disease,[9,10,14,30] and PDNS.[12,16,18] PCV3 has been associated with death and growth retardation in pigs with caudally rotated (thrown-back) ears[31,32] as well as skeletal lesions and spinal deformities.[33] PCV3 is also commonly found in healthy pigs.[10,34-41] The only sign of infection may be reduced average daily gain.[5]

PCV3 was first detected in sows with signs of PDNS (red-to-purple or dark crusted skin lesions, often on the hind limbs and perineum, along with enlarged and pale kidneys with petechiae) and reproductive failure.[4] The index farm had chronic reproductive problems, including high sow mortality and below-average conception rates.[12] Inflammatory histological lesions were found in the respiratory system, skin, and lymphoid tissues. Ten sows from the initial outbreak were torque teno virus (TTV)-positive.[12] Investigators also screened archived samples from PCV-2-negative PDNS cases and found that some were PCV3-positive by immunohistochemistry (IHC) and quantitative polymerase chain reaction (qPCR).[12]

In post-weaning pigs, PCV3 infection causes multisystemic inflammation that can lead to myocarditis, respiratory disease, and nervous system disease.[11] Co-infection with pathogens including porcine astrovirus, rotavirus A, porcine cytomegalovirus, and porcine hemagglutinating encephalomyelitis has also been documented.[11] PCV co-infections may be additive, worsening clinical signs and delaying recovery.[42]

Published studies on experimental PCV3 infection have had mixed results.

- In 4- and 8-week-old SPF pigs, intranasal inoculation with an infectious PCV3 clone led to fever, anorexia, diarrhea, and respiratory distress, plus PDNS-like lesions and sudden death in some pigs. PCV3 was demonstrated in lungs, heart, lymph nodes, liver, kidneys, and small intestines using IHC.[43]

- In 6-week-old CD/CD pigs, PCV3 intranasal and intramuscular inoculation (plus subcutaneous administration of an immunostimulant two days before and after inoculation) did not lead to the development of clinical disease.[44] However, multisystemic inflammation and perivasculitis were observed via histology, and PCV3 nucleic acids were detected in lesions by ISH.[44]

- In 5-week-old CD/CD pigs, PCV3-positive tissue homogenate was used for intramuscular and intranasal inoculation. Pigs were re-inoculated after seven days. No clinical signs were seen during the study. Viremia occurred in PCV3-inoculated pigs at three days post-infection (dpi) and continued until the end of the study. Histology demonstrated multisystemic inflammation and perivasculitis. PCV3 was confirmed in tissues via qPCR and ISH.[45]

- In 4-week-old pigs, PCV3 intranasal inoculation led to moderate clinical signs, including anorexia, emaciation, and coughing at 12 dpi. At >12 dpi, shivering and tachypnea were seen, plus the development of multifocal papules on the skin. Histology revealed necrosis of mucosal epithelial cells and lymphocytes in the small intestine. The presence of PCV3 antigen was confirmed by IHC.[46]

- In 3-week-old CD/CD pigs, PCV3 intranasal and intramuscular inoculation did not lead to the development of clinical disease. Despite this, PCV3 nucleic acids were detected in many organs/tissues via qPCR, with the highest amounts in the lung and inguinal lymph node. PCV3 replication was detected in these tissues by ISH. Histology revealed reduced lymphocyte numbers and inflammatory cell infiltration in the lymph nodes, and epithelial cell proliferation, inflammatory cell infiltration, and thickened alveolar septa in the lungs. Passage in PK-15 cells failed.[47]

- In 3-week-old piglets orally inoculated with PCV3-positive intestinal contents, diarrhea occurred along with anorexia and depression. Moderate to severe villus atrophy was observed in the small intestine.[30]

- In 28-day-old SPF pigs injected intramuscularly with PCV3, mild clinical signs were detected at 19 dpi. These included anorexia, depression, diarrhea, lameness, and fever. Weight loss occurred at 21 dpi and continued until the end of the study.[48]

- In 6–8-week-old PCV3-inoculated miniature pigs, one developed neurological disease. Histologically, respiratory lesions were also detected.[49]

- Pregnant gilts were inoculated with PCV3 during the second and third trimesters of gestation. All became viremic within 2 weeks post-inoculation. No clinical signs developed in the piglets; however, by weaning, most had become viremic. In particular, histological lesions consistent with cardiac and nervous system damage occurred in piglets infected in the second trimester. Lower body weight also occurred.[50]

To standardize diagnostic criteria and improve case finding, Saporiti and colleagues[51] proposed case definitions for reproductive and systemic disease caused by PCV3 (see *Table 1*).

Table 1. Proposed Diagnostic Criteria for PCV3-Associated Diseases*

Proposed Name	Main Clinical Signs	Individual Diagnostic Criteria
PCV-3-reproductive disease (PCV-3-RD)	Late abortion, malformations, mummified fetuses, stillborn fetuses, weak-born piglets	1. Late reproductive problems and higher perinatal mortality 2. Multisystemic lymphoplasmacytic to lymphohistiocytic perivascular inflammation 3. Moderate to high amount of PCV-3 genome in damaged tissues
PCV-3-systemic disease (PCV-3-SD)	Wasting, weight loss, ill thrift or poor-doers, neurological signs	1. Weight loss, rough hair, neurological signs 2. Multisystemic lymphoplasmacytic to lymphohistiocytic perivascular inflammation 3. Moderate to high amount of PCV-3 genome in damaged tissues

*Diagnostic criteria proposed by Saporiti et al. Porcine circovirus 3 (PCV-3) as a causal agent of disease in swine and a proposal of PCV-3 associated disease case definition. *Transbound Emerge Dis*. 2021. doi: 10.1111/tbed.14204

There is no proposed case definition for PCV3-PDNS. For PDNS associated with PCV2, detection of the virus is not a diagnostic requirement. PCV2-PDNS causes hemorrhagic and necrotizing skin lesions (primarily on the hind limbs and perineal area) and/or swollen and pale kidneys with generalized cortical petechiae; systemic necrotizing vasculitis; and necrotizing fibrinous glomerulonephritis.

PCV4 and PCV5

More information is needed to determine whether PCV4 causes clinical illness in pigs. Its pathogenesis is poorly understood, and PCV4 co-infection with PCV2, PCV3, and other pathogens appears to be common.[52] A newly described PCV, tentatively named PCV5, has been circulating in China in pigs with respiratory illness, diarrhea, and reproductive failure.[53]

TREATMENT

There is no treatment for pigs infected with PCVs. Antibiotics may be used to treat secondary bacterial infections.

CLEANING AND DISINFECTION

SURVIVAL

Circoviruses are very stable in the environment.[54] PCV1 survives at 70˚C (158˚F) for 15 minutes, and PCV2 survives at 75˚C (167˚F) for 15 minutes or 56˚C (133˚F) for one hour.[4] PCV2 has been detected in various water sources, including those treated with chlorination for human or swine consumption.[55] In fresh pork, PCV2b can survive for two days post-infection (dpi) at room temperature, six dpi at refrigeration temperature (4˚C/39.2˚F), and 30 dpi at freezer temperature (-20˚C/-4˚F).[56] PCVs are also resistant to extreme pH. PCV2 retains some infectivity at pH 2 and pH 11–12.[4] No information was found on PCV3 survival.

DISINFECTION

In the laboratory, potassium peroxymonosulfate, sodium chloride, sodium hypochlorite (bleach), and sodium hydroxide appear to be the most effective virucidal agents against PCV2. Other potentially effective products include quaternary ammonium compounds and phenolics. Chlorhexidine, ethanol, aldehydes, and iodine products are generally not effective disinfectants for PCVs.[57-59] No information was found on the disinfection of PCV3.

PREVENTION AND CONTROL

PCV2 prevention is based on factors that can influence susceptibility. These include good nutrition, biosecurity, and vaccination (see *Immunity*). Since females have a lower risk of developing PMWS, sorting nursery pigs by sex can be beneficial.[4] Increased risk in males may be due to infection following castration and genetic or hormonal influence.[60] Poor management, including overcrowding, inadequate ventilation, and frequent commingling, may contribute to increased disease severity. Management factors linked to lower disease risk include:

- Housing pregnant sows in groups
- Weaning at higher weights
- Vaccinating sows for atrophic rhinitis
- Treating for ectoparasites
- Adding spray-dried plasma to nursery rations[4]

There are no specific control measures for PCV3. However, standard biosecurity practices should be in place on all swine premises.

TRANSMISSION

Both PCV2 and PCV3 are transmitted vertically and horizontally.[6] PCVs are transmitted mainly through direct contact. The virus can be detected in nasal, ocular, tonsillar, and bronchial secretions, as well as saliva, urine, feces, milk, colostrum, and semen.[4,8] Fomites, contaminated feed, needles, and biting insects may contribute to transmission. Pigs might become infected by eating the raw tissues of viremic animals.[4] Fetal infection can occur if the dam is exposed during pregnancy or inseminated with virus-containing semen. The virus can also be spread from fetus to fetus, and the timing of in utero infection determines the clinical outcome.[61] Most fetal deaths occur during the last third of gestation.[12]

PATHOGENESIS

Circoviruses replicate in actively dividing cells of young animals. PCV infection is enhanced when the immune system is stimulated, and more lymphocytes are available for replication.[62] Likewise, virus replication can occur in other cells with a high mitotic index, such as endothelial, epithelial, and macrophage cells.[4]

Little is known about PCV3 pathogenesis. One recent study found that PCV3 utilizes a clathrin- and dynamin-2-mediated endocytic pathway, entering both early and late endosomes, the latter of which requires an acidic environment.[63] Another study found that, experimentally, PCV infection disrupts the gut microbiota.[46] In the field, PCV3 is linked to lymphoid depletion, vasculitis, and fetal mummification.[42] Persistent viremia can occur up to 42 days post-infection.[64]

DIAGNOSIS

PCVs are widely distributed in the global swine population. Diagnosis of PCVAD is based on a combination of clinical signs, characteristic gross and microscopic lesions, and detection of the virus in lesions.[4] Diagnosis of PCV3-associated disease requires the presence of lesions indicative of multisystemic inflammation, PCR testing (Ct values lower than 30), and direct detection.[65]

TESTS TO DETECT NUCLEIC ACIDS, VIRUS, OR ANTIGENS

Polymerase chain reaction (PCR) assays are very important for PCV3 diagnosis. The *cap* gene, which encodes the highly conserved Cap protein, is often used as a PCR target. Many PCR variations have been described in the literature.[15,66,67,12,17,18,20,29,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,45,84,85,86,87,88,89,90,91-96] Also described is a visual detection method for PCV3 that uses a CRISPR/Cas12a detection system combined with recombinase polymerase amplification (RPA).[97] Virus particles have been observed using transmission electron microscopy.[98]

In addition to PCR, demonstration of the virus within lesions is important for PCV diagnosis. Methods include IHC and ISH.[99] PCV3 was first identified by metagenomic sequencing[11,12] and confirmed in tissues from sows with PDNS-like lesions by PCR and IHC,[12] and postweaning pigs with weight loss and swollen joints by ISH.[11] Next-generation sequencing has been combined with ISH to detect challenging or emerging pathogens, such as PCV3.[100]

Porcine kidney cells (PK-15),[101] Vero cells, and other porcine-derived cell lines can be used for isolation of PCV2.[4] Until recently, PCV3 had not been isolated in cell culture. One study found that PCV3 did not induce cytopathic effects in PK-15 cells, but infection was confirmed by ISH.[102] PCV3 has also been isolated from diagnostic case samples (from weak-born, stillborn, or mummified pigs)[18] in PK-15 cells and confirmed by qPCR and next-generation sequencing.[44] Replication in porcine bone marrow-derived cells has also been described.[103]

TESTS TO DETECT ANTIBODY

Antibodies are not diagnostic for PCV infection, but they may be useful for herd-level confirmation. Tests described for PCV3 include several enzyme-linked immunosorbent assays (ELISAs) to detect recombinant Cap protein.[12,44,104-107] One assay utilized both a Cap-based peptide and a Rep-based peptide,[108] and another described a monoclonal antibody against Cap used to construct an epitope-blocking ELISA.[109]

SAMPLES

Like PCV2, PCV3 has been detected within various lesions.[11,13,18,24,26,32,110,111] Heart, lung, and lymphoid tissue should always be submitted for histology.[111] In cases of reproductive failure, fetal tissues should be submitted (including the myocardium) as well as any lesions found in sows.[12] PCV3 has been detected in testicular fluid,[112] preputial fluid[113] and sometimes in semen.[114] For suspected PDNS cases, diagnostic submissions should include skin lesions.[4]

Oral fluids can be used to detect PCV3 in prevalence studies.[115] In one study, the highest detection rate for PCV3 was observed in processing fluids (serosanguineous fluids obtained as part of castration and tail docking practices).[116] The use of processing fluids for surveillance versus oral fluids or serum may affect reported prevalence rates, making comparisons difficult.

EPIDEMIOLOGY

SPECIES AFFECTED

Circoviruses are found in mammals, fish, birds, and insects.[6] PCV2 has been detected in farmed minks with diarrhea,[117] buffaloes,[118] beef products,[119] dogs,[120] farmed shellfish,[121] and flies.[122] While PCV2 antibodies have been found in rodents,[3] few studies have confirmed PCV in field samples.[123]

PCV3 is found in both wild[124-137] and domestic pigs, but clinical disease seems to occur only in the latter. Other species susceptible to PCV3 include dogs,[138,139] cattle,[140] mice,[141] donkeys,[142] and mosquitoes.[143] There is evidence of PCV3 infection in chamois, roe deer, and ticks, including *Ixodes ricinus*[124] and *Amblyomma testudinarium*.[134] However, the role of wildlife (including rodents, ticks,[144] and free-ranging ruminants and lagomorphs)[145] in PCV3 epidemiology is unclear.

GEOGRAPHIC DISTRIBUTION

PCV2 and PCV3 are currently found in many swine-producing regions of the world, including North America,[11,12,146] South America,[21,25,31,67,147-150] the Caribbean,[151] Europe,[16,17,19,39,40,72,152-156] Africa,[157,158] and Asia.[7,8,15,28,36,66,159-170] PCV4 has been described in Asia,[66,84,171-177] and more recently, the United States.[52] A novel PCV, tentatively named PCV5, has emerged in China.[53]

MORBIDITY AND MORTALITY

Globally, PCV3 prevalence ranges from about 6.5% to 84%.[65] Co-infections with one or more pathogens are common, including PCV2, with a reported co-infection rate of up to 70%.[64]

From 2016–18, about 28% of clinical cases submitted to the Kansas State Veterinary Diagnostic Laboratory were PCV3-positive, and 16% were PCV2-positive, with a co-infection rate of 5.4%.[115] Both PCV2 and PCV3 prevalence increased over the study period.[115] Another U.S. study from that time period found PCV3 in 21% and 18% of samples from grower and finisher pigs submitted to the University of Minnesota Veterinary Diagnostic Laboratory.[178]

Retrospective analysis of serum collected in 2000, 2006, and 2012 showed that all PCV3 subtypes were present in the United States before 2016, and that overall prevalence decreased from 2000 to 2012.[65] PCV3 subtypes a1, a2, a3, 3b, and 3c were identified.[65] PCV2/PCV3 co-infection also decreased over the study period, likely due to the introduction of commercial PCV2 vaccines.[65,179] However, PCV2 vaccines do not affect PCV3 prevalence because of a lack of cross-reactivity. PCV3 prevalence has been consistently higher in adults (including sows) compared to younger pigs.[12,179,180]

Overall, PCV3 prevalence has remained relatively steady during the past 20 years.[65,115,178] However, increased testing at veterinary diagnostic laboratories, using multiplex PCR and processing fluid samples, may have contributed to the higher PCV3 prevalence observed on breeding farms after 2018.[179] Standardization of PCR cycle threshold (Ct) cutoff values is needed to ensure consistent PCV3 diagnosis across laboratories.[179] For PCV3, a Ct value lower than 30 has been recommended.[179]

PCV3 has been detected in pigs of all ages. PCV3 is present in farrowing barns throughout the pre-weaning period.[116,181] However, lower prevalence in piglets[182] and higher infection rates in older pigs, including sows, have been reported.[48,183] Primiparous sows shed PCV3 at higher levels in colostrum[37,38] and have more PCV3-infected fetuses compared to multiparous sows. In boars, age also correlates with seropositivity.[114]

Cases of PCV3 often involve co-infection with other swine pathogens, including PCV2[27,51,165,184,185] and even African swine fever.[158,186] Co-infection with *Mycoplasma suis* has been found in cases of reproductive disease.[187]

PCV3 infection is not associated with high mortality in young pigs, but perinatal mortality in sows is a feature of reproductive disease.[188]

ETIOLOGY

CHARACTERISTICS OF CIRCOVIRUSES

PCVs are members of the family *Circoviridae*. Circoviruses are very small (15–25 nm), non-enveloped viruses that contain a circular, single-stranded DNA genome.[54] As of 2024, the family includes two genera, *Circovirus* and *Cyclovirus*, which contain 65 and 90 species, respectively.[189,190] PCVs have at least two major open reading frames (ORFs). ORF1 encodes the replication-associated protein (Rep, encoded on the virion sense strand), and ORF2 encodes the capsid protein (Cap, encoded on the complementary sense strand, and related to immunogenicity).[54]

CHARACTERISTICS OF PORCINE CIRCOVIRUSES

Currently, four swine circovirus species are recognized (PCV1–4).[189] A new PCV, tentatively named PCV5, has recently been described.[53] PCV2 is divided into five genotypes (PCV2a-2e).[4] PCV3 is distinct from PCV2, with 48% homology.[154] Homology between the Cap proteins of PCV2 and PCV3 may be as low as 37%.[11,191]

There is no standard classification scheme for PCVs, although several have been proposed. Based on Cap features, PCV3 can be divided into two or three genotypes: PCV3a and PCV3b, or PCV3a, PCV3b, and PCV3c. Efforts to standardize the classification of the PCV3 virus at the subspecies level are ongoing.[192]

Phylogenetic analyses show that PCV3 is related to canine and bat circoviruses.[11,12] Additionally, the PCV3 *cap* gene shows similarities to avian *cap* genes, suggesting a recombinant origin.[193,194] It is likely that new PCVs will continue to emerge. Additionally, classification reshuffling will likely continue, in part due to the increasing recognition of recombinant PCVs.[147]

HISTORY IN SWINE

In 1974, a small, spherical virus-like contaminant was detected in a pig kidney cell line (PK-15).[195] The virus, later identified as PCV1, was found to be widespread in pigs but was not associated with disease.[196] In the mid-1990s, postweaning multisystemic wasting syndrome (PMWS) epidemics linked to PCV2 occurred across the United States, Canada, and Europe.[197] In 1997, the causative agent was determined to be PCV2, which is antigenically and genetically distinct from PCV1.[198]

In the United States, PCV3 was detected in tissues from sows that aborted and died acutely with PDNS-like clinical signs in 2016.[110] Since then, PCV3 has been detected nearly worldwide in swine (see *Epidemiology*). PCV4 was discovered in samples from pigs with respiratory disease, enteric disease, and PDNS in China in 2019.[171] Additional PCV4s have since been detected that are similar to the original isolate.[84,88,172,173,175,176] Most recently, PCV4 has been discovered in the United States[52] and a novel virus (PCV5) has been described in China.[53] Current evidence suggests that PCVs have been circulating in swine for decades before they were first detected.[6,65,67,166,184]

IMMUNITY

POST-EXPOSURE

Many swine herds have anti-PCV2 antibodies indicating previous exposure; however, these are not necessarily protective.[4] In piglets, seroconversion occurs as colostral antibody wanes around seven weeks of age.[60] PCV2 seroconversion occurs in both subclinical and clinical cases, although some studies have shown decreased humoral immunity, and specifically fewer neutralizing antibodies, in symptomatic pigs. This leads to a higher concentration of virus in the serum and increased viral shedding. Cell-mediated immunity may also contribute to viral clearance.[4]

A few experimental studies have examined the immune response to PCV3 infection.

- In 4-6-week-old CD/CD pigs, PCV3 antibody response (primarily IgM) was detected 7–10 days following intranasal and intramuscular inoculation.[44]

- In 5-week-old CD/CD pigs, an IgG response was dominant, appearing at 7 dpi and persisting at 42 dpi following intramuscular and intranasal inoculation with PCV3.[45]

- In 3-week-old CD/CD pigs, IgG was variable following intranasal and intramuscular inoculation with PCV3. Of the nine piglets tested, four showed an obvious IgG response at 7–10 dpi, one showed an obvious IgG response at 14 dpi, and the remaining four piglets either had a mild IgG response or did not seroconvert by the end of the study (28 dpi).[47]

- Maternal Cap IgG antibodies were detectable in piglet serum 7–9 weeks post-farrowing, and Rep IgG antibodies were detectable 5 weeks post-farrowing. In 5-week-old CD/CD pigs, experimental infection resulted in Cap IgG detection at 2 weeks post-inoculation, and Rep IgG detection was delayed until 4 weeks post-inoculation.[199]

VACCINES

PCV2 vaccines confer humoral and cellular immunity, reducing mortality while improving average daily weight gain, feed conversion, and uniformity at slaughter. In the United States, PCV2 prevalence has decreased due to widespread vaccination.[200] PCV2 vaccination efficacy may be impacted by PCV2 and PCV3 co-infection, as well as high levels of PCV3 in serum and oral fluids.[188,42] Disease susceptibility[201] and vaccination effectiveness may also be influenced by genetic differences (e.g., breed).

Immunogenicity of the Cap protein has been confirmed for PCV3.[202] There are no commercially available PCV3 vaccines, but vaccination is available through a veterinary prescription. Subunit vaccines based on recombinant Cap proteins and VLP vaccines have been described experimentally.[42] Multivalent PCV vaccines are also being tested. DNA vaccines contain plasmid DNA encoding the Cap protein, which is expressed and stimulates the immune response. See Zheng (2026) for a further review of potential vaccine strategies.[42]

CROSS-PROTECTION

Commercial vaccines confer cross-protection between PCV2 genotypes a–d.[6] However, due to the low degree of homology, there is no cross-protection between PCV3 and other PCVs.[199,207]

GAPS IN PREPAREDNESS

PCV3 has been associated with many PCVAD-like clinical signs. The strongest evidence of causality involves PCV3-systemic and PCV3-reproductive disease. However, as with PCV2, many PCV3 infections are subclinical, and infection with other swine pathogens is common. To better understand the impact of PCV3 on the swine industry, more evidence is needed on pathogenesis, host genomics, viral genomics, and immunology. Additionally, new diagnostic tools are needed for surveillance and detection of new PCV strains.[42]

REFERENCES

1. Turlewicz-Podbielska H, Augustyniak A, Pomorska-Mól M. Novel porcine circoviruses in view of lessons learned from porcine circovirus type 2-epidemiology and threat to pigs and other species. *Viruses*. 2022;14(2). doi:10.3390/v14020261

2. Krüger L, Längin M, Reichart B, et al. Transmission of porcine circovirus 3 (PCV3) by xenotransplantation of pig hearts into baboons. *Viruses*. 2019;11(7). doi:10.3390/v11070650

3. Tischer I, Bode L, Apodaca J, et al. Presence of antibodies reacting with porcine circovirus in sera of humans, mice, and cattle. *Arch Virol*. 1995;140(8):1427-1439. doi:10.1007/BF01322669

4. Segalés J, Allan G, Domingo M. Circoviruses. In: Zimmerman J, Karriker L, Ramirez A, Schwartz K, Stevenson G, Zhang J, eds. *Diseases of Swine*. 11th ed. John Wiley & Sons, Inc.; 2019:473-488:Chap 26.

5. Segalés J. Porcine circovirus type 2 (PCV2) infections: clinical signs, pathology and laboratory diagnosis. *Virus Res*. 2012;164(1-2):10-9. doi:10.1016/j.virusres.2011.10.007

6. Opriessnig T, Karuppannan AK, Castro AMMG, Xiao CT. Porcine circoviruses: current status, knowledge gaps and challenges. *Virus Res*. 2020;286:198044. doi:10.1016/j.virusres.2020.198044

7. Shen H, Liu X, Zhang P, et al. Genome characterization of a porcine circovirus type 3 in South China. *Transbound Emerg Dis*. 2018;65(1):264-266. doi:10.1111/tbed.12639

8. Kedkovid R, Woonwong Y, Arunorat J, et al. Porcine circovirus type 3 (PCV3) infection in grower pigs from a Thai farm suffering from porcine respiratory disease complex (PRDC). *Vet Microbiol*. 2018;215:71-76. doi:10.1016/j.vetmic.2018.01.004

9. Qi S, Su M, Guo D, et al. Molecular detection and phylogenetic analysis of porcine circovirus type 3 in 21 Provinces of China during 2015-2017. *Transbound Emerg Dis*. 2019;66(2):1004-1015. doi:10.1111/tbed.13125

10. Zhai SL, Zhou X, Zhang H, et al. Comparative epidemiology of porcine circovirus type 3 in pigs with different clinical presentations. *Virol J*. 2017;14(1):222. doi:10.1186/s12985-017-0892-4

11. Phan TG, Giannitti F, Rossow S, et al. Detection of a novel circovirus PCV3 in pigs with cardiac and multi-systemic inflammation. *Virol J*. 2016;13(1):184. doi:10.1186/s12985-016-0642-z

12. Palinski R, Pineyro P, Shang P, et al. A novel porcine circovirus distantly related to known circoviruses is associated with porcine dermatitis and nephropathy syndrome and reproductive failure. *J Virol*. 2017;91(1). doi:10.1128/jvi.01879-16

13. Kim SH, Park JY, Jung JY, et al. Detection and genetic characterization of porcine circovirus 3 from aborted fetuses and pigs with respiratory disease in Korea. *J Vet Sci*. 2018;19(5):721-724. doi:10.4142/jvs.2018.19.5.721

14. Saporiti V, Cruz TF, Correa-Fiz F, Núñez JI, Sibila M, Segalés J. Similar frequency of Porcine circovirus 3 (PCV-3) detection in serum samples of pigs affected by digestive or respiratory disorders and age-matched clinically healthy pigs. *Transbound Emerg Dis*. 2020;67(1):199-205. doi:10.1111/tbed.13341

15. Ku X, Chen F, Li P, et al. Identification and genetic characterization of porcine circovirus type 3 in China. *Transbound Emerg Dis*. 2017;64(3):703-708. doi:10.1111/tbed.12638

16. Yuzhakov AG, Raev SA, Alekseev KP, et al. First detection and full genome sequence of porcine circovirus type 3 in Russia. *Virus Genes*. 2018;54(4):608-611. doi:10.1007/s11262-018-1582-z

17. Deim Z, Dencső L, Erdélyi I, et al. Porcine circovirus type 3 detection in a Hungarian pig farm experiencing reproductive failures. *Vet Rec*. 07 2019;185(3):84. doi:10.1136/vr.104784

18. Arruda B, Piñeyro P, Derscheid R, et al. PCV3-associated disease in the United States swine herd. *Emerg Microbes Infect*. 2019;8(1):684-698. doi:10.1080/22221751.2019.1613176

19. Faccini S, Barbieri I, Gilioli A, et al. Detection and genetic characterization of Porcine circovirus type 3 in Italy. *Transbound Emerg Dis*. 2017;64(6):1661-1664. doi:10.1111/tbed.12714

20. Zou Y, Zhang N, Zhang J, et al. Molecular detection and sequence analysis of porcine circovirus type 3 in sow sera from farms with prolonged histories of reproductive problems in Hunan, China. *Arch Virol*. 2018;163(10):2841-2847. doi:10.1007/s00705-018-3914-7

21. Tochetto C, Lima DA, Varela APM, et al. Full-genome sequence of porcine circovirus type 3 recovered

from serum of sows with stillbirths in Brazil. *Transbound Emerg Dis*. 2018;65(1):5-9. doi:10.1111/tbed.12735

22. Dal Santo AC, Cezario KC, Bennemann PE, Machado SA, Martins M. Full-genome sequences of porcine circovirus 3 (PCV3) and high prevalence in mummified fetuses from commercial farms in Brazil. *Microb Pathog*. 2020;141:104027. doi:10.1016/j.micpath.2020.104027

23. Tochetto C, de Lima DA, Varela APM, et al. Investigation on porcine circovirus type 3 in serum of farrowing sows with stillbirths. *Microb Pathog*. 2020;149:104316. doi:10.1016/j.micpath.2020.104316

24. Saporiti V, Valls L, Maldonado J, et al. Porcine circovirus 3 detection in aborted fetuses and stillborn piglets from swine reproductive failure cases. *Viruses*. 2021;13(2). doi:10.3390/v13020264

25. Serena MS, Cappuccio JA, Barrales H, et al. First detection and genetic characterization of porcine circovirus type 3 (PCV3) in Argentina and its association with reproductive failure. *Transbound Emerg Dis*. 2021;68(4):1761-1766. doi:10.1111/tbed.13893

26. Vargas-Bermúdez DS, Vargas-Pinto MA, Mogollón JD, Jaime J. Field infection of a gilt and its litter demonstrates vertical transmission and effect on reproductive failure caused by porcine circovirus type 3 (PCV3). *BMC Vet Res*. 2021;17(1):150. doi:10.1186/s12917-021-02862-5

27. Mai J, Wang D, Zou Y, et al. High co-infection status of novel porcine parvovirus 7 with porcine circovirus 3 in sows that experienced reproductive failure. *Front Vet Sci*. 2021;8:695553. doi:10.3389/fvets.2021.695553

28. Nguyen NH, Do DT, Nguyen TQ, Nguyen TT, Nguyen MN. Genetic diversity of porcine circovirus subtypes from aborted sow fetuses in Vietnam. *Curr Microbiol*. 2021;78(10):3751-3756. doi:10.1007/s00284-021-02641-3

29. Chen GH, Mai KJ, Zhou L, et al. Detection and genome sequencing of porcine circovirus 3 in neonatal pigs with congenital tremors in South China. *Transbound Emerg Dis*. 2017;64(6):1650-1654. doi:10.1111/tbed.12702

30. Zhang F, Yuan W, Li Z, et al. Porcine circovirus type 3 in pig farms experiencing diarrhea in Jiangxi, China: prevalence, genome sequence and pathogenicity. *Animals (Basel)*. 2020;10(12). doi:10.3390/ani10122324

31. Molossi FA, de Almeida BA, de Cecco BS, et al. A putative PCV3-associated disease in piglets from Southern Brazil. *Braz J Microbiol*. 2022;53(1):491-498. doi:10.1007/s42770-021-00644-7

32. Alomar J, Saporiti V, Pérez M, Gonçalvez D, Sibila M, Segalés J. Multisystemic lymphoplasmacytic inflammation associated with PCV-3 in wasting pigs. *Transbound Emerg Dis*. 2021;68(6):2969-2974. doi:10.1111/tbed.14260

33. Rosato G, Makoni GM, Cobos À, et al. Concurrent histological lesions and molecular detection of porcine circovirus 3 in pigs with skeletal abnormalities and humpy-back posture. *Vet Pathol*. 2026;63(2):255-264. doi:10.1177/03009858251386914

34. Wen S, Sun W, Li Z, et al. The detection of porcine circovirus 3 in Guangxi, China. *Transbound Emerg Dis*. 2018;65(1):27-31. doi:10.1111/tbed.12754

35. Zheng S, Wu X, Zhang L, et al. The occurrence of porcine circovirus 3 without clinical infection signs in Shandong Province. *Transbound Emerg Dis*. 2017;64(5):1337-1341. doi:10.1111/tbed.12667

36. Kwon T, Yoo SJ, Park CK, Lyoo YS. Prevalence of novel porcine circovirus 3 in Korean pig populations. *Vet Microbiol*. 2017;207:178-180. doi:10.1016/j.vetmic.2017.06.013

37. Kedkovid R, Woonwong Y, Arunorat J, et al. Porcine circovirus type 3 (PCV3) shedding in sow colostrum. *Vet Microbiol*. 2018;220:12-17. doi:10.1016/j.vetmic.2018.04.032

38. Saporiti V, Martorell S, Cruz TF, et al. Frequency of detection and phylogenetic analysis of porcine circovirus 3 (PCV3) in healthy primiparous and multiparous sows and their mummified fetuses and stillborn. *Pathogens*. 2020;9(7). doi:10.3390/pathogens9070533

39. Franzo G, Legnardi M, Hjulsager CK, et al. Full-genome sequencing of porcine circovirus 3 field strains from Denmark, Italy and Spain demonstrates a high within-Europe genetic heterogeneity. *Transbound Emerg Dis*. 2018;doi:10.1111/tbed.12836

40. Stadejek T, Wozniak A, Milek D, Biernacka K. First detection of porcine circovirus type 3 on commercial pig farms in Poland. *Transbound Emerg Dis*. 2017;64(5):1350-1353. doi:10.1111/tbed.12672

41. Saporiti V, Huerta E, Correa-Fiz F, et al. Detection and genotyping of porcine circovirus 2 (PCV-2) and

detection of porcine circovirus 3 (PCV-3) in sera from fattening pigs of different European countries. *Transbound Emerg Dis*. 2020;67(6):2521-2531. doi:10.1111/tbed.13596

42. Zheng J, Zhang G, Li P, Ren L. Emerging challenges and advances in porcine circovirus: A decade in review. *Transbound Emerg Dis*. 2026;2026:4921135. doi:10.1155/tbed/4921135

43. Jiang H, Wang D, Wang J, et al. Induction of porcine dermatitis and nephropathy syndrome in piglets by infection with porcine circovirus type 3. *J Virol*. 2019;93(4). doi:10.1128/JVI.02045-18

44. Mora-Díaz J, Piñeyro P, Shen H, et al. Isolation of PCV3 from perinatal and reproductive cases of PCV3-associated disease and in vivo characterization of PCV3 replication in CD/CD growing pigs. *Viruses*. 2020;12(2). doi:10.3390/v12020219

45. Temeeyasen G, Lierman S, Arruda BL, et al. Pathogenicity and immune response against porcine circovirus type 3 infection in caesarean-derived, colostrum-deprived pigs. *J Gen Virol*. 2021;102(1). doi:10.1099/jgv.0.001502

46. Hou L, Wang J, Zhang W, et al. Dynamic alterations of gut microbiota in porcine circovirus type 3-infected piglets. *Front Microbiol*. 2020;11:1360. doi:10.3389/fmicb.2020.01360

47. Wang M, Yu Y, Wu J, et al. Pathogenic characterization of a porcine circovirus type 3 isolate from Heilongjiang, China. *Dis Markers*. 2021:9434944. doi:10.1155/2021/9434944

48. Deng H, Zhu S, Zhu L, et al. Histopathological changes and inflammatory response in specific pathogen-free (SPF) with porcine circovirus type 3 infection. *Animals (Basel)*. 2023;13(3). doi:10.3390/ani13030530

49. Hayashi S, Sato T, Ono H, et al. Experimental inoculation of a tissue homogenate containing porcine circovirus type 3 obtained after two in vivo passages in NIBS miniature pigs. *Vet Microbiol*. 2023;281:109740. doi:10.1016/j.vetmic.2023.109740

50. Cobos À, Ruiz A, Pérez M, et al. Experimental inoculation of porcine circovirus 3 (PCV-3) in pregnant gilts causes PCV-3-associated lesions in newborn piglets that persist until weaning. *Transbound Emerg Dis*. 2023:5270254. doi:10.1155/2023/5270254

51. Saporiti V, Franzo G, Sibila M, Segalés J. Porcine circovirus 3 (PCV-3) as a causal agent of disease in swine and a proposal of PCV-3 associated disease case definition. *Transbound Emerg Dis*. 2021; doi:10.1111/tbed.14204

52. Kroeger M, Vargas-Bermudez DS, Jaime J, et al. First detection of PCV4 in swine in the United States: codetection with PCV2 and PCV3 and direct detection within tissues. *Sci Rep*. 2024;14(1):15535. doi:10.1038/s41598-024-66328-y

53. Liu X, Wang L, Zhang X, et al. Identification and biochemical characterization of a novel porcine circovirus associated with porcine respiratory and diarrheal diseases. *Microbiol Spectr*. 2025;13(11):e0229925. doi:10.1128/spectrum.02299-25

54. Breitbart M, Delwart E, Rosario K, Segalés J, Varsani A, Ictv Report Consortium. ICTV Virus Taxonomy Profile: Circoviridae. *J Gen Virol*. 2017;98(8):1997-1998. doi:10.1099/jgv.0.000871

55. Garcia LA, Viancelli A, Rigotto C, et al. Surveillance of human and swine adenovirus, human norovirus and swine circovirus in water samples in Santa Catarina, Brazil. *J Water Health*. 2012;10(3):445-52. doi:10.2166/wh.2012.190

56. Abin M, Mor S, Popowski J, Cox R, Goyal S, Patnayak D. Effect of temperature on the survival of porcine circovirus type 2b in fresh pork. *Vet J*. 2013;197(3):898-899. doi:10.1016/j.tvjl.2013.03.015

57. Royer R, Nawagitgul P, Halbur P, Paul P. Susceptibility of porcine circovirus type 2 to commercial and laboratory disinfectants. *J Swine Health Prod*. 2001;9(6):281-4.

58. Kim HB, Lyoo KS, Joo HS. Efficacy of different disinfectants in vitro against porcine circovirus type 2. *Vet Rec*. 2009;164(19):599-600.

59. Martin H, Le Potier MF, Maris P. Virucidal efficacy of nine commercial disinfectants against porcine circovirus type 2. *Vet J*. 2008;177(3):388-93. doi:10.1016/j.tvjl.2007.06.016

60. Rodríguez-Arrioja G, Segalés J, Calsamiglia M, et al. Dynamics of porcine circovirus type 2 infection in a herd of pigs with postweaning multisystemic wasting syndrome. *Am J Vet Res*. 2002;63(3):354.

61. Yaeger MJ. Disorders of Pigs. In: Njaa BL, ed. *Kirkbride's Diagnosis of Abortion and Neonatal Loss in*

Animals. John Wiley & Sons; 2011. Ed.4.

62. Circoviridae. In: MacLachlan NJ, Dubovi EJ, eds. *Fenner's Veterinary Virology*. 4th ed. Academic Press; 2011:237-242:Chap 13.

63. Shi R, Hou L, Wei L, et al. Porcine circovirus type 3 enters into PK15 cells through clathrin- and dynamin-2-mediated endocytosis in a Rab5/Rab7 and pH-dependent fashion. *Front Microbiol*. 2021;12:636307. doi:10.3389/fmicb.2021.636307

64. Kroeger M, Temeeyasen G, Piñeyro PE. Five years of porcine circovirus 3: What have we learned about the clinical disease, immune pathogenesis, and diagnosis. *Virus Res*. 2022;314:198764. doi:10.1016/j.virusres.2022.198764

65. Kroeger M, James Stott C, Shen H, et al. Epidemiological and molecular retrospective analysis of porcine circovirus 3 in the US grower-finisher herd. *Infect Genet Evol*. 2025;134:105819. doi:10.1016/j.meegid.2025.105819

66. Tan CY, Opaskornkul K, Thanawongnuwech R, Arshad SS, Hassan L, Ooi PT. First molecular detection and complete sequence analysis of porcine circovirus type 3 (PCV3) in Peninsular Malaysia. *PLoS One*. 2020;15(7):e0235832. doi:10.1371/journal.pone.0235832

67. Rodrigues ILF, Cruz ACM, Souza AE, et al. Retrospective study of porcine circovirus 3 (PCV3) in swine tissue from Brazil (1967-2018). *Braz J Microbiol*. 2020;51(3):1391-1397. doi:10.1007/s42770-020-00281-6

68. Wang J, Zhang Y, Liu L, Pang X, Yuan W. Development of a TaqMan-based real-time PCR assay for the specific detection of porcine circovirus 3. *J Virol Methods*. 2017;248:177-180. doi:10.1016/j.jviromet.2017.07.007

69. Yuan L, Liu Y, Chen Y, et al. Optimized real-time fluorescence PCR assay for the detection of porcine circovirus type 3 (PCV3). *BMC Vet Res*. 2020;16(1):249. doi:10.1186/s12917-020-02435-y

70. Chen GH, Tang XY, Sun Y, et al. Development of a SYBR green-based real-time quantitative PCR assay to detect PCV3 in pigs. *J Virol Methods*. 2018;251:129-132. doi:10.1016/j.jviromet.2017.10.012

71. Franzo G, Legnardi M, Centelleghe C, et al. Development and validation of direct PCR and quantitative PCR assays for the rapid, sensitive, and economical detection of porcine circovirus 3. *J Vet Diagn Invest*. 2018;30(4):538-544. doi:10.1177/1040638718770495

72. Plut J, Jamnikar-Ciglenecki U, Golinar-Oven I, Knific T, Stukelj M. A molecular survey and phylogenetic analysis of porcine circovirus type 3 using oral fluid, faeces and serum. *BMC Vet Res*. 2020;16(1):281. doi:10.1186/s12917-020-02489-y

73. Park YR, Kim HR, Kim SH, et al. Loop-mediated isothermal amplification assay for the rapid and visual detection of novel porcine circovirus 3. *J Virol Methods*. 2018;253:26-30. doi:10.1016/j.jviromet.2017.12.006

74. Zheng S, Wu X, Shi J, et al. Rapid specific and visible detection of porcine circovirus type 3 using loop-mediated isothermal amplification (LAMP). *Transbound Emerg Dis*. 2018; doi:10.1111/tbed.12835

75. Wang J, Zhang Y, Zhang R, et al. Recombinase polymerase amplification assay for rapid detection of porcine circovirus 3. *Mol Cell Probes*. 2017;36:58-61. doi:10.1016/j.mcp.2017.09.001

76. Gou H, Bian Z, Cai R, et al. The colorimetric isothermal multiple-self-matching-initiated amplification using cresol red for rapid and sensitive detection of porcine circovirus 3. *Front Vet Sci*. 2020;7:407. doi:10.3389/fvets.2020.00407

77. Ji J, Xu X, Wang X, et al. Novel polymerase spiral reaction assay for the visible molecular detection of porcine circovirus type 3. *BMC Vet Res*. 2019;15(1):322. doi:10.1186/s12917-019-2072-9

78. Wang Y, Feng Y, Zheng W, et al. A multiplex real-time PCR assay for the detection and differentiation of the newly emerged porcine circovirus type 3 and continuously evolving type 2 strains in the United States. *J Virol Methods*. 2019;269:7-12. doi:10.1016/j.jviromet.2019.03.011

79. Yang K, Jiao Z, Zhou D, Guo R, Duan Z, Tian Y. Development of a multiplex PCR to detect and discriminate porcine circoviruses in clinical specimens. *BMC Infect Dis*. 2019;19(1):778. doi:10.1186/s12879-019-4398-0

80. Li X, Qiao M, Sun M, Tian K. A duplex real-time PCR assay for the simultaneous detection of porcine circovirus 2 and circovirus 3. *Virol Sin*. 2018;33(2):181-186. doi:10.1007/s12250-018-0025-2

81. Bai J. Detection and Differentiation of PCV3 from PCV2a, PCV2b, and the Highly Prevalent PCV2d Mutant Strains. *Diagnostic Assay Catalog*. 2016. https://www.swinehealth.org/wp-content/uploads/2020/09/SHIC-diagnostic-assay-catalog-21Sept2020.pdf

82. Kim HR, Park YR, Lim DR, et al. Multiplex real-time polymerase chain reaction for the differential detection of porcine circovirus 2 and 3. *J Virol Methods*. 2017;250:11-16. doi:10.1016/j.jviromet.2017.09.021

83. Zhao Y, Han HY, Fan L, et al. Development of a TB green II-based duplex real-time fluorescence quantitative PCR assay for the simultaneous detection of porcine circovirus 2 and 3. *Mol Cell Probes*. 2019;45:31-36. doi:10.1016/j.mcp.2019.04.001

84. Hou CY, Zhang LH, Zhang YH, et al. Phylogenetic analysis of porcine circovirus 4 in Henan Province of China: A retrospective study from 2011 to 2021. *Transbound Emerg Dis*. 2021; doi:10.1111/tbed.14172

85. Han HY, Zheng HH, Zhao Y, et al. Development of a SYBR green I-based duplex real-time fluorescence quantitative PCR assay for the simultaneous detection of porcine epidemic diarrhea virus and porcine circovirus 3. *Mol Cell Probes*. 2019;44:44-50. doi:10.1016/j.mcp.2019.02.002

86. Tian RB, Jin Y, Xu T, Zhao Y, Wang ZY, Chen HY. Development of a SYBR green I-based duplex real-time PCR assay for detection of pseudorabies virus and porcine circovirus 3. *Mol Cell Probes*. 10 2020;53:101593. doi:10.1016/j.mcp.2020.101593

87. Zheng HH, Zhang SJ, Cui JT, et al. Simultaneous detection of classical swine fever virus and porcine circovirus 3 by SYBR green I-based duplex real-time fluorescence quantitative PCR. *Mol Cell Probes*. 2020;50:101524. doi:10.1016/j.mcp.2020.101524

88. Chen N, Xiao Y, Li X, et al. Development and application of a quadruplex real-time PCR assay for differential detection of porcine circoviruses (PCV1 to PCV4) in Jiangsu province of China from 2016 to 2020. *Transbound Emerg Dis*. 2021;68(3):1615-1624. doi:10.1111/tbed.13833

89. Zhang J, Li M, Ou Y, et al. Development and clinical validation of a potential penside colorimetric loop-mediated isothermal amplification assay of porcine circovirus type 3. *Front Microbiol*. 2021;12:758064. doi:10.3389/fmicb.2021.758064

90. Bian Z, Cai R, Jiang Z, et al. Single multiple cross displacement amplification for rapid and real-time detection of porcine circovirus 3. *Front Vet Sci*. 2021;8:726723. doi:10.3389/fvets.2021.726723

91. Zhang W, Xu L, Liu Q, et al. Enzymatic recombinase amplification coupled with CRISPR-Cas12a for ultrasensitive, rapid, and specific Porcine circovirus 3 detection. *Mol Cell Probes*. 2021;59:101763. doi:10.1016/j.mcp.2021.101763

92. Chen Y, Luo S, Tan J, et al. Establishment and application of multiplex real-time PCR for simultaneous detection of four viruses associated with porcine reproductive failure. *Front Microbiol*. 2023;14:1092273. doi:10.3389/fmicb.2023.1092273

93. Wang G, Zhu H, Zhan C, et al. Establishment and application of a quadruplex real-time reverse-transcription polymerase chain reaction assay for differentiation of porcine reproductive and respiratory syndrome virus, porcine circovirus type 2, porcine circovirus type 3, and Streptococcus suis. *Microorganisms*. 2024;12(3). doi:10.3390/microorganisms12030427

94. Cao M, Wei Y, Shi W, Feng L, Huang L. Investigation of porcine circovirus type 2 and porcine circovirus type 3 infections based on dual TaqMan fluorescent quantitative PCR method and genetic evolutionary analysis of these two viruses. *Front Microbiol*. 2024;15:1385137. doi:10.3389/fmicb.2024.1385137

95. Shuai J, Chen K, Wang Z, et al. A multiplex digital PCR assay for detection and quantitation of porcine circovirus type 2 and type 3. *Arch Virol*. 2024;169(6):119. doi:10.1007/s00705-024-06044-0

96. Gao YY, Wang Q, Zhang S, et al. Establishment and preliminary application of duplex fluorescence quantitative PCR for porcine circoviruses type 2 and type 3. *Heliyon*. 2024;10(11):e31779. doi:10.1016/j.heliyon.2024.e31779

97. Jiang G, Yang X, Li Z, et al. Recombinant polymerase amplification coupled with CRISPR/Cas12a detection system for rapid visual detection of porcine circovirus 3. *Animals (Basel)*. 2024;14(17). doi:10.3390/ani14172527

98. Zhang B, Cai J, Zhu C, Zhang Y, Wu J, Li Y. Rescue of naïve porcine circovirus type 3 and its pathogenesis

in CD pigs. *J Virol*. 2025;99(6):e0034125. doi:10.1128/jvi.00341-25

99. Tan CY, Lin CN, Ooi PT. What do we know about porcine circovirus 3 (PCV3) diagnosis so far?: A review. *Transbound Emerg Dis*. 2021;doi:10.1111/tbed.14185

100. Resende TP, Marshall Lund L, Rossow S, Vannucci FA. Next-generation sequencing coupled with in situ hybridization: a novel diagnostic platform to investigate swine emerging pathogens and new variants of endemic viruses. *Front Vet Sci*. 2019;6:403. doi:10.3389/fvets.2019.00403

101. Gagnon C, Music N, Fontaine G, Tremblay D, Harel J. Emergence of a new type of porcine circovirus in swine (PCV): a type 1 and type 2 PCV recombinant. *Vet Microbiol*. 2010;144(1–2):18-23. doi:10.1016/j.vetmic.2009.09.072

102. Oh T, Chae C. First isolation and genetic characterization of porcine circovirus type 3 using primary porcine kidney cells. *Vet Microbiol*. 2020;241:108576. doi:10.1016/j.vetmic.2020.108576

103. Hayashi S, Katakura F, Moritomo T, Tsutsumi N, Sugiura K, Sato T. Isolation of porcine circovirus 3 using primary porcine bone marrow-derived cells. *Virol J*. 2024;21(1):184. doi:10.1186/s12985-024-02463-2

104. Deng J, Li X, Zheng D, et al. Establishment and application of an indirect ELISA for porcine circovirus 3. *Arch Virol*. 2018;163(2):479-482. doi:10.1007/s00705-017-3607-7

105. Zhang S, Wang D, Jiang Y, et al. Development and application of a baculovirus-expressed capsid protein-based indirect ELISA for detection of porcine circovirus 3 IgG antibodies. *BMC Vet Res*. 2019;15(1):79. doi:10.1186/s12917-019-1810-3

106. Wang Y, Wang G, Duan WT, et al. Self-assembly into virus-like particles of the recombinant capsid protein of porcine circovirus type 3 and its application on antibodies detection. *AMB Express*. 2020;10(1):3. doi:10.1186/s13568-019-0940-0

107. Cao X, Huang M, Wang Y, Chen Y, Yang H, Quan F. Immunogenicity analysis of PCV3 recombinant capsid protein virus-like particles and their application in antibodies detection. *Int J Mol Sci*. 2023;24(12). doi:10.3390/ijms241210377

108. Bai J. Development and Evaluation of Antibody Detection Assay for PCV3. *Diagnostic Assay Catalog*. Swine Health Information Center; 2017. https://www.swinehealth.org/wp-content/uploads/2020/09/SHIC-diagnostic-assay-catalog-21Sept2020.pdf

109. Wang J, Lei B, Zhang W, et al. Preparation of monoclonal antibodies against the capsid protein and development of an epitope-blocking enzyme-linked immunosorbent assay for detection of the antibody against porcine circovirus 3. *Animals (Basel)*. 2024;14(2). doi:10.3390/ani14020235

110. Palinski R, Piñeyro P, Shang P, et al. A novel porcine circovirus distantly related to known circoviruses is associated with porcine dermatitis and nephropathy syndrome and reproductive failure. *J Virol* 2017;91(1). doi:10.1128/JVI.01879-16

111. De Conti ER, Resende TP, Marshall-Lund L, Rovira A, Vannucci FA. Histological lesions and replication sites of PCV3 in naturally infected pigs. *Animals (Basel)*. 2021;11(6). doi:10.3390/ani11061520

112. Fan M, Hu Z, Bian L, et al. Detection rate of porcine circoviruses in different ages and production herds of intensive pig farms in China. *Animals (Basel)*. 2025;15(10). doi:10.3390/ani15101376

113. Qi S, He Q, Zhang Z, et al. Detection of porcine circovirus type 3 in serum, semen, oral fluid, and preputial fluid samples of boars. *Vet Sci*. 2023;10(12). doi:10.3390/vetsci10120689

114. Eddicks M, Müller M, Fux R, Ritzmann M, Stadler J. Detection of porcine circovirus type 3 DNA in serum and semen samples of boars from a German boar stud. *Vet J*. 2022;279:105784. doi:10.1016/j.tvjl.2021.105784

115. Wang Y, Noll L, Lu N, et al. Genetic diversity and prevalence of porcine circovirus type 3 (PCV3) and type 2 (PCV2) in the Midwest of the USA during 2016-2018. *Transbound Emerg Dis*. 2020;67(3):1284-1294. doi:10.1111/tbed.13467

116. Yang DA, Li M, Wang Y, et al. Dynamics of porcine circovirus type 3 detection in pre-weaning piglets: Insight from multiple sampling methods. *Transbound Emerg Dis*. 2025;2025:4735187. doi:10.1155/tbed/4735187

117. Wang GS, Sun N, Tian FL, et al. Genetic analysis of porcine circovirus type 2 from dead minks. *J Gen Virol*. 2016;doi:10.1099/jgv.0.000529

118. Zhai S-L, Chen R-A, Chen S-N, et al. First molecular detection of porcine circovirus type 2 in bovids in China. *Virus Genes*. 2014;49(3):507-511. doi:10.1007/s11262-014-1117-1

119. Li L, Shan T, Soji OB, et al. Possible cross-species transmission of circoviruses and cycloviruses among farm animals. *J Gen Virol*. 2011;92(Pt 4):768-72. doi:10.1099/vir.0.028704-0

120. Herbst W, Willems H. Detection of virus particles resembling circovirus and porcine circovirus 2a (PCV2a) sequences in feces of dogs. *Res Vet Sci*. 2017;115:51-53. doi:10.1016/j.rvsc.2017.01.014

121. Krog JS, Larsen LE, Schultz AC. Enteric porcine viruses in farmed shellfish in Denmark. *In J Food Microbiol*. 2014;186:105-109. doi:10.1016/j.ijfoodmicro.2014.06.012

122. Blunt R, McOrist S, McKillen J, McNair I, Jiang T, Mellits K. House fly vector for porcine circovirus 2b on commercial pig farms. *Vet Microbiol*. 2011;149(3-4):452-5. doi:10.1016/j.vetmic.2010.11.019

123. Zhai SL, Lu SS, Wei WK, et al. Reservoirs of porcine circoviruses: a mini review. *Front Vet Sci*. 2019;6:319. doi:10.3389/fvets.2019.00319

124. Franzo G, Grassi L, Tucciarone CM, et al. A wild circulation: high presence of porcine circovirus 3 in different mammalian wild hosts and ticks. *Transbound Emerg Dis*. 2019;66(4):1548-1557. doi:10.1111/tbed.13180

125. Klaumann F, Dias-Alves A, Cabezón O, et al. Porcine circovirus 3 is highly prevalent in serum and tissues and may persistently infect wild boar (*Sus scrofa scrofa*). *Transbound Emerg Dis*. 2019;66(1):91-101. doi:10.1111/tbed.12988

126. Franzo G, Tucciarone CM, Drigo M, et al. First report of wild boar susceptibility to porcine circovirus type 3: high prevalence in the Colli Euganei Regional Park (Italy) in the absence of clinical signs. *Transbound Emerg Dis*. 2018;65(4):957-962. doi:10.1111/tbed.12905

127. Prinz C, Stillfried M, Neubert LK, Denner J. Detection of PCV3 in German wild boars. *Virol J*. 2019;16(1):25. doi:10.1186/s12985-019-1133-9

128. Dei Giudici S, Franzoni G, Bonelli P, et al. Genetic characterization of porcine circovirus 3 strains circulating in Sardinian pigs and wild boars. *Pathogens*. 2020;9(5). doi:10.3390/pathogens9050344

129. Song S, Park KN, Choe S, et al. Complete genome sequences of two type 3 porcine circoviruses, WB17KW and WB20GG, isolated from Korean wild boar. *Microbiol Resour Announc*. 2021;10(6). doi:10.1128/MRA.01386-20

130. Dhandapani G, Yoon SW, Noh JY, et al. Detection of porcine circovirus 3 from captured wild boars in Korea. *Vet Med Sci*. 2021;doi:10.1002/vms3.518

131. Varela APM, Loiko MR, Andrade JDS, et al. Complete genome characterization of porcine circovirus 3 recovered from wild boars in Southern Brazil. *Transbound Emerg Dis*. 2021;68(2):240-247. doi:10.1111/tbed.13679

132. Amoroso MG, Serra F, Esposito C, et al. Prevalence of infection with porcine circovirus types 2 and 3 in the wild boar population in the Campania region (Southern Italy). *Animals (Basel)*. 2021;11(11). doi:10.3390/ani11113215

133. Czyżewska-Dors E, Dors A, Augustyniak A, Jabłoński A, Andrusiak E, Podgórska K. Detection of PCV3 in various sample types from wild boars in Poland. *BMC Vet Res*. 2026;doi:10.1186/s12917-025-05256-z

134. Sun F, Li M, Wang Y, et al. Detection of porcine circovirus type 3 in free-ranging wild boars and ticks in Jiangsu Province, China. *Viruses*. 2025;17(8). doi:10.3390/v17081049

135. Almeida B, Duarte MD, Duarte A, et al. Comprehensive survey of PCV2 and PCV3 in domestic pigs and wild boars across Portugal: Prevalence, geographical distribution and genetic diversity. *Pathogens*. 2025;14(7). doi:10.3390/pathogens14070675

136. Frant MP, Mazur-Panasiuk N, Gal-Cisoń A, Bocian Ł, Łyjak M, Szczotka-Bochniarz A. Porcine circovirus type 3 (PCV3) in Poland: Prevalence in wild boar population in connection with African Swine Fever (ASF). *Viruses*. 2024;16(5). doi:10.3390/v16050754

137. Park SC, Kim S, Jeong TW, Oh B, Lim CW, Kim B. Prevalence of porcine circovirus type 2 and type 3 in slaughtered pigs and wild boars in Korea. *Vet Med Sci*. 2024;10(1):e1329. doi:10.1002/vms3.1329

138. Zhang J, Liu Z, Zou Y, et al. First molecular detection of porcine circovirus type 3 in dogs in China. *Virus*

Genes. 2018;54(1):140-144. doi:10.1007/s11262-017-1509-0
139. Sun W, Wang W, Xin J, et al. An epidemiological investigation of porcine circovirus 3 infection in dogs in the Guangxi Province from 2015 to 2017, China. *Virus Res*. 2019;270:197663. doi:10.1016/j.virusres.2019.197663
140. Wang W, Sun W, Cao L, et al. An epidemiological investigation of porcine circovirus 3 infection in cattle in Shandong province, China. *BMC Vet Res*. 2019;15(1):60. doi:10.1186/s12917-019-1793-0
141. Jiang S, Zhou N, Li Y, An J, Chang T. Detection and sequencing of porcine circovirus 3 in commercially sourced laboratory mice. *Vet Med Sci*. 2019;5(2):176-181. doi:10.1002/vms3.144
142. Wang T, Chai W, Wang Y, et al. First detection and phylogenetic analysis of porcine circovirus 3 in female donkeys with reproductive disorders. *BMC Vet Res*. 2021;17(1):308. doi:10.1186/s12917-021-03013-6
143. Ha Z, Li JF, Xie CZ, et al. First detection and genomic characterization of porcine circovirus 3 in mosquitoes from pig farms in China. *Vet Microbiol*. 2020;240:108522. doi:10.1016/j.vetmic.2019.108522
144. Grassi L, Tagliapietra V, Rizzoli A, et al. Lack of evidence on the susceptibility of ticks and wild rodent species to PCV3 infection. *Pathogens*. 2020;9(9). doi:10.3390/pathogens9090682
145. Czyżewska-Dors E, Núñez JI, Saporiti V, et al. Detection of porcine circovirus 3 in wildlife species in Spain. *Pathogens*. 2020;9(5). doi:10.3390/pathogens9050341
146. Reséndiz-Sandoval M, Vázquez-García VA, Contreras-Vega K, et al. A retrospective analysis of porcine circovirus type 3 in samples collected from 2008 to 2021 in Mexico. *Viruses*. 2023;15(11). doi:10.3390/v15112225
147. Franzo G, Cortey M, Olvera A, et al. Revisiting the taxonomical classification of porcine circovirus type 2 (PCV2): still a real challenge. *Virol J*. 08/28 doi:10.1186/s12985-015-0361-x
148. Saraiva GL, Vidigal PMP, Fietto JLR, Bressan GC, Silva Junior A, de Almeida MR. Evolutionary analysis of porcine circovirus 3 (PCV3) indicates an ancient origin for its current strains and a worldwide dispersion. *Virus Genes*. 2018;doi:10.1007/s11262-018-1545-4
149. Souza TCGD, Gava D, Schaefer R, Leme RA, Porto GDS, Alfieri AA. Porcine circovirus 3a field strains in free-living wild boars in Paraná state, Brazil. *Animals (Basel)*. 2021;11(6). doi:10.3390/ani11061634
150. Vargas-Bermudez DS, Campos FS, Bonil L, Mogollon D, Jaime J. First detection of porcine circovirus type 3 in Colombia and the complete genome sequence demonstrates the circulation of PCV3a1 and PCV3a2. *Vet Med Sci*. 2019;5(2):182-188. doi:10.1002/vms3.155
151. Gainor K, Fortuna YC, Alakkaparambil AS, González W, Malik YS, Ghosh S. Detection and complete genomic analysis of porcine circovirus 3 (PCV3) in diarrheic pigs from the Dominican Republic: First report on PCV3 from the caribbean region. *Pathogens*. 2023;12(2). doi:10.3390/pathogens12020250
152. Allan GM, McNeilly F, Kennedy S, et al. Isolation of porcine circovirus-like viruses from pigs with a wasting disease in the USA and Europe. *J Vet Diagn Invest*. 1998;10(1):3-10. doi:10.1177/104063879801000102
153. Collins PJ, McKillen J, Allan G. Porcine circovirus type 3 in the UK. *Vet Rec*. 2017:599. vol. 22.
154. Ye X, Berg M, Fossum C, Wallgren P, Blomström AL. Detection and genetic characterisation of porcine circovirus 3 from pigs in Sweden. *Virus Genes*. 2018;54(3):466-469. doi:10.1007/s11262-018-1553-4
155. Woźniak A, Miłek D, Stadejek T. Wide range of the prevalence and viral loads of porcine circovirus type 3 (PCV3) in different clinical materials from 21 Polish pig farms. *Pathogens*. 2020;9(5). doi:10.3390/pathogens9050411
156. Rosato G, Makoni GM, Cobos À, et al. Retrospective analyses of porcine circovirus type 3 (PCV-3) in Switzerland. *Viruses*. 2024;16(9). doi:10.3390/v16091431
157. Molini U, Marruchella G, Matheus F, et al. Molecular investigation of porcine circovirus type 3 infection in pigs in Namibia. *Pathogens*. 2021;10(5). doi:10.3390/pathogens10050585
158. Anahory IV, Franzo G, Settypalli TBK, et al. Identification of porcine circovirus-3 in Mozambique. *Vet Res Commun*. 2021; doi:10.1007/s11259-021-09858-4
159. Liu Y, Zhang S, Song X, et al. The prevalence of novel porcine circovirus type 3 isolates in pig farms in China. *Transbound Emerg Dis*. 2019;66(5):2143-2151. doi:10.1111/tbed.13266
160. Cai L, Ni J, Xia Y, et al. Identification of an emerging recombinant cluster in porcine circovirus type 2. *Virus Res*. 2012;165(1):95-102. doi:10.1016/j.virusres.2012.01.008

161. Hayashi S, Ohshima Y, Furuya Y, et al. First detection of porcine circovirus type 3 in Japan. *J Vet Med Sci*. 2018;80(9):1468-1472. doi:10.1292/jvms.18-0079

162. Sukmak M, Thanantong N, Poolperm P, et al. The retrospective identification and molecular epidemiology of porcine circovirus type 3 (PCV3) in swine in Thailand from 2006 to 2017. *Transbound Emerg Dis*. 2019;66(1):611-616. doi:10.1111/tbed.13057

163. Bera BC, Choudhary M, Anand T, et al. Detection and genetic characterization of porcine circovirus 3 (PCV3) in pigs in India. *Transbound Emerg Dis*. 2020;67(3):1062-1067. doi:10.1111/tbed.13463

164. Chang CC, Wu CW, Chang YC, Wu CY, Chien MS, Huang C. Detection and phylogenetic analysis of porcine circovirus type 3 in Taiwan. *Arch Virol*. 2021;166(1):259-263. doi:10.1007/s00705-020-04870-6

165. Jia Y, Zhu Q, Xu T, et al. Detection and genetic characteristics of porcine circovirus type 2 and 3 in Henan province of China. *Mol Cell Probes*. 2022;61:101790. doi:10.1016/j.mcp.2022.101790

166. Visuthsak W, Woonwong Y, Thanantong N, et al. PCV3 in Thailand: molecular epidemiology and relationship with PCV2. *Transbound Emerg Dis*. 2021;68(6):2980-2989. doi:10.1111/tbed.14294

167. Pan Y, Qiu S, Chen R, et al. Molecular detection and phylogenetic analysis of porcine circovirus type 3 in Tibetan pigs on the Qinghai-Tibet Plateau of China. *Virol J*. 2022;19(1):64. doi:10.1186/s12985-022-01792-4

168. Dinh PX, Nguyen HN, Lai DC, Nguyen TT, Nguyen NM, Do DT. Genetic diversity in the capsid protein gene of porcine circovirus type 3 in Vietnam from 2018 to 2019. *Arch Virol*. 2023;168(1):30. doi:10.1007/s00705-022-05661-x

169. Pham LNH, Dinh PX, Ngo TNT, Le HTT, Do DT. Genetic characterization and evidence of capsid epitope variation in porcine circovirus type 3 strains from Vietnamese swine with reproductive disorders. *Curr Microbiol*. 2025;83(1):8. doi:10.1007/s00284-025-04600-8

170. Anukool W, Yamsakul P. Prevalence and genetic characterization of porcine circovirus type 2, 3 and 4 in the upper Northern region of Thailand. *Vet Res Commun*. 2025;49(4):218. doi:10.1007/s11259-025-10786-w

171. Zhang HH, Hu WQ, Li JY, et al. Novel circovirus species identified in farmed pigs designated as Porcine circovirus 4, Hunan province, China. *Transbound Emerg Dis*. 2020;67(3):1057-1061. doi:10.1111/tbed.13446

172. Tian RB, Zhao Y, Cui JT, et al. Molecular detection and phylogenetic analysis of Porcine circovirus 4 in Henan and Shanxi Provinces of China. *Transbound Emerg Dis*. 2021;68(2):276-282. doi:10.1111/tbed.13714

173. Sun W, Du Q, Han Z, et al. Detection and genetic characterization of porcine circovirus 4 (PCV4) in Guangxi, China. *Gene*. 2021;773:145384. doi:10.1016/j.gene.2020.145384

174. Li G, He W, Zhu H, et al. Origin, genetic diversity, and evolutionary dynamics of novel porcine circovirus 3. *Adv Sci (Weinh)*. 2018;5(9):1800275. doi:10.1002/advs.201800275

175. Ha Z, Yu C, Xie C, et al. Retrospective surveillance of porcine circovirus 4 in pigs in Inner Mongolia, China, from 2016 to 2018. *Arch Virol*. 2021;166(7):1951-1959. doi:10.1007/s00705-021-05088-w

176. Nguyen VG, Do HQ, Huynh TM, Park YH, Park BK, Chung HC. Molecular-based detection, genetic characterization and phylogenetic analysis of porcine circovirus 4 from Korean domestic swine farms. *Transbound Emerg Dis*. 2021;doi:10.1111/tbed.14017

177. Tan CY, Thanawongnuwech R, Arshad SS, et al. First molecular detection of porcine circovirus type 4 (PCV4) in Malaysia. *Trop Biomed*. 2023;40(3):301-306. doi:10.47665/tb.40.3.005

178. Yang Z, Marthaler DG, Rovira A. Frequency of porcine circovirus 3 detection and histologic lesions in clinical samples from swine in the United States. *J Vet Diagn Invest*. 2022;34(4):602-611. doi:10.1177/10406387221099538

179. Cezar G, Magalhães E, Rupasinghe K, et al. Using diagnostic data from veterinary diagnostic laboratories to unravel macroepidemiological aspects of porcine circoviruses 2 and 3 in the United States from 2002-2023. *PLoS One*. 2024;19(12):e0311807. doi:10.1371/journal.pone.0311807

180. Molossi FA, de Cecco BS, de Almeida BA, et al. PCV3-associated reproductive failure in pig herds in Brazil. *Trop Anim Health Prod*. 2022;54(5):293. doi:10.1007/s11250-022-03282-9

181. Wang Y, Yang DA, Zhao K, Laven R, Jiang P, Yang Z. Comparison of four clinical sample types for detection and investigation of PCV3 prevalence in the pig farrowing room. *Prev Vet Med*. 2023;221:106076.

doi:10.1016/j.prevetmed.2023.106076
182. Eddicks M, Maurer R, Deffner P, et al. Cross-sectional study on the prevalence of PCV types 2 and 3 DNA in suckling piglets compared to grow-finish pigs in downstream production. *Pathogens*. 2022;11(6). doi:10.3390/pathogens11060671
183. Ge M, Ren J, Xie YL, et al. Prevalence and genetic analysis of porcine circovirus 3 in China from 2019 to 2020. *Front Vet Sci*. 2021;8:773912. doi:10.3389/fvets.2021.773912
184. Ouyang T, Niu G, Liu X, Zhang X, Zhang Y, Ren L. Recent progress on porcine circovirus type 3. *Infect Genet Evol*. 2019;73:227-233. doi:10.1016/j.meegid.2019.05.009
185. Xu T, Zhang YH, Tian RB, et al. Prevalence and genetic analysis of porcine circovirus type 2 (PCV2) and type 3 (PCV3) between 2018 and 2020 in central China. *Infect Genet Evol*. 2021;94:105016. doi:10.1016/j.meegid.2021.105016
186. Luka PD, Adedeji AJ, Jambol AR, et al. Coinfections of African swine fever virus, porcine circovirus 2 and 3, and porcine parvovirus 1 in swine in Nigeria. *Arch Virol*. 2022;167(12):2715-2722. doi:10.1007/s00705-022-05593-6
187. Ngo TNT, Nguyen NM, Thanawongnuwech R, et al. Coinfection of Mycoplasma suis and porcine circovirus type 3 is linked to reproductive failure in pig farms. *Vet World*. 2024;17(11):2477-2487. doi:10.14202/vetworld.2024.2477-2487
188. Hernández J, Henao-Díaz A, Reséndiz-Sandoval M, Cota-Valdez A, Mata-Haro V, Gimenez-Lirola LG. Dynamics of PCV2 and PCV3 in the serum and oral fluids of pigs after PCV2 vaccination in a commercial farm. *Vaccines (Basel)*. 2024;12(12). doi:10.3390/vaccines12121318
189. International Committee on the Taxonomy of Viruses (ICTV). Virus Taxonomy Update: Circovirus. Accessed July 14, 2021. https://talk.ictvonline.org/ictv-reports/ictv_online_report/ssdna-viruses/w/circoviridae/659/genus-circovirus
190. Varsani A, Harrach B, Roumagnac P, et al. 2024 taxonomy update for the family Circoviridae. *Arch Virol*. 2024;169(9):176. doi:10.1007/s00705-024-06107-2
191. Woźniak A, Miłek D, Bąska P, Stadejek T. Does porcine circovirus type 3 (PCV3) interfere with porcine circovirus type 2 (PCV2) vaccine efficacy? *Transbound Emerg Dis*. 2019;66(4):1454-1461. doi:10.1111/tbed.13221
192. da Silva RR, da Silva DF, da Silva VH, de Castro AMMG. Porcine circovirus 3: a new challenge to explore. *Front Vet Sci*. 2023;10:1266499. doi:10.3389/fvets.2023.1266499
193. Franzo G, Segales J, Tucciarone CM, Cecchinato M, Drigo M. The analysis of genome composition and codon bias reveals distinctive patterns between avian and mammalian circoviruses which suggest a potential recombinant origin for Porcine circovirus 3. *PLoS One*. 2018;13(6):e0199950. doi:10.1371/journal.pone.0199950
194. Cui Y, Hou L, Pan Y, et al. Reconstruction of the evolutionary origin, phylodynamics, and phylogeography of the porcine circovirus type 3. *Front Microbiol*. 2022;13:898212. doi:10.3389/fmicb.2022.898212
195. Tischer I, Rasch R, Tochtermann G. Characterization of papovavirus-and picornavirus-like particles in permanent pig kidney cell lines. *Zentralbl Bakteriol Orig A*. 1974;226(2):153-67.
196. Tischer I, Gelderblom H, Vettermann W, Koch MA. A very small porcine virus with circular single-stranded DNA. *Nature*. 1982;295(5844):64-6. doi:10.1038/295064a0
197. Harding J, Clark E. Recognizing and diagnosing postweaning multisystemic wasting syndrome (PWS). *J Swine Health Prod*. 1997;5(5):201-203.
198. Nayar GP, Hamel A, Lin L. Detection and characterization of porcine circovirus associated with postweaning multisystemic wasting syndrome in pigs. *Can Vet J*. 1997;38(6):385-6.
199. Kroeger M, Temeeyasen G, Dilberger-Lawson S, et al. The porcine circovirus 3 humoral response: characterization of maternally derived antibodies and dynamic following experimental infection. *Microbiol Spectr*. 2024;12(8):e0087024. doi:10.1128/spectrum.00870-24
200. Dvorak C, Yang Y, Haley C, Sharma N, Murtaugh M. National reduction in porcine circovirus type 2 prevalence following introduction of vaccination. *Vet Microbiol*. 6/30/ 2016;189:86-90. doi:10.1016/j.vetmic.2016.05.002

201. Opriessnig T, Fenaux M, Thomas P, et al. Evidence of breed-dependent differences in susceptibility to porcine circovirus type-2-associated disease and lesions. *Vet Pathol*. 2006;43(3):281-93. doi:10.1354/vp.43-3-281

202. Wu X, Wang Q, Lu W, et al. The PCV3 Cap virus-like particle vaccine with the chimeric PCV2-neutralizing epitope gene is effective in mice. *Vet Sci*. 2024;11(6). doi:10.3390/vetsci11060264

203. Yao L, Cheng Y, Wu H, et al. The construction and immunogenicity analyses of a recombinant pseudorabies virus with porcine circovirus type 3 capsid protein co-expression. *Vet Microbiol*. 2022;264:109283. doi:10.1016/j.vetmic.2021.109283

204. Yang Y, Xu Z, Tao Q, et al. Construction of recombinant pseudorabies virus expressing PCV2 Cap, PCV3 Cap, and IL-4: investigation of their biological characteristics and immunogenicity. *Front Immunol*. 2024;15:1339387. doi:10.3389/fimmu.2024.1339387

205. Shi J, Wu X, Wang S, et al. A chimeric PCV rescued virus with the immunogenic cap gene of PCV3 cloned into the genomic backbone of the nonpathogenic PCV1 induces specific antibodies but with no pathogenic in pigs. *Microb Pathog*. 2022;173(Pt A):105839. doi:10.1016/j.micpath.2022.105839

206. Wang Y, Su M, Huang Y, et al. Development of a novel PCV2 and PCV3 vaccine using virus-like vesicles incorporating Venezuelan equine encephalomyelitis virus-containing vesicular stomatitis virus glycoprotein. *Front Vet Sci*. 2024;11:1359421. doi:10.3389/fvets.2024.1359421

207. Pranoto S, Wu HC, Chu CY. Porcine circovirus type 3: Diagnostics, genotyping, and challenges in vaccine development. *Transbound Emerg Dis*. 2023;2023:8858447. doi:10.1155/2023/8858447

208. Yin H, Zhao Z, Yuan Y, et al. Circovirus Rep evades immune restriction by disrupting cGAS oligomerization and phase separation. *PLoS Pathog*. 2025;21(6):e1013244. doi:10.1371/journal.ppat.1013244