Viral Enteritis in Cattle

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Livestock products supply about 13 percent of energy and 28 percent of protein in diets consumed worldwide. Diarrhea is a leading cause of sickness and death of beef and dairy calves in their first month of life and also affecting adult cattle, resulting in large economic losses and a negative impact on animal welfare. Despite the usual multifactorial origin, viruses are generally involved, being among the most important causes of diarrhea. There are several viruses that have been confirmed as etiological agents (i.e., rotavirus and coronavirus), and some viruses that are not yet confirmed as etiological agents.

Keywords: rotavirus ; coronavirus ; norovirus ; torovirus ; astrovirus ; nebovirus ; pestivirus ; kobuvirus ; bocaparvovirus ; enterovirus ; orthobunyavirus ; diarrhea ; cattle

1. Introduction

Cattle production constitutes an important component of the agricultural economy of many countries, a contribution that goes beyond direct food production. Furthermore, livestock are closely linked to the social and cultural lives of several million farmers [1]. Livestock products supply about 13 percent of energy and 28 percent of protein in diets consumed worldwide [2]. To meet the projected demand for animal products, the industry must streamline production and advance capacity to prevent, detect, diagnose, and treat animal diseases [2].

The cost of gastrointestinal disease per calf per year (including cost of prevention) was estimated to be 33.46 U.S. dollars, being the cause with the highest cost in dairy calves, while the cost of the same disease per cow per year (including cost of prevention) was estimated to be 11.13 U.S. dollars, being the third cause with major cost in adult dairy cattle [3].

2. Diarrhea in Cattle

Diarrhea is usually a multifactorial disease related to a combination of host, pathogen, management, and environmental factors. The cause of an outbreak of diarrhea is rarely known, and the most important reason for poor diagnosis is that little is known about the large number of microorganisms that have been shown, or claimed, to be causal [4]. Increased mortality and morbidity are often due to the presence of more than one pathogen [5]. Intestinal pathogens produce diarrhea via several mechanisms that include: villous atrophy, malabsorption, osmotic diarrhea, secretory diarrhea, and inflammatory diarrhea [6][7].

Prevention and control of diarrhea should be based on a good understanding of the complexities of the disease, such as multiple pathogens, coinfection, environmental, nutritional, and management factors. Among the non-viral pathogens, the most prevalent worldwide are Escherichia coli, Salmonella enterica, and Cryptosporidium parvum. Although there is no specific treatment for the latter, antibiotics can be used in the case of a bacterial infection. The main characteristics of viral agents are described in this review, but the role that non-viral agents play in diarrhea should not be underestimated.

To determine the causality of viruses is sometimes difficult due to several factors that can hinder this determination. Regarding the pathological anatomy, some viral infections damage may not be obvious, but infected cells may carry out their functions less effectively, and clinical signs may reflect this. The virus may cause a loss in specialized functions of cells required not so much for their own survival but for systemic homeostasis [8]. In addition, viruses can be detected several hours before the onset of clinical symptoms, during the presence of diarrhea, and several weeks after the feces return to normal, and this long shedding may interfere with the results obtained in case-control studies [9]. Depending on various factors, viruses can also infect asymptomatically in some animals, which increases the inaccuracies of determining the causality of viruses in the disease [10]; it is worthy to note that asymptomatic calves can shed viruses as symptomatic calves do [10]. In the same line, some viruses do not seem to be pathogenic, but in coinfection with other viruses, their infectious capacity can be increased [11]. Moreover, some enteric viruses also have extra-intestinal tropism, as occurs with bovine coronavirus [12]. Then, viruses causing respiratory disease can be excreted in feces, interfering with the observations that can be made regarding the virus excretion and diarrhea.

The persistence of this significant problem in the field may be attributed, in part, to the multifactorial nature of the disease. In addition, genetic diversity, continuous evolution, emergence, and/or environmental ubiquity of viruses are factors that hinder effective control of the disease. Therefore, the genetic evolution of viral pathogens should be kept in mind and monitored with regular genomic sequence updates, and emerging viruses should be regularly monitored [13].

2.1. Virus and the Disease

As stated above, viral infection is not synonymous with disease, as many viral infections are subclinical, whereas others result in diseases of varying severity and clinical signs, which is commonly called the iceberg concept of viral infection and diseases [14].

Among other factors, the virulence of the infecting virus and the susceptibility of the host are the most relevant in determining the course of infection and the appearance or not of the disease [14].

Viruses differ greatly in their virulence, but even in a population infected by a particular virus strain, there are usually striking differences in the outcome of infection between individual animals. In addition, there is much variation among viruses of the same species. Virus strain differences may be quantitative, involving the rate and yield of virus replication, lethal dose, infectious dose, the number of cells infected in a given organ, or they may be qualitative, involving organ or tissue tropism, extent of host-cell damage, mode and efficacy of spread in the body, and character of the disease they induce [14].

2.2. Neonatal Calf Diarrhea Syndrome

The health status of calves in the first days of life is essential for their survival and subsequent development, so the diseases that affect calves in those days are an important cause of economic losses worldwide [15][16][17]. Diarrhea is a leading cause of sickness and death of beef and dairy calves in their first month of life [18][19][20][21][22][23][24] and has a negative impact on animal welfare [15][16][17]. Overall, beef calf mortality from diarrhea should be about 1%, and in dairy calves, diarrhea accounts for about 5% of total mortality from live birth to weaning [6]. Economic losses are not only due to mortality but also due to the cost of treatment and management [25]. In addition, diarrhea has long-term effects on productive and reproductive performance, such as reduction in milk production, reduction in the average daily gain of weight, and the requirement of more inseminations to become pregnant [26].

2.3. Diarrhea in Adult Cattle

Epizootic diarrhea frequently occurs during the colder months in dairy and beef adult cattle [27][28], resulting in large economic losses from marked reductions in milk production that may not return to normal for several months in dairy cattle [28][29], and weight loss in beef cattle. The disease spreads rapidly among adult cattle within an affected herd leading to very high morbidity (50–100%) but a low mortality rate (1–2%) [28][29][30], but it is not usually spread among calves [29][31]. Diarrhea lasts from a few days to several weeks [27][29], and is generally characterized by an acute onset of dark diarrhea with or without blood, and can be accompanied by anorexia, respiratory symptoms (dyspnea, nasolacrimal discharge, and cough), and high body temperature in most severe cases [28][29][30]. Young adult animals, especially pregnant, recently calved, or lactating cows, are the most severely affected, but bulls, steers, and beef cattle are also affected, as well as feedlot cattle [27][30]. The most common viral etiologies of diarrhea in adult cattle are coronavirus and torovirus, and the disease is called winter dysentery in these cases, but diarrhea can also be observed in outbreaks caused by an orthobunyavirus.

3. Rotavirus

In 1969, it was confirmed for the first time that a “reo-type virus” was the cause of diarrhea in calves [32] and years later named rotavirus because electron microscopy had a similar appearance to a wheel (rota in Latin). Since the discovery, rotaviruses have been considered the main causal agent of neonatal calf diarrhea [33], inflicting serious losses on the livestock sector [34].

Some of the structural characteristics are: they are icosahedral particles of 100 nanometers (nm) in diameter (including spikes), they are non-enveloped viruses with a three-layer capsid (**Table 1**), and inside the capsid, they have all the enzymes necessary for the production of messenger RNA (mRNA). Shared genomic characteristics are: they consist of 11 segments of double-stranded RNA (dsRNA) (**Table 1**), these RNA segments are non-infectious, each RNA segment encodes at least one protein, and RNA segments from different viruses can be genetically reassorted with a high frequency during coinfection of a cell. Finally, the replicative characteristics are: culture is facilitated by proteases such as trypsin or pancreatin, replication occurs in the cytoplasm, they form inclusion bodies, morphogenesis involves transient enveloped particles, and viral particles are released by cell lysis or by non-classical vesicular transport in polarized epithelial cells [35].

Table 1. Main characteristics of the viruses reviewed.

Virus Genus	Genome	Envelope	Virion Diameter (nm)
Rotavirus	**dsRNA segmented**	**No**	**100**
Coronavirus	**ssRNA (+)**	**Yes**	**65–210**
Norovirus	**ssRNA (+)**	**No**	**27–35**

Virus Genus	Genome	Envelope	Virion Diameter (nm)
Torovirus	**ssRNA (+)**	**Yes**	**120–140**
Astrovirus	**ssRNA (+)**	**No**	**28**
Nebovirus	**ssRNA (+)**	**No**	**33**
Pestivirus	**ssRNA (+)**	**Yes**	**40–60**
Kobuvirus	**ssRNA (+)**	**No**	**30**
Bocaparvovirus	**ssDNA**	**No**	**30**
Enterovirus	**ssRNA (+)**	**No**	**30–32**
Orthobunyavirus	**ssRNA (−) segmented**	**Yes**	**100**

Taxonomically, rotaviruses, according to the International Committee for the Taxonomy of Viruses (ICTV), are currently classified as: Riboviria › Orthornavirae › Duplornaviricota › Resentoviricetes › Reovirales › Reoviridae › Sedoreovirinae › Rotavirus. Rotaviruses are serologically classified into 10 different groups or species, named Rotavirus A–J. Rotavirus A, Rotavirus B, and Rotavirus C have been detected in cattle, but the most widely dispersed and important are the Rotavirus A (RVA); this review is focused on this species. Furthermore, RVA is classified antigenically into serotypes (based on neutralizing epitopes of the VP4 and VP7 viral proteins) and genetically into genotypes, with certain differences between the classification of serotypes and genotypes in VP4 [35]. So far, there are 35 VP4 genotypes (P1–35) and 27 VP7 genotypes (G1–27) within the RVA group [36], of which 11 P types (P1, P3, P5, P6, P7, P11, P14, P17, P21, P29 and P33) and 12 G types (G1, G2, G3, G5, G6, G8, G10, G11, G15, G17, G21, and G24) have been identified in cattle. However, G6, G8, and G10 genotypes associated with P1, P5, and P11 are the most commonly found in bovines [37]. Classification within RVA is commonly performed using a binary system with the different types of VP7 and VP4, GXP[Y], where X is the G-type and Y is the P-type. VP4 and VP7 genotypes are determined by sequence analysis, while serotypes are determined by the reactivity of individual or recombinant strains selected with polyclonal or monoclonal antisera. For VP7, a correlation between genotype and serotype has been established. The lack of serum or monoclonal antibodies for different types of VP4 available has hampered the classification of VP4 into serotypes. However, a variable region, VP8*, extending from amino acid (aa) 71 to 204 of VP4, may define specific P-type epitopes [35]. Moreover, there is a broader classification based on the nucleotide sequence, in which for each of the 11 segments VP7-VP4-VP6-VP1-VP2-VP3-NSP1-NSP2-NSP3-NSP4-NSP5/6, a particular genotype is assigned using the abbreviations Gx-P[x]-Ix-Rx-Cx-Mx-Ax-Nx-Tx-Ex-Hx (where x corresponds to numbers starting from 1), respectively [38].

The disease is generally seen in young calves 2–8 weeks of age, and susceptibility decreases as age advances. In neonates, the infection has a very short incubation period, manifesting as profuse diarrhea and severe dehydration. Diarrhea occurs primarily due to decreased absorption efficiency of enterocytes due to virus infection, and the severity can range from an asymptomatic or subclinical condition to severe enteritis. Furthermore, concurrent infection with secondary pathogens can increase the severity of the disease [34].

Transmission is generally by the fecal-oral route, and they are highly contagious; a low infectious dose of cell culture is sufficient to cause disease in a fully susceptible host. In addition, they are very stable in the environment and are excreted in large quantities in the feces, further increasing the possibility of transmission [35].

The current strategy to control the disease in cattle is based on the vaccination of cows during the last third of gestation to protect calves by transferring passive maternal antibodies through the ingestion of colostrum [39]. Although vaccines seem not to be effective in preventing RVA infection, they significantly reduce morbidity, the severity of diarrhea, and mortality related to RVA [39][40].

Phylogenetic studies of circulating RVAs in cattle contribute to a better understanding of the epidemiology of this pathogen, which translates into important information to evaluate the need to update vaccine strains and add complete data to elucidate the mechanisms of evolution of the virus [41].

4. Coronavirus

The first report of bovine coronavirus (BCoV) was in 1971, during a trial of an oral rotavirus vaccine; coronavirus-like particles were found in the feces of a rotavirus-negative calf [42][43].

BCoVs are pleomorphic enveloped viruses with a diameter between 65 and 210 nm (**Table 1**). They are covered by a double layer of short (hemagglutinin esterase, HE) and long (spike, S) surface projections, which are involved in binding to cell receptors and are therefore important for immunity and vaccines [12]. The other two important structural proteins are the nucleocapsid protein (N) and the integral membrane glycoprotein (M). The genome consists of a positive-polarity single-stranded RNA of 27–30 kilobases (kb) in size and is organized into seven regions that contain one or more open reading frames (ORF) (**Table 1**). These regions are separated by sites that contain the signal for the transcription of subgenomic mRNAs. Toward the 5′ end of the genome, non-structural proteins are encoded, including viral RNA

polymerase, while toward the 3′ end, the order of structural proteins is 5′-HE-S-M-N-3′ [28]. Like cellular mRNAs, it has a cap at the 5′ end and a poly-A tail at the 3′ end [44].

Currently, the taxonomic classification for BCoV, according to the ICTV is: Riboviria Orthornavirae › Pisuviricota › Pisoniviricetes › Nidovirales › Cornidovirineae › Coronaviridae › Orthocoronavirinae › Betacoronavirus › Embecovirus 1. The Betacoronavirus 1 species contains viruses that affect different hosts (animals and human) species; some members of this species are the human coronavirus OC43, the equine coronavirus, the porcine hemagglutinating encephalomyelitis virus, and BCoV itself. In addition, other important members of the Betacoronavirus genus are the coronavirus associated with severe acute respiratory syndrome (SARS)-CoV, the Middle East respiratory syndrome (MERS)-CoV, and the recently described and causing the COVID-19 pandemic, SARS-CoV-2. Until now, all isolates of BCoV belong to the same serotype with minor antigenic variations [28].

Currently, BCoV is widely recognized as one of the main causative agents of neonatal diarrhea in calves. In addition, it is considered the second-largest pathogen that causes deaths in calves, demonstrating the great severity of the disease caused [5]. In addition to neonatal diarrhea, it can cause respiratory infections and winter dysentery in adult cattle [5][12]. The virus multiplies in the cells of the intestinal crypts, decreasing the digestive and absorption capacity leading to diarrhea, with loss of water and electrolytes. In severe infections, diarrhea can cause dehydration, acidosis, and hypoglycemia, and death can occur due to acute shock and heart failure. The severity of enteritis varies both with the age and immune status of the calf as well as the infectious dose and strain of virus, developing more rapidly and more severe diarrhea in calves less than three months old, typically affecting calves between one and two weeks of age [28].

Transmission can be through both fecal-oral and respiratory routes and occurs mainly in the winter months. Furthermore, coronaviruses have been described as being capable of being stable and infectious for weeks in different types of environmental matrices, including water [45][46].

The current strategy to control the disease in cattle is based on vaccinating pregnant cows to protect calves by transferring passive maternal antibodies through ingestion of colostrum [47] and seems to be effective in preventing BCoV infection [48].

5. Norovirus

Bovine noroviruses (BoNoV) were first described in 1978 together with bovine astrovirus (BoAstV) and bovine nebovirus (BoNeV) in stool samples from diarrheic calves [49]. Although they are studied to a lesser extent than rotavirus and coronavirus, several studies confirmed that BoNoVs are widely present in cases of diarrhea in cattle from different countries, ranging from 3% to more than 60% [50][51][52][53][54][55]. In some countries, BoNoV can be the most prevalent enteric pathogen detected in cattle [55][56]. Furthermore, serological studies indicate that circulation and exposure to this virus are very high, detecting antibodies against BoNoV in almost 100% of the samples studied [51].

BoNoVs are non-enveloped viruses of 27 to 35 nm in diameter (**Table 1**), with a capsid of icosahedral symmetry with 180 molecules of the capsid protein organized into 90 dimers and whose surface shows 32 cup-shaped depressions and protruding arches (calici derived from the Latin word calyx, meaning chalice or cup) [57][58]. The genome is a single-stranded RNA of the positive polarity of approximately 7.5 kb and contains 3 ORFs [58] (**Table 1**). The 5′ end is linked to a viral protein called VPg, it does not have a ribosome entry site or cap, and it is assumed that VPg interacts with the components of the translational machinery, initiating the translation of viral RNA [59][60]. The 3′ end contains a poly-A tail. ORF1 (located toward the 5′ end of the RNA) codes for at least six non-structural proteins (p48, NTPase, p22, VPg, 3CLPro, and RdRp), ORF2 for VP1 and ORF3 for VP2 [58].

BoNoVs are classified within the genus Norovirus of the Caliciviridae family. The complete ICTV classification is: Riboviria › Orthornavirae › Pisuviricota › Pisoniviricetes › Picornavirales › Caliciviridae › Norovirus. BoNoVs are classified within genogroup III (GIII). There have been recognized three genotypes within GIII, namely GIII.1, GIII.2, and GIII.3, being GIII.1 and GIII.2 associated with BoNoV, and GIII.3 to ovine norovirus. In addition, several studies have demonstrated the circulation of recombinant strains, with the recombination breakpoint within the ORF1-ORF2 junction genomic region [61]. Recently, the emergence of a new genotype was described [55][62].

The genotypes GIII.1 and GIII.2, formerly referred to as Jena virus and Newbury-2 virus, respectively, have been deeply studied, and both genotypes showed to be diarrheagenic when inoculated experimentally into calves [9][49][63][64]. Under such circumstances, BoNoV GIII.1 induced lesions in the small intestine, including villus atrophy with loss and attenuation of the villus epithelium, and expression of viral capsid antigen was demonstrated by immunohistochemistry in the enterocytes [63]. Calves inoculated with BoNoV GIII.2 showed lesions in the small intestine, including hemorrhagic foci and shortening and thickening of the villi, although viral particles were not observed in cells by electron microscopy and viral antigen was not observed by immunofluorescence in the small intestine of infected calves [49]; in a recent study, no significant intestinal lesions in the infected calves were observed [64].

Transmission of BoNoV is not well understood, but for human noroviruses, transmission is mainly the fecal-oral route, and it is also suggested that another natural route of infection could be the respiratory tract through aerosol particles in vomit

[58][65]. Caliciviruses are characterized by their high stability in the environment and resistance to inactivation [66][67][68]. In addition, low infectious doses, as well as its great diversity of strains, increase the risk of infection [58].

References

1. Sansoucy, R. Livestock—A Driving Force for Food Security and Sustainable Development. 1997. Available online: http://www.fao.org/3/v8180t/v8180t07.htm (accessed on 13 April 2021).
2. National Institute of Food Agiculture, USA. Available online: https://nifa.usda.gov/topic/animal-production (accessed on 13 April 2021).
3. Kaneene, J.B.; Hurd, H.S. The national animal health monitoring system in Michigan. III. Cost estimates of selected dairy cattle diseases. Prev. Vet. Med. 1990, 8, 127–140.
4. Selman, I.E. The care of young calves, neonatal calf diarrhea, the calf pneumonias. In Diseases of Cattle in the Tropics. Current Topics in Veterinary Medicine and Animal Science; Ristic, M., McIntyre, I., Eds.; Springer: Dordrecht, The Netherlands, 1981; Volume 6.
5. Blanchard, P.C. Diagnostics of dairy and beef cattle diarrhea. Vet. Clin. N. Am. Food Anim. Pract. 2012, 28, 443–464.
6. Naylor, J.M. Neonatal Calf Diarrhea. Food Anim. Pract. 2009, 70–77.
7. Heller, M.C.; Chigerwe, M. Diagnosis and Treatment of Infectious Enteritis in Neonatal and Juvenile Ruminants. Vet. Clin. N. Am. Food Anim. Pract. 2018, 34, 101–117.
8. Murphy, F.A.; Gibbs, E.P.J.; Horzinek, M.C.; Studdert, M.J. Veterinary Virology: The Third Edition; Academic Press: Cambridge, MA, USA, 1999.
9. Jor, E.; Myrmel, M.; Jonassen, C.M. SYBR Green based real-time RT-PCR assay for detection and genotype prediction of bovine noroviruses and assessment of clinical significance in Norway. J. Virol. Methods 2010, 169, 1–7.
10. Archambault, D.; Morin, G.; Elazhary, Y.; Roy, R.S. Study of virus excretion in feces of diarrheic and asymptomatic calves infected with rotavirus. Zentralbl. Veterinarmed. B 1990, 37, 73–76.
11. Woode, G.N.; Pohlenz, J.F.; Gourley, N.E.; Fagerland, J.A. Astrovirus and Breda virus infections of dome cell epithelium of bovine ileum. J. Clin. Microbiol. 1984, 19, 623–630.
12. Saif, L.J. Bovine respiratory coronavirus. Vet. Clin. N. Am. Food Anim. Pract. 2010, 26, 349–364.
13. Cho, Y.I.; Yoon, K.J. An overview of calf diarrhea-infectious etiology, diagnosis, and intervention. J. Vet. Sci. 2014, 15, 1–17.
14. Maclachlan, N.J.; Dubovi, E.J.; Barthold, S.W.; Swayne, D.E.; Winton, J.R. Fenner's Veterinary Virology: Fifth Edition; Academic Press: Cambridge, MA, USA, 2016.
15. Waltner-Toews, D.; Martin, S.W.; Meek, A.H. The effect of early calfhood health status on survivorship and age at first calving. Can. J. Vet. Res. 1986, 50, 314–317.
16. Donovan, G.A.; Dohoo, I.R.; Montgomery, D.M.; Bennett, F.L. Calf and disease factors affecting growth in female Holstein calves in Florida, USA. Prev. Vet. Med. 1998, 33, 1–10.
17. Windeyer, M.C.; Leslie, K.E.; Godden, S.M.; Hodgins, D.C.; Lissemore, K.D.; LeBlanc, S.J. Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. Prev. Vet. Med. 2014, 113, 231–240.
18. United States Department of Agriculture, USA. Part II: Reference of 1997 Beef Cow-Calf Health & Health Management Practices. 1997. Available online: https://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/downloads/beef97/Beef97_dr_PartII.pdf (accessed on 13 April 2021).
19. Smith, G.W. Treatment of calf diarrhea: Oral fluid therapy. Vet. Clin. N. Am. Food Anim. Pract. 2009, 25, 55–72.
20. Smith, D.R. Field disease diagnostic investigation of neonatal calf diarrhea. Vet. Clin. N. Am. Food Anim. Pract. 2012, 28, 465481.
21. Hur, T.Y.; Jung, Y.H.; Choe, C.Y.; Cho, Y.I.; Kang, S.J.; Lee, H.J.; Ki, K.S.; Baek, K.S.; Suh, G.H. The dairy calf mortality: The causes of calf death during ten years at a large dairy farm in Korea. Korean J. Vet. Res. 2013, 53, 103–108.
22. Hötzel, M.J.; Longo, C.; Balcão, L.F.; Cardoso, C.S.; Costa, J.H. A survey of management practices that influence performance and welfare of dairy calves reared in southern Brazil. PLoS ONE 2014, 15, e114995.
23. Mõtus, K.; Viltrop, A.; Emanuelson, U. Reasons and risk factors for beef calf and youngstock on-farm mortality in extensive cow-calf herds. Animal 2018, 12, 1958–1966.
24. Urie, N.J.; Lombard, J.E.; Shivley, C.B.; Kopral, C.A.; Adams, A.E.; Earleywine, T.J.; Olson, J.D.; Garry, F.B. Preweaned heifer management on US dairy operations: Part, V. Factors associated with morbidity and mortality in preweaned dairy heifer calves. J. Dairy Sci. 2018, 101, 9229–9244.
25. Roche, S.M.; Von Massow, M.; Renaud, D.; Shock, D.A.; Jones-Bitton, A.; Kelton, D.F. Cost-benefit of implementing a participatory extension model for improving on-farm adoption of Johne's disease control recommendations. J. Dairy

Sci. 2020, 103, 451–472.

26. Abuelo, A.; Cullens, F.; Brester, J.L. Effect of preweaning disease on the reproductive performance and first-lactation milk production of heifers in a large dairy herd. J. Dairy Sci. 2021, 104, 7008–7017.
27. Saif, L.J. A review of evidence implicating bovine coronavirus in the etiology of winter dysentery in cows: An enigma resolved? Cornell Vet. 1990, 80, 303–311.
28. Clark, M.A. Bovine coronavirus. Br. Vet. J. 1993, 149, 51–70.
29. Aita, T.; Kuwabara, M.; Murayama, K.; Sasagawa, Y.; Yabe, S.; Higuchi, R.; Tamura, T.; Miyazaki, A.; Tsunemitsu, H. Characterization of epidemic diarrhea outbreaks associated with bovine torovirus in adult cows. Arch. Virol. 2012, 157, 423–431.
30. Constable, P.D.; Hinchcliff, K.W.; Done, S.H.; Grünberg, W. Veterinary Medicine: A Textbook of the Diseases of Cattle, Horses, Sheep, Pigs, and Goats, 11th ed.; Elsevier: Amsterdam, The Netherlands, 2016.
31. Van Kruiningen, H.J.; Castellano, V.P.; Koopmans, M.; Harris, L.L. A serologic investigation for coronavirus and Breda virus antibody in winter dysentery of dairy cattle in the northeastern United States. J. Vet. Diagn. Investig. 1992, 4, 450–452.
32. Mebus, C.A.; Underdahl, N.R.; Rhodes, M.B.; Twiehaus, M.J. Calf diarrhea (scours): Reproduced with a virus from a field outbreak. Bull. Neb. Agric Exp. Station 1969, 233, 1–16.
33. Garaicoechea, L.; Bok, K.; Jones, L.R.; Combessies, G.; Odeón, A.; Fernandez, F.; Parreño, V. Molecular characterization of bovine rotavirus circulating in beef and dairy herds in Argentina during a 10-year period (1994–2003). Vet. Microbiol. 2006, 26, 1–11.
34. Dhama, K.; Chauhan, R.S.; Mahendran, M.; Malik, S.V. Rotavirus diarrhea in bovines and other domestic animals. Vet. Res. Commun. 2009, 33, 1–23.
35. Estes, M.; Greenberg, H. Rotaviruses. In Fields Virology, 6th ed.; Knipe, D.M., Howley, P.M., Cohen, J.I., Griffin, D.E., Lamb, R.A., Martin, M.A., Racaniello, V.R., Roizman, B., Eds.; Wolters Kluwer Business/Lippincott Williams and Wilkins: Philadelphia, PA, USA, 2013.
36. Matthijnssens, J.; Ciarlet, M.; McDonald, S.M.; Attoui, H.; Bányai, K.; Brister, J.R.; Buesa, J.; Esona, M.D.; Estes, M.K.; Gentsch, J.R.; et al. Uniformity of rotavirus strain nomenclature proposed by the Rotavirus Classification Working Group (RCWG). Arch. Virol. 2011, 156, 1397–1413.
37. Papp, H.; László, B.; Jakab, F.; Ganesh, B.; De Grazia, S.; Matthijnssens, J.; Ciarlet, M.; Martella, V.; Bányai, K. Review of group A rotavirus strains reported in swine and cattle. Vet. Microbiol. 2013, 30, 190–199.
38. Matthijnssens, J.; Ciarlet, M.; Heiman, E.; Arijs, I.; Delbeke, T.; McDonald, S.M.; Palombo, E.A.; Iturriza-Gómara, M.; Maes, P.; Patton, J.T.; et al. Full genome-based classification of rotaviruses reveals a common origin between human Wa-Like and porcine rotavirus strains and human DS-1-like and bovine rotavirus strains. J. Virol. 2008, 82, 3204–3219.
39. Parreño, V.; Béjar, C.; Vagnozzi, A.; Barrandeguy, M.; Costantini, V.; Craig, M.I.; Yuan, L.; Hodgins, D.; Saif, L.; Fernández, F. Modulation by colostrum-acquired maternal antibodies of systemic and mucosal antibody responses to rotavirus in calves experimentally challenged with bovine rotavirus. Vet. Immunol. Immunopathol. 2004, 100, 7–24.
40. Castells, M.; Caffarena, R.D.; Casaux, M.L.; Schild, C.; Miño, S.; Castells, F.; Castells, D.; Victoria, M.; Riet-Correa, F.; Giannitti, F.; et al. Phylogenetic Analyses of Rotavirus A from Cattle in Uruguay Reveal the Circulation of Common and Uncommon Genotypes and Suggest Interspecies Transmission. Pathogens 2020, 14, 570.
41. Badaracco, A.; Garaicoechea, L.; Matthijnssens, J.; Louge Uriarte, E.; Odeón, A.; Bilbao, G.; Fernandez, F.; Parra, G.I.; Parreño, V. Phylogenetic analyses of typical bovine rotavirus genotypes G6, G10, P[5] and P[11] circulating in Argentinean beef and dairy herds. Infect. Genet. Evol. 2013, 18, 18–30.
42. Stair, E.L.; Rhodes, M.B.; White, R.G.; Mebus, C.A. Neonatal calf diarrhea: Purification and electron microscopy of a coronavirus-like agent. Am. J. Vet. Res. 1972, 33, 1147–1156.
43. Mebus, C.A.; Stair, E.L.; Rhodes, M.B.; Twiehaus, M.J. Pathology of neonatal calf diarrea induced by a coronavirus-like agent. Vet. Pathol. 1973, 10, 45–64.
44. Masters, P.S. The molecular biology of coronaviruses. Adv. Virus Res. 2006, 66, 193–292.
45. Casanova, L.; Rutala, W.A.; Weber, D.J.; Sobsey, M.D. Survival of surrogate coronaviruses in water. Water Res. 2009, 43, 1893–1898.
46. Mullis, L.; Saif, L.J.; Zhang, Y.; Zhang, X.; Azevedo, M.S. Stability of bovine coronavirus on lettuce surfaces under household refrigeration conditions. Food Microbiol. 2012, 30, 180–186.
47. Bok, M.; Alassia, M.; Frank, F.; Vega, C.G.; Wigdorovitz, A.; Parreño, V. Passive immunity to control Bovine coronavirus diarrhea in a dairy herd in Argentina. Rev. Argent. Microbiol. 2018, 50, 23–30.
48. Castells, M.; Giannitti, F.; Caffarena, R.D.; Casaux, M.L.; Schild, C.; Castells, D.; Riet-Correa, F.; Victoria, M.; Parreño, V.; Colina, R. Bovine coronavirus in Uruguay: Genetic diversity, risk factors and transboundary introductions from neighboring countries. Arch. Virol. 2019, 164, 2715–2724.
49. Woode, G.N.; Bridger, J.C. Isolation of small viruses resembling astroviruses and caliciviruses from acute enteritis of calves. J. Med. Microbiol. 1978, 11, 441–452.

50. Van Der Poel, W.H.; Vinjé, J.; van Der Heide, R.; Herrera, M.I.; Vivo, A.; Koopmans, M.P. Norwalk-like calicivirus genes in farm animals. Emerg. Infect. Dis. 2000, 6, 36–41.
51. Deng, Y.; Batten, C.A.; Liu, B.L.; Lambden, P.R.; Elschner, M.; Günther, H.; Otto, P.; Schnürch, P.; Eichhorn, W.; Herbst, W.; et al. Studies of epidemiology and seroprevalence of bovine noroviruses in Germany. J. Clin. Microbiol. 2003, 41, 2300–2305.
52. Van der Poel, W.H.; van der Heide, R.; Verschoor, F.; Gelderblom, H.; Vinjé, J.; Koopmans, M.P. Epidemiology of Norwalk-like virus infections in cattle in The Netherlands. Vet. Microbiol. 2003, 92, 297–309.
53. Milnes, A.S.; Binns, S.H.; Oliver, S.L.; Bridger, J.C. Retrospective study of noroviruses in samples of diarrhoea from cattle, using the Veterinary Laboratories Agency's Farmfile database. Vet. Rec. 2007, 160, 326–330.
54. Ferragut, F.; Vega, C.G.; Mauroy, A.; Conceição-Neto, N.; Zeller, M.; Heylen, E.; Uriarte, E.L.; Bilbao, G.; Bok, M.; Matthijnssens, J.; et al. Molecular detection of bovine Noroviruses in Argentinean dairy calves: Circulation of a tentative new genotype. Infect. Genet. Evol. 2016, 40, 144–150.
55. Cho, Y.I.; Han, J.I.; Wang, C.; Cooper, V.; Schwartz, K.; Engelken, T.; Yoon, K.J. Case-control study of microbiological etiology associated with calf diarrhea. Vet. Microbiol. 2013, 166, 375–385.
56. Castells, M.; Caffarena, R.D.; Casaux, M.L.; Schild, C.; Castells, F.; Castells, D.; Victoria, M.; Riet-Correa, F.; Giannitti, F.; Parreño, V.; et al. Detection, risk factors and molecular diversity of GIII norovirus in Uruguay. Infect. Genet. Evol. 2020, 3, 104613.
57. Prasad, B.V.; Hardy, M.E.; Dokland, T.; Bella, J.; Rossmann, M.G.; Estes, M.K. X-ray crystallographic structure of the Norwalk virus capsid. Science 1999, 286, 287–290.
58. Scipioni, A.; Mauroy, A.; Vinjé, J.; Thiry, E. Animal noroviruses. Vet. J. 2008, 178, 32–45.
59. Daughenbaugh, K.F.; Fraser, C.S.; Hershey, J.W.; Hardy, M.E. The genome-linked protein VPg of the Norwalk virus binds eIF3, suggesting its role in translation initiation complex recruitment. EMBO J. 2003, 22, 2852–2859.
60. Goodfellow, I.; Chaudhry, Y.; Gioldasi, I.; Gerondopoulos, A.; Natoni, A.; Labrie, L.; Laliberté, J.F.; Roberts, L. Calicivirus translation initiation requires an interaction between VPg and eIF 4 E. EMBO Rep. 2005, 6, 968–972.
61. Bull, R.A.; Tanaka, M.M.; White, P.A. Norovirus recombination. J. Gen. Virol. 2007, 88 Pt 12, 3347–3359.
62. Wang, Y.; Yue, H.; Tang, C. Prevalence and complete genome of bovine norovirus with novel VP1 genotype in calves in China. Sci. Rep. 2019, 9, 12023.
63. Otto, P.H.; Clarke, I.N.; Lambden, P.R.; Salim, O.; Reetz, J.; Liebler-Tenorio, E.M. Infection of calves with bovine norovirus GIII.1 strain Jena virus: An experimental model to study the pathogenesis of norovirus infection. J. Virol. 2011, 85, 12013–12021.
64. Jung, K.; Scheuer, K.A.; Zhang, Z.; Wang, Q.; Saif, L.J. Pathogenesis of GIII.2 bovine norovirus, CV186-OH/00/US strain in gnotobiotic calves. Vet. Microbiol. 2014, 168, 202–207.
65. Sawyer, L.A.; Murphy, J.J.; Kaplan, J.E.; Pinsky, P.F.; Chacon, D.; Walmsley, S.; Schonberger, L.B.; Phillips, A.; Forward, K.; Goldman, C.; et al. 25- to 30-nm virus particle associated with a hospital outbreak of acute gastroenteritis with evidence for airborne transmission. Am. J. Epidemiol. 1988, 127, 1261–1271.
66. Duizer, E.; Bijkerk, P.; Rockx, B.; De Groot, A.; Twisk, F.; Koopmans, M. Inactivation of caliciviruses. Appl. Environ. Microbiol. 2004, 70, 4538–4543.
67. Rzezutka, A.; Cook, N. Survival of human enteric viruses in the environment and food. FEMS Microbiol. Rev. 2004, 28, 441–453.
68. Nims, R.; Plavsic, M. Inactivation of caliciviruses. Pharmaceuticals 2013, 6, 358–392.