

Border Disease Virus Transmitted to Sheep and Cattle by a Persistently Infected Ewe: Epidemiology and Control

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In a Swedish sheep flock comprising 202 ewes and 13 rams, a pair of twin lambs born in the spring of 1990 demonstrated signs of border disease (BD) and were persistently infected (PI) with border disease virus (BDV). Investigation showed that BDV had been introduced in the preceding tupping period 5-6 months earlier by a bought-in ewe which, on the basis of immunoperoxidase- and polymerase chain reaction techniques, was shown to be PI with BDV. Only 7 of the ewes, all of which had been in close contact with the PI ewe, seroconverted during the subsequent gestation. Apart from the PI twin lambs the losses caused by BDV were restricted to 2 barren ewes. The twin lambs, the PI ewe and lambs from the other 4 ewes that seroconverted were removed from the flock. The flock was thereafter free from an ongoing infection with BDV as shown by the absence of seroconversion.

In addition, 5 heifers in late pregnancy most probably seroconverted to bovine virus diarrhoea virus (BVDV) when kept in close contact with the same PI ewe during the winter of 1989-90. When these heifers were reintroduced to the BVDV-free dairy herd from which they originated, their serum antibody titres ranged between 1:250 and 1:1250. Neither these heifers – nor their calves – caused any spread of the infection in the herd, as indicated by the absence of seroconversion in 70 cows.

The present investigation shows that in the control of both BDV in sheep and BVDV in cattle, it is important to ensure that the risk of transmission of pestivirus between the 2 species is minimized.

BDV; BVDV; interspecies transmission.

Introduction

Border disease (BD), a congenital disorder of sheep, was first described in 1959 (*Hughes et al.* 1959). A BDV infection in pregnant ewes during early- or mid-gestation can result in fetal death with resorption, mummification, abortion, or stillbirth, but may also result in the birth of clinically affected or even apparently healthy lambs that are persistently in-

fectured (PI) with BDV (*Terpstra* 1985). These lambs can develop normally and reach mature age. Apart from being potent lateral transmitters of the virus, PI ewes infect their offspring in utero in consecutive years (*Barlow et al.* 1980, *Woldehiwet & Nettleton* 1991). Postnatal BDV infections are usually subclinical.

Due to their antigenic relationship, border disease virus (BDV), bovine virus diarrhoea

virus (BVDV) and hog cholera virus (HCV) are all classified in the pestivirus genus within the family Flaviviridae (Francki *et al.* 1991). BVDV has been shown to readily infect sheep under both experimental and natural conditions (Carlsson 1991). Although sequence analysis data from a recent study suggested that BVDV and BDV possibly were 2 distinct viruses (Berry *et al.* 1992), it remains a possibility that they have a common origin and that changes in epitope expression might arise during passages in different species.

In Sweden, the primary cause of BD outbreaks has been shown to be contact between cattle PI with BVDV and susceptible sheep (Carlsson 1991). Interspecies transmission between cattle and sheep has been suggested previously (French *et al.* 1974, Physick-Sheard *et al.* 1980, Nettleton 1988). Recently it was also demonstrated that goats, vaccinated with a pestivirus-contaminated orf vaccine, transmitted BDV/BVDV to sheep and cattle (Löken *et al.* 1991). Other sources of infection to sheep are bought-in PI animals or, pregnant antibody positive ewes carrying PI fetuses. Transmission from transiently viraemic sheep or cattle is probably less important, although it can occur (Moerman *et al.* 1993). Virus transmission by blood-feeding flies has also been suggested (Tarry *et al.* 1991).

The present paper reports the consequences of introducing a ewe PI with BDV into a flock with pregnant ewes and heifers. The infection was eradicated and control strategies to avoid the infection are discussed.

Materials and methods

Flock history

The flock comprised 202 ewes and 13 rams and was being used for research purposes to compare growth and slaughter traits in cross-bred lambs (Swedish landrace, Leicester and

Texel). The housing and tupping period started in October 1989 and the sheep were let out on pasture in May.

Five ewe lambs (designated A1-A5) from another farm were kept on the same pasture as lambs from the flock subjected to this investigation in the late summer of 1989. These 5 lambs and other lambs on the pasture were introduced to the flock in October 1989. In late 1988 a bull calf PI with BVDV had been detected on the farm where the lambs A1-A5 were born. Contact between this PI calf and the ewes that gave birth to lambs A1-A5 possibly occurred in the autumn of 1988.

Five heifers in late pregnancy, originating from a closed dairy herd, were housed together with the sheep flock during January-March 1990. All cattle in this herd had been found to be free from BVDV antibodies in serum when tested in the autumn of 1989. During the mentioned 3-month period there was close contact between the heifers, the bought-in ewes (A1-A5) and 20 ewes from the flock, all of which were thought to be pregnant. The 5 heifers were returned to the dairy herd at the end of March, 1 month prior to calving.

In the sheep flock, no illhealth was recorded and no abortions occurred during the gestation period, but 8 ewes, a few more than usual, were found to be barren. However, a pair of twin lambs, born in April 1990, were trembling violently at birth. When they were 2 days old, the twins and their dam were blood-sampled and tested for the presence of BDV antibodies. Both lambs, together with the dam, were removed from the flock and isolated. The nervous signs present at birth gradually became less marked and at about 2 months of age the twins were admitted to the Clinic of Department of Cattle and Sheep Diseases, Swedish University of Agricultural Sciences, Uppsala, for further investigation.

Flock and herd investigation

In April 1990 the entire sheep flock was blood-sampled and tested for the presence of antibodies to BDV. Since this was a flock used for research, sera were available from the time before breeding in October 1989 and ewes that had seroconverted to BDV during the gestation period of 1989-90 could therefore be detected. During this period 10 ewes had died or had been culled. The sheep were again tested for the presence of antibodies both in the spring and autumn of 1991. Rams as well as the lambs from ewes that seroconverted in 1989-90 were tested for the presence of both antibodies and BDV.

The 5 bought-in yearling lambs (A1-A5) which were raised separately together with their own lambs after lambing in the spring of 1990 were also investigated for serum antibodies and BDV.

In order to determine the persistence of the antibody titres, 13 ewes in the flock were blood-sampled at 6-month intervals for a period of 2-3½ years, beginning in October 1989. In July 1990, all 70 cows in the cattle herd were tested for antibodies to BVDV. The 5 heifers as well as 3 of their 3-month old calves were also tested for their antibody titres to BVDV.

Serological examinations

An enzyme-linked immunosorbent assay (SVANOVA Ubitech AB, Uppsala, Sweden) was used for detection of antibodies to BVDV (Juntti *et al.* 1987) and BDV (Lundén *et al.* 1992). Some sera (Table 1) were tested in 5-fold dilutions, starting from 1:10 to 1:1250.

Virological examinations

Immunoperoxidase technique. The presence of BDV in buffy coat and/or sera was tested by inoculation on cultures of embryonic bovine turbinate cells. After incuba-

tion for 4 days the cultures were examined for cytopathic effect and the presence of BDV was determined by an indirect immunoperoxidase (IPX) technique using a polyclonal antiserum to BVDV (Meyling 1984).

Polymerase chain reaction technique. Polymerase chain reaction (PCR) technique was applied for the detection of BDV/BVDV viral RNA in serum and buffy coat from 3 sheep (Table 2). Primers and probes were selected from viral genome coding for the p80 polypeptide of the cytopathic BVDV-strain NADL (Belák & Ballagi-Pordány unpublished results, Belák & Ballagi-Pordány 1991). Immunohistochemical examinations. Tissues from 3 sheep (Table 2) were examined with the peroxidase-antiperoxidase (PAP) technique (Belák *et al.* 1989).

BVDV antigens were demonstrated in Omni-Fix (Zymed Laboratories Inc., San Francisco, U.S.A.) fixed, paraffin-embedded tissue sections using a cocktail of 4 monoclonal antibodies, MAbs (kindly provided by Dr. Moenig, Hannover, Germany). The MAbs CA3, CA34 and CT6 were raised against different epitopes on the major glycoprotein of BVDV (gp 53) and C42 is specific for BVDV viral protein p125/p80.

Patho-anatomical examinations

The trembling twin lambs and the ewe A3 underwent gross post-mortem examination. Routine bacteriological examinations were carried out. The brains and spinal cords from the twins were fixed in 10% formol saline and paraffin-embedded according to routine histological procedure. Sections were stained with haematoxylin-eosin and examined by light microscopy.

Results

Investigation of sheep flock

The serological screening of 192 sheep re-

Table 1. BDV-antibody titres determined by a BVDV-ELISA in 24 ewes followed by an outbreak of border disease.

Ewe no	Born	1989 Oct	1990		1991		1992 Feb	1993 Feb
			Apr	Oct	Apr	Oct		
116◇	1981	<10	250	–	–	–	–	–
217	1982	<10	50	–	–	–	–	–
221	1982	<10	250	–	–	–	–	–
230◇	1982	<10	50	–	–	–	–	–
443	1984	<10	50	–	–	–	–	–
902*	1989	<10	≥1250	250	250	250	250	–
912	1989	<10	250	250	250	250	250	–
905	1989	250	250	250	250	250	250	250
909	1989	≥1250	≥1250	–	–	–	–	–
915	1989	250	250	–	–	–	–	–
920	1989	≥1250	250	250	250	250	250	250
927	1989	50	<10	–	–	–	–	–
930	1989	250	250	–	–	–	–	–
931	1989	250	250	250	250	250	250	50
938	1989	250	250	250	250	250	250	–
943	1989	≥1250	≥1250	≥1250	≥1250	≥1250	≥1250	250
307	1983	50	10	–	–	–	–	–
504	1985	50	50	50	50	50	50	–
512	1985	250	250	250	250	250	250	–
513	1985	250	50	50	50	50	50	–
524	1985	50	50	50	50	50	50	–
538	1985	50	10	10	10	10	10	–
638	1986	10	10	–	–	–	–	–
871	1988	–	50	50	50	50	50	–

– = not tested.

◇ Ewes 116 and 230 were barren.

* Ewe 902 gave birth to 2 BD-affected lambs in the spring of 1990.

vealed that 16 animals, of which 9 were ewe lambs and 7 were ewes 3 years or older, had detectable antibodies to BDV before tupping in October 1989. In April 1990, 23 sheep, including the previously positive ewes, proved antibody-positive and accordingly 7 ewes seroconverted during the gestation period of 1989-90. Out of these 7 ewes, 2 were barren and 4 produced 10 normal offspring, all of which were tested for the presence of BDV in serum and buffy coat. At an age of 6 months, all 10 lambs were seronegative to BDV and none was found to be persistently infected.

The seventh ewe that seroconverted gave birth to the 2 BD-affected lambs (Table 1).

All rams except 1 were tested seronegative and none was found to be infected with BDV. During the tupping period the seropositive ram had been placed with ewes A1-A5. According to the screenings performed in 1991, no further sheep had seroconverted.

The BDV-antibody titres studied in 13 ewes (Table 1) fell over a period of 2½ years by 1 titre step in 4 ewes, whereas in the remaining 9 the titre remained constant. This phenomenon was observed irrespective of whether the

Table 2. Results from different techniques used to detect BDV antigens in serum, buffy coat and different organs in PI sheep.

Material examined	Technique used	Twin* I	Twin** II	Ewe*** A3
Parotid	PAP	+	+	-
Spleen	PAP	-	n.e.	-
Esophagus	PAP	n.e.	n.e.	-
Lung	PAP	-	+	-
Kidney	PAP	n.e.	n.e.	-
Tonsil	PAP	n.e.	n.e.	-
Brain	PAP	+	+	+
Thyroidea	PAP	+	+	+
Ileum	PAP	-	-	-
Thymus	PAP	-	-	-
Uterus	PAP	n.e.	n.e.	-
Serum	IPX	-(2 d.) ^a	-(2 d.)	-(1 1/2 y.)
Buffy coat	IPX	+(5 w.)	+(5 w.)	-(1 1/2 y.)
Buffy coat	IPX	+(8 w.)	+(8 w.)	+(2 y.)
Serum	PCR	+(2 d.)	-(2 d.)	+(1 1/2y.)
Buffy coat	PCR	+(8 w.)	+(8 w.)	+(2 y.)

PAP = peroxidase-antiperoxidase; IPX, immunoperoxidase; PCR, polymerase chain reaction

n.e. = not examined. *seronegative when 2 days old, **seropositive when 2 days old,

***seronegative at all times tested.

a = Age when tested: d, days; w, weeks; y, years.

ewes were seropositive at the beginning of the observation period or whether they belonged to the group of ewes that seroconverted during the gestation period of 1989-90. The titres ranged between 1:10 and $\geq 1:1250$ (Table 1).

Investigation of cattle herd

The 5 heifers were in their last month of pregnancy when they rejoined the dairy herd in the spring of 1990. All 5 gave birth to healthy calves. Three months later, in July 1990, the heifers and 3 of their calves (2 had been sold) were tested BVDV-antibody positive with titres of 1:250 or more. The remaining 70 cows in the herd were at this time still BVDV-antibody negative.

Examination of BD-affected lambs

Examination of sera collected from the trem-

bling twin lambs when 2 days old showed that 1 of them lacked detectable antibodies to BDV, whereas its twin and the dam were antibody positive. Attempts to detect BDV antigens with the IPX technique from sera from these twins failed. However, when using the same technique, virus antigens were detected in buffy coat at 5 and 8 weeks when both lambs were seronegative (Table 2).

With the PCR technique, BDV RNA was found in buffy coat from both lambs and also from serum in the lamb lacking antibodies when 2 days old (Table 2).

Upon hospitalization in June 1990 the 2-month old and clinically BD affected twin lambs had signs of pneumonia and a rise in body temperature. The tremors were only noticeable when the lambs were exposed to stress. They were treated with benzylpenicil-

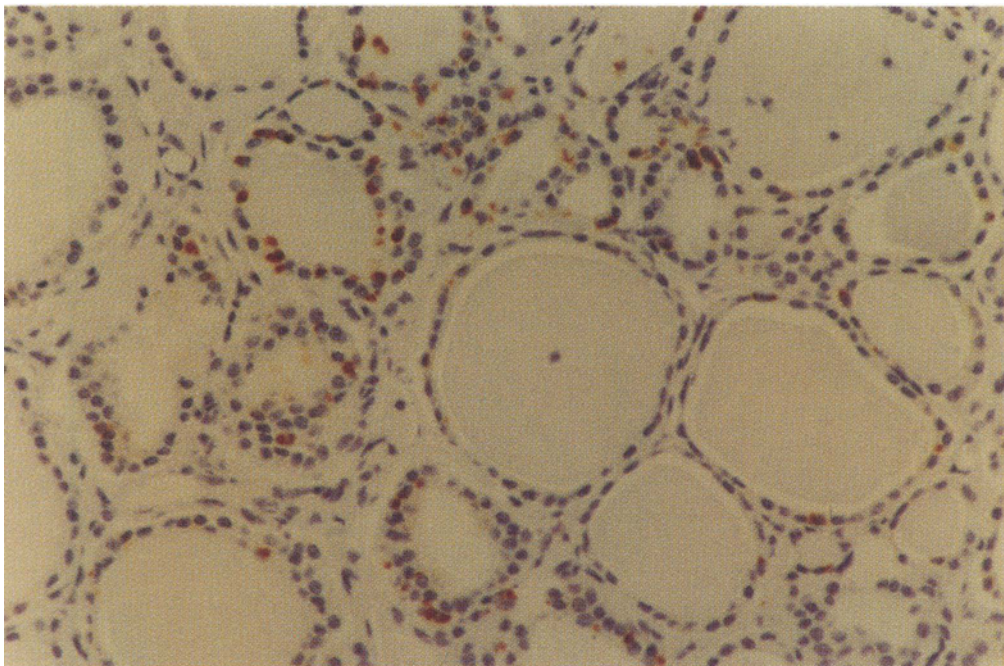


Figure 1. Border disease virus antigens in the cytoplasm of the follicular epithelial cells in thyroidea in a lamb persistently infected with BDV, demonstrated by the peroxidase-antiperoxidase (PAP) technique using monoclonal antibodies.

lin procaine for 7 days, but since no recovery was noted, they were euthanised shortly thereafter.

Gross post-mortem examination revealed major pneumonic changes in all lung lobes and bacteriological investigations from lung samples revealed growth of pasteurilla-like colonies. The histological examination of the central nervous system showed areas of hypomyelination in cerebellum and spinal cord.

Using the PAP technique, 7 different organs were examined and BDV antigens were demonstrated in both lambs in the cytoplasm of the follicular epithelial cells in the thyroid gland (Fig. 1), in neurons in the brain and in the parotid gland. In 1 of the lambs, BDV antigens were also found in the lungs (Table 2).

Examination of ewes A1-A5

Of the 5 ewes that had been introduced into the flock in the tupping period of 1989, ewe A3 was seronegative to BDV in the spring of 1990 and also found barren. The 4 age-matched ewes were seropositive and virus negative and each gave birth to 1 healthy lamb. The same serological status was seen from samples drawn from A1-A5 in November 1989.

Buffy coat and serum from A3 were tested using the IPX technique for BVDV. Only buffy coat was found virus-positive, whereas both serum and buffy coat proved positive for BVDV RNA when using the PCR technique (Table 2). This ewe which had never shown any clinical signs of disease was again tupped

in the autumn of 1990 and still appeared healthy at the time of euthanasia in February 1991.

Gross post-mortem examination, however, revealed a heavy load of gastro-intestinal parasites, a moderate amount of diffusely spread firm white foci with a diameter of 1 mm in the myocardium and a mummified fetus in the uterus. The histological examination showed lymphocytic follicles with a few plasma cells in the myocardium, a mild-moderate chronic bronchitis and bronchiolitis, eosinophilic infiltrates in the intestines and diffusely dispersed, small, mononuclear, perivascular infiltrates in the brain.

Tissue samples from A3 from 8 different organs (Table 2) were analysed for BDV antigens by the PAP technique. Only scattered infected follicular epithelial cells of the thyroid gland and neurons in the brain were found to be positive for BDV antigens.

Discussion

The results of the serologic investigation indicate that the BD infection was introduced by 5 bought-in ewe lambs (A1-A5) during the grazing period to lambs on pasture, and to the remaining flock in the tupping period of 1989. Of these 5 lambs only A3 was seronegative for BDV. In addition, only this lamb was shown to be PI with the virus. It is possible that the ewe that gave birth to A3 was infected during early pregnancy by contact with a PI bull-calf present at the farm where A3 was born. When BDV was introduced into the sheep flock in the autumn of 1989 the spread of the infection was restricted to 7 ewes that seroconverted, all of which had been kept in boxes adjacent to A3. The PI sheep (A3 and the twin lambs) were culled, as were lambs from ewes that seroconverted during the gestation period of 1989-90; the latter was a precautionary measure taken in order to minimize the risk of re-

introducing the virus. It was subsequently shown that the BDV infection was controlled, since seronegative ewes and retained lambs remained seronegative even 1½ years after the outbreak.

The antibody titres to BDV of 1:10 and 1:50 found in older ewes may indicate an infection some years ago (Table 1). The titre obtained in October 1989 in ewe lamb no. 927 might have been a remnant of maternal colostral antibodies. However, antibody titres in those ewes that contracted the infection in 1989-90 were still relatively high (1:250) 2 years after the outbreak. Five of these ewes contracted a transitory infection as lambs, most probably due to contact with A3 in the grazing period of 1989. They developed just as high antibody titres as those that seroconverted during the subsequent pregnancy period, including the dam with BD-affected lambs. It has been suggested, however, that BDV infections in non-pregnant ewes lead to lower antibody titres than in ewes infected in early pregnancy (Sawyer *et al.* 1986).

The 5 heifers from the BVDV-free dairy herd most probably seroconverted to BVDV during the period they spent in the sheep flock when 6-8 months pregnant, but the exact time when they became infected during this period cannot be stated. That the infection occurred in late pregnancy is strengthened by the high antibody titres ($\geq 1:250$) found in their 3-month old calves. This would indicate that the calves were infected in utero when immunocompetence had already been gained since, in our experience, maternally derived antibodies found in calves at this age are usually lower (1:10-1:50) and sometimes no longer detectable. Passively derived BVDV antibodies in calves PI have usually disappeared at an age of 2 months (Palfi *et al.* 1993).

We conclude that since other cattle in the herd remained seronegative after the 5 heifers had

returned, neither these heifers, nor their calves, passed on the virus after a recent transient BVDV-infection in late pregnancy.

The pathological findings in autopsied animals, such as the lung lesions or the heavy load of gastro-intestinal parasites in ewe A3, are not uncommon in PI animals and are referred to as an increased susceptibility to infections (Terpstra 1985, Barber et al. 1985). Myocardial lesions were also observed in A3 and have been described in BDV infected goat kids (Löken et al. 1990). Myocarditis and pneumonia have also been reported in adult PI sheep (Jeffrey & Roeder 1987).

The demonstration of BDV antigens based on the IPX was verified in organs or blood samples, with PAP and PCR techniques, respectively. The positive PCR results indicate that the primers selected from the BVDV genome were able to amplify BDV sequences in the present experiment. To our knowledge, this is the first report on PCR detection of BDV. It was also shown that BDV antigens are likely to be found in the brain and thyroid gland using the PAP technique. Negative results were encountered in the detection of antigens from sera using the IPX technique, an observation also made by others (Lees et al. 1991). However, when buffy coat was examined, both the affected twin lambs and A3 were found to be BDV positive. Attempts to re-isolate antigens from A3 using the same technique did not succeed. A recent report demonstrated that half as many peripheral blood lymphocytes (10%) are infected with virus in PI adult sheep as in PI lambs (22%) (Woldehiwet & Hussin 1992). This might account for the difficulties encountered in virus isolation from A3. However, it should be emphasized that with the PCR technique, viral RNA was detected in the buffy coat specimen as well as in the serum of ewe A3. This finding, which is similar to the result with the serum specimen from 1 of the twin

lambs, indicates that the PCR may detect the virus in clinical specimens when IPX fails.

This study has shown that an infection with BDV can be controlled, provided that an early diagnosis is made and adequate measures are taken. These must include removal of all diagnosed and suspected PI animals. In addition, as a result of increased knowledge of the epidemiology of BVDV/BDV, precautions in order to reduce the risk of transmission of the infection between herds should be taken. Introduction of animals with unknown BVDV/BDV status into virus-free herds should be avoided. To avoid transmission of a transient infection, the introduced animal should be placed in quarantine for at least 4 weeks and if it is both pregnant and has an antibody titre to the virus it should be kept isolated until its offspring has been shown not to be a virus carrier.

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Sammanfattning.

Smutöverföring av border disease virus till får och not via en persistent infekterad tacka. epidemiologi och kontroll

I en svensk fårbesättning om 215 djur konstaterades under lammingsperioden 1990 ett par tvillinglamm vara persistent infekterade med border disease virus (BDV). Serologiska respektive virologiska undersökningar indikerade att viruset hade introducerats med en med BDV persistent infekterad tacka vilken inköpts under föregående betäckningssäsong. Endast 7 tackor, vilka alla hade haft narkontakt med

det inköpta fåret, serokonverterade under efterföljande draktighetsperiod. Två av dessa gick gall. Lamm från de övriga 5 tackorna inklusive persistent infekterade djur slogs ut. Smittspridningen kontrollerades därmed och inga ytterligare djur serokonverterade i fårbesättningen.

Under samma period serokonverterade sannolikt även 5 kvigor i sent draktighetsstadium mot bovint virus diarrhoe virus (BVDV). Dessa var tillfälligt inhysta i fårbesättningen och hade haft kontakt med den inköpta tackan under månaderna januari-mars 1990. När kvigor återforenats med den BVDV-fria

mjolkbesättning de ursprungligen kommit ifrån hade de utvecklat höga antikroppstitrar mot BVDV. Detta noterades även hos deras kalvar. Varken kvigor, vilka smittats under sen draktighet, eller deras kalvar, förorsakade någon spridning av BVDV då de övriga 70 korna i besättningen förblev seronegativa.

Undersökningen visar att i kontrollen av BDV hos får och BVDV hos not är det även viktigt att minimera riskerna av överföring av BDV/BVDV mellan dessa bagge djurslag.

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