Identification and quantification of risk factors for introduction and spread of bovine viral diarrhea virus (BVDV) in Denmark: a knowledge synthesis from literature review and expert elicitation

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1. Introduction

Denmark achieved a status as free of BVDV in 2022. A total of 10 incidents of BVD have been reported in Danish dairy cattle farms in the period 2015 to 2024, and there is a continued effort to identify incidents prior to further spread of BVDV in the Danish cattle population following an introduction[1].

In Denmark, a routine surveillance of BVDV in cattle is implemented through a systematic sampling and testing scheme approved by the Danish Veterinary and Food Administration (DVFA). Bulk tank milk samples from milk-producing herds are screened four times a year. Non-dairy herds are screened via blood sampling at slaughterhouses following a computer-based selection of farms for sampling. In case of animal introductions into a herd from foreign country the surveillance is intensified. The samples are tested at the DVFA-approved (Danish Veterinary and Food Administration) laboratories, and the results are electronically reported to a central national cattle database[2,3]. If a herd is under suspicion or infected with BVDV, it is placed under official supervision, which may include movement restrictions, biosecurity measures, and a mandatory eradication plan. The official disease control mandate and oversight of the BVDV surveillance program lie with the DVFA, while the herd-level implementation and surveillance activities are coordinated and administered by the Danish cattle industry, i.e., SEGES Innovation[1,2].

To support early detection of BVDV reintroduction under conditions of low infection probability, our project aimed at identifying risk factors and indicators that could inform the development of a future risk-based surveillance system to complement the existing surveillance program. To achieve this, risk factors for dairy and non-dairy herds were evaluated under two epidemiological scenarios:

(i) introduction of BVDV into areas currently free of the virus; and

(ii) secondary spread of infection from an initial, potentially undetected outbreak to other farms.

2. Materials and methods

As a first step in the project, a literature review was conducted to identify studies that examined risk factors reported with odds ratios (ORs) for BVDV exposure that could be relevant to Danish cattle production systems and herd contexts. An initial search identified a recent systematic review that had already summarized evidence published between 1980 and September 2018 on risk factors associated with the introduction and delayed detection of BVDV. For this reason, the present review focused on updating the evidence base by identifying studies published from September 2018 to June 2025. The findings from the literature review were compiled into an evidence dossier to support a subsequent expert knowledge elicitation (EKE) process, which aimed to further assess and quantify expert opinion for two predefined epidemiological scenarios of BVDV.

The EKE was conducted in two phases. In Phase I, experts based in Europe were invited to participate via email and, upon initiating the phase, were provided with a material package, which included an invitation letter, detailed instructions, and the evidence dossier. In this phase, the experts were asked to identify and list risk factors and/or proxy indicators relevant to each of the two scenarios, categorizing them as either highly relevant or less relevant. All suggested risk factors were subsequently reviewed by the project group, and conceptually similar factors were grouped to avoid duplication. The final set of indicators and risk factors retained for further assessment was based not only on expert input but also on whether the variables could be observed or quantified within Danish data sources (the Central Husbandry Register and the Danish Cattle Database). The final list of indicators and risk factors was selected for Task 2.

In Phase II, all the experts who participated in Task 1 were contacted again and provided with a Task 2 material package, including a document describing the task with an example. The experts were asked to provide a “most likely” relative risk (RR) estimate for each final risk factor, along with a plausible “lowest” and “highest” RR value representing a 95% uncertainty range, based on their knowledge, experience, and assumptions regarding BVDV.

The medians for the “most likely”, “lowest”, and “highest” RR estimates were then calculated for each risk factor under both epidemiological scenarios and presented in tables. The median “lowest” and “highest” plausible bounds for the RR reflect 95% uncertainty around the estimate.

3. Results

Literature review: The final results from the literature review included a systematic review study [4], and three additional studies published after 2018, two from Ireland [5,6] and one from the Netherlands[7]. Across the systematic review and the three additional European studies included in the updated literature review, a consistent set of herd-level risk factors for BVDV introduction and re-emergence was identified. Animal movements were the most frequently reported predictors and were associated with increased odds of infection, e.g. cattle

introduction (OR = 1.41), participation in shows or markets (OR = 1.45), introduction of potential “trojan dams” (OR = 1.29–2.20), and purchases from herds without confirmed BVD-free status (OR = 1.25). Among herd characteristics, dairy herds were reported to be associated with higher risk than beef herds (OR = 1.63), and infection risk was reported to increase with the herd size (OR = 1.04).

Several management-related factors like farmers having external cattle contacts (OR = 1.25), mixed calf–cow housing (OR = 1.22), presence of group calving pens (OR = 1.16), and accidental contact with cattle from other farms (OR= 1.16) were also reported to be associated with increased risk. Spatial predictors included proximity to other herds (OR = 1.15), shared pasture (OR = 1.32), and BVD-positive herd density within 10 km distance (OR = 1.78–2.67). Production indicators, such as high calf mortality (>5.8%) (OR = 2.96), were likewise associated with infection risk.

All risk factors reported as statistically significant, along with their corresponding odds ratios, in the four studies identified through the literature review were extracted to form the evidence dossier for Task 1 of the EKE.

Table 1. Summary of indicators and risk factors identified as relevant for **BVDV introduction** and relative risk (RR) based on 18 European experts. The table presents the median values of most likely, lowest, and highest RR estimates.

Risk factor identified in Task 1	**Median of most likely RR value estimated in Task 2**	**Median of lowest – highest RR value**
Import of pregnant cattle from abroad	3.00	1.50 – 5.50
Import of cattle from abroad	2.75	1.35 – 4.50
Farm <5 km from endemic area	2.50	1.30 – 3.50
Increased abortions / embryonic loss	2.00	1.25 – 3.00
High calf morbidity / mortality	1.90	1.10 – 2.60
Purchase of cattle from local farms	1.75	1.05 – 3.00
Purchase of semen/embryos from BVD+ country	1.75	1.05 – 2.75
Herd size	1.65	1.00 – 2.50
Cattle purchase at markets/shows/fairs	1.50	1.05 – 2.25
Purchase of non-bovine camelids	1.25	1.00 – 2.00
Purchase of non-bovine ruminants/camelids	1.10	1.00 – 1.50
Herd type (dairy/non-dairy)	1.00	1.00 – 1.20

Expert knowledge elicitation: In total, 34 experts were contacted via email to participate in the EKE and 18 out of 34 agreed to participate in Task 1 and in Task 2. For the risk of introduction of BVDV, experts assigned the highest relative risks to variables involving

international movements of cattle, particularly the import of pregnant animals. These categories were also associated with the widest uncertainty ranges (Table 1). Risk factors related to reproductive problems and calf morbidity/mortality were also identified as relevant for BVDV introduction, but with comparatively less variability and uncertainty. Cattle purchase at shows, fairs, and markets were similarly judged important, although accompanied by substantial variation in expert assessments. In contrast, herd structural characteristics and the presence of non-bovine species received uniformly low RR values with minimal between-expert variation.

Table 2. Summary of indicators and risk factors identified as relevant for the **spread of BVDV** infection from an undetected farm to another non-infected farm and relative risk (RR) based on 18 European experts. The table presents the median values of most likely, lowest and highest RR estimates.

Risk factor identified in Task 1	**Median of most likely RR value estimated in Task 2**	**Median of lowest – highest RR value**
Purchase of pregnant cattle	3.00	1.50 – 5.00
Increased abortions / embryonic loss	2.00	1.35 – 3.00
Nearby cattle farm (<5 km)	2.00	1.05 – 3.00
Purchase at markets/shows/fairs	2.00	1.25 – 3.50
Purchase of cattle	2.00	1.45 – 4.00
Herd size	1.90	1.10 – 2.50
Increased antibiotic use in young stock	1.70	1.10 – 2.45
High calf morbidity / mortality	1.65	1.05 – 2.50
Multiple herds – same owner	1.50	1.10 – 2.00
Purchase of non-bovine camelids	1.30	1.00 – 2.00
Herd type (dairy/non-dairy)	1.20	1.00 – 1.80
Purchase non-bovine ruminants/camelids	1.10	1.00 – 1.65

For the risk of spread of BVDV, the experts assigned the highest relative risk to purchase of pregnant cattle, which was associated with a wide uncertainty range (Table 2). Other cattle movements and contact pathways, including purchase of cattle, purchase at markets/shows/fairs, and nearby cattle farms (<5 km), were also ranked relatively high, with most likely RRs around 2 and substantial variation across experts. Factors reflecting increased infection pressure within herds, such as reproductive problems (increased abortions/embryonic loss), larger herd size, increased antibiotic use in young stock, and high calf morbidity/mortality, were likewise considered important, although the uncertainty around these estimates was generally narrower than for the main movement-related factors. In contrast, multiple herds under the same owner, herd type, and the presence of non-bovine species received lower most likely RR values and relatively limited spread in plausible ranges.

4. Discussion and Conclusion

The expert-elicited results for both epidemiological scenarios aligned well with findings from studies conducted in settings comparable to the Danish cattle production. Animal movements, particularly the purchase or import of cattle and pregnant animals, were consistently identified by experts as the most important contributors to BVDV introduction. This agrees with evidence from Ireland and the Netherlands, where cattle purchases have repeatedly been associated with higher odds of BVDV exposure. These results highlight that movement-related pathways remain the primary route for both viral entry and undetected transmission in low-prevalence systems such as Denmark.

Indicators related to reproduction and calf health, including increased abortions and calf morbidity and mortality, were also judged relevant, and this is consistent with published evidence [5], particularly regarding calf mortality and calf performance indicators.

Management-related factors, such as sourcing animals from herds without confirmed BVD-free status or off-farm cattle contact through employees, received mid-range relative risk estimates, which mirror their moderate associations reported in the literature. In contrast, factors that have shown weak or inconsistent associations in empirical studies, such as proximity to neighboring herds, shared pastures, or the presence of non-bovine species, also received low relative risk values from experts, with very limited variation across respondents.

Across both scenarios, a similar set of variables emerged as the most influential. Cattle movements dominated expert assessments for both introduction and secondary spread, followed by reproductive and calf-health indicators. Herd size and certain management practices consistently occupied intermediate positions, while structural herd characteristics and presence or purchase of non-bovine species ranked low in both scenarios. The recurrence of key factors across scenarios indicates that these variables likely account for the majority of BVDV risk in Danish herds.

Overall, these results indicate that future risk-based surveillance strategies for BVDV in Denmark could focus on risk factors consistently ranked highest in both epidemiological scenarios. These factors could also serve as a basis for constructing scenario-tree models, in which surveillance sensitivity is determined by the probability of infection occurring through specific pathways. Although the risk factors in this project have been expressed as relative risks, incorporating population data to weigh these risks according to the distribution of herds and animals would allow estimation of the surveillance system's overall probability of detecting an introduction or secondary spread. Expert-derived uncertainty ranges could further support parameter uncertainty analyses in scenario-tree modelling, identifying where additional data collection may improve confidence in system performance. Together, the results from this project support the development of a risk-based surveillance system for BVDV in Denmark.

5. References

1. Overvågning af smitsomme kvægsygdomme, Rapport 2024 by SEGES. https://www.landbrugsinfo.dk/-/media/landbrugsinfo/public/9/c/4/osk_rapport_2024.pdf

2. Bekendtgørelse om bovin virus diarré. https://www.retsinformation.dk/eli/lta/2023/1660

3. Animal health in Denmark 2023. Report from the Ministry of Food, Agriculture, and Fisheries of Denmark. Danish Veterinary and Food Administration. https://en.foedevarestyrelsen.dk/Media/638642465830551614/Animal%20Health_2023.pdf

4. van Roon, A. M., Mercat, M., van Schaik, G., Nielen, M., Graham, D. A., More, S. J., Guelbenzu-Gonzalo, M., Fourichon, C., Madouasse, A., & Santman-Berends, I. M. G. A. (2020). Quantification of risk factors for bovine viral diarrhea virus in cattle herds: A systematic search and meta-analysis of observational studies. Journal of Dairy Science, 103(10), 9446–9463. https://doi.org/10.3168/jds.2020-18193

5. Barrett, D., Clegg, T., McGrath, G., Guelbenzu, M., O'Sullivan, P., More, S. J., & Graham, D. A. (2020). Herd-level factors associated with detection of calves persistently infected with bovine viral diarrhoea virus (BVDV) in Irish cattle herds with negative herd status (NHS) during 2017. *Preventive Veterinary Medicine, 179*, 104990. https://doi.org/10.1016/j.prevetmed.2020.104990

6. Casey-Bryars, M., Tratalos, J. A., Graham, D. A., Guelbenzu-Gonzalo, M. P., Barrett, D., O'Grady, L., Madden, J. M., McGrath, G., & More, S. J. (2022). Risk factors for detection of bovine viral diarrhoea virus in low-risk herds during the latter stages of Ireland's eradication programme. *Preventive Veterinary Medicine, 201*, 105607. https://doi.org/10.1016/j.prevetmed.2022.105607

7. Bisschop, P. I. H., Strous, E. E. C., Waldeck, H. W. F., van Duijn, L., Mars, M. H., Santman-Berends, I. M. G. A., Wever, P., & van Schaik, G. (2025). Risk factors for the introduction of bovine viral diarrhea virus in the context of a mandatory control program in Dutch dairy herds. *Journal of Dairy Science, 108*(2), 821–834. https://doi.org/10.3168/jds.2024-25006