MODELLING OF FMD OUTBREAKS IN THE NETHERLANDS: VACCINATION AND REGAINING THE STATUS ‘FREEDOM OF INFECTION’

J. A. Backer, T. J. Hagenaars, G. A. Nodelijk and H.J.W. van Roermund*

Quantitative Veterinary Epidemiology and Risk Analysis, Division Virology, Central Veterinary Institute of Wageningen UR, P.O. Box 65, 8200 AB Lelystad, the Netherlands

ABSTRACT

To limit the impact of Foot and Mouth Disease (FMD) epidemics on animal welfare and economics, control measures and end screening should be applied as effectively as possible. Here we study this for The Netherlands using an individual-based stochastic model. It describes virus transmission between animals and between farms, and takes differences between animal species into account (cattle, sheep, pigs). The effect of vaccination is included at the individual level, making a comparison between control strategies possible at the livestock area level. The results for individual animals indicate how many infected animals escape clinical detection during the epidemic (i.e. undetected minor outbreaks), enabling a comparison between end screening scenarios.

Our model results show that the minimal control measures required by the EU suffice in sparsely populated livestock areas (ca 2 farms per km²), but ring culling or vaccination is required in addition to curb epidemics in densely populated areas (>3 farms per km²). According to the model, 2 km ring vaccination is less effective than 1 km ring culling in terms of size and duration of the epidemic, but the difference is small when comparing with the minimal control strategy. 5 km vaccination and 1 km culling are equally effective, although the vaccination strategy yields higher and later epidemic peaks. Excluding pig farms from vaccination does not drastically reduce the effectiveness of vaccination strategies (for the studied virus strain O/NET/2001), because of the relatively low pig farm numbers (compared to cattle) and their low susceptibility for FMD.

The infected farms that escape clinical detection during the epidemic are mainly vaccinated cattle and sheep farms and unvaccinated sheep farms. Therefore, compared to the screening required by the EU, the relative risks are not markedly reduced in screening strategies in which more effort is placed on unvaccinated cattle and pig farms and, likewise, not markedly enhanced when less effort is placed on vaccinated pig farms.

1. INTRODUCTION

Outbreaks of Foot and Mouth Disease (FMD) in the Netherlands represent a risk of major importance to the Dutch farming industry, as around 17 million cattle, pigs and sheep are at risk of being infected by the virus. To control an ensuing epidemic as quickly as possible, emergency vaccination is preferred in The Netherlands (see Dutch contingency plan FMD, 2005). Concerns exist though that vaccination might not be as effective in controlling the epidemic as preemptive ring culling, because vaccinated animals are not instantaneously protected against infection. Another concern is that vaccination increases subclinical infections. These subclinically infected animals might escape clinical detection during the outbreak, and need to be detected serologically in the end screening. When they also escape the end screening they might pose a risk to a new outbreak and to the export position of the country (when detected later).

The Dutch contingency plan as well as the EU screening regulations for vaccinated animals do not make a distinction between animal species or farm sectors. However, virus transmission and the effect of vaccination differs considerably between species. Cattle are highly susceptible to infection, and they can become carriers of the disease. Infected sheep can also become carriers and show fewer clinical symptoms than cattle. Infected pigs excrete large amounts of virus, but they are not easily infected. Vaccination might not work as effectively on them as on cattle or sheep. Furthermore, the socio-economic impact of an FMD epidemic can vary for different farm sectors.
Pig and veal farmers will most probably encounter difficulties in marketing vaccinated meat, once the epidemic is under control. The hobby farm sector (i.e. small herds held for non-commercial purposes, in the Netherlands mainly small sheep flocks) on the other hand is largely unknown due to incomplete registration, but the social impact of an epidemic will be considerable here as well.

Here we will evaluate whether vaccination can be an effective and safe strategy to control an FMD epidemic, while taking the differences between four farm types (see below) into account. For this purpose we developed a mathematical model that describes the within-herd and between-herd dynamics at two distinct levels. Results of transmission experiments and data of the FMD outbreak that occurred in The Netherlands in 2001 (virus strain O/Net/2001) serve to estimate the model parameters. The model is applied to the farm density situation of 2006, involving 36000 cattle farms, 18000 sheep farms, 9000 pig farms and 20000 hobby farms (here small sheep flocks physically separated from commercial farms, held for non-commercial purposes), of varying farm sizes. Location coordinates and number of animals of each of these farms are taken into account. We did not distinguish between different commercial herd/flock types of the same animal species. With this model the outbreak size and duration is calculated for hypothetical epidemics of FMD, starting in different area’s of The Netherlands on a cattle or pig farm. Also the number of infected farms and animals that escape clinical detection, is predicted. This result is used as input for a model that describes the serological testing in the end screening. For different test characteristics and end screening strategies it predicts the number of seropositive animals (i.e. animals with a detectable anti-body response) that will remain when the country has been declared free of infection.

2. MATERIAL & METHODS

We developed a mathematical model that captures the key differences in the epidemiology of the four different farm types. It consists of two modules that describe the within-herd and between-herd transmission dynamics of FMD, as shown schematically in Figure 1. For the within-herd model, that is formulated in terms of individual animals, parameters are estimated for each species from literature on transmission and vaccination experiments. In the between-herd model the farm itself is the smallest unit. The transmission at this level is modelled by distant-dependent probabilities, calibrated by the outbreak data of 2001 in the Netherlands and other available data. This transmission kernel describes the between-herd transmission as occurred in the country after the high risk period (so during stand still). To apply the model to the 2006 situation, it needs the locations and type of all farms in the Netherlands, which are available in databases. The within-herd module produces simulated farm outbreaks; from these the profile of the infection pressure (i.e. number of infectious animals as a function of time) enters into the between-herd module, that determines which herds are infected by the source herd. The within-herd module also produces a detection time of the within-herd outbreak (if applicable), at which the between-herd module determines which herds need to be culled or vaccinated, depending on the control strategy. The information on infection, vaccination and culling times is returned to the within-herd module as input for calculating the simulated outbreak on the next infected farm. The result – after the last infected farm-outbreak is simulated – is the total course of the hypothetical epidemic. This model structure allows for the extrapolation of the effects of vaccinating individual animals to the level of an area with many farms.
3. RESULTS AND DISCUSSION

We evaluated several control strategies, by simulating 1000 hypothetical epidemics for each control strategy. Figure 2 shows the results of some important control strategies, when the epidemic starts on a cattle farm in the Gelderse Vallei (i.e. a cattle- and pig-dense area of 4.2 farms per km$^2$) and 10 farms have been infected by the time that the first detection of an infected herd occurs.

![Figure 2: Number of infected herds (95% percentile) during an epidemic in a densely populated livestock area under different control strategies](image)

From the model-evaluation of the control strategies it is concluded that:

- Additional measures such as preemptive culling or vaccination are necessary to control the epidemic in densely populated livestock areas (> 3 farms per km$^2$), but in sparsely populated livestock areas (of ca 2 farms per km$^2$) the minimal control strategy suffices (as required by the EU: culling of detected infected herds, tracing of their dangerous contacts and regulation of transport).

- In densely populated livestock areas 2 km ring vaccination is less effective than 1 km ring culling in terms of size and duration of the epidemic, but that difference is small when comparing with the minimal strategy as required by the EU.

- In densely populated livestock areas 5 km ring vaccination and 1 km ring culling are equally effective (when vaccination capacity is not limiting).
More than 75% of the infected farms are cattle farms, even in pig-dense areas, regardless of control strategy.

Excluding hobby farms (here small sheep flocks of 10 animals, physically separated from commercial farms) from preemptive culling has a negligible effect on epidemic control. In the ring culling strategy, it reduces the number of farms to be culled by 20% (and the number of animals to be culled by 3%).

Excluding pig farms from vaccination causes a significant but limited increase of the size and duration of the epidemic (for the virus strain under study). The number of animals to be vaccinated is more than halved. Whether this strategy is economically beneficial despite the increased risk, is to be evaluated in an economic analysis.

For non-vaccination strategies around 5% of the infected farms remains clinically undetected during the epidemic, consisting mainly of unvaccinated sheep farms. This percentage is between 11% and 20% for vaccination strategies, involving mainly vaccinated cattle and sheep farms.

Before the country can be declared free of infection, the EU requires all animals on all vaccinated farms to be serologically tested, as well as a sample of sheep on unvaccinated farms. We studied the results for this end screening strategy for three basic control strategies (for epidemics that started on a cattle farm in the Gelderse Vallei).

From the model-evaluation of the end screening it is concluded that:
- In non-vaccination strategies 1000-5000 farms need to be tested in the end screening, while vaccination strategies require twice as many farms (2000-11000) to be tested.
- About half of the tested farms must be retested to exclude or confirm infection.
- Before the end screening, vaccination yields approximately 5 times as many seropositive animals as ring culling.
- After the end screening the number of seropositive animals is similar for 1 km ring culling and 5 km ring vaccination, and slightly higher for 2 km vaccination.
- Compared to the screening required by the EU, screening strategies in which more effort is placed on unvaccinated cattle and pig farms (testing a sample of animals instead of none) do not provide added value.
- Compared to the screening required by the EU, screening strategies in which less effort is placed on vaccinated pig farms (testing a sample of animals instead of all) can be safely implemented.

In conclusion, vaccination is an effective control strategy to mitigate FMD epidemics, provided it can be applied on a large scale, especially in densely populated livestock areas. Control measures should primarily target cattle farms, as these are predicted to play the largest role in the epidemic (for the virus strain in this study). After the epidemic, most seropositive animals are expected on sheep farms and vaccinated cattle farms. An effective end screening strategy should focus on these farms. The simulation results are now being used in a socio-economical analysis of vaccination against FMD.

4. ACKNOWLEDGMENTS

The research was funded by the Ministry of Agriculture, Nature and Food Quality (LNV), the Netherlands (CVI Project nr. 1691026700, LNV-theme BO-08-010 Animal Health, 2008). We would like to thank Gert Jan Boender (CVI) for estimating the between-herd transmission kernel and Bas Engel, Aldo Dekker, Phaedra Eblé, Clazien de Vos (CVI), Mart de Jong (WUR), Ron Bergevoet (LEI), Stephanie Wiessenhaan, Wim Pelgrim, Eric van der Sommen and Huibert Maurice (LNV) for the discussions during the project.

5. REFERENCES