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AN EPIDEMIOLOGICAL AND ECONOMIC SIMULATION MODEL TO EVALUATE THE SPREAD AND CONTROL OF INFECTIOUS BOVINE RHINOTRACHEITIS IN DAIRY CATTLE

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Aux Pays-Bas, environ 42% des vaches laitières présentent des anticorps contre l'Herpesvirus bovin du type I (BHV1) qui est l'agent causal de l'IBR. Les conditions sanitaires que doivent satisfaire les animaux et les produits animaux exportés ne cesseront pas d'augmenter. Dans cette perspective, nous avons développé un modèle de simulation permettant d'évaluer plusieurs stratégies d'éradication de l'IBR en tenant compte à la fois des critères épidémiologiques et économiques. Le modèle repose sur l'estimation des probabilités dynamiques de transition hebdomadaire de l'état d'un élevage à un autre en fonction de l'état des animaux et des contacts aériens, avec le matériel et le personnel. Les cinq stratégies étudiées vont de la vaccination volontaire des animaux jusqu'au programme de vaccination obligatoire pour tous les élevages laitiers. La stratégie optimale est celle qui dispense les élevages certifiés et les jeunes animaux vivant dans un système fermé du programme de vaccination obligatoire. Cette stratégie a une période d'amortissement de 397 semaines et nécessite 241 semaines pour atteindre une prévalence de sérologie positive inférieure à 5%.

INTRODUCTION

In the near future more restrict demands are to be expected in the EU and some other countries outside the EU, considering the health status of exported breeding cows, semen and embryos. Therefore there is an increasing need for eradication of IBR, caused by BHV1, in exporting countries such as the Netherlands. Eradication of BHV1 can be done by culling all animals with antibodies against BHV1. This so called stamping-out method is however economically not feasible in countries with a high prevalence of BHV1, as in the Netherlands.

Recently marker vaccines and companion diagnostic test have been described (Kaashoek, 1995). Animals infected with BHV1 can be detected in populations that have been vaccinated with gE-deleted vaccines. In addition, Bosch et al. (1997) observed that vaccination significantly reduces the transmission of BHV1. Therefore, vaccination might be a valuable tool for the eradication of the virus in BHV1 endemic countries.

The aim of this study was to develop a computer simulation model to estimate the epidemiological and economic effects of different vaccination strategies applied on a national level, thereby supporting the policy-makers in their decision about IBR-eradication. Furthermore, this simulation model can provide insight into the impact of uncertain epidemiological and economic input factors on the outcome of the strategies through 'what-if' scenarios (sensitivity analysis). The input values used in this model are based on results of experiments where possible, and estimates of experts when experimental data were not available.

MODEL STRUCTURE AND CONTENT

To simulate the spread and control of infections over time, the State-Transition approach is often used (Dijkhuizen, 1989; Berentsen et al., 1992; Houben et al., 1993; Buijtels, 1997). The key factor in this technique is the transition between the states that the modelling unit (usually animals or herds) can be in. In this study the modelling unit is a dairy herd, because we focus on the spread of BHV1 between herds, and week is the time unit. First the population of dairy herds is subdivided into a limited number of mutually exclusive states. The herds in the different states are elements of the so-called state vector, and the probabilities that herds go to another state in the next time period are elements of the so-called transition matrix (Buijtels, 1997). By multiplication of the current state vector with the transition matrix, the development of the infection over time can be simulated.

To characterize the spread of an infection, the reproduction ratio R is an important factor. If the value of R is less than 1, only a minor outbreak will occur. When R is greater than 1, however, the virus may be transmitted extensively, infecting most of the susceptible animals in the population: a major outbreak (De Jong and Diekmann, 1992). In this study the 'R within herds' is used as an input value, to characterize the herds in the way the virus will spread if introduction of the virus occurs. Furthermore, the spread of the infection in a herd depends on the prevalence of gE-positive cows. Infection induces immunity, therefore the herd immunity increases as the number of gE-positive cows increases (De Jong et al., 1994). Within each value of R, 5 different gE-prevalence

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classes are distinguished in this model. When the virus is introduced in a herd, the number of infectious cows will depend on the prevalence of gE-positive cows and the vaccination strategy applied by the farmer. The calculation of the expected number of infectious cows per infectious herd is based on a deterministic S(usceptible) I(nfectious) R(emoved)-model (Becker, 1989). In summary, the different states that herds can be in depends on (1) the value of R, (2) the prevalence within each value of R and (3) the expected number of infectious animals in an infectious herd within each prevalence range.
The probability of herds to become infected depends on a several factors. Therefore a dynamic element is included in the calculation of the transition probabilities. The probability ($pi_s(t)$) of non-infectious herds with state s to become infected in week t is calculated as (Buijtels, 1997):

$$pi_s(t) = 1 - e^{-\sum_{s=1}^{14} (\gamma_s + \beta_s + \alpha_s) \times f_s(t-1)} \quad (1)$$

where
$f_s(t-1)$ = fraction of herds with state s in week (t-1)
γ = rate of introduction of virus by the purchase of infectious cows
b = rate of introduction of virus by the purchase of gE-positive cows which reactivate during transport
a = rate of introduction of virus by other contacts.

There is a large variation among herds in the number of cows purchased each year. To take this variation into account, the herds are divided into open, closed and intermediate, depending on the number of cows purchased per year. By including the different herd types and adding the reactivation in the own herd, the basic formula is expanded as follows:

$$pi_{js}(t) = 1 - e^{-(\sum_{s=1}^{14} \{\frac{(\gamma_s + \beta_s)}{N_j} + \frac{\alpha_s}{N}\} \times x_s(t-1))} + React_s(t) \quad (2)$$

where
x_s (t-1) = number of herds with state s in week t-1
N_j = total number of herds with which herd type j has animals contacts
N = total number of herds in the population
$React_s$ (t) = reactivation in a herd with state s in week t

In the simulation model the benefits of a vaccination program are calculated as the reduced economic losses due to IBR. The economic losses caused by IBR, included in this study, consist of a lower milk production by gE-positive cows, clinical and subclinical losses for infectious cows, outbreaks on AI-stations and potential losses due to export bans. The costs are divided into costs involved with vaccination, diagnosis, monitoring and early disposal of gE-positive cows.
The epidemiological and economic effects of five different vaccination strategies are simulated. Strategy I assumes a voluntary participation in the vaccination program of 30% and 50% of the dairy farms. Strategy II is based on a compulsory program for all herds. Strategy III will stimulate the farmers to cull their last gE-positive cows, because herds that are IBR-free can be certified, and exempted from a compulsory vaccination. It is required that these certified herds purchase cows from other certified herds only, in this way reducing the probability of introduction of the virus in a certified herd. Strategy IV is subdivided into IVa and IVb. These two strategies differ in the exemptions that are given to closed herds, the first exempting all young stock on closed herds to be vaccinated and the second exempting all gE-negative stock on closed herds with a prevalence less than 50% to be vaccinated. Strategy V is a combination of two years application of Strategy I, with 30% participation, followed by Strategy III.

RESULTS AND DISCUSSION

From the equilibrium situation when no vaccination occurs, it can be concluded that a major part of the outbreaks in the simulation model is caused by the so-called 'other contacts' and reactivation of purchased gE-positive cows. The probability of reactivation of a gE-positive cow and the impact of the 'other contacts' however could not be based on experimental results, but were derived from the prevalence on different herd types.
Table I shows the most important epidemiological and economic results of the different vaccination strategies.

Table I
Most important epidemiological and economic outcomes of the different vaccination strategies

	Time till 5% (weeks)	Costs till 5% (Million Dfl)	Diagnosis for culling cows (Million Dfl)	Culling (Million Dfl)	Pay-back period (weeks)
	1	2	3	4	5
Strategy I	Does not lead to eradication of IBR				
Strategy II	288	320	25.9	56	598
Strategy III	241	225	6.0	55	405
Strategy IVa	241	219	6.0	55	397
Strategy IVb	242	217	5.9	56	394
Strategy V	312	197	5.5	51	400

The first column displays the number of weeks before the prevalence of gE-positive cows reaches the threshold value of 5%. The total costs per vaccination program, made in the period displayed in the first column, are shown in the second column. The costs of detection of the last 5% gE-positive cows and the costs for culling of these cows are presented in the third and fourth column respectively. The most important economic parameter of a vaccination strategy is the 'pay-back period', in this study defined as the number of weeks after the beginning of the strategy that the cumulative benefits are equal to the cumulative costs of a program. From an economic point of view preference is given to a vaccination strategy with a short pay-back period.
For the final choice of a national vaccination strategy, not only the epidemiological and economic effects have to be taken into account. Also the support of farmers for a certain strategy, the favourable side effects of a strategy and the possibilities of supervision play an important role in the decision making for the eradication of IBR.

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