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A MODELLING APPROACH TO THE INVESTIGATION OF VACCINATION STRATEGIES FOR FOOT AND MOUTH DISEASE IN THAILAND

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Foot and mouth disease (FMD) serotypes O, A and Asia 1 occur in Thailand. The current control strategy includes division of the country into 3 zones: an FMD-free zone without vaccination in the south, a buffer zone with 100% vaccination coverage in the centre and east plus a control zone in the north and north-east with vaccination and response to outbreaks. The zoning is supported by strict movement control. Vaccination is twice yearly with a trivalent vaccine.

A project to examine the effectiveness of vaccination commenced in January 1991. Data were collected on vaccine responses and population dynamics of village cattle and buffalo. The findings were used to develop a model of changes in herd immunity over time due to regular vaccination. A number of alternative strategies were compared using the model. Of particular interest were the effects of different vaccination coverage rates and timing of first vaccination.

METHODS

Model structure

A simple state-transition model was constructed to determine the change over time in the percentage of animals immune to FMD in a village herd. A flow diagram depicting states and transitions is shown in Fig. 1.

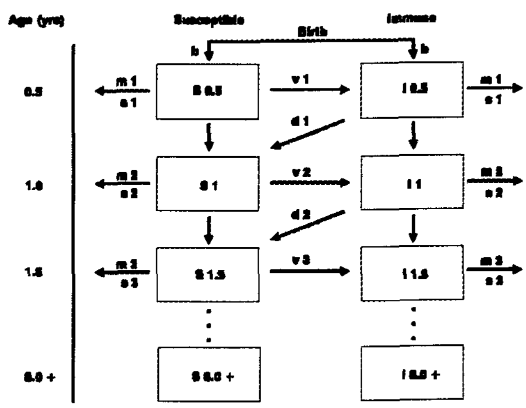

Fig.1. Flow diagram of the development of vaccination induced immunity to FMD in a northern Thai village cattle and buffalo herd.

The input parameters were the birth rate (b), vaccination rate, age specific death and culling rates (m,s),

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rates estimating the probability of a susceptible animal responding to vaccination and becoming immune one month later depending on the number of previous vaccinations it had received (v), and rates estimating the probability of an immune animal maintaining its immune status from one vaccination round to the next (d).

Data collection

Model parameters were estimated from observations in 60 northern Thai villages. For each village, the numbers and ages of cattle and buffalo present, the number of breeding females and the number of live calves born, the number of cattle and buffalo mortalities and the number of cattle and buffalo sales and purchases in the previous 12 months were obtained. Estimates of vaccine efficacy were made from a longitudinal study of serological responses to 6-monthly vaccination of cattle and buffalo in 21 of the study villages. Antibody titres to FMD virus types O, A and Asia 1 were measured by the serum neutralisation test (SNT) using standard methods (Golding et al., 1976). Animals which had reciprocal $\log_{10}$SNT titres of 1.5 or greater were classified as immune (Pay and Hingley, 1992).

Calculation of number of immune animals over time

For each age class, the number of immune animals one month after the first vaccination (I_1) was:

$$I_1 = N_1 e_1 c \qquad (1)$$

where N_1 was the number of animals present in the particular age class, e_1 was the probability of an animal becoming immune 1 month after receiving its first inoculation and c was the vaccination coverage rate.

The number of immune animals present at the start of the second 6-monthly vaccination round (I_2) was:

$$I_2 = I_1(1-m/2)(1-s/2)(1-d_1) \qquad (2)$$

where m and s were the annual mortality and sale rates for the particular age class and $(1-d_1)$ was the probability of individuals maintaining immunity from the first to the second vaccination round. To simplify the arithmetic, those animals maintaining immunity to the start of the second vaccination round were assumed to retain their immunity for an additional month, irrespective of whether they received vaccine at this round or not. Losses of immune animals as deaths and sales were also ignored during this month. The susceptibles present at the start of the second vaccination round were considered in 2 ways since they either received vaccine at the first vaccination round or they did not. The number of immune animals present one month after the second round (I_3) was:

$$I_3 = I_2 + (S_1 c^2 e_2) + (S_1 c[1-c] e_1) \qquad (3)$$

where S_1 was the number of susceptibles present at the second vaccination round and e_2 was the probability of responding to vaccination if the animal had also been inoculated at the first vaccination round. The above calculations were repeated for subsequent vaccination rounds. The number of immune animals present in intermediate months was calculated by assuming that the number of animals reverting to susceptible status doubled in each successive month. For the purposes of the study, a minimum acceptable level of 80 percent prevalence of immune animals was assumed to be necessary for a vaccination strategy to prevent the spread of FMDV (Henderson, 1970).

MODEL OUTPUTS

The simulated change in prevalence of immune animals over time is shown in Fig. 2. The percentage of animals protected increased in a stepwise manner, peaking one month after a vaccination round and then declining between vaccinations. At a vaccination coverage rate of 70 percent, herd immunity did not exceed the threshold level of 80 percent protection considered necessary for effective control. At a coverage rate of 90 percent, herd immunity first exceeded 80 percent one month after the third vaccination round (month 13) and remained above this threshold for 7 of the following 11 months. When 80 percent of animals were vaccinated and newcomers were revaccinated 1 month after the initial vaccination followed by regular 6 monthly boosters, an acceptable level of herd immunity of 80 percent protection was reached by month 8. It then fluctuated around this level, exceeding 80 percent in 8 of the following 16 months but dropping to as low as 56 percent in month 12.

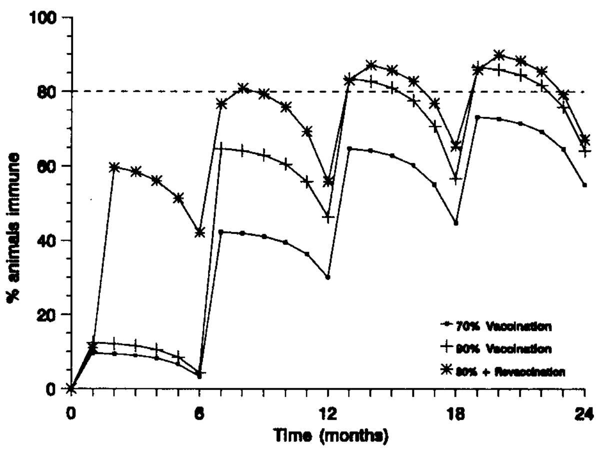

Fig.2. Model predictions of the development of herd immunity for three different vaccination strategies. 70% vaccination: 70% of animals > 6 months of age vaccinated every 6 months; 90% vaccination: 90% of animals > 6 months vaccinated every 6 months; 80% + revaccination: newcomers receive a primary course of 2 inoculations 1 month apart with 6 monthly revaccination of 80% of all animals.

DISCUSSION

The results from this study indicated that vaccinating 70% of village cattle and buffalo twice per year was unlikely to produce a level of herd immunity sufficient to prevent spread of FMDV. Reasons for the relatively low level of herd immunity resulting from this strategy include natural increases in the number of susceptibles through births, poor responses to initial vaccination and decline in titres between vaccinations. The method of estimating vaccine efficacy may be questioned on the grounds that it required an immune animal to have reciprocal $\log_{10}$ SNT titres greater than or equal to 1.5 to all three circulating serotypes at once. If the serotypes were considered one at a time, the vaccine efficacy rates improved substantially. However, since the serotype of any future outbreak virus cannot be known with certainty, it was considered safer to err on the side of caution and impose the harsher criterion requiring continuous protection which was used to define immune status. The relatively short-lived immunity induced by the trivalent FMD vaccine to all three circulating serotypes simultaneously highlighted the need for vaccination to include as near to

100 percent of the cattle and buffalo population within the control zone as possible.

Using an alternative approach of giving newcomers two inoculations a month apart followed by six monthly boosters improved the rate of development and overall level of herd immunity substantially. However, even with a dual inoculation priming vaccination, it appears that coverage rates in excess of 80 percent would be required to maintain continuous protection against outbreaks at the village level.

The FMD herd immunity model did not take into account the problem of sustaining herd immunity when the field virus is heterologous to the vaccine virus. Serological differences are frequently observed between field viruses within the same subtype group in countries where the disease is endemic. When serological differences occur between the field and vaccine virus, the herd immunity resulting from vaccination is lowered because of lowered vaccine efficacy (Brown, 1992).

A further limitation of the model is that the probability of being vaccinated may not be independent of FMD immune status. One of the reasons for failure of villagers in northern Thailand to present their animals for routine FMD vaccination is due to difficulties in assembling them on vaccination day. It is likely that animals missed at a vaccination round are at higher risk of being missed subsequently. Furthermore, there is substantial variation in vaccination coverage among villages in northern Thailand. Both factors would favour the maintenance of high levels of infection in the field and increase the level of challenge in villages in which animals have been well vaccinated. Effective control of FMD by vaccination therefore requires that not only must the proportion of the herd vaccinated be as high as possible, but also that there is little variation in vaccination coverage between villages.

Despite the potential pitfalls implicit in the assumptions used, the modelling approach taken has provided useful insights into what vaccination strategies may be required to achieve effective control of FMD under Thai village conditions. Further field trials are required to validate model predictions. If these trials are combined with carefully planned serological monitoring, it should be possible to evaluate the ongoing effectiveness of the vaccination program and to assess the risk of FMD outbreaks in specific control zones.

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