Simulations of the effect of badger vaccination on bovine tuberculosis in badgers and cattle within the IAA

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Executive Summary

We have taken an established simulation model of badger and cattle TB (bovine tuberculosis) and adjusted this to match the geographical aspects, badger density and cattle and farm density of the IAA. We have simulated the historical badger vaccination of the IAA in years 1-4 by vaccinating a similar number of animals in the simulation and then investigated the effect of different vaccination strategies going forward with the aim of determining the effect of not using any badger-BCG during 2016. The effect of increasing the duration of badger vaccination clearly reduced badger prevalence and the results suggest that a five year continuous strategy was very similar to five years of vaccination with a break in year four. This implies that herd immunity had built up sufficiently that a brief hiatus did not result in any increase in disease prevalence in badgers. This result will be sensitive to the way that vaccine is simulated, but we would not expect the changes to be markedly different if we assume that protection does not last for the lifetime of the badger.

Introduction

This analysis simulated a variety of different badger vaccine strategies to manage bovine TB (bTB) within the Intensive Action Area (IAA) in Wales. It used a current badger and cattle bTB model that has been repeatedly peer reviewed and published in the scientific literature [1-3] and used for reporting to Defra [4], the Welsh government [5,6] and DARDNI [7].

This work was performed to determine the most likely effects of not using the BCG vaccine for badgers in 2016, after successfully using the trap and inject approach with BCG for four year in Wales.

Methods

The model used for this study was a modification of the Badger-Cattle model used previously to model bovine tuberculosis [1-3]. It is a quasi-individual based spatial stochastic badger/bTB model combined with a cattle layer so that spatially realistic interactions and bTB transmission between badgers and cattle can be simulated. We used a model time step of two months so that farm management (such as repeat bTB tests) could be simulated. The badger and cattle layers were both modelled on a grid of 100x100
cells, each cell representing 200x200 m (total grid area represented 400 km\(^2\)). Model parameter settings (e.g. badger and farm density) were based on available data in and around the IAA to match exactly the situation on the ground, rather than using a random configuration of similar density. All explicit spatial locations were input from lists of coordinates stored within text files.

The coordinates and types (beef or dairy) of farms were obtained from data held by APHA in Weybridge and farms were added to the model grid at these locations. Farmland and grazing were then created around the farms following the standard model method. Some slight modification was required to the location of a small number of farms to ensure that each had sufficient land available for cattle grazing. While herd size data was available for each farm within the IAA and surrounding area, it was only used to construct a herd size distribution for each farm type in the area. Cattle were then stochastically added to farms based on this distribution and the amount of available grazing. It was not possible to simulate the history of specific individual farms; herd sizes, field locations and the buying and selling of cattle. Therefore predictions cannot be made for more localised areas, or individual farms.

The coordinates of badger main setts within the IAA were obtained and used to place all main setts within the IAA. Outside the IAA, setts were added to match the main sett density for that area found in the National Badger Survey. Badgers were then added to each territory following the standard model method.

Many statistics reported by the model and badger control methods are organised through zones. These zones have been preserved to represent the IAA, the 2km buffer around the IAA and the area around that respectively. Control was therefore undertaken in the IAA only, and results from each area recorded separately. Badger territories were allocated to zones according to the zone with the largest total area of all the farms that they overlap. The zone of each farm is based on the location of the farm centre. It is possible therefore that a number of badger groups that had the majority of their territory outside the IAA were categorised as being within the IAA for control purposes, although typically only part of the territory was available for trapping, and using the standard model ‘participation proportion’ routine, the probability of trapping these animals was reduced. The number of groups from which animals were trapped and vaccinated was therefore greater than the number within the IAA but many groups were only partially available for trapping. This reflected the situation that occurred within the IAA.

The standard model grid was structured as a full torus where one edge is considered the neighbour of the opposite edge. This is the case for badger territory and farm neighbours,
badger dispersal and perturbation and cattle movements. In this version, the torus was maintained in the north-south direction but converted to a reflective boundary in the east-west direction to simulate the coastal boundary of the IAA.

The cattle testing regime has recently been strengthened across the UK and additional measures are present in Wales and the IAA. The whole of Wales was placed on annual surveillance testing (12 monthly) in 2010 following the Health Check Wales when all cattle herds were tested in a 15 month window between October 2008 and December 2009. Farms within the IAA were placed on 6-monthly testing in 2010. These changes have been implemented in the model. The use of interferon-gamma blood tests which has been encouraged within the IAA was considered too complex to model for the small number of cases where it was actually used. This should have no effect on the mean results reported, even if it has affected individual farms.

Within the IAA, the number of clear tests required for OTF-S farms (TB free status suspended due to non-confirmed positive or inconclusive test result) to regain OTF (TB-free) status was set to the same as that for OTF-W farms (TB free status withdrawn due to confirmed test results). In the standard model, all tests for regaining OTF status for OTF-W farm were at the severe interpretation.

Up-to-date (2014) data were used for herd sizes, age profile and mortality rates for farms in Wales and specifically within the IAA. These were not categorised by sex, so new sex-based profile and mortality rates were generated using existing sex ratios for each farm type, which are unlikely to have changed. We assumed that this was representative of the farms throughout the simulated period.

Using these figures and the farm creation routine described above, we checked that the farm-size distribution and total number of cattle generated by the model matched the data provided and tweaked the herd-size distribution and stocking density until the match was judged sufficiently close to be comparable with the IAA.

The badger social group size for this area was taken from recent field surveys (APHA, unpublished). The badger population parameters (carrying capacity, litter size, birth rate and mortality rate) were tweaked until this figure was matched under ‘no control’ conditions. More exact data on badger social group size will become available in the near future, but this would not affect the overall conclusions.

Incorporating the new badger group and herd sizes and population densities resulted in changes to badger TB prevalence and CHB rate. These were restored to the values reported in the IAA reports by adjusting the TB transmission rates between badgers and
between badgers and cattle. This process resulted in further changes to the badger population which required further manipulation of population parameters as described above until the iterative process resulted in population and disease rates at the required levels. For this reason, the exact badger prevalence or herd breakdown rate within the IAA is not very important, as this would only rescale the graphs, and not change the relative impact of each vaccination strategy.

Simulated control methods were straightforward: vaccination of animals within the modelled IAA, simulated as historically accurate for the first four years of management, and then different options for year five onward, assuming a similar efficacy to that in the first four years. The number of animals trapped and vaccinated in each year of the IAA was used to inform and simulate the first four years of management. In the model, each badger was given a probability of capture and farms participated in the vaccination program with a set probability. These two probabilities were subjected to minor adjustment until the total number of badgers trapped matched that reported. While data was available for the number of badgers trapped around each main sett in the IAA, there was insufficient time to develop a method to match this exactly at such a fine scale, so only the total number of trapped animals was matched. This should not have any effect on the output.

The following strategies were simulated and reported:

1. Four years of vaccination
2. Five years of vaccination
3. Four years of vaccination, one year without and then vaccination in year 6. Referred to as strategy 411.
4. Six years of vaccination

For all cases, the output presented is the mean of 100 simulations, and this is compared to a 'no control' scenario (i.e. no badger management, but cattle controls continue as normal) to permit relative effects to be seen. We re-ran all the simulations to ensure the results was consistent and repeatable

Results and Discussion

Since badgers are only responsible for a proportion of all cattle herd breakdowns (CHBs), we would expect the output of badger prevalence within the IAA to be less variable than
the corresponding CHB rate over time. For all scenarios we report the mean value over the 100 simulations for 10 years following the initiation of vaccination.

We find for continuous vaccination that badger prevalence over a ten year period declines as the duration of vaccination increases as expected, with all vaccination strategies substantially reducing mean badger prevalence compared to 'no control' (Figure 1). Thus every additional year of continuous vaccination reduced badger prevalence although, as expected, the absolute benefit of each later year of vaccination was less than in earlier years. The strategy of four years vaccination, one year off and one year on (411) gives a result comparable with five years of continuous vaccination.

Since all the vaccination strategies were identical during the first four years we see no clear difference between them in terms of badger prevalence in Figure 1.
As stated above we expected to see greater variation in the CHB rate over time. The difference between the badger vaccination strategies in Figure 1 will be responsible for slightly changing the probability of roughly half of the cases of breakdowns in cattle. Thus the actual probability of a breakdown in the model does not change much between the different strategies. Thus the decline may be expected to mirror the badger prevalence, but demonstrate greater variability over time.

This variation can be clearly seen when we look at the simulated CHB rate over time (Figure 2), where even the background ‘no control’ option shows greater variability than occurred in badger prevalence (Figure 1). Here we can see that all simulated strategies reduced the CHB rate but the difference between strategies was not as obvious. Nonetheless, in any one simulation, an additional year of vaccination will have reduced the risk of a herd breakdown.
Figure 2. The simulated annual mean herd breakdown rate per farm within the IAA over a ten year period from the start of control.

The overall conclusion from this work is that all simulated strategies should substantially reduce badger prevalence and will thus reduce herd breakdowns compared to ‘no control’ and that after four years of vaccination, having one year with no vaccination does not result in any noticeable disadvantage. This raises the possibility that after a period of annual vaccination, it may be possible to reduce the effort by vaccinating every other year instead of very year. This potential option could be investigated further with simulations but it is likely to be sensitive to assumptions about how the vaccine works. In these simulations we assumed life-long protection. If the actual level of protection is reduced over time, this simulated benefit of reduced effort may no longer apply.
References


