Control Strategies for Wildlife Tuberculosis in Ireland

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Keywords: tuberculosis; Mycobacterium bovis; wildlife; badgers; cattle; vaccination

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Received for publication November 30, 2012

doi:10.1111/tbed.12095

Summary

The principal domestic maintenance host for Mycobacterium bovis is infected cattle. In countries where comprehensive surveillance schemes have been applied, tuberculosis rarely affects an animal to the extent that it presents with clinical disease. In the latter stages of an eradication campaign, the aim is to maintain the disease-free status of clear herds and eliminate foci of infection in herds as well as restricting movement of infected animals from these herds, other than to slaughter. However, the eradication of tuberculosis from cattle herds may be compromised if infected wildlife species, such as Eurasian badgers (Meles meles), share the same environment and contribute to transmission of infection. The options for dealing with tuberculosis in the wildlife reservoir hosts are limited to segregation of domestic animals from the wildlife, culling of the wildlife host or vaccination. Options are further limited by conservation and social reasons, particularly where culling is concerned. In Ireland and the UK, vaccination of badgers against M. bovis, if successfully employed, could directly facilitate the completion of bovine tuberculosis eradication. Programmes of research into vaccination of badgers are being undertaken in both countries, and there is clear evidence that vaccination induces protection. Vaccine trials in captive badgers have established that the M. bovis bacille Calmette-Guérin (BCG) vaccine can induce a protective response that limits the distribution and severity of tuberculosis disease following experimental challenge. In Ireland, a large-scale field trial of oral BCG vaccination is being conducted to measure the protection generated in wild badgers subjected to natural transmission of infection and to estimate vaccine efficacy. The results will provide a framework for the development and implementation of a national strategy to address the disease in badger populations and if successful will remove this major impediment to tuberculosis eradication from cattle.

Introduction

Bovine tuberculosis caused by Mycobacterium bovis is a significant zoonotic disease of cattle in many countries worldwide (O’Reilly and Daborn, 1995). In the past, when left unchecked, the disease had significant economic and health consequences for herd owners and the general public. The benefits of developing, applying and maintaining control and eradication strategies for tuberculosis in cattle are manifold and directly impact on animal and human health. In developed countries, the application of comprehensive test and slaughter campaigns has served to reduce the incidence of disease in national herds to the extent that the disease has been either eradicated or the incidence substantially reduced (Collins, 2006). From a public health perspective, the reduction of disease levels, in combination with improved animal husbandry and routine pasteurization of milk, has also helped to lessen the risk of zoonotic transmission.

The implementation of a successful control or eradication campaign requires a sound knowledge of the epidemiological factors contributing to persistence of the infection in herds and of the constraints imposed by limitations in the various testing methodologies. In many countries, one of the major impediments to eradication of tuberculosis in bovines is the presence of wildlife reservoirs of M. bovis...
infection. Tuberculosis is found in many wildlife species throughout the world, and the transmission of infection from wildlife to livestock may directly affect human health. The experience of countries attempting to eradicate tuberculosis from livestock where a wildlife reservoir exists, for example New Zealand, Ireland and the UK, may be instructive for countries having to confront a wildlife tuberculosis reservoir.

Infection with *M. bovis* is endemic in badgers (*Meles meles*) in Ireland and the UK, and these mammals are recognized as a reservoir of infection for domestic livestock (Corner et al., 2011). It is unlikely that the disease can be eradicated from cattle in these countries without the reservoir of *M. bovis* infection being adequately addressed (Gormley and Collins, 2000).

**Bovine Tuberculosis in the Republic of Ireland**

In Ireland, the current bovine tuberculosis eradication strategy is based on a test and cull policy for cattle and focal (reactive) badger culling. On an annual basis, all eligible cattle (>6 weeks of age) in all herds are skin tested using the single intradermal comparative tuberculin test (SICTT), with the testing regulated according to the requirements of the EU trading Directive 64/432/EEC. The test is conducted using avian and bovine tuberculin of matched potency. Additional testing is focussed on infected and at-risk herds that emerge from the annual testing programme, and also from routine slaughter monitoring and contact tracing of animals. The Bovigam Interferon-γ (IFN-γ) assay is used as an ancillary test in conjunction with the SICTT, exploiting its higher sensitivity and where the reduced specificity is considered acceptable (Gormley et al., 2006). The IFN-γ assay is targeted at herds or groups of animals where there is a high probability of infected animals being present, that is, severe breakdowns or herds chronically infected over a number of years. Comprehensive and strict application of the programme has lead to a sustained improvement in the national bovine tuberculosis statistics. The herd incidence of disease in cattle has fallen from 7.5% in 2000 to 4.2% in 2011, and the number of serious breakdowns has reduced significantly. Further, the number of reactors has declined from an average of 33 000 in the 1990s to 18 531 in 2011. This is the first time reactor numbers have fallen below 20 000 since the nationwide compulsory test and slaughter programme for cattle began 60 years ago.

**The Role of Badgers in Transmission of Tuberculosis**

Tuberculosis in Irish badgers was first reported in 1974 (Noonan et al., 1975), and in the following years, epidemiological evidence emerged to demonstrate that disease was widespread in this species and suggested that it was a significant factor in constraining progress in the eradication of tuberculosis from cattle. *M. bovis* infection has also been found in wild deer in areas where they are known to enter cattle pastures (Quigley et al., 1997). However, the estimated prevalence of *M. bovis* infection in wild deer is low, and they are generally considered a spill-over host for this disease (Corner et al., 2011).

Several studies were undertaken that showed an apparent improvement in bovine tuberculosis levels following the removal of the local badger population (O’Connor and O’Malley, 1989; More and Good, 2006). Further evidence in support of transmission between badgers and cattle became available following the development of *M. bovis* strain typing (Grange et al., 1990; Collins et al., 1994; Costello et al., 1999; Olea-Popelka et al., 2005). These studies revealed many different strains were circulating in cattle populations in Ireland and the UK, although detailed analysis has recently revealed that over 99% of strains originate from a single clonal complex named Eul (Smith et al., 2011). Genotyping analysis of 452 isolates of *M. bovis* by restriction fragment length polymorphism (RFLP) analysis in Ireland revealed that the most prevalent RFLP types were widely distributed and present in both cattle and badgers (Costello et al., 1999). The relationships between the strains isolated from cattle and badgers over large areas revealed also that badgers and cattle tended to have similar strains, consistent with the sharing of *M. bovis* strains within an area and providing evidence of cross-species transmission (Olea-Popelka et al., 2005).

The first major research project investigating the contribution of badgers to the epidemiology of bovine tuberculosis in Ireland took place in east Co. Offaly between 1989 and 1995. This was followed by the Four Area project, conducted in four different areas of Ireland from 1997 to 2002. These field trials compared the incidence of disease in cattle in large areas of proactive badger removal with matched areas of minimal badger disturbance. In the east Offaly study, proactive badger removal was associated with a significantly reduced risk of confirmed tuberculosis breakdowns in associated cattle herds (Ó Máirtín et al., 1998a,b; Eves, 1999). This effect was sustained and herd incidence continued to fall subsequent to the end of the trial in association with continued, but less intensive, badger removal (Kelly et al., 2008). The results from the Four Area project were very similar, with proactive badger removal leading to a substantial and significant reduction in the incidence of tuberculosis in herds in the removal area compared with the reference area in every year of the study period and in each of the four counties (Griffin et al., 2005). These studies provided compelling evidence of the central role played by badgers in the epidemiology of bovine tuberculosis in Ireland (Griffin et al., 2005; More, 2009). More focused
prevalence studies in badgers conducted using a detailed post-mortem and bacteriological examination have shown that the prevalence of *M. bovis* infection in badgers differs in areas associated with varying prevalence levels of infection in cattle. In these studies, a prevalence of *M. bovis* infection of 14.9% was found in areas of low herd tuberculosis prevalence, significantly lower than in the badgers from focal culling (36.6%) where culling was based on high prevalence in cattle (Murphy et al., 2010, 2011). The results validate the use of cattle as sentinels for tuberculosis in badgers and support the medium-term culling strategy for the control of bovine tuberculosis.

**Tuberculosis in Badgers**

Badgers are considered to be highly susceptible to, and an ideal host for *M. bovis* (Corner et al., 2007). Based on a consideration of the location of infection and the low levels of excretion in urine and faeces, and the low prevalence of bite wounds, the most important route of infection among badgers appears to occur via the respiratory tract. Following establishment of pulmonary infection after inhalation of an infectious aerosol, there is slow progression to overt disease (Gallagher and Clifton-Hadley, 2000). In a naturally infected population, infection is chronic and infected animals can present a range of disease conditions from latent subclinical infection (with no visible lesions or clinical signs of disease) to mild disease (with small pulmonary and extra-pulmonary lesions) and to severe disease with generalized pathology. Only a small proportion of badgers develop generalized disease (Dolan, 1993; Gallagher, 1998; Gallagher and Clifton-Hadley, 2000), and the mortality rate due to tuberculosis is low (Wilkinson et al., 2000). In a recent study employing comprehensive diagnostic procedures, the prevalence of infection in badgers from a naturally infected population was 43.2%. However, of the infected badgers, 54.4% had latent infection with no detectable gross lesions (Corner et al., 2012). A combination of spoligotyping and variable tandem nucleotide repeat (VNTR) analysis has provided evidence that individual badgers may be infected with multiple different *M. bovis* strains (Furphy et al., 2012).

The risk of transmission of infection in any species is likely to be dependent on the stage of disease progression, and the routes of exposure and excretion. For aerosol transmission to occur, badgers must be in close proximity (i.e. <1.5 m). Among badgers, there is within-sett clustering of infection, suggestive of close contact and either direct or indirect transmission (Olea-Popelka et al., 2005; Kelly and More, 2011). Although there is an overall trend for increased prevalence with age, the acquisition of infection may first arise by pseudo-vertical transmission from mother to cub and at any age by aerosol and bite wounds, with bite wound transmission occurring more frequently in adult males (Corner et al., 2011, 2012). The transmission and maintenance of *M. bovis* in badger populations is a complex process where many factors influence within-population prevalence and rates of transmission. Because respiratory lesions are most common in infected badgers, there seems little doubt that aerosol is the main mechanism of badger-to-badger transmission (Corner et al., 2012). However, those between badgers and cattle are less well understood and remain to be characterized. It probably occurs most frequently by aerosol, but transmission through ingestion of contaminated food is also possible. Our studies on pathogenesis of *M. bovis* infection in naturally infected badgers suggest that transmission via urine (or faeces) is not a dominant mechanism of badger–badger or badger–cattle transmission (Corner et al., 2012). Transmission between naturally infected badgers and calves in a housed situation has been demonstrated, but it occurred after a lapse of 6 months, and the frequency of transmission was very low (Little et al., 1982). Considering the longevity of infected badgers, non-visible lesioned badgers with lung infection may be a greater risk as a source of transmission than terminally-ill badgers that have higher excretion rates, but a shorter period of risk. A review of the pathology, pathogenesis and epidemiology of tuberculosis in badgers has recently been published (Corner et al., 2011).

**The Interim Strategy for Control of Tuberculosis in Badgers**

Since tuberculosis in badgers was first identified over 30 years ago, both selective and non-selective badger culling have been undertaken in both Ireland and the UK in attempts to limit transmission to cattle. The primary goal of proactive (non-selective) culling is to decrease the size of the badger population in order to reduce the risk of transmission to cattle. When sustained over large areas, non-selective removal of badgers leads to a significant reduction in the incidence of tuberculosis in associated cattle populations (Griffin et al., 2005; Donnelly et al., 2006). The aim of selective culling, on the other hand, is to remove the most heavily infected animals or social groups in a population, and in Ireland is carried out in response to severe breakdowns in cattle. This strategy has been shown to decrease the risk of tuberculosis transmission to cattle in Ireland (Olea-Popelka et al., 2009).

Culling activities are focussed in areas of higher disease prevalence in cattle. These areas also have higher disease prevalence in badgers (Murphy et al., 2010, 2011; Corner et al., 2012). In these high prevalence areas, badger removal forms the basis of the disease control strategy by reducing badger numbers and minimizing contact between cattle and infected badgers. An annual culling programme is
managed to ensure these lower density levels are maintained. Currently, badgers are culled on 28% of the national area of agricultural land. This area may increase but by agreement with conservation authorities will not exceed 30%. The total badger population in Ireland is estimated to be approximately 84,000 (Sleeman et al., 2009), and between 5000 and 6000 badgers are removed per annum.

The badger is a species protected by law in Ireland and in the UK, and this limits the option for culling as a disease control strategy. If used on badger populations independent of any other disease control measure, culling would need to be continued indefinitely if disease eradication from cattle is to be achieved nationally, although local removal of badgers can be effective in controlling the disease in targeted areas. Data collection in association with current badger removal operations is playing a key role in identifying locations for future vaccination trials and ultimate vaccine deployment.

**Badger Vaccination Studies**

Once the presence of tuberculosis in badgers had been recognized as a constraint to eradication of the disease in cattle, the national bovine tuberculosis research programme in Ireland was refocussed to identify novel management strategies that could serve to reduce the impact of the disease in both host species. Culling of badgers was sanctioned but could only be used in a limited way because of their legal protected status. The feasibility of developing a vaccination programme for badgers was considered as a potential pragmatic solution to the problem (Gormley and Collins, 2000). The aim of vaccination would be to reduce the prevalence of infection in the badger population or to change the expression of the disease and limit the rate of M. bovis excretion, thereby reducing the transmission of M. bovis between infected badgers and susceptible cattle.

In the early stages of the research programmes in Ireland and the UK, little was known about the pathogenesis of tuberculosis in the badger or about its immune system, and whether it could mount an effective immune response to M. bovis infection. Detailed research has been conducted jointly in Ireland and the UK to address these deficits with a view to the development of an effective badger vaccine and the implementation of a strategic programme of badger vaccination (Gormley and Collins, 2000). In Ireland, the research on BCG vaccination of badgers against tuberculosis was first conducted in captive badgers and involved an integrated series of experiments and associated studies to determine the efficacy of BCG vaccination (Corner et al., 2008). The BCG vaccine was chosen for use based on its availability, low production cost and the extensive literature on its application in domestic and wild animals, and humans. To carry out these studies in a controlled environment, the Badger Research and Observation Centre (BROC) was designed and constructed to hold 6–7 small groups of badgers. In studies carried out at the BROC, significant progress has been made in demonstrating that badgers mount a protective immune response against experimental challenge with M. bovis and that the BCG vaccine, when delivered by a variety of routes, including parenteral [subcutaneous (s/c) and intramuscular (i/m)] or mucosal (conjunctival and oral) routes, is effective in generating protective immunity (Corner et al., 2008, 2010). The BCG protective response was measured as fewer sites with gross lesions, a decrease in the severity of gross lesions, fewer sites of infection, and lower bacterial load in the lungs and thoracic lymph nodes compared with control groups.

**The Badger Vaccine Field Trial**

An injectable BCG vaccine has been granted a licence for use in the UK, and a field trial of this vaccine has demonstrated that the vaccine reduced the number of M. bovis seropositive badgers by up to 74%, compared with non-vaccinated badgers (Chambers et al., 2011). A badger vaccine deployment project is also underway in the UK using the injectable vaccine; the stated aim is to build confidence in the principle and practicalities of vaccination (Defra, 2010).

Whereas captive badger studies are the most cost-effective way of examining the protective response to vaccination, such studies cannot be used to predict whether BCG will be protective in free-ranging badgers subject to natural transmission or to estimate vaccine efficacy. Estimates of vaccine efficacy are extremely valuable in modelling potential vaccination strategies, and data from field trials are needed to reliably estimate protection and vaccine efficacy (Aznar et al., 2011). Whereas the UK trial demonstrated that BCG showed some measures of protection in wild badgers, it was not able to estimate vaccine efficacy. A BCG vaccine field trial has commenced in Ireland designed to address two principal objectives. These were to validate the results of captive badger studies and show that BCG vaccine is protective in naturally exposed wild badgers, and to estimate vaccine efficacy under field conditions. The secondary objective is to measure the effect of BCG vaccine in badgers with pre-existing M. bovis infection. In addition to providing a measurement of protection and an estimate of vaccine efficacy, the field trial also provided a practical basis for understanding the logistics of oral vaccine delivery to wild badger populations (Gormley and Corner, 2011). Taking into account the logistical challenges associated with vaccinating wild badger populations, the design of the vaccine field trial in Ireland considered, as necessary, the use of an oral vaccine delivery system, because this is the method of
choice for any broad-scale mass vaccination of free-ranging badger populations.

In the Irish field trial, the area has been divided into three equally representative zones with different proportions (0%, 50% and 100%) of the badger population in each zone being vaccinated with either BCG Danish strain or placebo. The advantage of this design is that effects on vaccine efficacy arising from changes in the force of infection as a result of different levels of vaccination coverage can be estimated. When first encountered, individual badgers are allocated to either the vaccination or placebo group as required for the particular zone. The BCG Danish strain, encapsulated in a lipid formulation for oral administration and containing about 10^5 cfu/ml, is being used in the field trial (produced by Immune Solutions Ltd, Otago, New Zealand). Badgers are individually vaccinated by administration of the lipid vaccine or lipid placebo directly into the pharynx. The vaccine and the placebo are ‘double-blind’ coded. Badgers are revaccinated annually and the population examined twice per year by trapping the entire study site in a continuous process. Throughout the trial, estimates of changing tuberculosis incidence will be made from the measurements of serological immune responses using the Brock (TB) Stat-Pak test (Chembio Diagnostic Systems Inc., Medford, NY, USA) and a modified badger Enfer serology test (Enfer Group, Co., Kildare, Ireland). We have previously shown in vaccination and experimental M. bovis challenge studies that badgers do not generate serological responses to M. bovis-specific antigens following BCG vaccination (Lesellier et al., 2009), and in a badger vaccine field trial conducted in the UK, this feature was used to distinguish vaccinated from infected badgers (Chambers et al., 2011). To allow for continued exposure to infection, the trial is being conducted over a 3-year period. It was estimated that an initial population of 300 badgers (100 in each of the treatment zones) was required to accurately estimate vaccine efficacy, based on an assumed initial tuberculosis prevalence of 20–30% and vaccine efficacy of 50–70% for an individual badger (Aznar et al., 2011). At the end of the 3-year study period, the trial site will be depopulated and all badgers will be examined for tuberculosis by detailed post-mortem examination that will include an examination for visible lesions, histological lesions and bacteriology to demonstrate infection with M. bovis. Tissue samples from 36 pre-determined anatomical sites (a variety of lymph nodes and organs) will be removed from each badger and submitted for histopathology and culture. The isolation of M. bovis from these post-mortem tissues or additional clinical samples (wound exudates, urine, faeces or tracheal swabs) will be used to define a case of tuberculosis. Vaccine protection and vaccine efficacy will be estimated by comparing the number of infected badgers in the vaccinated group with the number in the non-vaccinated control group. The primary outcome variable will be the prevalence of infection in the two treatment groups. The variables used to assess protection will include an assessment of gross lesions and their quantification by means of a severity score, a measure of the number and size of lesions in infected organs. The purpose is to gain an in-depth assessment of the severity and profiles of disease between the two groups. This intensive level of lymph node and tissue sample culturing is required as it is likely that the BCG will not prevent some animals from becoming infected. Where BCG has been shown to be effective, it is in limiting the dissemination of infection. Therefore, our analysis parameters must include examination of the distribution of infection and whether it differs between the vaccinated and control groups. The trial is due to be completed in 2013.

The results and experience gained from the field trial will facilitate the development of strategies for the introduction of vaccination into the national bovine tuberculosis eradication programme. As the field trial reaches its conclusion, a further field vaccination project has commenced to vaccinate significant subpopulations of badgers by means of a capture/vaccinate/release protocol using intramuscular vaccination. Badgers caught in previously culled, low-density badger areas, areas that had been burdened with high levels of tuberculosis in both cattle and badgers in the past, will be vaccinated instead of culled. This study will comprise a vaccinated area and a control area where culling will be maintained. The levels of tuberculosis in cattle in the two areas will be monitored and compared over 5–10 years. It is a strongly held opinion that the optimal delivery system for vaccination of badgers at field level will involve oral baits, and thus, research into an oral delivery strategy is continuing.

Vaccine Strategies for Control of Tuberculosis in Badgers

As a disease eradication strategy, the aim of the badger vaccine is to reduce the risk of spread of disease to associated cattle herds. However, this poses particular challenges, as there is still a lack of information on many aspects of badger-to-cattle transmission. For example, identification of cattle exposed to M. bovis using the skin test detects an immunological response to a previous transmission event, the timing of which is exceptionally difficult to determine. The effectiveness of disease control by vaccination under field conditions has yet to be assessed, and future vaccination strategies may involve not only the use of vaccine alone but in combination with non-selective or selective culling. There is no guarantee that successful vaccination of badgers will impact significantly on the incidence of tuberculosis in cattle without enhanced control measures targeted at cattle.
With badger vaccine field trials underway, attention is beginning to focus on the types of strategies that might be implemented as part of a vaccination programme. A number of fundamental immunological principles need to be considered in the vaccination of wild populations in order to achieve success. These include the estimation of vaccine efficacy, which is a measure of the proportion of vaccinated animals successfully protected; herd immunity, which is the positive effect conferred on the non-vaccinated portion of the population as a result of vaccinating the remaining portion of the susceptible animals in the population and can result in a decrease in the overall disease risk. Whereas vaccination directly impacts on the transmission risk to individuals in the population, herd immunity is an indirect effect on the non-vaccinated (susceptible) proportion and decreases their risk of infection through decreased infection pressure. The generation and maintenance of herd immunity will occur through the accumulation of protected individuals above a threshold level. When this threshold is reached and maintained, the disease will eventually become extinct in the population. The accumulation of immune individuals is best achieved by revaccination of the population, the increased survival of vaccinated over non-vaccinated badgers, and the slow decline in the number of tuberculosis badgers through disease-induced mortality and deaths due to other causes. The BCG vaccine will only be protective against new infections and will have no therapeutic effect in animals already infected.

When vaccination of badgers is incorporated as a major component of a disease control strategy, it could be used to control the disease in badgers in a specified area, or as an eradication tool applied on a broad geographic scale up to the national level. The objectives in each strategy, control or eradication, would be similar and would serve to reduce or remove the risk of transmission from badgers to cattle in a defined population of badgers. To achieve either objective, the programme would, by necessity, be conducted over the long term. If control was the objective, the programme would have no foreseeable endpoint as infected populations would continue to exist outside of the control area and would continue to act as a high-risk source of re-infection. If eradication in the targeted population was the objective, uniform vaccination of the entire population, or a significant proportion of it, will need to continue until the last infected badger is removed from the population (Gormley and Corner, 2011). As some infected individuals are likely to survive and live with tuberculosis for many years, it is these animals that will determine the length of time that vaccination for eradication must continue.

To date, studies on tuberculosis in badgers have only addressed rural badger populations as the context of the research was the understanding and control of transmission between badgers and cattle. However, tuberculosis in urban badgers has not previously been considered, and the infection status and risks posed by these badgers are unknown. As an adjunct to a study of the pathology and pathogenesis of M. bovis infection in badgers culled in response to a tuberculosis breakdown in cattle in Ireland (Corner et al., 2012), three badgers killed in road traffic accidents close to parklands in urban Dublin were examined. They were an old adult female, an adult male and a juvenile female. None had visible lesions of tuberculosis, but the old adult female was culture positive for M. bovis. This finding highlights the need to include all badger populations, those on farmland, forests, national parks and urban areas, when considering vaccination strategies.

Additional studies are still required to address key components of a wild badger vaccination programme. The development of mathematical models will help to devise optimal vaccination strategies for reducing disease prevalence (Aznar et al., 2011). Additional captive badger studies to examine transmission between badgers (both vaccinated and non-vaccinated) and between badgers and cattle will help evaluate the level of vaccine coverage required to generate and maintain a threshold of herd immunity. In Ireland, bait-uptake studies have been conducted (Kelly et al., 2011), further to earlier work on badger diets (Cleary et al., 2009, 2011), providing information on the effects of season, population density and diet on bait uptake. Studies in relation to the safety, efficiency and product quality of the vaccine are now required for registration of oral BCG for use in badgers.

Conclusions

The development of strategies to successfully control or eradicate tuberculosis in badgers and cattle requires detailed epidemiological knowledge of the factors contributing to persistence of the infection in both hosts, transmission between host species and also an understanding of the constraints to achieving success. In Ireland, the ability to eradicate tuberculosis from cattle at the national level is severely constrained while infection continues to spread from badgers. Although the interim badger control programme based on focal culling coupled with a comprehensive tuberculosis testing programme has made significant progress in reducing infection levels in both species, the strategy is limited by the numbers of badgers that are permitted to be removed, and the proportion of the agricultural land that can be subjected to badger culling. Ultimate success is dependent on further reducing the level of infection in the badger population, and to achieve this, vaccination is the only strategic option available. Providing scientific support for the incorporation of BCG vaccination of badgers into the national tuberculosis eradication programme would be an important component of such a strategy.

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programme is the ultimate goal of the badger research studies. Although research has yet to be completed in field situations, particularly with respect to vaccine efficacy and cost-effective vaccine delivery, there is good reason to be optimistic that effective badger vaccination can be implemented nationally within a medium-term timeframe and that it will contribute to the enhanced control and ultimately the eradication of tuberculosis from the national cattle herd.

Acknowledgements

All researches conducted on badgers and cattle in Ireland were funded by the Department of Agriculture, Food & the Marine. Experiments in badgers were conducted under licences issued by the Department of Health & Children, and with approval from the UCD animal ethics committee.

Conflicts of Interest

Neither of the authors, Eamonn Gormley and Leigh Corner, have received any payments or assistance from commercial bodies that could influence or bias the results and opinions expressed in this paper. There are no other potential conflicts of interest.

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