Progress in Tuberculosis Eradication in Ireland
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Title: Progress in Tuberculosis Eradication in Ireland
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Abstract

Ireland ran a conventional test and slaughter Bovine Tuberculosis eradication programme from 1954 until 1988. This programme fulfilled our trading requirements but failed to eradicate TB. At this point a major initiative, ERAD, was launched targeted with reducing the disease levels by half within a four-year period and devising the strategy and supports necessary to achieve final eradication. The lessons learned at that time have informed Ireland’s eradication programme ever since. Eradication was not possible without developing solutions to address the wildlife disease reservoir and other identified constraints. Since 1992 the programme objectives have been restated. It is now effectively an interim control programme where significant resources have been invested in research and development aimed at overcoming the identified constraints to eradication. Policy is informed by science and debate among stakeholders is generally knowledgeable and balanced. This paper outlines developments in recent years and sets out our expectations for progress in the period ahead.

Keywords: Bovine Tuberculosis; Wildlife disease reservoir; Programme objectives; Policy

Origins of the current eradication programme

A Bovine Tuberculosis Eradication Programme has operated in Ireland, in some form, since 1954, when it commenced on a pilot basis. It was later extended across the country on a regional and voluntary basis and by 1962 had become both national in scope and compulsory in nature. Substantial progress was made in the early years, the animal incidence being driven down from an initial level of approximately 17% in cows to an average across all animal categories of just 0.44% by 1965 (Watchhorne, 1965). From that point forward, however little further progress was made in eradicating the disease with animal incidence remaining at approximately 0.5%. The primary programme measures, as for most such eradication programmes, comprised an annual round of herd testing using the single intradermal cervical comparative tuberculin test, follow up testing in diseased herds, compensation for reactor animals and a range of movement controls.

By 1968, the quality of testing by private practitioners was being blamed for the lack of progress. Measures to address this, including the employment of a dedicated testing task force, were put in place. While disease levels were driven down to a slightly lower level no substantive progress was made.

The first identification of the disease in the badger was reported in 1974 (Noonan et al., 1975) but it was not until 1986 that the first epidemiological assessment of the temporal
pattern of bovine disease showed that the disease was now primarily a disease of cattle at pasture with peak transmission occurring in late spring and early autumn. The national programme was formulated around the classical model that assumed bovine-to-bovine transmission as the primary pathway, arising from clinical cases of the disease and with much of this transmission taking place during the winter housing period when contact opportunities were greatest.

At about this time major stakeholder dissatisfaction gave rise to the creation of a new executive agency, ERAD, tasked with providing a more dynamic management of the programme and reducing the disease levels by half within a four year time frame. The board of ERAD comprised all relevant stakeholder interests and its chief executive, Dr Liam Downey, was given very considerable resources to achieve this objective.

During its three and a half years of operation under Liam Downey from August 1988 until December 1991, ERAD implemented a number of key measures that have paved the way to future advances and hopefully ultimate success in controlling and eradicating bovine tuberculosis. However, in the absence of the required progress within the four-year time frame the importance of some of these measures was not fully appreciated at that time.

Arising from a study tour in 1989, Dr Downey established that the programme managers in a number of developed countries were struggling with similar constraints to eradication – in particular in Australia, New Zealand, and the United Kingdom and to a lesser degree the United States. There was no forum in existence at that time that provided for information exchange or mutual assistance. Arising from this the first meeting in this series of international conferences on \textit{M bovis} was held in Dublin in 1990 using the same format as we have today – in essence a meeting where the programme managers and their supporting epidemiology teams and various research groups come together to share ideas and experiences, coordinate research and generally to focus our collective efforts in a shared objective of achieving eradication.

The second major achievement of Liam Downey was the platform he created for tuberculosis research in Ireland. The key elements being the creation of (a) a dedicated TB epidemiology unit known as the Tuberculosis Investigation Unit – since renamed the Centre for Veterinary Epidemiology and Risk Analysis, CVERA, (b) a programme of research targeted with improving the diagnostic tools available for use in the bovine and (c) a programme of research designed to study the role played by the badger in the maintenance of the disease in bovines.

A key input to this policy direction was provided in a confidential report prepared for ERAD in 1990 (Morris and Pfeiffer, 1990). The broad conclusion of their report was that the Irish programme faced significant constraints in relation to the disease in wildlife and they recommended that the programme should refocus on control at least cost. The monies saved were to be invested in R&D to overcome the identified constraints before subsequently re-launching the drive towards final eradication. This focus was restated in a subsequent economic analysis commissioned by ERAD the following year (Sheehy and Christensen, 1991). The authors recommended that we ‘retain eradication as a long-term goal while taking the necessary steps to make that objective a reality. Only with new technology can eradication become possible’. In an EU context, the minimum control programme that can be undertaken is set down in Council Directive 64/432/EEC. This does not allow for significant savings in overall programme costs in Ireland’s situation, as a full annual screening test programme is
mandatory along with reactive measures where disease is revealed. Nevertheless, the formal restatement of objectives as set down by ERAD brought much needed clarity to the programme and effectively provided the strategic framework for the management of the tuberculosis eradication programme since that time. The interim and long term objectives are consistent and the longer time-frame allows for a more considered roadmap for progress to be described.

Ironically the final key legacy of the ERAD executive years was the ultimate proof that addressing the bovine side of the disease equation in isolation from the wildlife component was not going to work. During the four year period 1989 to 1992 the most comprehensive programme of bovine TB eradication, possibly ever undertaken in any country, was implemented (Downey 1991) Table 1. The frequency of testing within the screening programmes, the severity of interpretation, the strategic response where disease was discovered and the range of supporting measures implemented were unmatched. The net outcome of all of this effort and resource use was simply the generation of additional reactors without producing any net effect on the underlying disease level. The confidence of the stakeholders was undermined and morale suffered accordingly.

The ‘Downey’ era
1988 – 1991

Table 1

| • Exhaustive tuberculin testing (~44 million tests, ~7 million cattle, 4 years) |
| • Improved support measures |
| ✓ the refinement of a programme management system; |
| ✓ a reactor collection service and improved compensation/hardship grants; |
| ✓ random sample testing of herds by government veterinarians; |
| ✓ the establishment of a specialised research, TB investigation unit, epidemiology and laboratory services; |
| ✓ continuation of a pre-movement test; |
| ✓ improved control of dealers; |
| ✓ depopulation of problem herds; |
| ✓ improved cattle identity tags and checking of cattle at factories and marts; |
| ✓ extended restriction and de-restriction; |
| ✓ the establishment of local ERAD committees and a TB farm advisory service; |
| ✓ a farmer awareness campaign; |
| ✓ improved post-mortem procedures during factory surveillance; |
| ✓ establishment of badger research and control services; |
| ✓ improved control of slurry/factory waste; |
| ✓ control of calf movements; |
| ✓ attention to the cleaning of trucks of the reactor collection service; |
| ✓ improved District Veterinary Office (DVO) procedures |

Table 1

**Progress in recent years**

A detailed review of scientific and policy advances in the Irish TB Eradication Programme in the period 1988 to 2005 was presented at the *M bovis* IV meeting in Dublin (More and Good, 2006). In this paper, I will present the more recent advances in regard to scientific research, policy changes and programme supports.
Data handling support systems
A key aspect of any modern eradication programme is the type of Information and Communication Technologies (ICT) used to support the programme. With the availability of good quality on-line information, many controls are much easier to implement. Similarly, with ready access to good data, analysis of performance and outcomes of various elements of the eradication programme is greatly facilitated. The Irish TB programme has benefited from good data systems for a number of years but significant updates, improvements and integrations have arisen in recent times:

Animal Health Computer System (AHCS)
AHCS was developed as part of a significant investment by the Department in the modernisation of its general ICT capabilities. It came fully into service in 2005, expanding the functionality of the previous, standalone Nixdorf Animal Health computer system, which was designed for the management of TB only and had been in operation since 1986. AHCS is a modern fully networked, 3-tier internet-based Oracle database, providing a much greater range of functionality than the previous system. It allows staff to access information in respect of all herds and animals throughout the country. AHCS records the full details generated by the 9 or 10 million animal tests carried out annually on the cattle population of over six and a half million animals, originating from 119,000 herds. The system serves some 1,300 internal users and a further 1,500 external users, located in private veterinary practices (Dept. of Agriculture, 2006). Core field data is usually captured electronically at source and transmitted electronically to the management system. AHCS augments and shares data with other computer systems particularly those relating to cattle traceability and farm location. It is fully integrated with the Corporate Customer System (CCS), the Department’s Financial System (SAP), the Animal Identification and Movement system (AIM) and the Agriculture Field Inspection and Testing system (AFIT), and is available to all internal users in all Department sites and offices.

Animal Identification and Movement System (AIM)
Ireland has operated an individual animal identification and tracing system for cattle since the 1950’s based on individual ear tags and accompanying cattle identity cards. In compliance with EU legislation, Ireland developed a computerised Cattle Movement Monitoring System (CMMS) containing all animal identity and location information, and this has been fully operational since January 2000. A major upgrade of the CMMS system onto the Department’s strategic ICT platform has now been implemented, and this fully integrated internet-based system has been re-named the Animal Identification and Movement System (AIM). This provides a generic identification and movement system capable of recording the births, movements and disposals of a number of animal species. AIM manages the tag numbering system for cattle and sheep and is therefore on-line with all approved tag vendors. AIM is also on-line in the livestock marts, export assembly points and export-approved slaughter plants across the country. Each year it records approximately 2.1 million calf births, all 1.6 million movements into and out of commercial registered mart premises and processes circa 470,000 animal movement forms arising from direct farm-to-farm movements. The system generates full herd profiles before any herd inspection or test is undertaken and such profiles are available to keepers over the Internet.

The Trace-Onward and Epidemiological Investigation Tracking System
The Tracing Onward Tracking System (TOTS) was developed as an aid to the management and tracking of animals originating from TB, brucellosis and BSE-infected herds which move to other herds where they may pose a disease risk. At-risk animals in infected herds are logged onto the TOTS system for tracing through the national network of District Veterinary Offices (DVOs). Within each DVO, a list of work in progress is maintained and checked on a regular basis. The system prints any follow-up documentation required and provides for the recording of the outcome in respect of each animal tracing completed. In addition to the core tracing functions, the system also logs contiguity visits for TB, Wildlife Unit survey requests and the allocation of wildlife unit surveys to field staff. The functionality of the TOTS system has now been enhanced and integrated into AHCS.

**Herdfinder**

This is a GIS facility based on the Department’s main spatial mapping system developed originally for use by farmers in submitting their EU applications for the Single Farm Payment support programme. It is software that permits Department field staff to view the geographical relationship between an infected index herd, contiguous herds and topographical features. It is also a web-based system capable of serving several thousand users simultaneously and linked to other components of the strategic ICT platform such as AHCS. Herdfinder also forms the basis for the Wildlife Unit software which manages the mapping of badger setts throughout the country.

**Measuring performance in the context of the ‘statement of objective’**

Data systems such as those described here, in addition to facilitating routine operations management, provide for the use of any number of indices for measuring performance and outcomes of the TB programme. The measures used routinely include the following:

- Percentage of herd tests completed within the year;
- Number of reactors;
- Number of Visible Lesion reactors at routine post mortem
- Reactor animals per thousand animal tests (APT);
- Herd disease incidence
- Disease-free herds as a percentage of all herds;
- Animal disease incidence;
- Reactor animals per thousand population (RPT);
- Duration of restriction;
- Average number of reactors per restriction;
- Singleton breakdowns as a percentage of all breakdowns;

Some measures are best suited to assess the effectiveness of surveillance (e.g., herd incidence, percentage of herds remaining disease free) while others give a perspective of the effectiveness of the controls used once the infection is detected (restriction duration, number of reactors per restriction, % singleton breakdowns, numbers of reactor retests, inter episode interval, repeat restrictions). The Irish eradication programme applies different measures as appropriate for assessing both surveillance and control using the on-line data sources

As such the programme managers are well informed of change in disease levels. The real issue is in communicating this information to the stakeholders and public at large. Ultimately reactor numbers and the number of herds restricted per annum are seen as the primary indices of disease. These measures in turn are directly related to the
volume/frequency of testing and the specific performance of the test. In Ireland we have used an un-interrupted standard EU mandated annual screening programme since 1992. Variation in total testing volumes has been small and arises solely as a consequence of the disease revealed in the primary screening programme. In addition we have standardised the tuberculin test and its implementation. Our primary index of disease at animal level continues to be the reactor number per thousand tests carried out (APT) as this takes account of testing volumes. However reactor numbers in the bovine population tend to cycle within a fairly well defined range over a period of approximately three years. Such variation is natural within any biological system and possibly more so in one where there are key external drivers of disease that are not directly linked to the annual programme measures and also where one is dealing with a slow developing disease. Thus the temporal position of the annual programme within the overall periodicity of the cycle is often the biggest single factor affecting change in year to year outcome. No matter how this is explained the media will focus on year to year changes and inevitably this gives rise to alternating reports of ‘progress’, ‘regress’ and ‘steady state’ every other year.

This problem was again looked at in the recent Value for Money and Policy Review carried out on the Irish Programme (O’Flaherty, 2008) in the context of assessing programme performance against the stated interim objective. The author proposed that the stated objective of the programme, ‘to control bovine tuberculosis at levels consistent with maintaining trade in bovine animals and their products, at minimum cost to the Exchequer, while overcoming the constraints to eventual eradication through investment in research and technology’, should be clarified with the following statement. ‘As long as the constraint imposed by the existence of an infected wildlife reservoir continues to exist, progress towards the interim objective will be considered adequate if the herd incidence, the absolute number of reactor animals and the number of reactor animals per thousand animal tests (APT) continue to follow a declining trend as represented by the respective five-year exponential moving averages. The interim objective will be formally reassessed in 2013, at which time it is expected that research into badger vaccination will have reached a point that will enable projections to be made as to its likely long-term impact on bovine tuberculosis’. The use of five year moving averages applied to three standard indices of disease will undoubtedly provide a very useful yardstick for measuring future progress for policy makers. Whether we can persuade the media or farmers to adopt moving averages remains to be seen.

**Wildlife disease control strategy**

**Vaccination development programme**

The results from the East Offaly Project (O’Máirtín et al, 1998) (Kelly et al, 2008) and subsequently the Four Area Project (Griffin et al, 2005) demonstrated the constraining role that wildlife infection was having on bovine TB eradication. While infection arises in other species in Ireland, most noticeably in wild deer, the badger is considered to be the primary wildlife source acting as a maintenance host for the disease. The opinion expressed by Morris and Pfieffer in 1990, based on the observed levels and geographic distribution of disease in badgers, was that the infection was self sustaining within the species and that it had transmitted to the badger at least thirty years previously. More recent studies based on the Four Area Project data and using restriction fragment length polymorphism strain typing techniques have demonstrated that cattle and badgers tend to have the same strains in geographic areas indicating cross-over of the disease
between species while there is also spatial clustering within species (Olea-Popelka \textit{et al.}, 2005).

By 1994 it had become clear that the TB eradication programme now faced two separate challenges. It had to address eradication in bovines in parallel with a programme to eliminate the disease in badgers if progress was to be achieved. To attempt one without the other was not logical. The decision was taken at policy level that a vaccination programme for TB in badgers was the only plausible option available. The reasoning was simple. Badgers were a protected species. Existing control and eradication measures in bovines had been proven to be capable of significant progress and possible eradication in the absence of badger infection. Vaccination of badgers offered a potential end point to the programme whereas the alternative scenario, i.e., the vaccination of bovines, would deal only with the effect of wildlife disease and not address the cause. The expectation was that, if badger vaccination was successful in preventing or significantly reducing disease transmission between badgers and subsequently between badgers and cattle, the existing comprehensive control and surveillance programme for cattle would then be capable of bringing about eradication. The fox rabies vaccination programme in Europe had proved highly successful despite all of the initial reservations and this example provided the model (Pastoret and Brochier, 1999). The expectation was that, if badger vaccination was successful in preventing or significantly reducing disease transmission between badgers, the fox rabies vaccination programme in Europe had proved highly successful despite all of the initial reservations and this example provided the model (Pastoret and Brochier, 1999). The expectation was that, if badger vaccination was successful in preventing or significantly reducing disease transmission between badgers and subsequently between badgers and cattle, the existing comprehensive control and surveillance programme for cattle would then be capable of bringing about eradication. Modelling had suggested that it would not be necessary for the vaccine to provide full protection to the badger to have significant effect on the overall programme. (Aznar \textit{et al.}, 2010)

The question then was one of feasibility. A study was undertaken in 1994, consulting with experts worldwide, and this concluded that the strategy was feasible (Report of Steering Committee, 1994). Arising from this, a three-day consultation meeting was arranged with experts including many of those consulted during the feasibility study. The report of this meeting effectively set down the roadmap for the development of a vaccine for use in badgers (Report of a WHO/FAO/OIE Consultation on Animal Tuberculosis Vaccines, 1994).

The key issues to be addressed in the first instance were the fact that very little was known about the pathogenesis of the disease in the badger, nothing about the immune response and there were no diagnostic tools to work with. After that it was determined that BCG Pasteur strain would be the reference strain against which any other candidate vaccine would be evaluated. To carry out the necessary research work on the target species, evaluate the candidate vaccine and deal with the licensing issues the minimum time scale was considered to be at least fifteen years. At the political and economic level most policy horizons are significantly shorter than this. However in this instance the setting of such a long term goal publicly, which was considered plausible and politically acceptable, allowed for the implementation of interim control strategies that might otherwise have met with greater resistance. Of equal significance was the fact that there were no other viable options available

The initial captive badger facility, BROC I, was developed in 1997 and proved to be very successful in fulfilling its purpose. In more recent times the relocation and building of a new Veterinary Laboratory complex near Dublin has required that a new captive facility be built and work will continue there. The current phase of the badger TB vaccination programme commenced in 2001 and has involved parallel laboratory (pen) and field studies. The nature of these studies, their inter-relationships, and the time span over which they were expected to take place are represented graphically in Figure 1.
Forensic pathology
The use of very detailed post-mortem examination techniques on both experimental and field animals from ‘hot-spot’ areas has demonstrated (1) the extent to which badgers can accommodate this disease, (2) the distribution of infection within the body and (3) the very high incidence of the disease in affected wild population. In a recent study (Murphy et al., 2009) enhanced post-mortem procedures detected infection in 36.3% of feral badgers removed under licence as against a 12.1% detection rate using standard techniques. Two thirds of infected animals had no visible lesions of the disease.

Challenge trials
A suitable M. bovis challenge model was developed for use in the badger (Corner et al., 2007, 2008 a) and BCG Pasteur vaccine was shown to induce a significant protective effect in badgers using both the subcutaneous and mucosal routes of administration (Corner et al., 2008b) The level of protection provided to badgers is considered significant having regard to the challenge doses used and equals or exceeds that seen in comparable studies on brushtail possums in New Zealand. Similar levels of protection were demonstrated subsequently with the use of an oral vaccine preparation (Corner et al., 2007)

The field trial
The field vaccination trial, which is a critical component of the vaccination programme, is a substantial undertaking that will involve the administration of an oral vaccine preparation to a population of some 300 badgers over a large area for a period of at least 3 years. This study is running one year behind the original schedule and will now commences on the 1st September 2009. Badgers will be trapped twice per year over the duration of the trial and their disease status evaluated. At the end of the trial they will be euthanased and subject to detailed post-mortem. The field study design involves the creation of a vaccination gradient whereby one third of the trail area will be subject to 100% vaccination, the mid third will receive 50% vaccination and the badgers in the remainder will receive a placebo. Infection pressure is deemed to be uniform at the outset. Changes in disease incidence in the badger population will be monitored over time. Further details of the design of this trial will be presented elsewhere at this conference (Aznar et al, In Press).

Consideration is also being given to undertaking separate, smaller badger vaccination trials with the objective of providing information on the other aspects of badger vaccination, including its empirical contribution to reducing levels of bovine tuberculosis in cattle.

In the event that the vaccination trial is successful, incorporation of field vaccination of badgers into the national Bovine TB Eradication Programme – the culmination of the various research elements described above – is scheduled to commence, at the earliest, in 2013

Other studies
In parallel with badger vaccination trials, ancillary work continues in a number of related areas, including: badger movement studies (Kelly et al., 2009), (Sleeman et al., 2008), (Sleeman et al., 2009a); adverse reactions to BCG (Murphy et al., 2008) and capture injuries to badgers (Murphy et al., 2009).

**Modelling**

The use of the BCG vaccine will reduce the level of transmission between infected and naive badgers and ultimately to cattle but it is unlikely to break the transmission pathways completely, at least in the short term. However, initial modelling suggested that significant benefits could still be achieved with only moderate vaccine efficacy. Detailed modelling studies are now under way with colleagues in Wageningen University to determine how different vaccine efficacy scenarios can be used to best effect in field use.

**Badger diet and bait studies**

As with fox rabies, it is intended that vaccine will be delivered in oral baits that are highly specific to badgers. To inform bait design, the diet of a representative sample of Irish badgers was examined (Cleary et al, 2009). Overall the composition of the diet of Irish badgers differed significantly from that reported for badgers in UK studies. In particular insect larvae comprise a significant component of the diet in spring and autumn. The breath of diet and the foraging habits of badgers differ significantly by season of year. Such differences and indeed geographic differences in badger diet between Ireland and the UK may require the development of a range of bait attractants for use in different circumstances. Studies on bait flavours are in train.

**Culling strategy**

Investigation of the possible role of wildlife in TB breakdowns can be traced back to the mid 1980s to a number of small-scale field investigations, including those in Counties Galway and Cork that predated the East Offaly and Four Area Badger Projects. The scale of government intervention in relation to the wildlife reservoir increased significantly following the Social Partnership Agreement of 2000 (Programme for Prosperity and Fairness). Under the terms of this agreement, the objective of reducing the incidence of TB by 50% over the following four years was adopted by the parties involved, and a number of specific measures aimed at making this a reality were put in place. Responsibility for the implementation of these measures was vested in the Wildlife Unit, which was formally established within the Department of Agriculture, Fisheries and Food in 2002. Its remit, subject to licensing by the National Parks and Wildlife Division of the Department of the Environment, is to implement the badger control policy agreed through Social Partnership in those areas of the country where, following a thorough epidemiological investigation, it is considered that the local badger population may be contributing to the persistence of tuberculosis in cattle in the area. The Unit is also responsible for undertaking field trials in support of the badger vaccination strategy.

Badger capture is concentrated on those areas of the country where the greatest numbers of reactors in cattle occur; previous studies show that approximately two-thirds of all standard reactors are found in approximately one third of the agricultural land. Within these areas, [Figure 2], badger capture is limited to 60% of the agricultural land, while, in the remainder of the country, the upper limit for badger capture is 20%. Overall, badger capturing is limited to 30% of the agricultural land area of Ireland (O’Keeffe, 2006). The aim of the strategy outlined above, which has been in place since January 2004, in combination with ongoing research into badger vaccination, is to permit the
business of farming to continue in tandem with the conservation of a healthy badger population nationally.

Figure 2 Areas of country with highest levels of TB in cattle

![Map showing areas with highest levels of TB in cattle](Image)

Source: DAFF (Wildlife Unit)

In December 2005, the total land area under treatment was 4,022 km$^2$ (8.1% of agricultural land), while the corresponding figure in December 2008 was 10,960 km$^2$ (22.07% of agricultural land) (O’Keeffe, pers. comm.). The number of badgers removed in 2008 was 7,284. This must be set against a recent estimate for the total adult population in the republic of Ireland of 84k (Sleeman et al., 2009b)

**Effect of badger removal**

In the United Kingdom there has been considerable debate on the effects of localised culling. This followed the results of the Randomised Badger Culling Trials (RBCT) where disease levels in the bovine population were observed to increase in areas adjacent to reactive culling (Donnelly *et al.*, 2007). In Ireland where such a culling programme has been run at farm level for many years there is an increasing body of evidence suggesting a different outcome. In a study in County Laois a survival analysis was conducted on the herds surrounding some 122 individual badger removal operations that had taken place between 1989 and 2005 (Olea-Popelka *et al* 2009). There was no evidence of a negative effect. Herds were categorised into five levels depending on distance from the index herd where the badger removals had taken place. There was no difference in the hazard ratio for the index herds after badger removal and for all other category of herds at varying distances from the index herd the hazards were lower than in areas not subject to badger removals. In another study of the effect of varying levels of population control on the prevalence of tuberculosis in badgers, proactive culling led to a reduction of disease in the re-emergent badger population while reactive culling showed no consistent change in the prevalence of infection in the badger population (Corner *et al*., 2008c). In a long-term observational study of the
impact of badger removal on herd restrictions due to bovine TB carried out in Co Offaly over a sixteen year period proactive culling lead to a progressive reduction in herd incidence in each successive year (Kelly et al., 2007). There was no evidence of increased disease risk in associated areas where reactive culling was used.

The explanation for this difference between the Irish experience and the results of the RBCT remains speculative but there are a number of potential explanations. Badger densities are lower in Ireland. The effectiveness of the culling procedures employed differ significantly both in terms of methodology and frequency, estimated at 30% – 70% in the UK and 80% in Ireland. Interference is less in Ireland and conversely compliance and participation levels are much higher. In both of the major proactive removal studies, the EOP and the Four Area Studies, the permeability of boundaries was taken into account in the experimental designs. Finally the interpretation of the RBCT results have been questioned in regard to causality (More et al., 2007).

In any culling operation involving a population of diseased badgers, if 30-70% of the badgers are to be left behind, it is inevitable that there will be social adjustment and that the movements associated with this could give rise to increased disease incidence. Any assessment of the benefits of culling per se must critically determine if culling in its correct meaning has taken place in the first instance.

**Diagnostics – test performance and quality controls**

The tuberculin test remains the primary diagnostic tool used in the TB eradication programme. This pertains both for legal reasons and also because of lack of progress in developing alternative screening tests. In the context of modern farming practice and in particular with the advent of part-time farming the tuberculin test is demanding both in terms of time and labour resource. It is susceptible to operator variance and on occasion fraudulent manipulation. Tuberculin production is somewhat problematic being as much an art as a science and standardisation of the product is difficult to achieve and validate.

The Irish programme has used Lelystad tuberculin for over twenty years. Both bovine and avian tuberculin is formulated to provide 3000 i.u. and 2500 i.u. per dose and these are matched. Protein content and guinea pig assay are used routinely but these provide only a proxy assurance as to quality as evidenced by the results of the routine potency assays carried out on naturally affected cattle derived from the programme.

**Tuberculin potency testing**

Ireland is possibly the only country where routine potency assays are carried out in naturally sensitised animals gathered from infected holdings. For the purpose of such assays production batches of tuberculin are pooled such that the assay itself is more representative of the total tuberculin supply. One particular benefit of such quality control of the tuberculin along with the implementation of a uniform and consistent annual programme of testing is the ability it affords to measuring programme performance over time. With two of the key variables for the identification of reactors controlled any changes in observed disease incidence are more likely to be real.

**Quality control across the programme**

However there are many operational factors that can affect the outcome of the programme apart from disease incidence. Thus quality control over a broad range of
programme elements, including diagnostics, is a core function for the management of the programme in Ireland (Duignan et al., 2010).

**Blood based tests**
While tuberculin testing continues to be the primary surveillance and disease clearance test used in Ireland a number of ancillary tests have been used over the years with a view to improving (1) the overall sensitivity of the testing protocol within identified diseased herds and (2) occasionally to evaluate specificity in situations with high levels of non-specific reactions or where interference with the tuberculin test is suspected.

In terms of programme management there are many potential advantages, both economic and technical, for a blood based test over a skin test including (1) the requirement for a single visit/round-up of the herd, (2) simplified field procedures that are less demanding on facilities and human resource, (3) the avoidance of desensitisation and therefore the ability to repeat test at optimal intervals in diseased herds, (4) standardisation of test results, and (5) much reduced susceptibility to third party interference. Hence the goal of developing a blood based screening test remains to be fulfilled.

**γ-interferon test:**
The only routine ancillary test in current use is the Bovigam® γ-interferon test. Its use is confined to heavily infected herds due to its relatively low specificity. In combination with the Tuberculin test it provides high sensitivity and has proven very successful in reducing the time taken to clear infected herds and in ensuring that fewer infected animals are missed. This approach has proved to be as successful as whole herd depopulation such that the latter strategy is rarely used in Ireland nowadays.

**Tests based on antibody responses - Multiplex ELISA Immunoassay**
For years many researchers have sought to develop an improved antibody test that was based on the use of one or two key antigens that would provide high specificity and good sensitivity. In the last twenty years many candidate antigens have been identified. However individually they tended to detect the presence of disease during defined phases of the course of the disease thus limiting their overall sensitivity. No single antigen was identified that could elicit a useful response over the full course of the disease.

The approach taken by Enfer Scientific (Whelan et al., 2008) was to combine a series of different antigens in a single test described as a ‘multiplex chemiluminescent immunoassay’. It was claimed that thirteen antigens used simultaneously in a single ELISA test can provide for a high level of sensitivity and specificity over a much wider time frame of infection. The individual responses are read electronically and collectively subject to a computerised macro analysis such that maximum sensitivity and specificity can be determined. Initial sensitivity and specificity values are reported to be 93.1% and 98.4% based on panels of bloods of known status. Also the spectral range is reported to be good.

More recently a comparative trial was undertaken between the Tuberculin SICCT (Lelystad), the γ-interferon (Bovigam®) and the multiplex ELISA (Enfer) on 4831 animals from 189 herds (Clegg et al., 2010). This work will be presented elsewhere during M bovis V. The test promises to be a useful ancillary test and may have the potential for use as a screening test with further refinement. Currently an extended field trial involving 1000 herds and up to 100,000 animals using the Enfer multiplex test is
being carried out in parallel with the routine tuberculin test programme in targeted herds. The results from this evaluation should be available in 2010.

**Pre-movement testing**

Movement controls are an integral part of any disease eradication programme. This relates both to restriction of movement between herds of different disease status and to pre-movement testing of animals coming from clear herds. Ireland operated a TB pre-movement test for all animals for both internal and export movements until 1996 at which point the test requirement for internal movement ceased. In the context of a control programme where disease risk was relatively uniform throughout the country, where every herd was tested at least once per year and where the pre-movement test had a much higher unit cost per animal than that associated with full herd testing it was argued by the farmer stakeholders that the economic justification for this measure was poor. Pre-movement testing had contributed 6% - 7% of all herd restrictions over many years and in most cases the severity of the outbreak was low with only small numbers of additional reactors being generated by the introduced animals – a factor attributable to the frequency of the annual herd test (Hahesy, 1996). In the outturn there was no significant change in the disease levels after this control measure was removed in 1996.

Nevertheless it is contended that pre-movement controls will again become important in the context of the final drive towards eradication. In this context an assessment of the potential infection control benefit for Ireland from pre-movement testing was undertaken (Clegg et al, 2008). The study involved looking at the subsequent test results of animals that had moved from recently de-restricted herds and similarly at the potential involvement of recently introduced animals in newly restricted herds. Again the study confirmed that approximately 6% to 7% of all herd breakdowns are potentially attributable to animal movements and it calculated that 15.9 herd restrictions could be avoided for every additional 10,000 animal tests undertaken as part of a pre-movement policy. Given that the disease is subsequently detected and controlled at the annual round test the economic return here is not justified. The study also described other scenarios where a more strategic use of pre-movement testing in ‘high-risk’ herds could be justified and such policies are under consideration. In the final drive for eradication it is expected that some form of pre-movement test will inevitably have to be introduced and especially in circumstances where the frequency of herd testing decreases below the annual level. A conventional regional or zonal approach for the implementation of such measures may not equate with the risk differential for herds and so these controls may be more strategically targeted at specific high risk herds or herds within small areas of known high disease risk.

**Projections for the next five years**

In 1991 Liam Downey identified three constraints to eradication of TB in Ireland (Downey, L. 1991). These included the need for a computerised animal movement control system, the need for a vaccine to control TB in badgers and/or cattle and finally the need for a laboratory based test for bovine TB. In line with the recommendations of Morris and Pfeiffer, he advocated an interim control strategy while investing heavily in the R&D to overcome the identified constraints. In 1994, the most difficult and protracted of the challenges facing the programme manager was the development of a vaccine for use in badgers.
Fifteen years further on we are much closer to re-launching the programme as an eradication programme. The data handling and animal movement recording issues have been comprehensively addressed. Good ancillary blood tests are available to supplement tuberculin testing and the prospect of a blood based screening test for general use is much improved. BCG Vaccine has proved effective in providing protection to badgers challenged experimentally with TB. Based on the research completed to date and that in progress, there is now a very real prospect that we will have an effective vaccine for field use in wild badgers before 2014. We are moving steadily towards the final phase of eradication. The outcome of the Kilkenny badger vaccination field trial over the next three years will determine if this last technical constraint is finally to be removed and if the objective of the programme can be re-stated to what it was before 1992 – i.e., the eradication of bovine tuberculosis.

Allowing that we do have a successful outcome to the field trial, the final challenge in a re-launched eradication programme will be political – i.e., to persuade the farmers and other stakeholders that it is necessary for them to take back a higher level of ownership of the programme as in the 1988-1992 ERAD model. Additional controls such as pre-movement testing, enhanced clearance procedures for high risk herds and a renewed focus on bio-security will become important in the context of eradication and for these measures to be effective farmers will have to re-engage fully with the programme.

**Conflict of Interest Statement**

The author has no conflict of interest.


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