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Tuberculosis in Ireland

Review of the literature on Bovine Tuberculosis in Ireland with a focus on its Eradication

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List of Abbreviations

bTB – Bovine Tuberculosis

IFNy- Interferon Gamma

GIT – Gamma Interferon Test

OFS- Official Free Status

1. Introduction

In my paper I shall focus on a particular type of tuberculosis which is called Bovine tuberculosis and the several problems surrounding this topic in Ireland both in the past and present and why it has become such an important focus in Ireland for eradication of the disease. Bovine Tuberculosis (bTB) which is caused by a bacterium called *Mycobacterium bovis* or *Mycobacterium caprae* causing the disease to become highly infectious (www.daera-ni.gov.uk).

With regard to cattle, it is a respiratory disease predominantly being most commonly found in the lymph glands of the throat and lungs. The bacteria which cause the disease are passed out through the respiratory system by breathing or discharge.

The Department of Agriculture have recognised the devastating effects of the disease on cattle and farmers livelihood with herds being completely shut down. To give an insight into the seriousness of the problem in Ireland and the incidence of bTB, I will refer to some of the recent figures from the end of the September 2019 until September 2020 which saw 4,492 herds being restricted. During this same time 21,289, reactors were identified by skin testing and Gamma interferon testing (GIT). By the end of 2020 herd incidence was 4.25% (www.bovinetb.ie).

Figure 1 below highlights the new restrictions enforced from September 2019-20 and also shows the areas in Ireland that are most affected by bTB like the north east and other counties such as Clare, Cork, Galway and Wicklow.

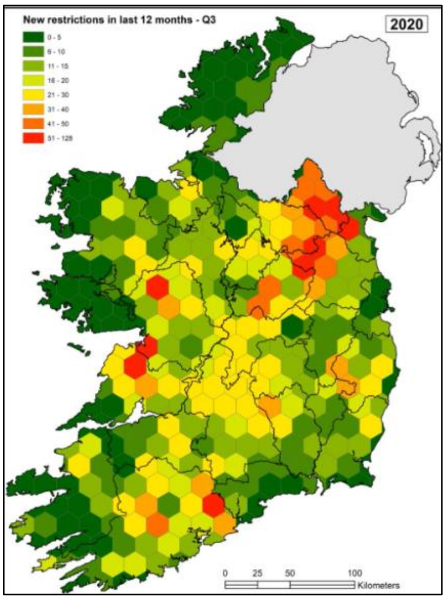

Figure 1. New restrictions in Ireland to the end of September 2020 from September 2019

2. History of Human Tuberculosis in Ireland

As early as the late 19th century tuberculosis was an endemic in Ireland being responsible for more deaths than any other single cause. As there was no medical cure for the disease, there was little or no success with different treatments (Carthy, 2015). It is William Wild (1815-1876) who documented the earliest records of tuberculosis in Ireland, as they show that the basis for an epidemic was firmly established before 1700 . (Breathnach & Moynihan, 2011)

Scientific knowledge about its spread was limited until Robert Koch's ground breaking lecture on tubercule bacillus in Berlin in 1882. Then with the tuberculin test, the pathogen yielded in 1907 the development of the bacillus Calmette-Guerin (BCG) vaccine.

Several measures were taken in Ireland such as signs and warnings about the dangers of spitting, public health awareness campaigns (Figures 2 &3) and advice on good respiratory hygiene with respect to coughing, sneezing and spitting.

Sanatoriums were also set up and people stayed there indefinitely until they were well but not cured as there was none at the time. There were also possible consequences of relapse.

Figure 2 & 3. Public health campaigns issued by the Irish government in the 19th century to prevent the spread of TB

For early Irish health officials, from early 1900's Bovine Tuberculosis was essentially a public health problem mostly attached by inspection to protect consumers from ingesting meat and milk from livestock affected by TB. Anxiety grew about the concern and interest that bTB was having on food safety, child health, national efficiency (Overy & Tansey, 2015).

For the people of Ireland, it was a very trying time especially with infants and children particularly susceptible to infection from animal sources, one of which was drinking unpasteurised milk. This was very common in Ireland as the milk source was directly on the farm. At one time it used to be said that "child TB equals bovine TB" (Kleeberg, 1984).

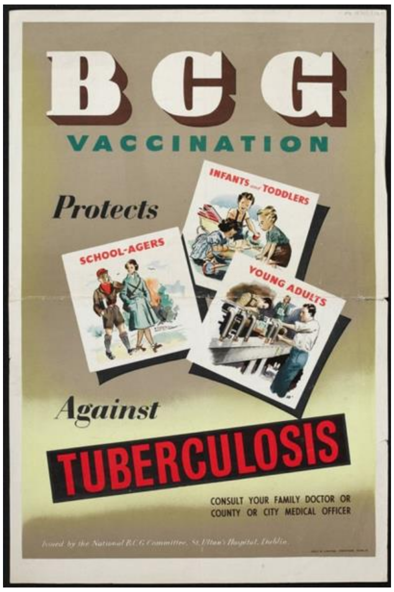

Fig 4. BCG vaccination poster circa 1950-1962 (Ireland)

As astonishing figure of 40% of extrapulmonary TB used to be due to infection from cattle in certain countries such as Ireland in years gone past (Kleeberg, 1984).

All these factors drew a progression towards the idea of eradication of bTB. Apart from the implications and factors contributing to human health, it was also hugely impacting the health and productivity of the country's cattle stocks. It had become a vital necessity for the maintenance of export of store cattle between Ireland and Britain, a huge part of our exports in 1954 being 20% of the total value of our entire export trade.

Also the fact that an eradication scheme had been started in Britain in 1935, and despite war and other factors, they were able to certify 50% of their herds clear. The day would come where Irish cattle would be cleared as well (Watchorn, 1965).

In Ireland the bovine tuberculosis eradication began for farmers in 1950 and became compulsory in 1962, and encouraging the program were production losses in cattle, human health problems and a desire to trade in live bovine animals (Good, 2006).

3. Transmission

The transmission of tuberculosis is quite easy since it is airborne and can prove to be fatal in many cases. Cattle are so much more easily affected by the respiratory tract, that even heavily contaminated pastures do not have such a huge impact as opposed to when the cows enter the cow shed. The bronchopneumonia focus may progress or remain latent, but it is different to human primary lesions, which usually don't ever heal completely. So, therefore each rector must be considered as infectious. Pulmonary spread is bronchogenic - lymph nodes being the main target. Haematogenous dissemination is ~~not~~ common and the more~~but some of the more~~ advanced stages can see 20% of cows or even 5% of all tuberculous cows develop uterine lesions, usually through pregnancy from the bloodstream or from an infected bull on regular occasions ~~occasionally~~ (Good, 2006)

Human and bovine TB share similar reasons and immune responses which bring colonisation and spread to the same organs, namely the lungs and lymphatic tissues. Just as in humans, aerosolised bacteria are the most common source of infectious organisms in cattle and the primary site of an actual infection is the respiratory tract (Alvarez, 2009).

With one of the most confined routes of infection being the respiratory system, a single droplet of bacillus inside a nucleus is already sufficient to provide infection within a bovine lung. Studies have revealed that a large proportion of tuberculous cattle excreted *M. bovis*. The route in which cattle to cattle transmission occurs is through inhalation and respiratory excretion (Menzies, 2000)

Strong evidence also suggests that in addition to protecting animals from the lethal effects of TB, T-cells of the body also contribute to the destruction of lung tissue and can therefore also contribute to host-to-host transmission (Ernst, 2012).

Shedding of *M. bovis* in milk, urine and faeces is really significant~~insignificant~~ ~~in more developed countries~~ as calves and humans are infected with M. bovis per os. (Hardie & Watson, 1992). So, therefore it would suggest that the excretion of *M. bovis* is less important to the transmission between cattle as alimentary lesions being less frequent than of course those in the respiratory tract (Menzies 2000).

There have been some reports of transmission of *M. bovis* through faecal excretion but it is thought to be mainly because of exudate being consumed from lesions in the lung (Menzies 2000).

From a histopathological point of view, bTB spreads from animals not just with typical lung lesions but indeed from those considered to represent a latent like persistent infection without any visible lung lesions (McIlroy, 1986). This would give a strong argument, that the immune response does affect *M. bovis* persistence, although this argument should be supported that there is a latent bTB phase by post mortem analysis of samples from cattle with a positive tuberculin skin test and IFNy test reactors. Large lesions, mainly in the tracheobronchial, mediastinal and retropharyngeal lymph nodes are usually found (Taylor, 2007).

3.1 Routes of Natural Infection

Cattle can have udder infections, being more uncommon with just 1-2% reactors having lesions within the udder (Hardie & Watson, 1992).

Consumption of contaminated food and water is considered to be the next most common route of infection to the respiratory infection (Pritchard, 1988). If a cow on a pasture or in a farmyard is salivating a lot, in the case of an infected animal, would leave traces of saliva on the grass which would cause other cows grazing to be infected as well. Also cows coughing uncontrollably should be in isolation to prevent more potential infections (Sichewo, 2020).

Cattle can also become infected by the movement of infected animals into previously clear herds. Contact with other infected animals at common feeding points and watering areas could also lead to infection of a healthy animal.

Farmers also sharing machinery such as cattle trailers, slurry spreaders, where the mycobacterium is especially persistent (slurry). The sharing of crushes, another farming equipment all pose a potential risk of infection. The transport of animals with unhygienic or contaminated lorries is also a common factor for spread of disease. (www.bovinetb.ie)

Recent controlled studies in Ireland have identified several risk factors that are closely related with bTB, herd breakdowns. These include the occurrence of bovine TB in contagious herds, on the surrounding areas, herd size, the purchase of cattle and the most popular identified risk for herd-to-herd transmission included movements and trading, where general trading or purchase from market or herds in hotspot areas or from infected herds (Skuce, 2012).

3.2 Transmission from Animals

Mycobacterium bovis have a very broad range of host of all known pathogens has been reported to be found in the following species – domesticated and feral cattle, goat, pig, sheep, horse, cat, dog, fox, deer, bison, buffalo, badger, opossum, hare, ferret, wild and feral pig, antelope, Arabian oryx, camel, llama, alpaca, human and non-human primates.

In cattle the main cause of the disease *M. bovis,* is the badger where it acts as the main reservoir of the disease, having self-maintaining infection creating huge obstacles for disease control problems (Menzies, 2000)

Figure 10 gives a better understanding of the different ways bTB can spread.

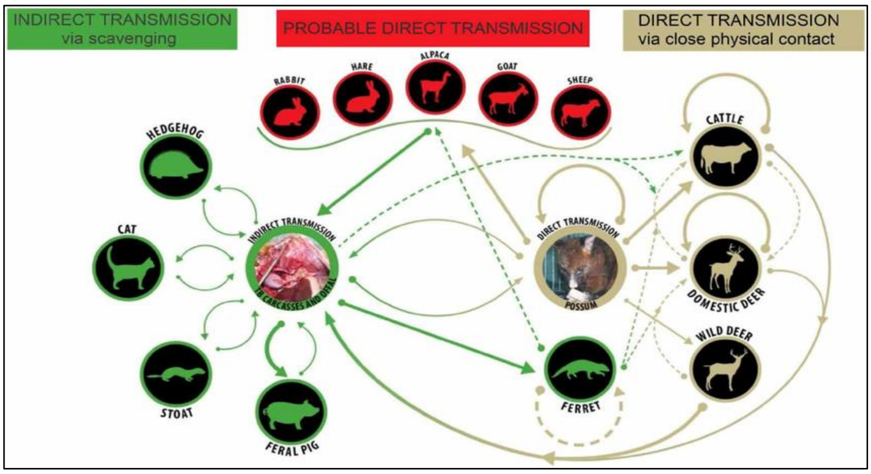

Figure 10. Different routes of transmission of bTB

3.3 Herd Size

Herd size is the most recognised risk factor for bTB occurrence, Dynamic modelling has shown that the increased probability of between animal-to-animal contacts in larger herds could increase within herd transmission (Vial et al., 2015). Studies have shown that the risk of infection when detected in a herd does increase with herd size and a high percentage of such herds are shown to have at least one infected animal. The persistence of the disease could also be caused by factors related to increased herd size such as replacement policy number of premises, and neighbouring herds all of which alone can be associated with the risk of a bTB outbreak (Omer MK et al., 2001).

A great variation has been reported in studies of dairy cattle related to heritability of susceptibility to bTB, these being mainly Holstein-Friesian purebred or crosses in Ireland. The responsiveness to the heritability of the single intradermal comparative cervical tuberculin test was around 16% and 18% of the variance of bTB was measured and along with post mortem evidence, both showed to be heritable (Bermingham et al., 2009).

With regards to the sex of the animal, most studies detail a greater prevalence or incidence of bTB in female cattle, but not all (Kazwala et al., 2001).

Greater differences in resistance may side with beef cattle rather than cattle in the dairy sector since the second one is more homogenous in terms of breed (Bermingham et al., 2009).

The occurrence of bTB infection in dairy cattle aged greater than 3 years was 40% higher than that of beef cattle, although occurrence in young cattle between the age of 0-1 years was also similar. Dairy cattle or milk-producing cattle and suckler cows usually have longer lives than beef cattle, therefore increasing susceptibility of infection of *M. bovis.* Most studies have reported that occurrence of bTB infection increased with age, the most likely reason for this is the result of cumulative exposure and higher probability of contact or delayed exposure to infected cattle, wildlife or environmental contamination. Cattle that are over 36 months may be more responsive to the skin test and can be detected more easily in surveillance tests (Brooks-Pollock et al., 2013).

3.4 Wildlife Transmission

In Ireland, the badgers have been shown to be a leading factor for the spread of bTB to cattle. So therefore, it is crucially important to recognize the risk posed by bTB in badgers. The Department of Agriculture in Ireland have taken steps such as removing badgers from areas where there are severe bTB outbreaks. They have also begun vaccinations of badgers in areas that have been brought under control and also in hotspots where cattle have an epidemiological link to badgers. This can ease the burden on farmers and allow them to concentrate more on good farm management and proper hygiene control to reduce the overall levels of bTB. The Minister of Agriculture in Ireland has announced in February 2018 that the policy of vaccination of badgers is now a compulsory part of the TB eradication program (www.gov.ie, 2018).

Badgers transmit TB to cattle in several ways, such as direct contact between cattle ad badgers, cattle and badgers in pastures, indirect contact between cattle and an infected badger's urine, faeces and wound discharge and also in areas where cattle can access badger setts and latrines or badgers access cattle feed and water trough. There's also strong evidence of badger visits to farmyards and buildings which have access to cattle feed sources. All these factors included would increase the chance of direct and indirect transmission infection (Ward, 2010).

Although cattle are acting as the maintenance host in many countries, the infection has still proved extremely difficult to eradicate once it has become established in a wildlife reservoir. (Palmar, 2013) Badgers' urine presents a very high risk of bTB transmission risk to cattle as it contains up to 300,000 bacilli/ml. The reason for this is that *M. bovis* can cause generalised tuberculosis in badgers meaning they will shed the bacterium in faeces, urine and other discharges. Cattle are always grazing in areas where badgers' urine is flowing away from latrines. This behaviour of badgers urinating and defecating may potentially cause infection and give rise to enhanced infection risk to cattle at certain locations, although it may conversely reduce risk elsewhere (White, 1993).

Figure 7. Irish badger- one of the main hosts of bTB in Ireland

A small number of bacilli are needed to infect cattle through the respiratory system and inhalation of bacteria, is likely to be the main route of infection. This may happen during nose-to-nose contact with badgers, but also while grazing as cattle aerosolize and inhale bacilli on contaminated pasture or forage (Phillips, 2003).

Recent analysis of the randomized badger culling trial would say that in an endemic area, badgers are directly responsible for 6% of bTB infections in cattle, and the overall transmission from badgers with cattle-cattle transmission is 50% (Godfray et al., 2013)

In the case of deer, and the risk of transmission from deer to cattle in Ireland, based on prevalence of infection, the extent of potential bacterial infection and that there would be contact with cattle, semiquantitative assessments suggested that red and fallow deer posed as risk. Although the likelihood of such risk is very small as the deer population has a large variation geographically (Delahay et al.,2007).

3.5 Zoonotic tuberculosis

Mycobacterium tuberculosis is the primary agent which causes human tuberculosis all over the world, although the evidence suggests that the agent of bTB may not be fully estimated in humans as the cause of zoonotic tuberculosis (Olea-Popelka, 2017).

M. bovis is mainly transmitted to humans from cattle through the consumption of cattle products such as non-pasteurized milk, raw meat products, contaminated *M. bovis* lesions and aerogenously (Luciano, 2020).

The occurrence of zoonotic tuberculosis remains uncertain due to surveillance, data and lack of sensitivity in testing and incompetent laboratory techniques. So, therefore the number of people affected and suffering with such public health issues through *M. bovis* may be higher than currently estimated (Olea-Popelka, 2017).

M. bovis is the causative agent of bTB in animals that are used for production of food and it does account for a small scale of human cases of TB in Ireland. Just as in animals, in humans, the preclinical infection can be recognized by use of the tuberculin test. In recent years, the main route of human infection with *M. bovis* in Ireland was through ingestion of raw cow's milk contaminated with *M. bovis* rather than by inhalation. The alimentary route of infection is now very uncommon in Ireland as there is the heat treatment of milk that inactivates *M. bovis*. Great preventative measures were put in place in recent years, such as the well-controlled pasteurization of milk and dairy products, heat treatment of milk. In the case of meat, all animals entering the food chain must undergo ante mortem and post mortem inspection. Cattle must take a tuberculin test 12 months prior to their slaughter. If no test is present, the cattle are restricted for slaughter and they are returned to their farm of origin (www.fsai.ie)

Figure 8. Public Health campaigns in Ireland to prevent zoonotic effect of TB

4. Clinical Signs of Bovine Tuberculosis

bTB is usually a chronic severe debilitating disease in cattle, although it can sometimes be acute and rapidly progressive. In countries like Ireland with eradication programs in place, a lot of the infected cattle are recognized early on and symptomatic infections are common. The clinical symptoms of bTB can take up to months to appear in cattle and infections can also remain dormant for years and reactivation can occur in cattle that in older years. So, in countries such as Ireland it is very difficult to diagnose based on clinical signs alone and most of the cattle are diagnosed through routine testing or found to be diseased at the slaughterhouse (Ramos et al., 2015)

With the early stages of infection in cattle show no clinical signs, we begin to see the cattle's temperature fluctuate as the disease progresses, body conditions begin to deteriorate and signs of anorexia are visible. The lymph nodes become enlarged, mainly the head and thorax's and there is also a persistent cough and dyspnoea with an increase in respiratory rate. The induration of the udder can also occur (Ramos et al., 2015).

Figure 9. General clinical signs of a diseased cow

In some cases, the disease may be mistakenly diagnosed in the absence of proper testing for contagious bovine pleuropneumonia or bacterial pneumonia caused by *Pasteurella* or *Trueperella* pyogenes, inhalation pneumonia, traumatic pericarditis, or chronic liver fluke infestation. This is why a diagnosis should be based on a live animal through skin testing, intradermal tuberculin testing, and a thorough clinical examination (Kleeberg, 1984).

5. Diagnostic Techniques

As previously mentioned, clinical signs can be limited in cattle, so it is through qualified veterinarians, personnel and the farmer's responsibility that early detection of bTB is possible in animals.

5.1 Post Mortem Diagnosis

The pathological or post mortem diagnosis in refrigerated slaughterhouses can prove difficult since carcasses may house pathogens that have similar characteristics to bTB. Such pathogens being, *Actinomyces bovis*, *Trueperella pyogenes* and many others (Ramos et al., 2015. Although it is also seen as a major control point as it has a huge part to play in the identification of bTB in Ireland as well as prevention of human cases of tuberculosis caused by *M. bovis* (Ramos et al., 2015).

Qualified veterinary inspectors and personnel are able to identify the tubercles which are a cause of formation of granulomas or bacteria that are located in the lymph nodes, mainly of the head and thorax. Tubercles are also commonly located in the spleen, liver, lung and surfaces of the body cavities (Ramos et al., 2015).

Figure 10. Disseminated Bovine Tuberculosis lesions seen, calcified and invasive, in lungs of a bull carcass at necropsy

The anatom-pathology analyses are crucial in Ireland for bTB eradication although some negative factors in slaughterhouses are lack of qualified veterinarians and personnel and also lesion detection exhibiting major lack of sensitivity.

5.2 Histopathological Diagnosis

Presumptions can be made on histopathology by examining the acid -fast bacilli by microscopically demonstrating tissues on post mortem lesions. Bacterium or Sputum samples at post mortem level from tuberculosis organ lesions usually in animals and the presence of mycobacteria can be studied by staining with Ziehl-Neelsen and then using light microscopy (Ramos et al., 2015).

Culturing is also a distinctive method of identifying *M. bovis* by isolating it. This can be done if the particular tissue organ has characteristic histological lesions (e.g., Caseous necrosis or multinucleated giant cells) (Ramos et al., 2015) Histopathology offers a major advantage in producing results in two days. It can also distinguish from other non-mycobacterial agents such ad parasites and neoplasia. The histopathology will show lesions that are very compatible to Tubercular granulomas (Varello, 2008).

5.3 Immunological Diagnosis

Immunological diagnosis is based on a delayed type hypersensitivity reaction by using the tuberculin skin test. This indirect method can reveal infections between 3-8 weeks of contact with *M. bovis* and has been used in large amounts since its recommendation by Robert Koch in 1890 (Ramos et al., 2015).

Initially the test was performed with a purified protein derivative obtained from a *M. tuberculosis* strain. However, since the early 60s, the test was performed with PPD gathered from the *M. bovis* AN5 strain. Some of the advantages of this diagnosis are the low costs, high availability and it being in circulation since a long time although this test has some negative aspects such as it is usually able to detect around 40-80% of infected animals with effects of sensitization, genetic background of the animal, incorrect interpretation of results, difficulties in administration and the test being not a 100% accurate (Ramos et al., 2015).

In Ireland, for the complete success of the eradication program, the test needs to be significantly improved so that the test and slaughter policy can be enforced reducing the number of false positive as well as false negative results

These ante mortem tests of cellular immunity are very important as identification of *M. bovis* infection is possible early. The two tests in Ireland are the tuberculin skin test and the interferon gamma test. They are both based on the detection of the early cell mediated immune response in tuberculosis infection. The disadvantage however, in the late stages of the disease would be the immune response decreasing as opposed to a generally increase in humoral immune response. These tests, therefore can give false negative results (Ramos et al., 2015). Sensitivity is a very crucial factor as this is the ability of the test to give a correct identification of an animal as positive. So, to give an understanding, it is more probable that when a test shows a high sensitivity that there will be a lower probability of incorrectly identifying an infected animal as false negative or found not to be infected (www.daera-ni.gov.uk).

The major problem in skin testing is the lack of response of the immune system to the bTB bacteria so early. As the disease progresses and the animal's immune system becomes more diminished, the test has less chance of being successful. Positively, cattle which test positive to the skin test; a very high percentage are likely to have bTB and a small minority of 1 in 5000 will not have bTB. The single intradermal comparative test in Ireland is the most common to be used and is a major asset in the move towards BTB eradication.

Figure 11. Farmer performing Tuberculin skin test

The test is scheduled for an exact date and time notified to the farmer. The vet begins by measuring the thickness of the skin in two places on the animal's neck and then proceeds to inject bovine tuberculin in one area and avian tuberculin in another part of the neck. Tuberculin is a derivative of the purified protein of the *M. bovis* bacteria.

The infected cattle will form an increase in thickness in the skin of the neck where the tuberculin was administered and the swelling can rise to a few millimetres and the lump becomes visible to the vet. The idea of using the avian tuberculin on the other area of the neck is to help distinguish between other bacteria that have similar characteristics to BTB like bacteria. A short time after, usually on the third day, the vet will return and identify the animals who reacted to the tuberculin on his first test visit.

Results clarify that if the thickness of the skin is more than 4mm, where the bovine tuberculin was injected in comparison to the avian tuberculin administration site then this animal is identified as having bTB. Inconclusive results are given in low risk herds with measurements between 1 and 4 mm greater than that of the avian reaction. High risk herds are more closely observed and only short increase of 1mm or more in comparison to the avian injection site which will have a severe interpretation to be given and the animal is also identified as being infected (www.daera-ni.gov.uk).

5.4 Gamma Interferon Test

These are whole blood tests that can help in diagnosing *M. bovis* infection. Blood samples are obtained from the animals and are then taken directly to the laboratory where the samples are revitalized with bovine tuberculin and avian tuberculin which then cause the T-lymphocytes in the blood to produce gamma interferon. Gamma interferon levels are measured in response to both of the tuberculin administration both bovine and avian. If results display that there is more gamma interferon produced by the animals immune cells by bovine tuberculin administration in comparison to avian tuberculin the animal is deemed to be infected with bovine tuberculosis (bTB) (www.daera-ni.gov.uk).

The gamma interferon test has the capability to even detect more than 90% of the cattle infected with bTB. As an in vitro test, it has the advantage of not interfering with the immune system of the animal and repetitive test in the same animal can be used. Also overall objective test procedures and interpretation in comparison to the thermal skin test (TST) would be more accurate (Ramos et al., 2015)

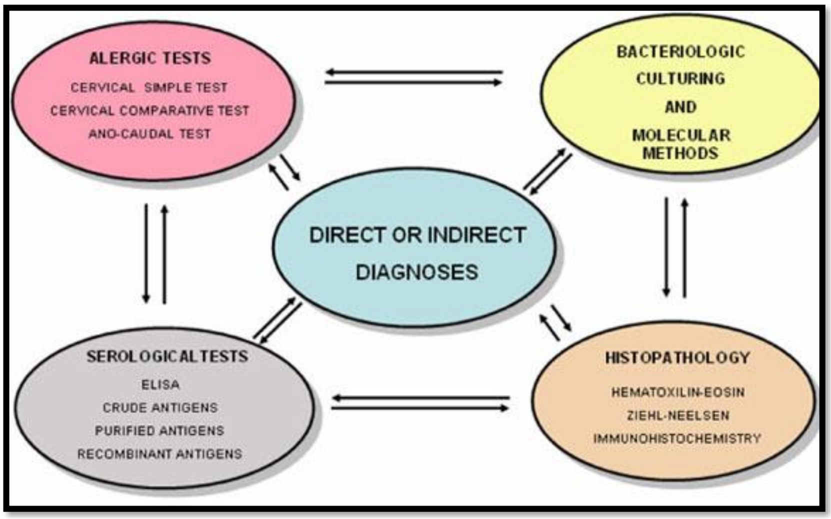

Figure 12. Interaction among different diagnostic methods used to determine bT

6. Farm Management and Control of bTB in Ireland

Although veterinarians play a huge role in trying to bring about the eradication of tuberculosis in Ireland, they are other factors that are also identified having an effect on tuberculosis managed efficiently and effectively.

These include nutritional factors, cattle purchase and spreading of slurry. Farm management practices such as the frequency of intra-herd cattle movements, use of spatially fragmented pastures and the time spent on grass are all factors contributing to bTB incidence (Griffin et al.,1993).

There can be direct contact between cattle from different herds which can be at marts, veterinary practices, sharing of transport, shared housing and contact across the hedge as in nose-to-nose contact with neighbouring herds (Griffin et al.,1993).

There is always an increased risk of bTB herd breakdown if in the local surroundings or geographical area the prevalence is high (White et al., 2013).

The knowledge of farmers of intra-herd movements during grazing season has not been very well implicated and so therefore the transmission of *M. bovis* is barely understood (Griffin et al., 1993).

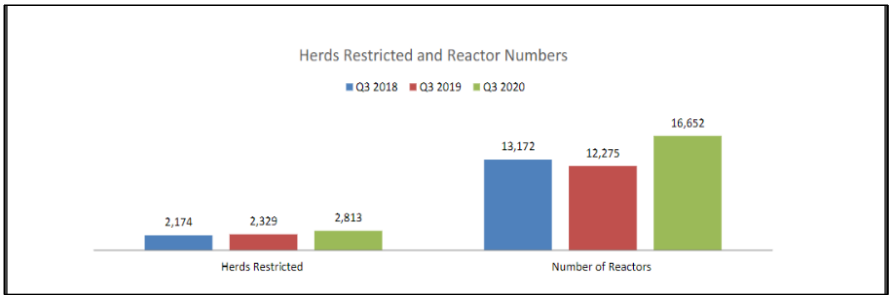

Figure 13. Herds affected by bTB (Ireland)

Listed in Figure 13 we see the number of herds restricted and the number of reactors from those herds in the final quarters of 2018, 2019 and 2020 respectively.

Cattle are frequently moved during the grazing season between fields ensuring that there is enough forage to meet nutritional requirements. These higher number of intra-herd movements between pastures during the grazing season would not only increase intra-herd contact rates between different batches of cattle, but also intra-herd contact rates between different groups of cattle are more frequently exposed to neighbouring herds (Allen et al., 2018). Intra-herd movements of animals may contribute to the exposure risk and may also impact on every day epidemiological studies investigating spatial association of the wild and domesticated hosts of bTB (Lahuerta-Marin et al., 2015).

In Ireland the issue of intra-herd movements can vary and is due largely by local and regional practices, types of field boundary, patterns of land inheritance, ownership or lease, and the frequency of cattle movements. To give an example of such an occurrence, where land has been inherited and farms have been divided between children, and therefore become fragmented, so these fields within a farm may not be spatially contagious but there may be scattered single fields or contagious yards (Allen, 2018). Farmers also with small herds and areas of land may decide to purchase or rent conacre to increase their herd size. This in turn will lead to longer distance and greater movements of cattle between consecutively great land patches and maximising increasing intra and inter-herd contacts creating opportunities for bTB transmission (Brennan et al., 2008).

A study was carried out in County Down, Northern Ireland, U.K. which accounted for the difficulties in examining inter and intra-herd contacts as there is a huge spatial and temporal variability, showing a high volume of structural complexity and heterogenicity. There was a total of 25 cattle farms of which 56% were beef and 44% were dairy. It was a very suitable area for such a study as the area had a high cattle density and with record of outbreaks over several years, it would have been a bTB hotspot (Trewby et al., 2016)

That study aimed to receive data on cattle movements for a number of farms on a daily basis over the course of a complete grazing season. Objectives were to quantify the density of stocks of cattle on pasture, time spent on fragmented land and finally intra-herd movement perimeters including the actual number of times the animal moved, distance moved and the sheer number of grasslands used for grazing. The dairy herds had the highest stocking density and larger herds, with higher metabolic demands of milk being produced. (Trewby et al., 2016)

Dairy herds show twice the number of movements than the beef production systems. In these high stocking dairy farms, grass was likely to last shorter time in comparison to dairy herds.

Dairy cattle stocked at higher densities were known to be at greater risk of bTB outbreaks (Doyle et al., 2014). Dairy farms had both lactating cows and dried cows close to the farm at home, which meant easy access to the milking parlour with dairy cows spending less time on land elsewhere. Dried cows were also kept close to the home farm as farmers wanted them nearby for close attention to be given to them near to the time of calving. In turn, older cattle and dairy cattle are huge risk factors of bTB. So, in an already routine of grazing dairy cows in non-fragmented land only may potentially reduce the number of neighbouring herds exposed.

Beef herds usually being grazed at lower stocking density than dairy cattle, for the reason that the beef cattle were allowed access to multiple fields would explain their lower stock density. Maintaining lower density and spatially dispersed stocking would reduce intra-herd contact rates.

The farms of beef herds have the longest distances moved per farm, also beef bullocks spend the most time on conacre, so these animals may be at a higher risk of bTB transmission.

There is a huge variation in the extent of grazed land with some of the farms having up to 8 spatially or fragmented land parcels resulting in greater number of boundaries with adjacent farms therefore increasing the time cattle spend adjacent to other herds increasing nose to nose contact. It is inevitable that there is a higher risk potential of a bTB-free herd in greater contact with neighbouring herds than those herds that spend their time on a single field.

The herds that cover larger areas may come into contact with an increasing number of badger population and increases the risk of bTB transmission. (Tuyttens et al., 2000)

The results of bTB outbreak status did not show great attributes to the following perimeters of stocking densities, amounts of movements and fragmentation of grazing lands, this may be due to the small sample size of only 18 farms, however its suggested that herd connectivity may play an important role in the bTB maintenance (Brown et al., 2019).

Already the Department of Agriculture restrict herd movements after an occurrence or a reactor are found in a herd to prevent further outbreaks in the farmer’s herds or neighbouring herds. Also there are restrictions at cattle sales, markets and agricultural shows but there are currently no restrictions on intra-herd movements. These restrictions maybe hard to implement but farmers which are subjected to a bTB outbreak should be educated and advised to try and minimise intra-herd movements to reduce transmission risks to another herd. Where these measures are implemented, decrease the spatial exposure to neighbours and indirectly to wildlife hosts (Campbell et al., 2019).

7. State Veterinary Control

Farmers are advised on appropriate biosecurity measures to aid in the protection of their herd from bTB. The Department of Agriculture does this on a yearly basis through the test notification letters that they need to be aware of the importance of good biosecurity farming to avoid entry and the spread of the disease on their farms.

Some of the most important measures that farmers are reminded to take include isolation of sick animals, isolating cattle entering the farm either from another herd or returning from an agricultural show or market, the maintenance of secured fencing providing disinfection foot baths and necessary clothing for people visiting the farms.

Clean drinking water for animals, feedstuff must be secured to keep out livestock, wildlife or vermin, prevention of rodents on the farms as best possible, fencing off badger sets or latrines in pasture lands, clean feeding troughs which are not accessible to wildlife.

In accordance with the farmers taking these measures, veterinary inspectors will also advise farmers who have experienced a bTB breakdown of what is to be disinfected and what disinfectant should be used. There will be farm checks carried out to ensure that all appropriate actions are taken and guidelines are followed. Otherwise, compensation will not be given where the appropriate disinfection and cleansing has not taken place (www.bovinetb.ie).

Farmers are never isolated to deal with breakdowns of bTB incidence alone. The department will arrange the removal of animals identified as reactors by licenced hauliers paid by the department. The reactors are sent to be slaughtered at EU approved slaughtering plants and farmers are given a residual price for their infected animals. The prices are based on market value by independent valuers as if they are not affected by bTB and the market value at the time.

In the case of a herd breakdown of bTB where the number of reactors has reached a certain threshold, there is an income supplement scheme available to farmers to cover the removal of reactors. In the period from November to April there is also a scheme called the "Hardship" scheme which give support to famers that are not allowed to sell animals due to their herds being restricted and locked down. This payment can be received up to a maximum of 4 months.

There is also a depopulation grant available when a decision has been made to depopulate a herd when other eradication methods have failed. Testing is carried out and authorized by private veterinarian practitioners around strict guidelines and rules set by the Department of Agriculture. Figure 14 shows the number of herds tested in comparison to number of herd incidence from 2019 to Q3 of 2020.

With regard to milk processors, the Department of Agriculture will notify the milk customers of herds that have been restricted and derestricted. This is a legal requirement that Irish farmers do not supply milk or that its not collected from milk processors in a herd that has reactors or inconclusive reactors from an official bTB test (www.bovinetb.ie).

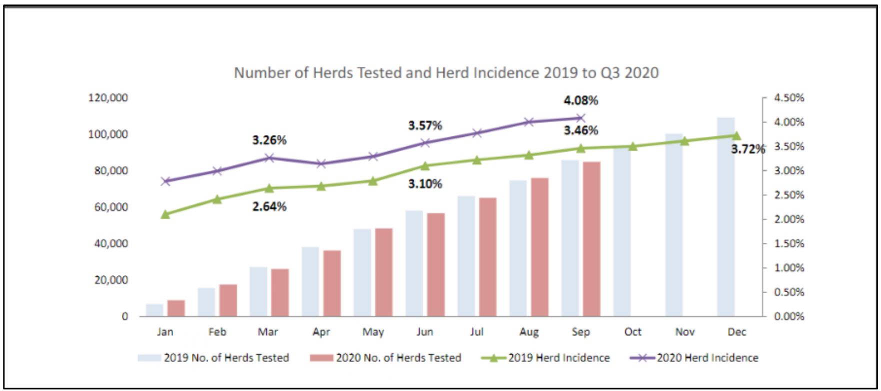

Figure 14. Graphical representation of Herd Testing and Incidence in Ireland (2019-2020)

8. Economic Losses

Ireland on a yearly basis exports some 125,000 live cattle to other EU countries which is worth over 50 million Euros. To protect this trade and the countries we are exporting to also comes at a huge cost. Figures published by Teagasc had shown that the Irish Agri-food sector had generated 7% of gross value to be exact 13.9 million during 2016 and accounted for 8.5% of national employment and also 9.8% of Ireland's merchandise exports. These were mainly cattle, beef and dairy product exports. Among these are very high valued dairy brands (O'Connor, 1986).

The eradication scheme's first period in Ireland which ran from 1954-1965 generated up to 368.8 million Pounds and including the cost of the scheme from 1965-1985 which was 361.1 million Pounds of total net expenditure which cost the Irish exchequer 730 million Pounds (O'Connor, 1986).

Fast forward to more recent times in 2017, the eradication program of bTB cost an astonishing 84 million Euros. This was distributed among the exchequer who paid 42 million Euros and the EU co-funding provided 10 million Euros which left a remaining 32 million Euros which was paid by farmers through the cost of annual herd bTB and disease levies.

These costs represent a huge investment not only in animal health but it also highlights the drain on financial resources that could be better navigated by objectives that expand the broader Agri-food sector (www.bovinetb.ie).

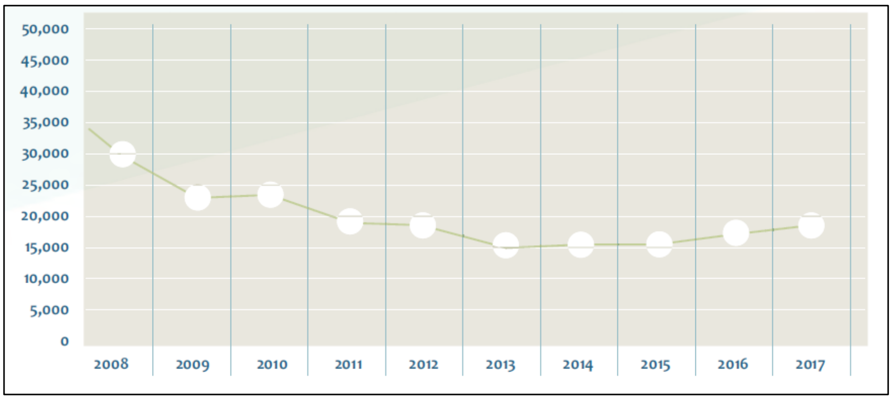

Figure 15. Herd Reactors (numbers) from 2008-2017

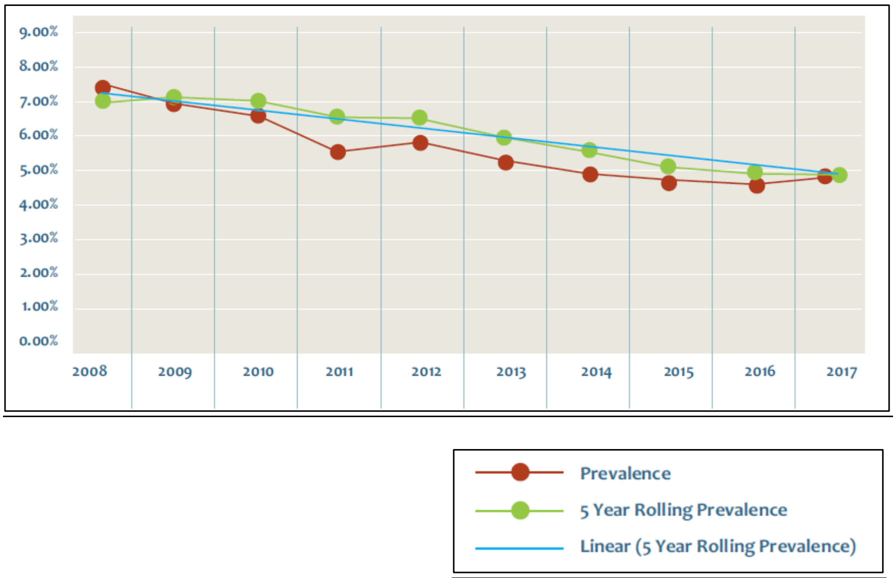

Figure 16. Herd Prevalence 2008-2017 along with graph key

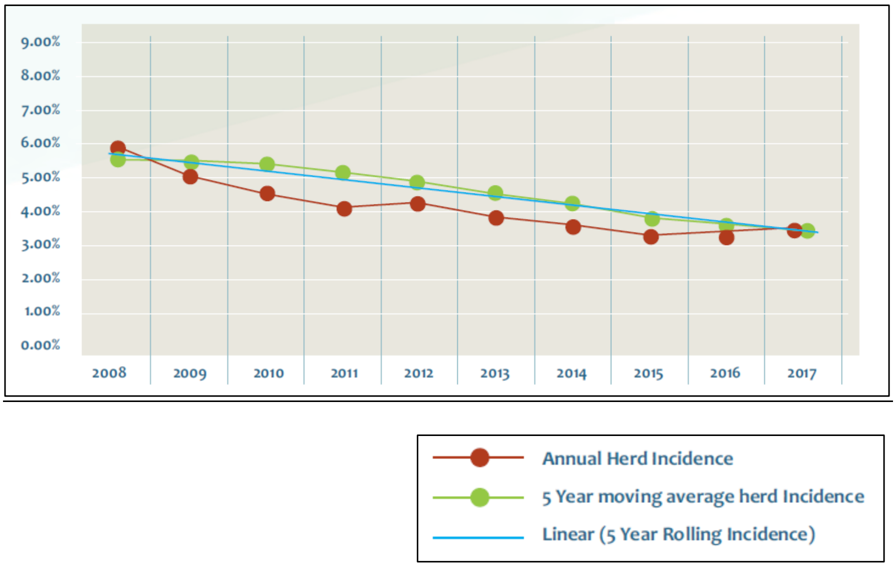

Figure 17. Herd Incidence 2008-2017 along with graph key

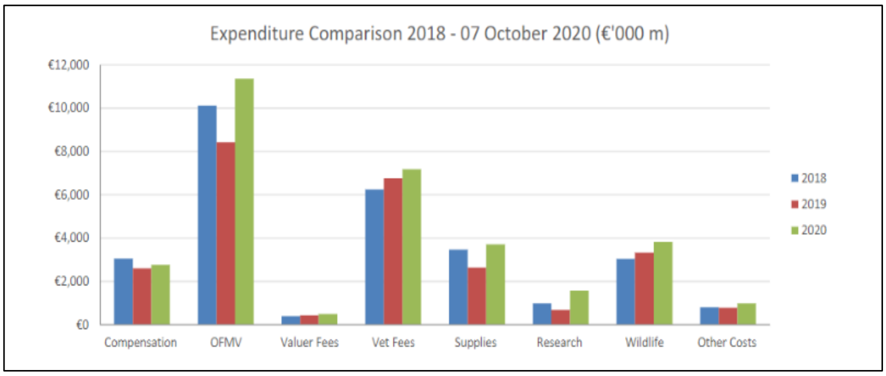

Figure 18. Graph showing expenditure comparison on the bTB programme in Ireland (First 3 quarters of 2017-2020 respectively)

Expenditure to end of Q3				% Difference 2020-2019	% Difference 2020-2018	% Difference 2019-2018
	2018	2019	2020			
Compensation	€3,052	€2,605	€2,761	6%	-10%	-15%
OFMV#	€10,132	€8,430	€11,358	35%	12%	-17%
Valuer Fees	€392	€431	€496	15%	27%	10%
Vet Fees	€6,248	€6,753	€7,182	6%	15%	8%
Supplies	€3,468	€2,641	€3,707	40%	7%	-24%
Research *	€974	€688	€1,571	128%	61%	-29%
Wildlife	€3,033	€3,329	€3,821	15%	26%	10%
Other Costs	€808	€776	€990	28%	23%	-4%
Total	**€28,107**	**€25,653**	**€31,886**	**24%**	**13%**	**-9%**

* Increase in research due to timing factors. # OFMV – On farm market valuation

Figure 19. Tabulation of contents from Fig. 18

In Figure 18 we have a graphical comparison on the expenditure of herds and their maintenance from 2018 -2020.

Figure 19 shows a tabulation of aforementioned expenditure graph with the differences between first 3 quarters of the individual years.

9. Conclusion

The aim of every issue discussed throughout this review is to highlight just how notifiable of a disease bTB is in Ireland and leading towards the question of what the future will hold regarding Ireland's target of eradication by 2030.

The Minister of Agriculture- Minister Creed has publicly announced that the initiative and goal for eradicating bTB by 2030 would cost another estimated 1 billion Euros.

Under EU legislation, Official Free Status (OFS) can only be achieved when less than 0.1% of herds in the country are affected by bTB. The eradication program costs farmers, the Exchequer and the EU an estimated figure of 84 million Euros per year. Both the Minister of Agriculture and the Government know that current controls, policies on badger vaccinations, etc. will not achieve eradication by 2030 as more needs to be done (www.bovinetb.ie).

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I would like to take this opportunity to appreciatively thank all of the Department faculty members for their help and support over the years. I also thank my parents for their encouragement, support and attention. I also extend my thanks to University of Veterinary Medicine, Budapest for helping me achieve my dream of being a vet and for all the experiences and friends I made here in Budapest. I also place on record, my sense of gratitude to one and all, who directly or indirectly, have lent their hand in this venture.

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Appendix 4.

I hereby confirm that I am familiar with the content of the thesis entitled "Tuberculosis in Ireland. Review of the literature on Bovine Tuberculosis in Ireland with a focus on its Eradication" written by Patrick Connolly which I deem suitable for submission and defence.

Date: Budapest, 26th March 2021

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László Fodor

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