Review article

Classification of worldwide bovine tuberculosis risk factors in cattle: a stratified approach

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Abstract – The worldwide status of bovine tuberculosis (bTB) as a zoonosis remains of great concern. This article reviews the main risk factors for bTB in cattle based on a three-level classification: animal, herd and region/country level. A distinction is also made, whenever possible, between situations in developed and developing countries as the difference of context might have consequences in terms of risk of bTB. Recommendations are suggested to animal health professionals and scientists directly involved in the control and prevention of bTB in cattle. The determination of Millenium Development Goals for bTB is proposed to improve the control/eradication of the disease worldwide.

zoonosis / *Mycobacterium bovis* / cattle / risk factor / epidemiology

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1. INTRODUCTION

Bovine tuberculosis (bTB) caused by *Mycobacterium bovis* is a chronic, infectious and contagious disease of livestock, wildlife and humans [89]. Zoonotic tuberculosis is an important public health concern worldwide, especially in developing countries, because of deficiencies in preventive and/or control measures [37]. In developed countries, the disease has almost been eradicated after the implementation of preventive and control measures such as testing, culling or pasteurisation of milk. Since bTB remains a worldwide problem, it is imperative to intensify control and preventive measures aimed at its eradication. The incidence of *M. bovis* in humans probably remains underestimated, as a distinction between the *Mycobacterium* species, i.e. *M. bovis* and *M. tuberculosis,* is not systematically performed [4]. Since the real incidence of *M. bovis* on human health is still unknown, it is essential to advance the eradication of bTB worldwide by means of adequate programmes, especially in developing countries [46]. Even if the risk to human health is low in most developed countries, the HIV pandemic raises concern about its

impact on the transmission of *M. bovis* to and between humans [46]. The highest risk groups are actually individuals with concomitant HIV/AIDS infection [8]. HIV is the major factor responsible for the progression of tuberculosis infection to active tuberculosis disease[1]. Since there are few available and updated reviews dealing with the numerous risk factors identified in cattle so far in different parts of the world, the aim of this article was to review the potential ones, which we scaled at three levels: animal, herd and region or country, as illustrated in Figure 1. This is the first review to consider bTB risk factors worldwide; other reviews generally focus on a specific region of the world, or on a specific category of risk factors (e.g. wildlife, herd management, etc.). Farming practices, in terms of stocking densities, pasturing systems and contacts between animals, differ substantially in developed and developing countries. This review will therefore attempt to make a distinction between situations

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[1] WHO, The control of neglected zoonotic diseases: a route to poverty alleviation, Report of a joint WHO/DFID-AHP Meeting, with the participation of FAO and OIE, Geneva, 2005, p. 12.
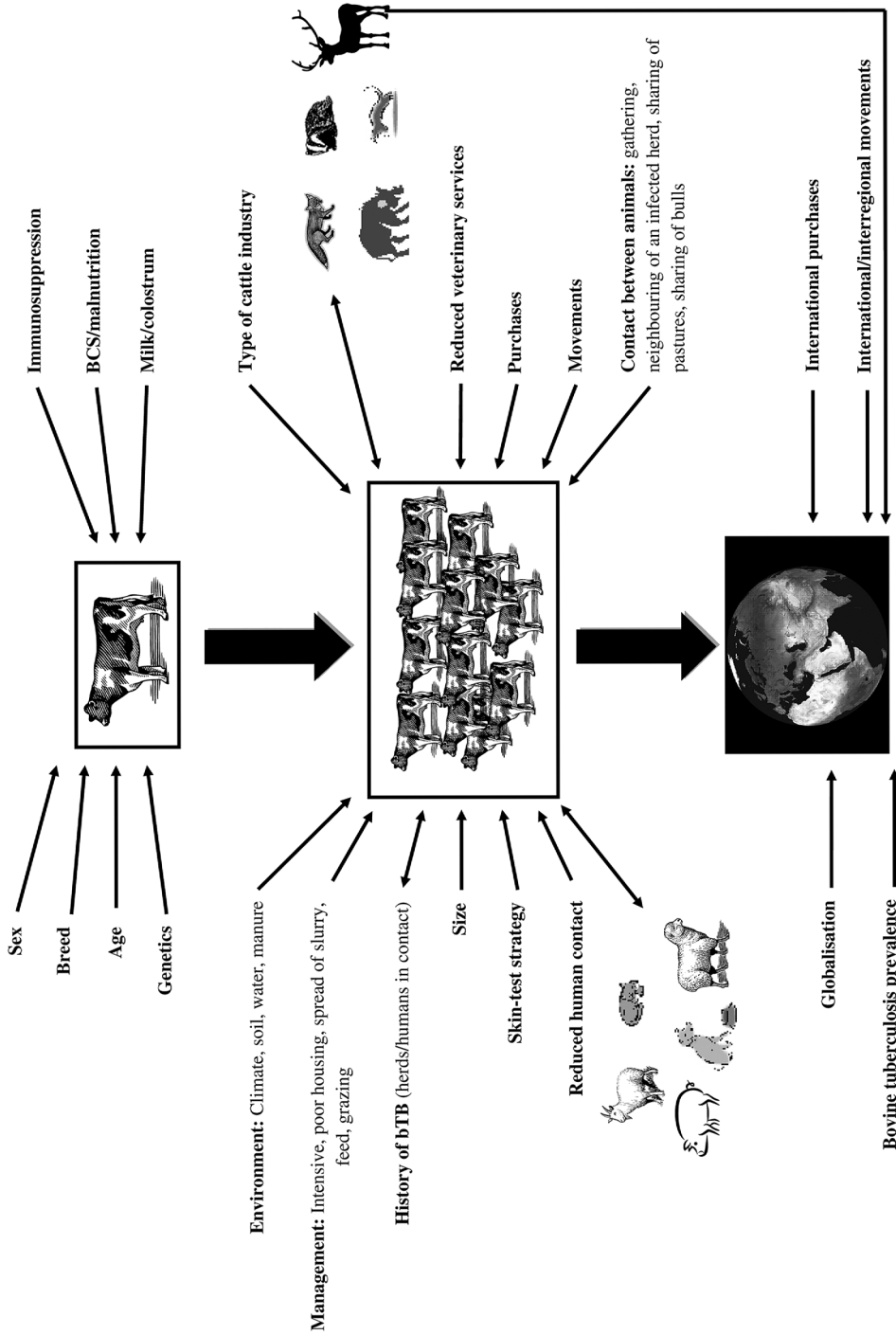
Figure 1. Main bovine tuberculosis risk factors classified into animal, herd and region/country levels.

in developed and developing countries whenever possible. Most studies dealing with *M. bovis* in developing countries were carried out in Africa. Some of them focussed on the risks for cattle in Tanzania, Zambia, Chad, Uganda, Eritrea, Ethiopia and others dealt with wildlife in South Africa and Tanzania. In developed regions, countries mainly involved in bTB research are found in Western Europe (United Kingdom, Ireland, Spain, Italy or France), in North America (USA and Canada) and New Zealand. Wildlife has been identified as a risk factor for bTB in cattle all over the world, but the range of wild hosts varies according to the region: buffaloes in Africa, possums in New Zealand, cervids in North America and Europe, but also wild boars and badgers in Western Europe.

The aim of this review was to provide a tool for scientists and sanitary authorities involved in the fight against bTB in order to guide them on specific topics that would help eradicate and control bTB. It will also be useful to theoretical researchers such as disease modellers (both spatial, simulation and statistical) whose work may in turn feed into the recommendations made by disease management advisers.

2. RISK FACTORS AT THE ANIMAL LEVEL

2.1. Age

One of the main individual risk factors identified by numerous studies in both developed and developing countries is the age of animals. The duration of exposure increases with age; older animals are more likely to have been exposed than younger ones, as shown by several cross-sectional studies carried out in Tanzania, Zambia and Chad [16, 18, 29, 54, 59, 82]. In a 1996 cross-sectional study, which included more than 2 000 individuals issued from 200 herds, Irish authors observed that calves were less likely to be positive reactors than older animals [48]. Animals might get infected at a young age, but only express the disease clinically when they are adults [48]. Mycobacteria have the ability to remain in a latent state for a long period before reactivation

at an older age [96]. Nevertheless, scientists have not proved that a true dormant state exists in cattle [115]. A lot still remains to be done in terms of scientific research to obtain an experimental latency model in cattle and to assess if there are any consequences, such as underdiagnosis of the disease, particularly in developed countries, in relation to it.

2.2. Gender

Gender has only been mentioned as a risk factor in studies carried out in Africa. Opinions diverge regarding its influence on the susceptibility to a *M. bovis* infection. A cross-sectional study conducted in Tanzania from 1994 to 1997, which included 5 692 indigenous and 244 exotic cattle, revealed that male cattle were significantly more affected by bTB than female animals [59]. Male cattle are mostly used as oxen, which are kept longer in the herd than females. Due to this particular longevity, it is more probable that they get in contact with infected cattle from other affected herds and in turn get infected; this would imply that between-herd contact is a major source of bTB transmission [59]. From 2006 to 2007, a cross-sectional study on 1 470 animals in Uganda revealed significantly more females positive to the skin test than males [54]. Gender-linked factors are probably related to management practices or behavioural habits; males and females are managed differently, both in developed and developing countries. In developed countries, dairy cows usually reach an older age than males because of their role in calving and milk production.

2.3. Breed

Studies performed in Africa also identified the animals' breed as a risk factor for a positive skin test. In 1998, a cross-sectional study carried out on 1 813 animals (494 intensive dairy farms) of Eritrea suggested that imported breeds, used to improve the dairy industry in tropical areas, may be less resistant to bTB compared to indigenous breeds, e.g. zebu [88]. Elias et al. observed a (not significantly) higher bTB infection rate in imported cattle

during their 2005–2006 survey including 1 572 dairy cattle in Ethiopia [36]. The difference of susceptibility between breeds is likely to be related to differences in management: imported dairy animals are generally kept under intensive conditions [36]. This suggested that a risk factor for bTB needs confirmation through additional studies. Another question is whether a variability of the reaction to the skin test exists depending on the cattle breed. If established, this variability would imply that diagnostic tests should be suitably designed and applied according to the animal breed to be tested.

2.4. Body condition

The body condition score (BCS) relies on palpation of the sharpness, muscle and fat covering the backbones and lumbar processes and is determined on a 1 (emaciated) to 5 (obese) scale [35]. In 1996, Cook et al. linked a low BCS to an increased risk of a positive skin test result in their cross-sectional study including 2 226 animals in Zambia [18]. During a matched case-control study including 80 chronic bTB herds carried out in 1990 in Ireland, Griffin et al. demonstrated that an animal's resistance to tuberculosis was reduced by a shortage of feed and/or an unbalanced diet [47]. This follow-up was carried out during three months, thus it is not sure a possible link between diet shortage and bTB could have been observed. A more recent study carried out in the same country over a one-year period dealing with 20 young steers positive to the Single Intradermal Comparative Cervical Tuberculin Test (SICCT), fed a restricted diet and housed in contact with positive reactor steers showed no evidence that dietary restriction had any effect on bTB transmission [22]. Skin test reactors might have a poor BCS as a consequence of an advanced stage of bTB, as suggested by a cross-sectional study including 5 692 indigenous cattle carried out in Tanzania between 1994 and 1997; animals suffering from a clinically advanced bTB often present a low BCS as a result of the long-lasting pathological process [59]. These cross-sectional studies were carried out during a definite period of time, so that this parameter should be considered carefully.

In cross-sectional studies, scientists do not know the initial status of animals. It is not possible to distinguish a low BCS as a risk factor or as a consequence of clinically advanced bTB. The real impact of BCS should be the subject of directed studies dealing with diet restriction.

2.5. Immune status

Immunosuppression is a predisposing factor for a number of diseases. Thus, the risk of becoming infected with *M. bovis* also increases, although it has not been scientifically demonstrated in cattle to date [72]. Susceptibility to *M. bovis* may be as well enhanced in cattle infected with immunosuppressive viruses such as bovine viral diarrhoea or immunodeficiency viruses [25]. Further research will help to elucidate many aspects in this area.

2.6. Genetic resistance and susceptibility to bTB

The importance of heritability of bTB resistance has only started to be investigated in cattle. Genetic mechanisms of non-specific immunity could eliminate a low-dose *M. bovis* challenge: bronchial mucus, efficiency of the mucociliary escalator, active non-specific macrophages in the lungs (and their lysosomal enzymes) as well as their destructive efficiency are some examples [94]. In mice, the natural resistance-associated macrophage protein 1 gene (NRAMP 1 gene) has been shown to confer host resistance to tuberculosis and brucellosis [79], but the same association could not be demonstrated in cattle [10]. In 2007, a real-time qRT-PCR allowed the identification of several genes expressed at lower levels in cattle infected with bTB [71]. Focus on the genetic aspects of bTB is quite new, and a lot still needs to be done to really investigate their importance in cattle and to identify which mechanisms are involved. Further studies are required to investigate clearly the potential use of genes as stable biomarkers of bTB infection [71].

2.7. Vertical and pseudo-vertical transmissions

In 2007, Turkish scientists described the vertical transmission of *M. bovis* from an infected

dam to her calf through congenital infection in utero [90]. Ingestion of contaminated colostrum/milk is another way of bTB transmission from cow to calf, as suggested by Italian scientists in 1998 [125]. The risk is more important in developing countries where control measures are not very effective. Pseudo-vertical transmission through close contact between a cow and its calf (grooming) has been mentioned as a possible risk factor too [95]. In developed countries, however, where regular testing programmes are implemented and where outbreaks are rare, the risk may be considered negligible.

2.8. Auto-contamination

A cattle becoming infected through the oral route might further emit contaminated aerosols during the rumination process [95]. The animal might inhale these contaminated aerosols and a subsequent respiratory infection can occur: as few as one bacillus can infect an individual via the respiratory route [83].

3. HERD-LEVEL RISK FACTORS

3.1. History of bTB outbreak in the herd and human antecedent of tuberculosis in the household

A 1996 cross-sectional study carried out in Ireland including more than 2 000 individuals (200 herds) failed to demonstrate that residual source of bTB infection was a main herd-level risk factor; however, this study mainly included store and beef enterprises, whose turnover is important [48]. This factor is probably primordial in dairy herds, where animals often remain in the same herd for several years. The severity of a current bTB outbreak was indeed shown in 2004 to be useful in predicting the rate of future outbreaks in Ireland for a herd with a history of bTB, as suggested by a retrospective cohort study including 6 757 bTB-exposed and 10 926 non-exposed herds [86].

At the excreting stage of *M. bovis* tuberculosis, a human with clinical genitourinary tuberculosis could contaminate cattle e.g. in Africa, where people often urinate on pastures [8, 45].

Still in Africa, in 1996, the occurrence of a human case of tuberculosis among people in contact with a herd during the preceding 12 months was identified as a risk factor for finding a skin test reactor during a cross-sectional study including 2 226 animals in Zambia [19]. Cattle contamination by a human excreting *M. bovis* was also reported in Switzerland in 1998 [38].

3.2. Herd size

Studies carried out in several parts of the world, both in developed and developing countries, identified herd size as one of the major bTB herd-level risk factors [16, 18, 48, 58, 80, 86, 97]. The more cattle there are on a farm, the greater the probability that one of them will acquire the infection. Large herds generally pasture on a larger area, with a higher probability to have more contiguous herds, thus increasing the risk of cattle-to-cattle spread, as suggested by an English questionnaire-based study carried out in 1999[2]. Since skin test specificity is not perfect, if herd size increases, the probability of a false positive reactor will be greater [25]. The more animals are skin tested, the higher the probability to have a reactor [75]. Two comparative case-control studies carried out in England between 2000 and 2003 (a study of transient herd outbreaks including 58 case-herds and 121 control farms, and another study of persistent herd outbreaks including 50 case-farms and the same controls) associated herd size with management-related risk factors such as herd turnover rates, stocking density, farm enterprise and foodstuffs [100]. Herd size and animal density are important if exposure, but also subsequent infection, occurs. The type of management influences contacts between animals, as discussed in Section 2.4. Aerogenic transmission is indeed the major infection pathway in cattle, as suggested by Irish authors in a study including 20 two-year old naturally

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[2] Veterinary Laboratories Agency, A multivariate analysis of risk factors of TB transmission associated with farm management practices, Final Report of the Milk Development Council Project 98/R1/16, UK, 2000, p. 5.

infected tuberculous steers housed in close confinement with 10 bTB-free animals for one year [22].

3.3. Type of cattle industry or enterprise

Animals raised outdoors and kept alive long enough to express lesions are more susceptible to develop clinical signs [7]. Munroe et al., however, found no risk difference between dairy and beef herds, during their study based on the survey of 151 dairy and 477 beef herds carried out between 1985 and 1994 in Canada [80]. Nevertheless, dairy herds were far less numerous than beef herds. New Zealand dairy herds were recently identified as being more at risk during a retrospective cohort study that included 430 bTB-infected cattle from 1980 to 2004 [97]. Differences in terms of management are probably involved: dairy cows experience more production stress and gathering of cattle during milking increases the risk of bTB transmission as shown by bTB transmission modelling in New Zealand in 1997 [9]. The life expectancy of dairy cattle is also longer than beef cattle, as suggested in Section 2.1.

3.4. Management

Management system will define contact between cattle, but also between cattle and contaminated environmental sources and wildlife. Therefore here is a summary of the risk factors. Nevertheless, large-scale studies are required to identify clearly the management practices to be pointed out as risk factors in order to adopt preventive and control measures.

3.4.1. Intensity of the farming system and housing of cattle

Management practices differ in developed and in developing countries. In developing countries, Holstein cattle are increasingly imported in order to improve milk production and are usually kept under intensive conditions. The highest incidence of bTB is generally found in areas where intensive dairy systems are practiced [21]. Dairy production in developed countries follows a trend towards increased intensification on a smaller number of larger production units, which implies increased contact between animals and thus an enhanced risk of bTB transmission [114]. In these intensive systems, aerogenic transmission of bTB seems to dominate [72]. The use of hired/shared bulls also increases the risk of bTB-introduction in a herd as suggested by a retrospective matched case-control study carried out in 2002 in 18 bTB-infected farms of Michigan [58]. In Ethiopia, in a 2006-study comparing the effects of zero grazing versus free grazing among 54 Holstein and 37 zebu cattle, it was reported that the severity of bTB was significantly higher (with significantly higher interferon-gamma (IFN-γ) levels and more severe lesions) in cattle kept indoors at a higher population density than in cattle kept on pasture [3]. In addition to close contact, stress caused by overcrowding or nutritional differences between housed and pastured animals was mentioned as contributing to the spread of the disease [3]. An Irish case-control study carried out in 1993 showed a link between recurrent bTB and the presence of cubicle housing, which is associated with intensive dairy livestock farming. Cubicle housing is thought to be more stressful for cattle, therefore increasing the susceptibility to bTB [47]. In a cross-sectional study of 1 869 cattle, Ethiopian scientists observed that poor housing and management could be involved in the reduction of an animal's resistance to bTB [36]. These authors did not specify what they regarded as "poor housing". In 1998, Costello et al. suggested, thanks to a longitudinal study carried out in Ireland including young steers kept in feedlots for a one-year period, that defective ventilation may facilitate the transmission of bTB [22]. The lack of hygiene predisposes to the proliferation of pathogens in general.

A cross-sectional study on 1 813 animals from 494 herds carried out in Eritrea in 2001 suggested that farm size (surface), was a risk factor for bTB but no information was provided regarding what farm size was considered as being at risk [88]. Farm size, in terms of number of holdings and boundary length, has an

impact on bTB risk, as shown in the UK[3]. Nevertheless, herd size could probably be related to farm size, larger farms having more cattle.

3.4.2. Manure

It was reported in a 1993-case-control study on 160 Irish farms that spreading of slurry on pasture without prior storage presents a higher probability of bTB occurrence in the herd than on farms producing other types of manure or storing the slurry before spreading; cattle can indeed become infected through the digestive route or after inhalation of contaminated aerosols during the spreading of slurry. Cattle may be at risk if slurry is spread within the two months preceding grazing [47]. Nevertheless, to get orally infected, cattle need to ingest much higher doses of M. bovis compared to the aerogenic transmission, but more detailed information on infective doses will be given in Section 3.14 [77]. Spreading of slurry might be of particular importance in Africa, especially when considering the existence of a rainy and a dry season, since the survival of organisms may be shortened during the dry season [123]. As such, it would be interesting to investigate more deeply the risk of persistence in slurry in Africa.

3.4.3. Feeding, supplementary feeding and feed storage

Feeding habits were only investigated in developed countries as a risk factor for bTB. In 1993, an Irish case-control study including 160 farms found that a self-feed silage system was more stressful for animals and thus increased susceptibility to bTB [47]. Feeding silage could increase the risk of a confirmed outbreak in the UK, as suggested by two case-control studies carried out in 2004[3]. Feeding maize silage, grass silage or molasses was recently identified in the UK as a risk factor

for transient and persistent outbreaks [100]. Silages were proved to be attractive to badgers in two English farms monitored in 1999 [40]. In the examples above, wildlife (deer and badgers) could access cattle feed. It is worth investigating the possible implication of feeding habits in the risk of bTB infection though ruling out the wildlife factor. Supplement feeding was found to diminish the risk of transient bTB outbreaks in two case-control studies on 229 herds carried out in the UK between 1995 and 1999 [100]. In 2002, a retrospective matched case-control study carried out on 18 bTB-infected farms of Michigan demonstrated that providing hay on the ground, rather than in feeders, and providing loose hay, rather than in bales, were associated with an increased risk of bTB [58].

Feed storage seems to be of great importance, especially regarding silage. Studies conducted in the UK showed that badgers, thought to be the main M. bovis wildlife reservoir, appeared to be a source of contamination for silage with urine, faeces or sputum containing M. bovis [40, 100]. In 2002, during a monitoring survey of two English farms, badgers were often seen entering farm buildings to feed directly from cattle facilities and silo yards [40].

3.4.4. Cattle-to-cattle transmission via the faeco-oral route

Aerogenic transmission is important in intensively managed systems. At this stage, it is worthwhile mentioning the role of cattle-to-cattle faecal-oral transmission. Since cattle do not usually graze where other cattle deposit faeces, some authors suggest that M. bovis infection is unlikely to be acquired directly from eating grass contaminated by other cattle [95]. Nevertheless, once faeces are disaggregated, mycobacteria may survive longer in the environment under adequate climatic conditions (further discussed in Section 3.14). Mycobacteria are not frequently and regularly excreted in cattle faeces, even by a heavily infected animal as demonstrated in a study conducted in three groups of five calves (4 to 7 months of age) infected intra-nasally with M. bovis: two animals presented intermittent excretion over

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[3] Independent Scientific Group on cattle TB, Analysis of farm level risk factors, in: Bovine TB: the scientific evidence, pp. 121–138 [on line] (2002) http://www.defra.gov.uk/animalh/tb/isg/report/final_report.pdf [consulted 26 February 2009].

several months [83]. However, these observations were made under experimental conditions; in field conditions, it is impossible to know the precise mycobacterial load leading to cattle infection.

3.5. Lack of performance of diagnostic tests

The Single Intradermal Tuberculin test and the SICCT remain the international field diagnosis methods of bTB [25]. Nevertheless, these tests seem to lack sensitivity [75]. Even if standardised, the skin test is not always performed as recommended because of management conditions making it difficult to perform. The IFN-γ test, another widely used diagnosis test for bTB, lacks perfect specificity and sensitivity. Vordermeier et al. summarised the results of several studies carried out throughout the world [117]. As for the skin test, sensitivity and specificity vary widely according to the area where they have been tested [25, 117]. The skin test can identify positive reactors that differ from the positive animals identified with the IFN-γ [25]. The skin test has shown its limits before[3]. This lack of performance can have serious implications. Indeed, false positives involve eliminating more cattle than required and imposing unnecessary herd restrictions. Similarly, previous studies have demonstrated the under-diagnosing of bTB-infected cattle by the skin test and as a consequence, false negatives can be responsible for the re-ermergence of bTB in a herd. This lack of sensitivity can have serious consequences in large herds or in herds containing single infected animals[3]. More efficient tests need to be developed, and the way in which they are administered needs to be improved. Studies designed to evaluate the application and efficacy of diagnostic methods should be undertaken.

3.6. Intradermal tuberculin test frequency (reduced opportunity of detection)

Programmes based on regular herd skin test and slaughter allowed the eradication of bTB in several countries, which have thus obtained the Officially Tuberculosis-Free status (OTF). bTB prevalence in these countries is generally low,

but it would be dangerous to relax vigilance by reducing the frequency of herd skin test in the European Union, once a Member State has acquired the OTF status[4], since the chance to detect a positive reactor would be reduced and would depend on meat inspection only. Evaluation strategies for meat inspection are required, as suggested in a recent study carried out in Switzerland which describes an approach for the quantification and evaluation of surveillance systems [51].

3.7. Reduced human handling and contact with veterinary services

A greater risk of repeated bTB outbreaks could be the consequence of less human contact in a herd, as suggested by an English study on two cross-sectional time-series data sets gathered during a eight-year long study starting in 1988 [119]. Reduced handling of the animals can have serious implications when these must be skin tested. The test can be performed wrongly and reactors not detected in scared animals. Organic farming promotes less human intervention both by a reduction of pharmaceutical treatments and animal handling in general. As a result, a reduced access to veterinary services lowers the probability of detecting reactors. Organic farming is becoming more and more popular in developed countries, as the general public very much approves of the idea of a natural agricultural system. Veterinary services should be regarded as a public international good and work as a link between farmers and international animal health authorities.

3.8. Introduction of cattle in a herd: purchase

The arrival of an infected animal in a bTB-free herd is one of the major risk factors for introducing the disease, as suggested by studies carried out in the UK, Michigan, Italy and Tanzania [43, 57, 58, 67, 109]. The source of

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[4] Clifton-Hadley R., Wilesmith J., An epidemiological outlook on bovine tuberculosis in the developed world, Proc. 2nd Int. Conference on *Mycobacterium bovis*, Otago, New Zealand, 1995, pp. 178–182.

bTB was investigated in 31 herds in north east (NE) England that experienced confirmed bTB outbreaks between 2002 and 2004; nine herds had bought cattle after the 2001 foot and mouth disease (FMD) episode [43]. A Canadian study including nine outbreaks that occurred in cattle and cervid herds between 1985 and 1994 demonstrated that herds tested in outbreak situations were at greater risk if they had either purchased animals from positive farms, requested testing because of possible contact with positive animals, or provided animals to a positive farm [80]. Here, the herd's status was determined on the basis of skin test results, without systematic confirmation of the presence of *M. bovis* by culture [80]. It would be interesting to evaluate the compliance with procedures for the introduction of new animals and to assess the most appropriate testing to identify positive animals at purchase. The evaluation of the use and relevance of skin test and/or IFN-γ should be recommended according to the epidemiological context.

3.9. Movements of animals

Movement of animals was recently shown to be a critical risk factor in a study analysing cattle movements between 1985 and 2003 in Great Britain [42]. Molecular typing demonstrated that animal movements were greatly responsible for most outbreaks reported in NE England between 2002 and 2004, as shown in 31 herds that experienced a bTB outbreak during that period [43]. This specific factor has a major impact if animals are moved from an endemic zone to a bTB-free one. Before the 2001 FMD epidemic, English authors also identified the movement of cattle onto the farm, from markets or farm sales, as an important bTB risk factor in a case-control study including 151 case and 117 control farms [57]. This study included a broad category of risk factors but the potential role of wildlife, developed in Section 3.13, was not considered.

Nomadic transhumance relies on the movement of livestock to follow grazing and water over considerable distances following seasonal changes. During the wet season, animals graze in pastures shared by several farmers. During the dry season, several herds are gathered in mobile groups migrating together, and share grazing areas and watering sources along the way [87]. Transhumance was recently associated with an increased bTB status in a cross-sectional study including 106 herds carried out from 2003 to 2004 in three pastoral areas of Zambia [81]. In this study, bias may have been introduced in sample size estimation, because it relied on studies carried out in other countries. In regions of OTF developing countries where nomadic transhumance is widely practiced, a particular status should be allocated to areas of intensive animal movements as they are high risk zones.

3.10. Contact between animals

Since transmission of bTB between animals is mainly aerogenic, close contact between animals is a major risk factor [3, 72]. Ameni et al. conducted a study with 91 skin test positive reactors in Ethiopia housed in two different farming systems. The severity of bTB was significantly greater in cattle kept indoors at a higher population density than in cattle kept on pasture; close contact facilitates the transmission of infective aerosols between animals [3]. Several practices detailed below may enhance contact between infected and healthy cattle.

Sharing of pastures or facilities was identified as a risk factor for the transmission of bTB in a retrospective matched case-control study including 17 cattle farms, conducted in Michigan in 2001, e.g. when animals come in contact with another herd after escaping [58]. Nevertheless, a contiguous bTB-infected herd could indicate a common source of infection for both farms. The mixing of animals from different herds is common in Africa, increasing contact between animals, as suggested in a 1999 study carried out in Chad on 848 cattle from 58 herds [29]. However, in this study, the interpretation of the skin test differed from the international recommendations.

3.11. Culling rate

The probability of detecting lesions increases with the number of animals sent to the

slaughterhouse (high culling rate) especially in countries where surveillance programmes based on meat inspection are effective. A high culling rate also indicates an increased herd turnover and more animals being purchased, thus increasing the rate of skin tests. Smaller herds with a low culling rate might represent a risk by themselves. Even if abattoir monitoring remains essential in the detection of bTB-infected cattle, a study carried out in Australia in 1990 comparing detailed necropsy procedure with routine abattoir inspection showed that routine abattoir inspection failed to identify all animals with tuberculous lesions [19]. It would be interesting to move towards a standardisation of abattoir inspection procedures and to improve the training of young veterinary graduates in this area. Moreover, studies of compliance at slaughterhouses could be applied in order to control the quality of inspection.

3.12. Other domestic species

Infection with *M. bovis* has been described in dogs [41] and cats [120], but no transmission to cattle has been reported so far. Even if swine are susceptible to infection with *M. bovis* [112], they are probably not a major risk factor for cattle in countries where pig farming has become industrialised. Goats are very susceptible to an infection with *M. bovis*, but outbreaks of caprine *M. bovis* TB are only reported occasionally; they could nevertheless interfere with bTB eradication programmes as already observed in cases reported in Spain and western Wales [1, 24, 50, 108]. The risk of contaminating bTB-free cattle herds by introducing infected goats should not be dismissed. Individual cases of *M. bovis* tuberculosis in sheep have been reported, but ovine disease is rare and usually associated with cattle cases [53, 66]. Horses are also susceptible to infection with *M. bovis* [76]. They could be a potential source of infection in regions where close contact between horses and cattle occur, e.g. in the Camargue area, southern France[5].

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[5] Boschiroli M.L., unpublished results.

Where deer farming is widely practiced, e.g. in New Zealand, the risk to domestic cattle should not be underestimated [64]. In developed countries it is essential to intensify the bTB surveillance in farmed red deer and to assign a bTB status to the herds; if bTB is identified in a previously OTF cattle herd, the possible implication of farmed red deer must be investigated. Further investigations could identify the potential role of domestic species in the epidemiology of bTB. In developed countries, dogs, cats, goats and sheep should be monitored, but in developing countries, all species should be of interest, as they are often in close contact with each other.

3.13. Wildlife

M. bovis can infect a wide range of wild animals [27, 77, 89]. Two categories of hosts are distinguished: maintenance hosts, capable of maintaining and spreading the infection, versus spill over hosts, which cannot maintain it. The localisation of lesions in infected animals may partly characterise them: lesions mainly located in the thoracic cavity suggest an aerogenic infection, which is commonly observed in maintenance hosts like cattle [27]. Digestive lesions suggest oral contamination by eating contaminated carcasses, which is a characteristic of spill over, mostly carnivorous species. The capacity of excretion, the ethology and ecology of wild animals, as well as the prevalence of the disease determine their role as a reservoir for *M. bovis* [7]. Nevertheless, the borderline between these host categories is not clearly established, as shown in Table I, since the relationship between maintenance and spill over hosts is dynamic [31]. Spill over hosts may also transmit the infection to other host populations, as suspected by British scientists in a cross-sectional survey of 4 180 wild animals (16 different species) performed on 12 dairy farms, among which eight had a recent history of bTB in cattle and 4 controls [70]. Where the density of hosts is high, infection can spread among spill over hosts, and these may act as maintenance hosts, as was recently suggested in France: 33 infected red deer captured during the 2005/2006 hunting season presented lesions with a great capacity of

Table I. Isolation of *M. bovis* in wildlife species and their possible role as maintenance or spill over hosts in the transmission of bovine tuberculosis to domestic cattle.

Species	Country/area	Spill over	Maintenance	References
Cervids				
White-tailed deer (*Odocoileus virginianus*)	USA (Michigan)	X	X	[12, 58]
Red deer (*Cervus elaphus*)	Spain, NZ, UK, Czech Rep., France	X	X	[6, 32, 64, 65, 93, 124]
Sika deer (*Cervus nippon*)	UK	X	X	[31]
Fallow deer (*Dama dama*)	Spain, UK	X	X	[6, 31, 32]
Roe deer (*Capreolus capreolus*)	UK	X	?	[31, 32]
Elk or Wapiti (*Cervus canadensis*)	Canada	X	X	[62]
Muntjac (*Muntiacus reevesi*)	UK	X	?	[32]
Suids				
Wild Boar (*Sus scrofa*)	Spain, Italy, Croatia, Slovakia, Hungary, France	X		[92, 93, 124]
Feral pigs (*Sus domesticus*)	NZ	X		[20]
Warthog (*Phacochoerus aethiopicus*)	South Africa	X	X	[73, 122]
Carnivores				
Red Fox (*Vulpes vulpes*)	USA, UK, Spain	X		[12, 31, 32, 63, 69]
Feral ferret (*Mustela furo*)	NZ, UK	X	X?	[17, 30]
Stoat (*Mustela erminea*)	NZ, UK	X		[17, 30, 32]
Polecat (*Mustela putorius*)	UK	X		[32]
Mink (*Mustela vison*)	UK	X		[30]
Feral cat (*Felis catus*)	NZ, UK	X		[30, 99]
Lion (*Panthera leo*)	Tanzania, South Africa	X	?	[17, 73]
Cheetah (*Acinonyx jubatus*)	South Africa, Zambia	X		[60, 126]
Iberian Lynx (*Lynx pardinus*)	Spain	X		[11, 69]
Leopard (*Panthera pardus*)	Zambia	X		[126]
Spotted hyaena (*Crocuta crocuta*)	South Africa	X		[73]
Bobcat (*Lynx rufus*)	USA (Michigan)	X		[12]
Coyotes (*Canis latrans*)	USA	X		[12]
Black Bear (*Ursus americanus*)	USA (Michigan)	X		[12]
Raccoon (*Procyon lotor*)	USA (Michigan)	X		[12]
Wild ruminants				
African Buffalo (*Syncerus caffer*)	South Africa, Uganda		X	[37, 73, 122]
Asian water Buffalo (*Bubalus arnee*)	Australia		X	[20]
Bison (*Bison bison*)	Canada, Poland		X	[84, 93]
Kudu (*Tragelaphus imberbis*)	Tanzania		X	[15]
Greater Kudu (*Tragelaphus strepsiceros*)	South Africa, Zambia		X	[60, 126]

Table I. Continued.

Lechwe antelope (*Kobus leche*)	South Africa, Tanzania		X	[27, 126]
Bushbuck (*Targelaphus scriptus*)	Zambia		X	[126]
Feral goat (*Capra hircus*)	NZ		X	[17]
Wildebeest (*Connochaetes taurinus*)	Tanzania	X	X	[15]
Topi (*Damaliscus lunatus*)	Tanzania	X		[15]
Small mammals				
Hedgehog (*Erinaceus europaeus*)	NZ	X		[17]
Mole (*Talpa europaea*)	UK	X		[30, 31]
Brown rat (*Rattus norvegicus*)	UK	X	?	[31]
Common shrew (*Sorex araneus*)	UK	X		[32]
Grey Squirrel (*Sciurus carolinensis*)	UK	X		[32]
Bank vole (*Clethrionomys glareolus*)	UK	X		[70]
Field vole (*Microtus agrestis*)	UK	X		[32]
Yellow-necked mouse (*Apodemus flavicollis*)	UK	X		[32]
Others				
European badger (*Meles meles*)	UK, Ireland, Spain		X	[33, 47, 69]
Possum (*Trichosurus vulpecula*)	NZ		X	[55]
Baboon (*Papio cynocephalus*)	Kenya	X		[111]

disseminating bTB [124]. Table I provides additional information about the possible implications of different wild species in the dynamics of *M. bovis*. bTB is prevalent in European badger (*Meles meles*) populations of UK and Ireland [14, 33, 47]. Brushtail possums (*Trichosurus vulpecula*) are the primary wild maintenance host of bTB in New Zealand [78]. The exact role of cervids in the epidemiology of *M. bovis* tuberculosis and in transmission to cattle still remains unclear [20]. *M. bovis* has been isolated from different species of cervids all around the world: white-tailed deer in Michigan [58, 106], red deer in New Zealand [26], muntjac, roe, red and fallow deer in the UK [30, 32, 49], red and fallow deer in Ireland [98], red deer in France [124] or in Spain [5, 44]. In Europe, wild boar (*Sus scrofa*) tuberculosis has been identified in several countries such as Spain, France and Italy [5, 91, 107, 124]. Long thought to be a spill over host, the pattern of lesions observed in Spain suggests a possible role of the wild boar as a maintenance host [92, 116]. The African buffalo (*Syncerus caffer*) has become a maintenance host for *M. bovis* in areas such

as the Kruger National Park, South Africa [28, 74, 102]. The disease has spread widely among buffaloes and other mammalian species, including predators such as lions, have become spill over hosts [73].

Scientists from South Africa and England recently introduced the theory of multi-species host-pathogen systems [101]: transmission rates between species will partly be determined by the resource utilisation and the spatial distributions of hosts. A number of spill over hosts could act as maintenance hosts and a combination of species could function as a host community instead of a single species acting as a maintenance or spill over host by itself [52].

The ecology of susceptible wild hosts should be considered. In a retrospective matched case-control study performed in 2001 in Michigan on 17 cattle farms with bTB-infected cattle, scientists observed a decreased risk of bTB strongly associated with a greater percentage of natural open land in the surrounding area, which is probably related to the ecology of white-tailed deer considered as a maintenance host: deer actually prefer staying in woodlands rather than moving out to open

pasture [58]. It would be interesting to assess the efficacy of implementing buffer zones to wooded areas in order to separate deer habitat from pastures.

Wildlife may contaminate cattle by direct or indirect contact. Direct contact is rare but animals reaching a late stage of clinical tuberculosis may show modified behaviour: they lose fear, are more active in the daylight and attract cattle, as reported in observations of tuberculous possums during the clinical and terminal stages of disease [85]. The second pathway of transmission to cattle is indirect: cattle can become infected through the contamination of the environment by excretions of wild animals such as faeces, urine or pus. Cattle share grazing land and water points with infected wildlife, a situation frequently observed in Africa, as suggested in a cross-sectional study including 106 herds carried out in 2003–2004 in Zambia [81]. In the UK, badgers' urine was shown to contain more bacilli (from 217×10^3 cfu/mL) than bronchial pus (73×10^3 cfu/mL) and faeces (from 68/g); the risk of contracting bTB through inhalation of urine-born aerosols is the highest [39]. A full urination could contain several million organisms [39]. Several factors may affect the faecal-oral route of *M. bovis* transmission. Defecation patterns, e.g. random defecation across the pasture versus latrines, may affect cattle contact with faeces [110]. The infective dose is also of great importance: a dispersed faecal pattern will have less contamination power relative to a latrine pattern, as shown in an experiment carried out in 2005 in the UK where the grazing behaviour of cattle on pastures artificially contaminated with different wildlife species faeces (e.g. badgers, deer) was monitored [110]. UK scientists demonstrated that if the required infective dose is high, latrines would play a major role despite cattle having less contact with them [68]. On the contrary, if the required infective dose is low, the major risk would come from the dispersed faecal distributions [68]. In a study carried out in SE England in 2000, it was shown that the type of grazing system could affect the duration of avoidance of badger latrines in the monitoring of the grazing behaviour of 150 lactating cows [105]. In extensive systems, badger latrines

were avoided for a longer period of time, while in intensive systems, they were grazed sooner [105]. Further investigations are necessary to clearly establish the relationship between cattle grazing behaviour, contact with wildlife excreta and dose-exposure in the environment.

Multiple host communities should be further considered, since they may have induced interference in areas where bTB control measures in wildlife against one single species have failed to achieve eradication so far. Since the role of some species remains unknown in the epidemiology of bTB and in its transmission to domestic cattle, it is crucial to increase surveillance or implement it in areas where it does not yet exist. Control measures such as culling of wild species are often thought to be the solution to eradicate the problem, but have not always reduced bTB prevalence in contiguous cattle herds. Diagnosis methods applicable in wildlife need further investigation. Herd management respectful of wildlife should be promoted. Reducing contact with potentially infected wildlife must be the basics of every control program (biosecurity).

3.14. Environmental persistence of *M. bovis* and influence of climate

Information on survival of *M. bovis* outside living animals is controversial. In their review, Menzies and Neill state that *M. bovis* is able to survive in the environment for only a few weeks under natural conditions, considering that environmental contamination is a less effective means of disease transmission to cattle [72]. Infection of cattle through environmental contamination is probably negligible, because the required infective dose is high: 10^7 bacilli would be necessary for oral contamination, as suggested by Irish authors in 1995 [89], whereas an aerosol containing only one bacillus was shown to contaminate 4–7 month old calves in an English study carried out in 1988 [83]. Morris et al. concluded in 1994 that contaminated feed and pasture play a negligible role in the transmission of the disease to cattle because *M. bovis* does not survive long enough on fomites to be infective, but also because animals are not commonly exposed to a high

enough dose to become infected orally [77]. The importance of environmental contamination in the transmission of bTB to healthy cattle might differ between developed and developing countries. The results of cross-sectional surveys conducted in Tanzania were published in 2007: out of 10 549 tested cattle, 91 were positive with major visible lesions recorded in the gastrointestinal tract [16]. The survival time of *M. bovis* in soil has been estimated in different studies. Wray argues that the availability of nutrients is the limiting factor. Sunlight causes desiccation, and ultraviolet light may strongly influence survival in tropical areas. Adequate levels of moisture are necessary for survival [123]. Kelly and Collins later suggested that the major factors influencing survival in soil and on pasture are temperature, moisture, and pH, exposure to sunlight, dissolved oxygen, presence of naturally occurring antibiotics in the soil, natural microflora and types of microfloral associations [61]. Soil ecology is also of major importance in the environmental survival of *M. bovis* [7]. *M. bovis* is expected to persist in slurry-treated soil for up to two years [61]. In 1985, Duffield and Young inoculated *M. bovis* into faeces, dry soil and moist soils of tropical Australia. It survived for four weeks in nonsterile dry and moist soils under 80% shade, in darkness and in the laboratory and for a similar time in sterile moist soil kept in the shade and in darkness [34]. Conclusions drawn under experimental conditions should nevertheless be considered carefully since they differ from field conditions. Between 2003 and 2005, Courtenay et al. detected viable *M. bovis* DNA by PCR at badger setts and latrines in bTB endemic regions of the UK long after they were abandoned by badgers [23]. As a result, environmental persistence of *M. bovis* becomes a risk if bTB bacilli persist once faecal contamination is no longer obvious since cattle no longer avoid grazing these areas. The real epidemiological significance of the environmental reservoir of *M. bovis*, especially soil, still needs further investigation, especially when an epidemiological investigation remains inconclusive. Molecular techniques will probably help in better identifying potential environmental sources of *M. bovis*.

Water points must be mentioned as a potential risk factor: areas around pounds are generally moister, with greater amounts of shade, two favourable conditions for *M. bovis* survival identified by New Zealand scientists in 1992–1993. Once again, shade and moisture were found favourable under experimental conditions only, so that these results should be interpreted carefully [56]. When cattle drink, splashing could favour the entry of bacilli into the respiratory tract through inhalation of contaminated droplets [95]. As demonstrated in the USA, excreting animals can contaminate running water directly [95]. This may pose a particular risk in Africa where most herds share water points: an excreting animal has thus a high infective potential [16]. Other environmental mycobacteria may as well contaminate water sources, and cause false positive reactions to the skin test. In order to minimise the risk, cattle should be fenced away from natural water sources whenever possible [95].

In Africa, flooding has also been suggested as a propagating factor of *M. bovis* in the environment, as demonstrated by the results of cross-sectional surveys of 10 549 cattle conducted in Tanzania and published in 2007 [16]. Nevertheless, this risk factor needs further confirmation.

Climate influences the survival of *M. bovis* bacilli in the environment, as mentioned above [95]. The survival period of *M. bovis* in the environment was shown to be inversely proportional to mean daily temperatures in a New Zealand study carried out in 1992–1993 [56]. Temperatures just above 0 °C and a strong hygrometry are favourable for *M. bovis* survival; hot and dry weather do not allow a long-time survival of *M. bovis* in the environment [7]. In 1997, models of data from England and Wales suggested the occurrence of bTB was linked to seasonality and changes from one year to the next. However, it is not clear whether authors modelled the disease, the cattle or the distribution of farmlands suited to cattle production [121]. Further studies could clarify the role played by the climate in the environmental survival of *M. bovis*.

Landscape heterogeneity was shown to have an impact on bTB in cattle from SW England,

where badgers were believed to be the source of infection for cattle: linear features would restrict badger movements to some crossing points (urination sites); this direct contamination of pasture enhances the risk of contamination to cattle [118]. In this study, landscape heterogeneity was directly related to badger habitat and behaviour.

4. RISK FACTORS AT THE REGION/ COUNTRY LEVEL

4.1. bTB prevalence and antecedents in the region/country

The incidence and scale of bTB in cattle in an area is likely to be related to the history of bTB in that specific area. UK scientists have shown that herd bTB outbreaks occur repeatedly in the same areas, probably because the source of the disease failed to be removed and/or permanent factors make specific areas particularly suitable for the recurrence of infection [119]. These scientists used two cross-sectional time-series data sets for their analysis, which were collected in SW England from 1986 to 1996 and included 1 899 observations [119]. A retrospective cross-sectional survey in the Krueger National Park, divided into three geographic zones and including 3 743 buffalo culled between 1991 and 1998, showed that the risk of bTB was enhanced as prevalence in the herd increased [103].

4.2. Contiguity with other bTB restricted herds

In 1996, Griffin et al. conducted a case-control study in Ireland: 100 herds were selected in an area under a badger removal programme operated since 1989. They found that during a short delay bTB outbreaks were more likely to affect several herds rather than only one herd, because the contiguity with other bTB restricted herds was a significant risk factor [48]. A case-control study conducted in Ireland and including 215 dairy herds showed in 1993–1995 that the neighbouring with a bTB breakdown-herd was associated with a bTB breakdown in a specific herd. Outbreaks

confirmed in adjacent herds might indicate a common source of infection [33]. In 2002, a retrospective matched case-control study carried out in 18 bTB-infected farms of Michigan highlighted fence-line contacts as a particular risk for the transmission of *M. bovis* from infected to healthy animals [58]. A total of 995 herds from nine Canadian bTB outbreaks that occurred between 1985 and 1994 were investigated, and fenceline contact with a positive herd was also identified as a risk factor for bTB [80]. It is thus important to limit contacts between contiguous herds whenever possible.

4.3. International trade and trans-border movements of cattle

The importation of living cattle, especially from a not-OTF to an OTF country, is likely to be responsible for the introduction of bTB, as shown by a study conducted in 2003–2004 in four transhumant districts of Uganda on 1 864 animals from 37 cattle herds. The sampling plan encountered problems because of the lack of information on distribution of animal populations in transhumant communities [87]. The source of bTB was investigated in 31 herds in NE England, where outbreaks were confirmed in 2002–2004. In 17 outbreaks, reactor animals were traced, thanks to molecular typing, to herds located in Wales and the west and north of England and three outbreaks were traced to Irish imports [43]. Animals purchased from a high bTB incidence area and introduced in a low bTB incidence region increase the risk of a herd breakdown as suggested by a study carried out on 2 914 British cattle farms located in 58 counties of England, Wales and Scotland that were depopulated during the 2001 FMD epidemic [13]. Trans-border movements of live cattle are constantly increasing, thus the risk of importing infected cattle is higher: a 6%-annual growth of international trade is actually projected, as it is constantly increasing[6]. Border controls should

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be increased or implemented in areas where they are not applied.

4.4. Migration – Globalisation

Migration and people's travelling habits are additional risk factors for the spread of *M. bovis*. Since bTB is present in most developing countries where surveillance and controls are often inadequate or unavailable [21], international migration plays a key role in the spread of infectious diseases. In many developing countries, milk and dairy products are still consumed unpasteurised, and the risk of *M. bovis* transmission remains likely [2]. Human to cattle transmission of *M. bovis* has been described before (see Sect. 2.1), thus, a foreign-born person, contaminated in his/her childhood and clinically expressing the disease, represents a risk if he comes in contact with a bTB-free herd. This phenomenon was reported recently on the USA-Mexico border [113]. In 2007, 58% of TB cases occurred in foreign-born individuals, and the case rate among them was nearly 10 times higher than among USA-born individuals. Between 1994 and 2005, the incidence of *M. bovis* TB cases increased significantly in the USA as demonstrated by a retrospective analysis of TB case surveillance data from California. In this study compiling data from 3 291 culture-positive cases, more than 96% of *M. bovis* cases were found in people of Hispanic, especially those of Mexican, origin [104].

Finally, wildlife, a risk factor already developed in Section 3.13, must be considered at the region/country level too, since wild species movements include border crossing. These trans-border movements of wildlife can occur naturally or be human-induced, e.g. via legal importations to zoological parks or animal reintroduction for conservation programmes. Illegal importations of wild species can be considered as a risk factor on an international scale as well.

5. CONCLUSIONS

Bovine tuberculosis remains of great concern worldwide. Many risk factors, at individual, herd and region/country levels have been reviewed above. Although some of them may have a major impact in some regions of the world, they may not be significant elsewhere, due to the different control programmes applied and specific epidemiological situations. From this review, differences in the importance of risk factors between cattle systems in the developed versus developing countries emerge. Some risk factors were more specifically identified in developing countries: management, reduced interactions with veterinary services, uncontrolled movements of animals, lack of a bTB status for the herds, practices increasing contacts between animals from different herds such as transhumance, but also the lack of surveillance at slaughterhouse and of other domestic and wild species. In developed countries, management was identified as a risk factor but also purchase, increased contacts between animals, proximity with herds under movement restrictions, bTB antecedents and bTB prevalence, movements, wildlife, environment but also the lack of performance of the skin test.

As a result, better testing is required, in terms of implementation in developing countries and of performance in developed countries. The practice of skin testing is currently on a decrease in terms of control measures used in Western Europe, which might further lead to the re-emergence of bTB. Furthermore, since international trade of living cattle is constantly increasing, the risk of importing infected cattle from an OTF region into an OTF-country/area exists. The risk related to the importation of living animals must be emphasised. It is thus necessary to remind the people involved in cattle trading of the importance of testing at purchase, especially if the animal introduced in an OTF-country comes from a not-OTF-region. Pre-movement testing is thus primordial. It is also necessary to develop standardised methodologies to evaluate diagnostic methods via meat inspection, purchase- and herd-skin testing. More importance should be given to bTB diagnostic tests, their performance and compliance of veterinary services (e.g. skin test).

A better surveillance of wildlife is required to reduce the risk for transmission to cattle, at national but also international levels since wildlife epidemio-surveillance is poorly

implemented in an international context. Few countries have established an efficient wildlife surveillance system; some countries have surveillance mainly run by some research institutes and others have almost no wildlife surveillance at all. The implementation of an international wildlife surveillance network in order to minimise the risk of transmission to domestic cattle is recommended.

To allow a better identification of areas at risk, the World Animal Health Information Database has been created[7]: it is an interface providing access to all data held within the OIE's new "World Animal Health Information System". In this interface, complete information is found about disease events occurring in OIE Member Countries as well as follow-up reports about them. Data are available for domestic animals but also for wild species: a yearly report compiling data about wildlife is available[8].

Control measures must be applied to domestic cattle, but also to wildlife in areas where the incidence of *M. bovis* tuberculosis is high. These measures require the implementation of not only offensive, but also defensive (preventive) measures. Improved farm biosecurity is required in order to reduce bTB risks at the herd level: e.g. secure feed storage, correct management of slurry spreading, secure feeding habits, correct hygiene but also a grazing system minimising the cattle/wildlife interface.

Scientific research should target several points or particular risk factors discussed in this paper but also improve diagnosis methods, focus on the role of the environment on bTB transmission as well as determining the exact role of wild species potentially implicated in the transmission of bTB. Further studies are needed to better understand the transmission mechanisms between probable wild mainte-

nance hosts and cattle. The role of environmental persistence of *M. bovis* needs further investigation in order to assess its role in the epidemiology and transmission of bTB to cattle. Genetic resistance, the possibility of latency for *M. bovis* and the host-pathogen relation in cattle and wildlife species are areas that could be targeted by researchers.

In 2000, in order to improve world health, the United Nations adopted different agreements leading to the implementation of Millennium Development Goals (MDG); the improvement of world health is included in these goals[9]. The sixth Goal aims to combat HIV/AIDS, malaria and other diseases. In order to achieve the goal of bTB eradication, the adoption of MDG in animal health should be definitely considered as the main challenge for the future. The proposed animal health MDG could rely on several points: (1) to increase biosecurity on farms in order to improve animal health, (2) to increase preventive and control measures such as animal testing but also to improve the tests with regards to their precocity and their inherent sensitivity and specificity, (3) to develop a wildlife surveillance network. Surveillance should involve not only bTB but as many diseases as possible in order to improve the infectious status in cattle, other livestock and ultimately in wildlife.

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