Epidemiology of *Mycobacterium bovis* infection in animals and humans, with particular reference to Africa

O. COSIVI *, F.-X. MESLIN *, C.J. DABORN ** and J.M. GRANGE ***

Summary: The epidemiology of Mycobacterium bovis infection in animals and humans is described, together with a review of available reports on the distribution and prevalence of this mycobacteriosis in Africa. The significance of these reports is considered, with particular emphasis on the potential zoonotic importance of bovine tuberculosis as a cause for public health concern in Africa. Published data describing tuberculosis in Europe in the 1930s and 1940s show that bovine tuberculosis was considered to be a significant zoonosis: *M. bovis* was responsible for more than 50% of cervical lymphadenitis cases in children. Despite the paucity of information on *M. bovis* infection in Africa, there is sufficient evidence to suggest that it is widely distributed and is found at significantly high prevalence in some populations of animals. Some epidemiological conditions for the spread of *M. bovis* infection between animals and humans are very similar in Africa today to those in Europe in the 1930s, with the added and potent impact of the epidemic of human immunodeficiency virus infection. The public health threat of tuberculosis in Africa requires urgent investigation through collaborative veterinary/medical research programmes.


INTRODUCTION

Tuberculosis is still the greatest single cause of human morbidity and mortality in many developing countries (33). *Mycobacterium tuberculosis* is the most frequent cause of human tuberculosis (HTB), but some cases are caused by *M. bovis*. In developed countries, before the control and elimination of bovine tuberculosis (BTB) and the wide introduction of milk pasteurisation, zoonotic infection with *M. bovis* was a major cause of HTB (19, 25, 35, 38, 51). Despite complete or virtual elimination of BTB from many countries in Europe, the zoonotic implications of the disease are still considered a priority by the European Union (16). In developing countries – especially in Africa, where *M. bovis* infection has been reported in a wide range of animal species – there is generally insufficient reliable and recent information to draw a comprehensive picture.

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of the current distribution, epidemiology and zoonotic impact of this important zoonosis. The factors contributing to this situation and other research priorities concerning zoonotic tuberculosis have recently been emphasised by the Veterinary Public Health unit of the World Health Organisation (WHO) (60, 61, 62). This paper reviews the epidemiological features of *M. bovis* infection in animals which are relevant to developing countries, and outlines some recent reports describing the distribution and prevalence of the disease in Africa.

**EPIDEMIOLOGY OF ANIMAL TUBERCULOSIS DUE TO MYCOBACTERIUM BOVIS**

**Hosts**

*M. bovis* is the most common cause of tuberculosis in cattle. The organism also infects humans and non-human primates, domestic animals (e.g. swine, sheep, goats, horses, water buffalo, camels [1, 27], deer [8], cats and dogs [52]). Zoo, laboratory, and wild animals can also be infected with *M. bovis* (55). In developing countries, particularly in Africa, a wide range of other potential domestic and wild animal hosts exists, in addition to large cattle populations. Table I lists some of the feral and wild animal species from which *M. bovis* has been isolated.

**TABLE I**

*Some of the domesticated and wild mammal species from which *Mycobacterium bovis* has been isolated (56, 12)*

<table>
<thead>
<tr>
<th>English name</th>
<th>Latin name</th>
</tr>
</thead>
<tbody>
<tr>
<td>African buffalo *</td>
<td>Syncerus caffer</td>
</tr>
<tr>
<td>African elephant **</td>
<td>Loxodonta africana</td>
</tr>
<tr>
<td>Baboon</td>
<td>Papio cynocephalus</td>
</tr>
<tr>
<td>Bactrian camel</td>
<td>Camelus bactrianus</td>
</tr>
<tr>
<td>Black rhinoceros **</td>
<td>Diceros bicornis</td>
</tr>
<tr>
<td>Giraffe **</td>
<td>Giraffa camelopardalis</td>
</tr>
<tr>
<td>Goat</td>
<td>Capra hircus</td>
</tr>
<tr>
<td>Greater kudu</td>
<td>Tragelaphus strepsiceros</td>
</tr>
<tr>
<td>Grey duiker **</td>
<td>Sylvicapra grimmia</td>
</tr>
<tr>
<td>Kudu *</td>
<td>Tragelaphus strepsiceros</td>
</tr>
<tr>
<td>Lechwe *</td>
<td>Kobus leche</td>
</tr>
<tr>
<td>Rhesus monkey</td>
<td>Macaca mulatta</td>
</tr>
<tr>
<td>Spider monkey</td>
<td>Ateles geoffroyi</td>
</tr>
<tr>
<td>Rock hyrax</td>
<td>Procavia capensis</td>
</tr>
<tr>
<td>Springbok **</td>
<td>Antidorcas marsupialis</td>
</tr>
<tr>
<td>Warthog *</td>
<td>Phacochoerus aethiopicus</td>
</tr>
<tr>
<td>Wild boar</td>
<td>Sus scrofa</td>
</tr>
<tr>
<td>Water buffalo</td>
<td>Bubalus bubalis</td>
</tr>
<tr>
<td>Lion</td>
<td>Panthera leo</td>
</tr>
</tbody>
</table>

* *M. bovis* infection is endemic in the African population (46)

** M. bovis** has been isolated in the African population (46)
Pathogenesis

Development of overt disease after infection under field conditions may be dependent not only on the number of virulent organisms to which a susceptible host is exposed, but also on the frequency of exposure and route of infection, as well as the general health and immunological status of the animal. Although tuberculous lesions can be found in all parts of the body in cattle infected with M. bovis, they are most frequently found in the lungs and in the broncho-mediastinal lymph nodes, most probably in association with air-borne infection. In contrast to human infection, the primary pulmonary lesion in cattle rarely heals spontaneously, but tends to disseminate locally through the natural cavities, such as the bronchi, or more widely via the lymphatic and haematogenous routes (21). Infection of the udder has been found in varying proportions of tuberculous animals, from 1-2% (21) up to 5.4% (50). The outcome of the infection, with few exceptions, is a chronic wasting disease of long duration (4).

Geographical distribution and environmental determinants

The prevalence of tuberculosis within a country varies widely between different areas. South American reports show the highest levels of tuberculosis occurrence in the surrounding areas of larger cities where intensive dairy production is most common (54). Large variations in disease occurrence within different regions of the same country have also been reported in Africa (17). The distribution of the domestic ruminant population and dairy production varies within the ecological zones of Africa (Table II). This factor, together with the differences in the production systems under which livestock are managed on the African continent (i.e. pastoralism, ‘agro-pastoralism’, mixed farming and intensive dairy farming), may have a significant influence on the distribution of animal tuberculosis.

**TABLE II**

*Percentage of the total area, and total livestock and milk production in the various eco-geographical zones in Africa*

(30, 57)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Area</th>
<th>Livestock</th>
<th>Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arid</td>
<td>37.3</td>
<td>30.4</td>
<td>42.2</td>
</tr>
<tr>
<td>Semi-arid</td>
<td>18.1</td>
<td>27.3</td>
<td>21.4</td>
</tr>
<tr>
<td>Sub-humid</td>
<td>21.7</td>
<td>19.2</td>
<td>14.7</td>
</tr>
<tr>
<td>Humid</td>
<td>18.5</td>
<td>5.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Highlands</td>
<td>4.4</td>
<td>17.2</td>
<td>17.8</td>
</tr>
</tbody>
</table>

The distribution and transmission of the disease are also likely to be influenced by macro- and micro-climates affecting the stability of the agent in the environment. Table III gives M. bovis survival times under different environmental conditions.

Husbandry

Higher prevalence of tuberculosis is expected in cattle which are housed or not grazed. In extensive husbandry, however, individual herds with high morbidity may also be encountered (4). The higher prevalence observed in dairy cows (average age 4.5 years) compared with the overall cattle population (average age 2.5 years) has been
Table III

*Survival time of Mycobacterium bovis under different environmental conditions*

(40)

<table>
<thead>
<tr>
<th>Contaminated material</th>
<th>Conditions</th>
<th>Survival time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purulent emulsion</td>
<td>Direct sunlight</td>
<td>&gt; 10 h but &lt; 12 h</td>
</tr>
<tr>
<td></td>
<td>Diffuse sunlight</td>
<td>At least 30 days *</td>
</tr>
<tr>
<td>Cattle dung</td>
<td>Direct sunlight</td>
<td>&gt; 6 h but &lt; 37 h</td>
</tr>
<tr>
<td></td>
<td>Diffuse sunlight</td>
<td>14-150 days</td>
</tr>
<tr>
<td></td>
<td>Covered</td>
<td>365-730 days</td>
</tr>
<tr>
<td>Pasture</td>
<td>Temperate climate</td>
<td>Dependent on season and climatic conditions (7-63 days)</td>
</tr>
<tr>
<td>Water (experimentally contaminated)</td>
<td>–</td>
<td>18 days</td>
</tr>
</tbody>
</table>

* not tested further

attributed to the longer productive life and the type of husbandry (i.e. housing, fencing, frequent pregnancies and high milk yields), which are likely to expose dairy cows to aerogenous infection (20).

Under extensive systems of deer management, tuberculosis is normally of low prevalence and negligible economic importance. Intensification of the deer-farming industry, however, has led to this disease becoming a serious problem, particularly for the farmed deer industry in the United Kingdom and New Zealand (8).

Transmission

Mycobacteria are transmitted by many different routes, depending on the localisation of the foci of infection in animal tissues and organs. In the case of open pulmonary lesions, mycobacteria are normally discharged and disseminated by the aerogenous route but, if swallowed, they may also be excreted in the faeces. Disease may spread from the initial focus to regional lymph nodes and then further via the lymphatic and aerogenous routes, resulting in generalised tuberculosis. Dissemination can follow, through excretion in faeces, urine, semen, uterine discharges or milk, in addition to respiratory spread. If peripheral lymphatics become involved, fistulae may develop and mycobacteria may be discharged. Under natural conditions, 90-95% of all tuberculous cattle contract infection by the aerogenous route (4). Cattle in the early stages of the disease may also excrete viable mycobacteria in nasal and tracheal mucus secretions (37).

The dose required to produce disease in a susceptible animal by the alimentary route has been considered to be several times larger than when the disease is contracted by the respiratory route (20, 22). Nevertheless, it has been reported that a single cow can excrete sufficient viable mycobacteria in milk to make even pooled milk infective (32). It should be noted that mycobacteria have been isolated from the milk of apparently healthy Fulani cattle, and also from udder and supramammary lymph nodes which were free from macroscopic lesions (47).

Almost all diseased cattle must be considered a potential hazard for healthy animals (37, 44, 45). This view contrasts with the concept of 'open' (i.e. able to spread infection)
and 'closed' (i.e. unable to spread infection) cases of tuberculosis (4). In some countries, campaigns to eradicate tuberculosis in the cattle population have been complicated by wild animal reservoirs. The badger (Meles meles) in the United Kingdom (53) and the brush-tailed possum (Trichosurus vulpecula) in New Zealand (36) serve as major reservoirs and vectors of M. bovis for domestic and other feral/wild animals. Infected human beings have been found to be a source of re-infection for cattle in some countries where eradication of BTB has been achieved (39, 3).

Goats and sheep may become infected when sharing pasture with infected cattle. Sheep seem to be more resistant to mycobacteria than goats. Pigs can also acquire the infection when fed with infected milk or milk by-products (1). Infection may also be transmitted through ingestion of raw tuberculous meat and by infected semen at coitus or during artificial insemination (4). Congenitally-transmitted tuberculosis is extremely rare, occurring in approximately 1% of calves born to infected cows (22).

RECENT REPORTS ON THE DISTRIBUTION AND PREVALENCE OF ANIMAL TUBERCULOSIS DUE TO MYCOBACTERIUM BOVIS IN AFRICA

According to the Office International des Epizooties (OIE) world animal health tables (46), 33 of 41 African countries reported the presence of BTB in 1992. Only four countries - Kenya, Namibia, the Seychelles and Zimbabwe - reported freedom from the disease. More than 50% of the total African populations of dairy and other cattle are found in countries with no control measures for BTB, and only approximately 10% are found in countries where BTB is a notifiable disease and where testing and stamping-out are applied. Thus BTB control is either partial or non-existent in approximately 90% of the populations of dairy and other cattle in Africa. It is also estimated that approximately 90% of the human population lives in countries where dairy cows and other cattle are subject to no control or only partial control for BTB (18, 46). Recent reports on animal tuberculosis in specific countries in Africa are outlined below.

Egypt

Tuberculin testing has been performed in Egypt since 1920, when the overall rate of infection in the cattle and buffalo population was estimated at 2-9%. In 1981 a national programme was commenced in three governorates, and in 1986 this was extended to cover the entire country (17, 46). This programme is based on compulsory periodical testing of females aged over six months and bulls for breeding, followed by slaughter of reactors and compensation. In 1981 the overall proportion of positive reactors in two of the controlled governorates was 6.16% and 9.40%, respectively; in 1985 reactivity dropped to around 2.60%.

Table IV shows the number (and percentage) of positive reactors to the single intradermal tuberculin test for the period 1989-1992. In recent years, the percentage of positive reactor cattle in some governorates has increased sharply: in Port Said, the percentage rose from 11.75% in 1990, to 15.91% in 1991; in Behera from 2.69% in 1990, to 13.41% in 1991; and in Dakahlia from 0.39% in 1989, to 23.35% in 1991. The national estimate of positive reactors in buffalo is 0.10-2.10%, except in Behera, where according to the most recent data - the percentage has reached 14.28%.

In Egypt, HTB infection caused by M. bovis was reported to account for 12.2% of the total number of HTB cases in 1953, falling to 10.0% in 1969, and 5.4% in 1980.
Approximately 63% of these patients were from rural areas (17). In a recent investigation, nine of twenty randomly-selected mycobacteria samples isolated from patients with abdominal tuberculosis were found to be *M. bovis* (42). Other authors reported that 5% of 300 mycobacteria cultured from human sputum were *M. bovis* (15). The observed *M. bovis* occurrence was attributed to the fact that most patients lived in the Cairo abattoir area, and some were workers at the abattoir.

**South Africa**

At the end of 1992, 34 herds were known to be infected with BTB in South Africa (46). The prevalence in the cattle population dropped from 0.17% in 1981 to 0.04% in 1992. Tuberculosis has been reported in African buffalo in the Kruger National Park. Of a total of 32 buffalo herds tested, 13 contained positive cases (40%). The prevalence of the disease in infected herds varied between 3% and 33%. *M. bovis* was also isolated from a lion in northern Natal. Surveys are being conducted to assess the prevalence of the disease in the buffalo population in different parts of the country.

**Côte d'Ivoire**

Among the causes of total condemnation in slaughtered cattle in Côte d'Ivoire, tuberculosis was reported in 50% of cases (approximately 10% in sheep and goats) (46). Government action to address the situation is expected during 1993.

**Mali**

In Mali, a total of 237 cattle and 124 sheep were found to be infected with tuberculosis during 1992, and their entire carcasses were condemned (46). Dairy cattle and animals in artificial insemination centres are tuberculin tested, and those yielding positive results are slaughtered.

**Morocco**

BTB control in Morocco is restricted to certain intensive cattle units and dairy farms (46). In some districts, slaughtered female cattle were found to be heavily infected, with isolation rates of 30% for *M. bovis* and 9.7% for *M. tuberculosis* (60).

**Somalia**

According to a recent report, the proportion of cattle infected with BTB in Somalia is 4.54-10.2% (17).
ANIMAL TUBERCULOSIS AND ZOONOTIC ASPECTS IN AFRICA

Although much information regarding the epidemiology of *M. bovis* infection in animals and humans can be derived from studies on the disease in developed countries, a number of significantly different factors may be present in tropical areas (e.g. some countries in Africa). A number of such factors – which are likely to facilitate *M. bovis* spread, increase occurrence in the African animal population and affect the zoonotic aspects of *M. bovis* infection – can be identified, as follows:

- The almost ubiquitous distribution of *M. bovis* in farmed animals and, to a large extent, in wild animal populations (Table 1) represents a vast reservoir of this mycobacterium. The role of wild animals in Africa as potential reservoir hosts has been investigated, but this has not yet been fully elucidated (7, 11, 23, 24 [quoted in 55], 34, 58). It is possible to hypothesise, however, that where wild and domesticated animals share pasture or territory, cross-transmission of infection between affected and non-affected animals is likely to occur (59).

- The increase in the demand for milk – estimated at 2.5% per year over the period 1970-1988 in sub-Saharan Africa (57) – will be met not only by an increase in the number of productive animals and imports, but also by intensification of animal production. Animal tuberculosis occurrence has been shown to have close links with intensive management, and incidence could thus increase in the absence of sufficient veterinary supervision. Where intensification does not occur, other factors still play a major role in the spread of animal tuberculosis, such as animals from different sources gathering at watering points, at markets and in overnight enclosures. All these widespread practices can play a key role in the maintenance and spread of *M. bovis* within the traditional farming sector.

- Control and elimination measures for animal tuberculosis are lacking in most African countries. The present situation is most probably due to the chronic lack of funds, trained professionals and political will, but also to the under-estimation of the economic and zoonotic consequences of animal tuberculosis by African governments and donor agencies.

- A close physical association between humans and potentially-infected animals has been reported in some traditional African communities (6, 28, 41).

- Approximately 90% of the total volume of milk produced in sub-Saharan Africa is consumed fresh or soured, and only a very small proportion of the total production follows official marketing channels (57). Although these authors stated that Africans generally boil milk and that the souring process destroys *M. bovis* (57), others sources contradict this view (17, 29, 40, 47; A.J. Cook *et al.*, unpublished findings, 1993). The very serious zoonotic implication of these conflicting opinions should not be underestimated, and a case-by-case assessment is required, rather than broad generalisations.

- Tuberculosis has a close link with human immunodeficiency virus (HIV) infection and acquired immunodeficiency syndrome (AIDS), and by far the largest numbers of people carrying both these infections live in the developing countries. HIV seroprevalence rates have been found in over 40% of tuberculous patients in a number of African countries (43). *M. bovis* has also been isolated in HIV-infected persons in developed countries (5, 10, 13, 14, 26, 63). In France, *M. bovis* infection
accounted for 1.6% of tuberculous HIV-positive patients, and all isolated bacilli were resistant to isoniazid (14). If the intrinsic resistance of *M. bovis* to pyrazinamide is taken into consideration, two of the first-line anti-tuberculosis drugs were ineffective for these patients. In another report from a hospital in Paris (France), a source case infected five HIV-positive patients with a multidrug-resistant strain of *M. bovis* (5). In a North American study, 12 (25%) of 48 adults infected with *M. bovis* were AIDS patients (13). The same authors suggest a significant increase in prevalence of *M. bovis* infection within AIDS patients.

- The relatively low isolation rate of *M. bovis* from human tuberculosis cases in developing countries (in Africa and elsewhere) could be partly explained by the extensive use of microscopy for confirmation of suspected cases of tuberculosis. This technique does not permit differentiation between species of mycobacteria. In addition, accurate diagnosis is difficult even when culture facilities are available, as *M. bovis* grows poorly in standard Löwenstein-Jensen medium containing glycerol, which is one of the most widely-used culture media (9).

- Finally, the direct correlation between *M. bovis* infection in cattle populations and the zoonotic implications of the infection has been well documented in developed countries, while information on this zoonosis is scarce in the African literature (6, 28, 29, 31, 41, 48). The potential under-estimation of the zoonotic consequences of animal tuberculosis on the African population seems, in this context, to be a matter of some concern.

**INTERNATIONAL CO-OPERATION IN CONTROL AND RESEARCH ON ZOONOTIC ASPECTS OF ANIMAL TUBERCULOSIS IN AFRICA**

Close intersectoral collaboration between the medical and veterinary professions is needed, to assess and evaluate the scale of the problem posed by *M. bovis* infection in humans. Further attention to the following areas is also required from health professionals:

- Animal and human tuberculosis surveillance needs to be established or strengthened in most African countries, taking zoonotic aspects into consideration. There is also a need to elucidate the epidemiological role of wild animals within the different African environments.

- Diagnostic methods which are able to differentiate between *M. bovis* and *M. tuberculosis* infection in humans should always be applied when feasible. In the light of the recent increase in the prevalence of multidrug-resistant mycobacteria (2, 5), which has also been reported in Africa (49), culture and sensitivity tests may be required and should be established in African laboratories. Whenever possible, it is preferable for a single reference centre or laboratory to perform these tasks for both medical and veterinary services.

- Consideration of the food safety aspects of *M. bovis* infection should always take into account the public health implications. In the present circumstances, education is the most suitable and effective tool for prevention where infrastructure and technologies for the commercialisation of safe milk are insufficient or non-existent. The medical profession should also be made more aware of the potential presence of *M. bovis* in human tuberculosis patients.
International co-operation at the regional level should be strengthened. Assistance is needed from the WHO, the Food and Agriculture Organisation of the United Nations (FAO), the International Union Against Tuberculosis and Lung Disease (IUATLD), the United Nations International Children's Emergency Fund and other international organisations. An African working group, or sub-regional groups, on animal and zoonotic aspects of *M. bovis* infection should be established with WHO and FAO assistance and IUATLD collaboration.

Finally, scientifically-sound economic justification – including an evaluation of the overall costs of *M. bovis* infection in animals and humans under different circumstances in Africa – may also be required to facilitate decision-making at the district, national, regional and international levels.

ACKNOWLEDGEMENT

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Résumé : Les auteurs décrivent l’infection due à *Mycobacterium bovis* chez l’animal et chez l’homme et passent en revue les études sur la répartition et la prévalence de cette mycobactériose en Afrique. Dans leur analyse, ils mettent notamment l’accent sur l’importance de la tuberculose bovine et les risques qu’elle présente pour la santé publique sur ce continent. D’après les données publiées sur la tuberculose en Europe dans les années 1930 et 1940, la tuberculose bovine était considérée comme une importante zoonose : *M. bovis* était responsable de 50 % des cas de lymphadénite cervicale chez les enfants. Malgré la rareté des informations relatives à l’infection par *M. bovis* en Afrique, les données dont on dispose montrent qu’elle est largement répandue et que son taux de prévalence est même très élevé chez certaines populations animales. Les conditions épidémiologiques actuelles en Afrique sont très similaires à celles qui avaient favorisé la transmission de l’infection par *M. bovis* entre l’animal et l’homme en Europe dans les années 1930 ; elles sont de plus aggravées par l’existence de l’infection due au virus de l’immunodéficience humaine. Devant les risques que présente la tuberculose pour la santé publique sur ce continent, des enquêtes s'imposent d'urgence dans le cadre de programmes conjoints de recherche vétérinaire/médicale.


Resumen: Los autores describen la epidemiología de las infecciones causadas por Mycobacterium bovis en animales y seres humanos, al tiempo que efectúan una revisión de los informes disponibles acerca de la distribución y prevalencia de esta micobacteriosis en África. Se considera la posible significación de tales informes, con énfasis particular en la potencial importancia zoonótica de la tuberculosis bovina como causa de problemas de salud pública en África. Las publicaciones que describen la tuberculosis en Europa durante los años 1930 y 1940 ponen de manifiesto que la tuberculosis bovina era considerada ya una importante zoonosis: M. bovis era responsable de más del 50% de los casos infantiles de linfadenitis cervical. Pese a la escasa información disponible sobre la infección causada por M. bovis en África, hay datos suficientes como para suponer que se trata de una infección muy extendida, con una prevalencia significativamente alta entre algunas poblaciones animales. Las condiciones epidemiológicas para la propagación de M. bovis entre animales y humanos son muy similares en el África de hoy en día a las europeas de los años 1930, con el poderoso impacto añadido de la epidemia de inmunodeficiencia vírica humana. Para hacer frente a la amenaza que la tuberculosis representa para la salud pública en el continente africano, es urgente adoptar programas de investigación en cuyo marco aún esfuerzos tanto la investigación veterinaria como la médica.


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REFERENCES


