

Mycobacterium caprae Infection in Livestock and Wildlife, Spain

Sabrina Rodríguez, Javier Bezos, Beatriz Romero, Lucía de Juan, Julio Álvarez, Elena Castellanos, Nuria Moya, Francisco Lozano, M. Tariq Javed, José L. Sáez-Llorente, Ernesto Liébana, Ana Mateos, Lucas Domínguez, Alicia Aranaz, and The Spanish Network on Surveillance and Monitoring of Animal Tuberculosis¹

Mycobacterium caprae is a pathogen that can infect animals and humans. To better understand the epidemiology of *M. caprae*, we spoligotyped 791 animal isolates. Results suggest infection is widespread in Spain, affecting 6 domestic and wild animal species. The epidemiology is driven by infections in caprids, although the organism has emerged in cattle.

Mycobacterium caprae is a cluster within the *M. tuberculosis* complex (online Technical Appendix, www.cdc.gov/EID/content/17/3/532-Techapp.pdf). This pathogen has been recognized mainly in central Europe, where it has been occasionally isolated from tuberculous lesions from cattle (1–5), pigs (4), red deer (*Cervus elaphus*) (4,5), and wild boars (*Sus scrofa*) (3). Its isolation from humans has also been described (3,6); often, a contact with livestock has been suggested as a likely means of transmission (5). To our knowledge, this pathogen has never been isolated outside continental Europe, except from a European patient in Australia (7) and a cow in Algeria (8).

The combination of disease tracing and molecular typing is needed to understand the epidemiology of tuberculosis. This report describes the molecular epidemiology of *M. caprae* infection in Spain compared with other countries. We characterized *M. caprae* isolates from goats and other domestic and wild animals by

Author affiliations: Universidad Complutense de Madrid, Madrid, Spain (S. Rodríguez, J. Bezos, B. Romero, L. de Juan, J. Álvarez, E. Castellanos, N. Moya, F. Lozano, A. Mateos, L. Domínguez, A. Aranaz); University of Agriculture, Faisalabad, Pakistan (M.T. Javed); Ministerio de Medio Ambiente, y Medio Rural y Marino, Madrid, (J.L. Sáez-Llorente); and European Food Safety Authority, Parma, Italy (E. Liébana)

DOI: 10.3201/eid1703.100618

spoligotyping (9). The relative contribution of each animal and its role in animal tuberculosis are discussed.

The Study

This study included 791 *M. caprae* isolates from domestic goats (*Capra aegagrus hircus*, n = 542), sheep (*Ovis aries*, n = 2), cattle (*Bos taurus*, n = 229), domestic pigs (*S. scrofa domestica*, n = 2), wild boars (*S. scrofa*, n = 14), red deer (*Cervus elaphus*, n = 1), and a fox (*Vulpes vulpes*, n = 1). The samples originated from skin test-positive animals identified within the national or regional eradication programs, from abattoir surveillance, and from postmortem inspections of wildlife, and were collected from 1992 through June 2009 in different geographic areas in Spain (Figure 1). Spoligotyping was performed as described (9), and authoritative names for spoligotype

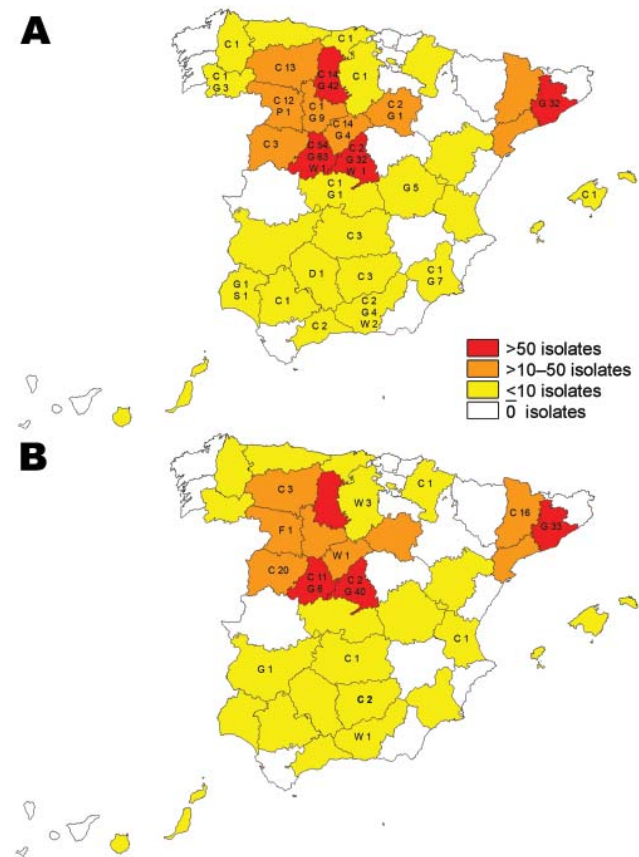


Figure 1. Map of Spain showing the distribution of the 2 most frequent *Mycobacterium caprae* spoligotypes and affected animals: C, cattle; D, red deer; F, fox; G, goats; S, sheep; P, pigs; WB, wild boar. A) Spoligotype SB0157. B) Spoligotype SB0416.

¹A list of members of The Spanish Network on Surveillance and Monitoring of Animal Tuberculosis can be found in the online Technical Appendix (www.cdc.gov/EID/content/17/3/532-Techapp.pdf).

Table 2. Variable number tandem repeat analysis of isolates from 10 farms that presented mixed *Mycobacterium caprae* infection (different spoligotype patterns), Spain, 1992–2009*

Farm	Animal	Spoligotype	No. alleles at locus							
			ETR-A	ETR-B	ETR-D	QUB3232	QUB 11a	QUB 11b	MIRU 26	MIRU 31
1	Goat	SB0416	4	4	4	8	7	2	5	2
		SB0866	5	3	3	8	7	4	2	4
2	Goat	SB0416	4	3	4	8	7	2	4	2
		SB0157	4	3	4	8	7	2	4	2
3	Goat	SB0416	4	5	5	7	6	4	5	5
		SB0415	5	1	3	8	7	3	5	5
4	Cattle	SB0157	3	3	4	8	7	2	5	2
		SB1081	3	3	4	8	7	2	5	2
5	Cattle	SB0157	4	3	4	3	7	2	5	2
		SB1081	4	3	4	3	7	2	5	2
6	Goat	SB0157	4	3	4	8	7	2	5	2
		SB1078	4	3	4	8	7	2	5	2
7	Goat	SB1084	5	1	3	9	5†	3	5	4
		SB1889	5	1	3	9	5†	3	5	4
8	Cattle	SB0157	4	3	4	8	7	2	5	2
		SB1081	4	3	4	8	7	2	5	2
9	Cattle	SB0416	5	3	3	8	6	4	2	3
		SB0157	4	3	4	8	7	2	5	2
10	Goat	SB0973	4	3	–	–	–	–	–	–
		SB0157	4	3	4	9	–	2	5	–

*–, no amplification.

†Gel band of ≈1,800 bp. Sequencing showed that insertion sequence IS6110 is inserted within the third repetition of QUB11a.

disseminated tuberculous lesions that it produces and its fast transmission within a herd. Second, caprine herds have not been included in the national eradication campaign (except when coexisting with cattle or as part of some regional programs). Therefore, *M. caprae* infection can spread easily through animal movements, such as purchase for replacement or genetic improvement.

The emergence of this pathogen in cattle has been observed. Cattle were involved in 106 outbreaks (53.3%) during the study period. Since 2004, cattle from 2,218 herds identified in the eradication program have been inspected by bacteriology. The number of cattle properties infected with *M. caprae* represented 0.85%–6.67% of the total number of herds diagnosed with bovine tuberculosis. Temporal trend of *M. caprae* isolates cultured over time was assessed by using the software WINPEPI 9.4 (13). The proportion of *M. caprae* isolated from bovine samples has increased consistently during 2004–2009, showing a significant positive trend ($p = 0.009$, by Mantel trend test) (Figure 2). We observed more *M. caprae* infections in cattle in regions with a high goat density. However, an analysis of the type of farm production shows that 86.7% of *M. caprae*-infected cattle have been raised in farms without any contact with small ruminants. This fact indicates recirculation of the pathogen within and between cattle herds. In countries that are virtually free of animal tuberculosis such as Germany, Austria, and the Czech Republic, a large number of cases in cattle and red deer are caused by *M. caprae*.

Identification of isolates from human patients has shown *M. caprae* as a human pathogen (3,6,14). A recent study suggests that *M. caprae* causes 0.3% of the cases of human tuberculosis in Spain, with SB0157 also being the most dominant spoligotype (14). The role of the pathogen as a public health risk is highlighted by lesions that can

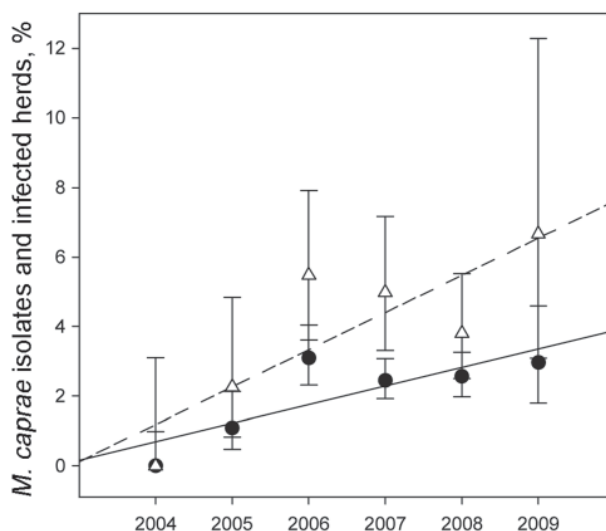


Figure 2. Proportion and regression lines of *Mycobacterium caprae* isolates (black dots, continuous line) and *M. caprae*-infected herds (white triangles, dashed lines) of the total number of *M. tuberculosis* complex isolates and *M. tuberculosis* complex-infected herds identified in cattle during 2004–2009. Error bars indicate 95% confidence intervals.

also be found in the mammary glands of infected goats; thus, consumption of unpasteurized dairy products remains a concern (15).

Conclusions

Compelling evidence indicates that *M. caprae* poses a serious health risk not only for goats, but also for other domestic and wild animal species and humans. Our results indicate that *M. caprae* infection is widespread in Spain and that the epidemiology is driven by caprine infections. Considering the role of *M. caprae* in animal tuberculosis, relevant legislation should be considered to address the infection as was done for *M. bovis*.

Acknowledgments

We thank the National and Regional Animal Health authorities, especially L. Carbajo, for their continuous encouragement. We are grateful to T. Alende, A. Gutiérrez, C. Viñolo, L. Guijarro, J. Gimeno, N. Álvarez, N. Montero, C. Lozano, L. Pazos and S. González for technical help. We acknowledge the staff of SADNA (Centro de Investigaciones Biológicas, Madrid) for sequencing.

This research was supported by European Union project TB-STEP (KBBE-2007-1-3-04, no. 212414), the Ministry of Environment and Rural and Marine Affairs, the Comunidad de Madrid, and the Junta de Castilla y León.

Ms Rodríguez is a PhD candidate in the Departamento de Sanidad Animal, Facultad de Veterinaria, Universidad Complutense de Madrid and received predoctoral research fellowship AP2006-01630 from the Spanish Ministry of Education. Her research focuses on molecular characterization of *M. tuberculosis* complex isolates and its application in epidemiology of these pathogens.

References

- Boniotti MB, Gorla M, Loda D, Garrone A, Benedetto A, Mondo A, et al. Molecular typing of *Mycobacterium bovis* strains isolated in Italy from 2000 to 2006 and evaluation of variable-number-tandem-repeats for a geographic optimized genotyping. *J Clin Microbiol*. 2009;47:636–44. DOI: 10.1128/JCM.01192-08
- Duarte EL, Domingos M, Amado A, Botelho A. Spoligotype diversity of *Mycobacterium bovis* and *Mycobacterium caprae* animal isolates. *Vet Microbiol*. 2008;130:415–21. DOI: 10.1016/j.vetmic.2008.02.012
- Erler W, Martin G, Sachse K, Naumann L, Kahlau D, Beer J, et al. Molecular fingerprinting of *Mycobacterium bovis* subsp. *caprae* isolates from central Europe. *J Clin Microbiol*. 2004;42:2234–8. DOI: 10.1128/JCM.42.5.2234-2238.2004
- Pavlik I, Dvorska L, Bartos M, Parmova I, Meliciarek I, Jesenska A, et al. Molecular epidemiology of bovine tuberculosis in the Czech Republic and Slovakia in the period 1965–2001 studied by spoligotyping. *Vet Med (Praha)*. 2002;47:181–94.
- Prodinger WM, Eigentler A, Allerberger F, Schonbauer M, Glawischig W. Infection of red deer, cattle, and humans with *Mycobacterium bovis* subsp. *caprae* in Western Austria. *J Clin Microbiol*. 2002;40:2270–2. DOI: 10.1128/JCM.40.6.2270-2272.2002
- Kubica T, Rüsche-Gerdes S, Niemann S. *Mycobacterium bovis* subsp. *caprae* caused one-third of human *M. bovis*-associated tuberculosis cases reported in Germany between 1999 and 2001. *J Clin Microbiol*. 2003;41:3070–7. DOI: 10.1128/JCM.41.7.3070-3077.2003
- Sintchenko V, Jelfs P, Dally M, Crichton T, Gilbert GL. A case of urinary tuberculosis due to *Mycobacterium bovis* subspecies *caprae*. *Pathology*. 2006;38:376–8. DOI: 10.1080/00313020600821391
- Sahraoui N, Müller B, Guetarni D, Boulahbal F, Yala D, Ouzrout R, et al. Molecular characterization of *Mycobacterium bovis* strains isolated from cattle slaughtered at two abattoirs in Algeria. *BMC Vet Res*. 2009;5:4. DOI: 10.1186/1746-6148-5-4
- Kamerbeek J, Schouls L, Kolk A, van Agterveld M, van Soolingen D, Kuijper S, et al. Simultaneous detection and strain differentiation of *Mycobacterium tuberculosis* for diagnosis and epidemiology. *J Clin Microbiol*. 1997;35:907–14.
- Hunter PR, Gaston MA. Numerical index of the discriminatory ability of typing systems: an application of Simpson's index of diversity. *J Clin Microbiol*. 1988;26:2465–6.
- Rodríguez S, Romero B, Bezos J, de Juan L, Álvarez J, Castellanos E, et al. High spoligotype diversity within a *Mycobacterium bovis* population: clues to understanding the demography of the pathogen in Europe. *Vet Microbiol*. 2010;141:89–95. DOI: 10.1016/j.vetmic.2009.08.007
- Frothingham R, Meeker-O'Connell WA. Genetic diversity in the *Mycobacterium tuberculosis* complex based on variable numbers of tandem DNA repeats. *Microbiology*. 1998;144:1189–96. DOI: 10.1099/002221287-144-5-1189
- Abramson JH. WINPEPI (PEPI-for-Windows): computer programs for epidemiologists. *Epidemiol Perspect Innov*. 2004;1:6. DOI: 10.1186/1742-5573-1-6
- Rodríguez E, Sánchez LP, Pérez S, Herrera L, Jiménez MS, Samper S, et al. Human tuberculosis due to *Mycobacterium bovis* and *M. caprae* in Spain, 2004–2007. *Int J Tuberc Lung Dis*. 2009;13:1536–41.
- Rodwell TC, Moore M, Moser KS, Brodine SK, Strathdee SA. Tuberculosis from *Mycobacterium bovis* in binational communities, United States. *Emerg Infect Dis*. 2008;14:909–16. DOI: 10.3201/eid1406.071485

Address for correspondence: Alicia Aranaz, Facultad de Veterinaria, Universidad Complutense de Madrid, Departamento de Sanidad Animal, Avda. Puerta de Hierro s/n, Madrid 28040, Spain; email: alaranaz@vet.ucm.es

The opinions expressed by authors contributing to this journal do not necessarily reflect the opinions of the Centers for Disease Control and Prevention or the institutions with which the authors are affiliated.

Search past issues of EID at www.cdc.gov/eid

Mycobacterium caprae Infection in Livestock and Wildlife, Spain

Technical Appendix

Specific Characteristics

Mycobacterium caprae (1), formerly known as *M. tuberculosis* subsp. *caprae* (2), and *M. bovis* subsp. *caprae* (3) forms a genetically distinct cluster within the *M. tuberculosis* complex. The main features differentiating these isolates from the other members are a special combination of polymorphisms at pyrazinamidase (*pncA*), catalase (*katG*), and subunits A and B of the gyrase (*gyrA* and *gyrB*) genes (4,5); the pattern of regions of difference (presence of RD4 and absence of RD5 to 10) (6–8); and specific patterns obtained by direct variable repeat spacer oligonucleotide typing technique (spoligotyping); and restriction fragment length polymorphism associated with IS6110, polymorphic GC-rich sequences, and direct repeat elements (9,10).

Bacteriology

Tissue samples consisted usually of retropharyngeal, mediastinal, bronchial, and mesenteric lymph nodes, lung and liver. All samples were maintained at -20°C until culture. Samples from each animal were pooled, homogenized with sterile distilled water, decontaminated with 0.35% hexadecylpyridinium chloride for 30 min (11), centrifuged at $1,068 \times g$ for 30 min, and cultured on Coletsos and 0.2% (w/v) pyruvate-enriched Löwenstein-Jensen media (bioMérieux España and Biomedics, Madrid, Spain) at 37°C for 3 mo. The isolates were identified as members of the *M. tuberculosis* complex by PCR amplification of *Mycobacterium* genus-specific 16S rRNA fragment (12) and MPB70 sequences (13) (primers used in the study are listed in the Table). All PCRs were performed on heat-killed cell suspensions.

Spoligotyping and Data Analysis

The spacer oligonucleotide typing (spoligotyping) method was performed as described by Kamerbeek et al. (14). The biotin-labelled amplified product was detected by hybridization onto a spoligotyping membrane (Isogen Bioscience BV, Maarsse, the Netherlands). Hybridized

product was detected with the streptavidin-peroxidase conjugate (Boehringer, Mannheim, Germany) and the electrochemical luminescence system (Amersham, Little Chalfont, UK) by exposing the radiograph film to the membrane. Purified sterile water and a clinical isolate of *M. tuberculosis* and *M. bovis* were included as controls in every batch of tests.

The spoligotyping results were enlisted in a Microsoft Office Access (Microsoft, Redmond, WA, USA) database along with the epidemiologic data (isolation date, animal species and geographical origin). The index of discrimination (D) described by Hunter and Gaston (15) was calculated to determine the discriminatory power of the spoligotyping at a national level. We used the website of the University of the Basque Country (www.insilico.ehu.es), filling in the number of unrelated strains for each spoligotype. For this purpose we only counted 1 spoligotype when isolates of the same herd or a precise geographical area shared identical patterns.

Detection of RD4 and Gene Polymorphisms

We used the 3-primer PCR described by Mostowy et al. (16). Purified sterile water and a clinical isolate of *M. bovis* were included as controls. The presence (545-bp gel band) or absence (210-bp gel band) of RD4 was detected by agarose gel electrophoresis.

The complete *pncA* gene (17) and a part of the *gyrB* (18) containing the expected polymorphism for *M. caprae* were amplified. The products were purified with the Qiaquick PCR Purification kit (QIAGEN GmbH, Hilden, Germany) and sequenced with the DyeDeoxy (dRhodamine) Terminator Cycle Sequencing kit in an automatic ABI Prism 373 DNA sequencer (Applied Biosystems, C.I.B. Sequencing Facilities, Madrid, Spain). The sequences generated were aligned with published mycobacterial sequences from the GenBank database (www.ncbi.nlm.nih.gov/GenBank, accession nos. U59967 [17] and L27512 [18]). Sequencing of the *pncA* demonstrated a C at nucleotide 169, a common characteristic for *M. tuberculosis*, *M. africanum*, *M. microti*, and *M. caprae* that results in the functional wild-type *pncA* (17). The *gyrB* gene sequence polymorphisms analysis detected, as well the characteristic profile for *M. caprae* that consists of a G at nucleotide 1311 and a C at position 1410, are common to caprine strains and the other members of the complex, except *M. bovis* (5).

Variable Number Tandem Repeat Analysis

The PCR for each locus was carried out by using the HotStar Taq DNA polymerase kit (QIAGEN) in a Bio-Rad (Hercules, CA, USA) MyCycler Thermal Cycler. Genomic DNA from

M. bovis BCG Danish was used as a positive control, reaction mixtures lacking mycobacterial DNA were used as a negative control. The number of tandem repeats (alleles) was determined by estimating the amplicon size of the PCR product by electrophoresis on 2.5% agarose gel at 45V for 3 h with a 100-bp ladder (Biotools, B&M Labs, Madrid, Spain).

Members of the Spanish Network on Surveillance and Monitoring of Animal Tuberculosis: F. Garrido (Laboratorio Central de Sanidad Animal de Santa Fé, Granada, Ministerio de Medio Ambiente, Rural y Marino), staff of Government and Regional and Research Laboratories of Autonomous Communities (C. Fornell, J.M. Gómez, A. Jiménez, I. Muñoz, J.A. Téllez, E.J. Villalba [Andalucía], N. Abacens, I. Belanche, J. Gracia, S. Izquierdo, J.M. Malo [Aragón], M.F. Copano, E. Fernández, I. Merediz [Asturias], P. Peláez, C. Pieltain, V. Vigo [Canarias], C. Fernández, F.M. Fernández, M.G. Gradillas, M. Gutiérrez, E. Sola [Cantabria], V. Alcaide, J. Alia, J. Alonso, M.R. Bermúdez, C. Fernández, P. García, E. Grande, F. Plaza, M.L. Rando, C. Rojas, A. Sánchez, J.A. Viñuelas [Castilla La Mancha], J.A. Anguiano, I. Burón, J. Cermeño, C. Domínguez, F. Fernández, A. Grau, S. Marques, O. Martín, C. Martínez, O. Mínguez, F. Moreno, F. Reviriego, I. Romero [Castilla y León], J. Gou [Cataluña], J.R. Puy [Euskadi], E. Dorado, C. Sanz [Extremadura], C. Calvo, D. Fernández, J.E. Mourelo [Galicia], C. Aguilo, M.J. Portau, C. Vidal [Islas Baleares], J.M. Cámara, J. Carpintero, C. Delso, R. Díaz, E. Fernández, C. Fernández-Zapata, M. García, E. Pages, J.J. Urquía [Madrid], J. Pastor, C. Rivas [Murcia], J. Eguiluz, F. Eslava, C. Fernández [Navarra], F.J. Puértolas, J.F. Soldevilla [La Rioja], C. Caballero, M. Lázaro [Valencia]); A. Jacoste, M. Moreno (Patrimonio Nacional); academic and research members from Faculties of Veterinary Sciences (S. Lavin, G. Mentaberre [Universidad Autónoma de Barcelona], A. Perea [Universidad de Córdoba], A. García, J. Hermoso de Mendoza, A. Parra, [Universidad de Extremadura], E.F. Rodríguez-Ferri, O. González-Llamazares [Universidad de León], J. Blanco, M. Castaño, A.A. Díez-Guerrier, J.V. González, F. Mazzucchelli, C. Novoa, X. Pickering, M. Pizarro, G. Santurde, I. Simarro [Universidad Complutense de Madrid], A. Contreras, J. Sánchez [Universidad de Murcia], A. Fernández, O. Quesada [Universidad de Las Palmas de Gran Canaria], M.V. Latre [Universidad de Zaragoza]); colleagues from research centers on animal health (M. Domingo, B. Pérez, S. López, D. Vidal [Centre de Recerca en Sanitat Animal], J. Garrido, R. Juste [Instituto Vasco de Investigación y Desarrollo Agrario], M. Galka, C. Sánchez, [P.N. Doñana], J. de la Fuente, C. Gortázar, J. Vicente [Instituto de Investigación en Recursos Cinegéticos-Consejo Superior de Investigaciones Científicas], A. Espí, J.M. Prieto and [Servicio Regional de Investigación y Desarrollo Agrario, Asturias], I. Carpio [Unión de Criadores del Toro de Lidia]; veterinary inspectors at abattoirs (A.J. Domínguez, M. Fernández, J.M. Rubio [Ciudad Real], M. García, J. Guedeja, F. Osuna, J.L. del Pozo [Madrid]); M.D. E. Gómez-Mampaso [H. Ramón y Cajal, Madrid] and R. Borrás [Facultad de Medicina, Valencia]); and veterinary practitioners (P. Díez de Tejada, J.M. Fernández [A.D.S. Cabra del Guadarrama, Madrid], C. Gil, F. Moneo-López, I. Larrauri [Albacete], J. Cermeño, D. Martín [Badajoz], J.L. García [Burgos], A. Rodríguez, E. Sainz [Cáceres], P.J. Mora [Ciudad Real], J.M. Amigo, N. Castro, V. Collado, J.L. Cumbreño, J.M. Finat, M.P. Herranz, E. Legaz, L.M. Portas, J. Rodríguez, L. Sánchez, J.M. Sebastián, T. Yuste [Madrid], A. Santos (Toledo), J. Fonbellida [Zamora], and J. Rodríguez [Laboratorios Syva]).

References

1. Aranaz A, Cousins D, Mateos A, Domínguez L. Elevation of *Mycobacterium tuberculosis* subsp. *caprae* Aranaz et al. 1999 to species rank as *Mycobacterium caprae* comb. nov., sp. nov. *Int J Syst Evol Microbiol.* 2003;53:1785–9. [PubMed DOI: 10.1099/ijs.0.02532-0](#)
2. Aranaz A, Liébana E, Gómez-Mampaso E, Galán JC, Cousins D, Ortega A, et al. *Mycobacterium tuberculosis* subsp. *caprae* subsp. nov.: a taxonomic study of a new member of the *Mycobacterium tuberculosis* complex isolated from goats in Spain. *Int J Syst Bacteriol.* 1999;49:1263–73. [PubMed DOI: 10.1099/00207713-49-3-1263](#)
3. Niemann S, Richter E, Rüscher-Gerdes S. Biochemical and genetic evidence for the transfer of *Mycobacterium tuberculosis* subsp. *caprae* Aranaz et al. 1999 to the species *Mycobacterium bovis* Karlson and Lessel 1970 (approved lists 1980) as *Mycobacterium bovis* subsp. *caprae* comb. nov. *Int J Syst Evol Microbiol.* 2002;52:433–6. [PubMed](#)
4. Espinosa de los Monteros LE, Galán JC, Gutiérrez M, Samper S, García Marin JF, Martín C, et al. Allele-specific PCR method based on *pncA* and *oxyR* sequences for distinguishing *Mycobacterium bovis* from *Mycobacterium tuberculosis*: intraspecific *M. bovis pncA* sequence polymorphism. *J Clin Microbiol.* 1998;36:239–42. [PubMed](#)
5. Niemann S, Harmsen D, Rüscher-Gerdes S, Richter E. Differentiation of clinical *Mycobacterium tuberculosis* complex isolates by *gyrB* DNA sequence polymorphism analysis. *J Clin Microbiol.* 2000;38:3231–4. [PubMed](#)
6. Mostowy S, Inwald J, Gordon S, Martín C, Warren R, Kremer K, et al. Revisiting the evolution of *Mycobacterium bovis*. *J Bacteriol.* 2005;187:6386–95. [PubMed DOI: 10.1128/JB.187.18.6386-6395.2005](#)
7. Huard RC, Fabre M, de Haas P, Lazzarini LC, van Soolingen D, Cousins D, et al. Novel genetic polymorphisms that further delineate the phylogeny of the *Mycobacterium tuberculosis* complex. *J Bacteriol.* 2006;188:4271–87. [PubMed DOI: 10.1128/JB.01783-05](#)
8. Brosch R, Gordon SV, Marmiesse M, Brodin P, Buchrieser C, Eiglmeier K, et al. A new evolutionary scenario for the *Mycobacterium tuberculosis* complex. *Proc Natl Acad Sci U S A.* 2002;99:3684–9. [PubMed DOI: 10.1073/pnas.052548299](#)
9. Aranaz A, Liébana E, Mateos A, Domínguez L, Cousins D. Restriction fragment length polymorphism and spacer oligonucleotide typing: a comparative analysis of fingerprinting strategies for

- Mycobacterium bovis*. Vet Microbiol. 1998;61:311–24. [PubMed DOI: 10.1016/S0378-1135\(98\)00192-8](#)
10. Gutiérrez M, Samper S, Gavigan JA, García Marín JF, Martín C. Differentiation by molecular typing of *Mycobacterium bovis* strains causing tuberculosis in cattle and goats. J Clin Microbiol. 1995;33:2953–6. [PubMed](#)
 11. Corner LA, Trajstman AC. An evaluation of 1-hexadecylpyridinium chloride as a decontaminant in the primary isolation of *Mycobacterium bovis* from bovine lesions. Vet Microbiol. 1988;18:127–34. [PubMed DOI: 10.1016/0378-1135\(88\)90058-2](#)
 12. Böddinghaus B, Rogall T, Flohr T, Blöcker H, Böttger EC. Detection and identification of mycobacteria by amplification of rRNA. J Clin Microbiol. 1990;28:1751–9. [PubMed](#)
 13. Wilton S, Cousins D. Detection and identification of multiple mycobacterial pathogens by DNA amplification in a single tube. PCR Methods Appl. 1992;1:269–73. [PubMed](#)
 14. Kamerbeek J, Schouls L, Kolk A, van Agterveld M, van Soolingen D, Kuijper S, et al. Simultaneous detection and strain differentiation of *Mycobacterium tuberculosis* for diagnosis and epidemiology. J Clin Microbiol. 1997;35:907–14. [PubMed](#)
 15. Hunter PR, Gaston MA. Numerical index of the discriminatory ability of typing systems: an application of Simpson's index of diversity. J Clin Microbiol. 1988;26:2465–6. [PubMed](#)
 16. Mostowy S, Cousins D, Brinkman J, Aranaz A, Behr MA. Genomic deletions suggest a phylogeny for the *Mycobacterium tuberculosis* complex. J Infect Dis. 2002;186:74–80. [PubMed DOI: 10.1086/341068](#)
 17. Scorpio A, Zhang Y. Mutations in *pncA*, a gene encoding pyrazinamidase/nicotinamidase, cause resistance to the antituberculous drug pyrazinamide in tubercle bacillus. Nat Med. 1996;2:662–7. [PubMed DOI: 10.1038/nm0696-662](#)
 18. Kasai H, Ezaki T, Harayama S. Differentiation of phylogenetically related slowly growing mycobacteria by their *gyrB* sequences. J Clin Microbiol. 2000;38:301–8. [PubMed](#)
 19. Allix C, Walravens K, Saegerman C, Godfroid J, Supply P, Fauville-Dufaux M. Evaluation of the epidemiological relevance of variable-number tandem-repeat genotyping of *Mycobacterium bovis* and comparison of the method with *IS6110* restriction fragment length polymorphism analysis and spoligotyping. J Clin Microbiol. 2006;44:1951–62. [PubMed DOI: 10.1128/JCM.01775-05](#)

20. Frothingham R, Meeker-O'Connell WA. Genetic diversity in the *Mycobacterium tuberculosis* complex based on variable numbers of tandem DNA repeats. *Microbiology*. 1998;144:1189–96. [PubMed DOI: 10.1099/00221287-144-5-1189](#)
21. Supply P. Protocol and Guidelines for Multilocus Variable Number Tandem Repeat Genotyping of *M. bovis* VENoMYC (Veterinary Network of Laboratories Researching into Improved Diagnosis and Epidemiology of Mycobacterial Diseases) WP7 Workshop, October 19-22 2006, Toledo, Spain, pp.15-16. WP7 Workshop VENoMYC Coordination Action EU SSPE-CT-2004-501903. 2006
22. Supply P, Lesjean S, Savine E, Kremer K, van Soolingen D, Locht C. Automated high-throughput genotyping for study of global epidemiology of *Mycobacterium tuberculosis* based on mycobacterial interspersed repetitive units. *J Clin Microbiol*. 2001;39:3563–71. [PubMed DOI: 10.1128/JCM.39.10.3563-3571.2001](#)
23. O'Brien R, Danilowicz BS, Bailey L, Flynn O, Costello E, O'Grady D, et al. Characterization of the *Mycobacterium bovis* restriction fragment length polymorphism DNA probe pUCD and performance comparison with standard methods. *J Clin Microbiol*. 2000;38:3362–9. [PubMed](#)
24. Skuce RA, McCorry TP, McCarroll JF, Roring SM, Scott AN, Brittain D, et al. Discrimination of *Mycobacterium tuberculosis* complex bacteria using novel VNTR-PCR targets. *Microbiology*. 2002;148:519–28. [PubMed](#)

Table. List of primers used in a study of *Mycobacterium caprae* infection in livestock and wildlife, Spain*

Target†	Primer	Sequence, 5' → 3'	Product, bp	Reference
16S rRNA	MYCGEN-F	AGAGTTTGATCCTGGCTCAG	1,030	(12)
	MYCGEN-R	TGCACACAGGCCACAAGGGA		
MPB70	TB1-F	GAACAATCCGGAGTTGACAA	372	(13)
	TB1-R	AGCACGCTGTCAATCATGTA		
DR spoligotyping	DR-a	GGTTTTGGGTCTGACGAC	ladder	(14)
	DR-b	CCGAGAGGGGACGGAAAC		
RD4	RD4-L	GAACGCGACGACCTCATATTCC	545/210 (presence/ absence)	(6,16)
	RD4-R	CTAAGATATCCGGTACGCCCGC		
	RD4-wtR	CTGTGGCTATGGGGCTCTAC		
<i>pncA</i>	pncATB-1	ATGCGGGCGTTGATCATCGT	574	(4,17)
	pncATB-2	TCAGGAGCTGCAAACCAACTC		
<i>gyrB</i>	MTUBf	TCGGACGCGTATGCGATATC	1,020	(5,18)
	MTUBr	ACATACAGTTCGGACTTGCG		
VNTR2165 (ETR-A)	ETRA-F	AAATCGGTCCCATCACCTTCTTAT	†	(19)
	ETRA-R	CGAAGCCTGGGGTGCCCGCATTT		
VNTR2461 (ETR-B)	ETRB-F	GCGAACACCAGGACAGCATCATG	†	(20)
	ETRB-R	GGCATGCCGGTGATCGAGTGG		
VNTR580 (ETR-D, MIRU 4)	ETRD-F	GCGCGAGAGCCCGAACTGC	†	(19,21)
	ETRD-R	GCGCAGCAGAAACGCCAGC		
VNTR3192 (ETR E, MIRU 31)	MIRU31-F	ACTGATTGGCTTCATACGGCTTTA	†	(22)
	MIRU31-R	GTGCCGACGTGGTCTTGAT		
VNTR2996 (MIRU 26)	MIRU26-F	TAGGTCTACCGTCGAAATCTGTGAC	†	(21)
	MIRU26-R	CATAGGCGACCAGGCCAATAG		
VNTR2163a (QUB11a)	QUB11a-F	CCCATCCCCTTAGCACATTCGTA	†	(23,24)
	QUB11a-R	TTCAGGGGGGATCCGGGA		
VNTR2163b (QUB11b)	QUB11b-F	CGTAAGGGGGATGCGGGAAATAGG	†	(23,24)
	QUB11b-R	CGAAGTGAATGGTGGCAT		
VNTR3232 (QUB3232)	3232-F	CGGCGATGGTGCCGCCATG	†	(21)
	3232-R	CTTGGTGAAGGCCCGATG		

*VNTR, variable number tandem repeat; MIRU, mycobacterial interspersed repetitive unit.

†According to respective allele calling tables.