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The Enlarging Spectrum of Tick-Borne Spirochetoses: R. R. Parker Memorial Address

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The author reviews his changing interest in tick-borne spirochetoses during his career (1951–1985) as a medical entomologist at the U.S. Public Health Service's Rocky Mountain Laboratory. The discoveries of relapsing fevers in the western United States in the 1930s and 1940s led to well-supported epidemiologic research, including studies on the relationships between vectors and spirochetes. When tick-borne relapsing fever in the United States was shown to be a relatively rare and readily treatable disease, financial support was withdrawn, and ongoing research was limited or terminated. Interest in relapsing fever spirochetes, particularly the relation to the relapse phenomenon in animal hosts, resurfaced in the 1960s and 1970s with the introduction of immunofluorescence assays and with the development of Kelly's medium for continuous cultivation of certain spirochetes. This interest increased significantly in 1981 when the author discovered a tick-borne spirochete to be the causative agent of Lyme disease and of several clinically related disorders in Europe. The discovery of this agent, now known as *Borrelia burgdorferi*, has led not only to intensive clinical, epidemiologic, and ecologic investigations in the United States and abroad but also to the identification of molecular and immunochemical techniques necessary for the study of the complex biology of tick-borne spirochetes. Reference is also made to a new species of *Borrelia* that may be the etiologic agent of epizootic bovine abortion in the western United States.

It is indeed a great honor to come before this gathering—the 40th International Northwest Conference of Diseases in Nature Communicable to Man—to present the R. R. Parker Lecture in memory of the first director of the Rocky Mountain Laboratory (RML) in Hamilton, Montana, and the founder of this organization.

Although like many of you here, I did not know Dr. Parker personally, I am greatly indebted to him, for he made possible my U.S. Public Health Service fellowship in 1951. Dr. Parker and my former teacher Professor Dr. Rudolf Geigy, who was not only professor of zoology at the University of Basel in Switzerland but also the first director of the Swiss Tropical Institute, were good friends. Not only did they share their research interests in epidemiology and ecology of arthropod-borne, particularly tick-borne, diseases, they were also enthusiastic stamp collectors and maintained a vigorous exchange program.

When Professor Geigy visited the RML in 1948, Dr. Parker promised him a U.S. Public Health Service fellowship for any of Geigy's students interested in the biology of ticks or in the behavior of human and animal pathogens in tick vectors. Although my ongoing thesis research on the development of the relapsing fever spirochete *Borrelia duttonii* in its tick vector *Ornithodoros moubata* made me a prime candidate, other colleagues were interested in going to RML. A flip of the coin finally decided that I should apply.

Dr. Parker's death, September 4, 1949, changed my plans somewhat but not his promise; on December 23, 1951, I reported for duty at RML to study the relationship(s) between spirochetes causing relapsing fever and their argasid tick vectors under the sponsorship of Dr. Gordon E. Davis, a world-renowned expert on this subject.

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Historical Background: Endemic Relapsing Fever

Tick-borne or endemic relapsing fever was first recorded in the United States in 1915 when five persons contracted the disease in Bear Creek Canyon,

Jefferson County, Colorado [1]. Other states reporting first cases included California in 1922 [2]; Texas in 1927 [3]; Arizona in 1930 [4]; Kansas in 1934 [5]; Nevada in 1937 [6]; Utah, Washington, and Montana in 1939 [7]; Oklahoma, Oregon, and Idaho in 1940 [8–10]; and New Mexico in 1941 [11]. Although most reports dealt with relatively few cases, in 1937 Beck [12] reviewed 106 cases that had occurred between 1921 and 1935 in California at altitudes of more than 5,000 feet, especially at Big Bear Lake, Lake Tahoe, and Packer Lake. Similarly, Kemp and associates [13] presented details of 258 cases in Texas for the period 1930–1934. In Canada, the first record of relapsing fever dates back to 1933 when six cases were reported in British Columbia [14].

In the United States, a tick vector was not recognized until 1930 when Weller and Graham [15] in Texas reported that cases of relapsing fever seen by them were caused by spirochetes transmitted by the argasid tick *Ornithodoros turicata*. Five years later, Wheeler et al. [16] showed *Ornithodoros hermsi* to be a vector in California, and in 1939 Davis [7] speculated that *Ornithodoros parkeri* was a likely vector in Wyoming, Montana, Utah, and Washington. Although found infected with spirochetes, this tick (to the present) has never been associated with human relapsing fever; it is often found in burrowing owls' nests and rarely comes in contact with humans.

Not only in North America but also in South and Central America, southern Europe (Spain), Africa, and Asia, numerous ticks of the genus *Ornithodoros* have been shown to be infected with spirochetes and

Table 1. Characteristics and distribution of *Ornithodoros*-borne borreliae.

Borrelia species	Arthropod vector (*Ornithodoros*)	Animal reservoir	Distribution	Disease
B. duttonii	*O. moubata*	Humans	Central, eastern, southern Africa	East African tick-borne endemic relapsing fever
B. hispanica	*O. erraticus* (large variety)	Rodents	Spain, Portugal, Morocco, Algeria, Tunisia	Hispano-African tick-borne relapsing fever
B. crocidurae, *B. merionesi*, *B. microti*, *B. dipodilli*	*O. erraticus* (small variety)	Rodents	Morocco, Libya, Egypt, Iran, Turkey, Senegal, Kenya	North African tick-borne relapsing fever
B. persica	*O. tholozani* (syn. *O. papillipes*, *O. crossi*?)	Rodents	From west China and Kashmir to Iraq and Egypt, USSR, India	Asiatic-African tick-borne relapsing fever
B. caucasica	*O. verrucosus*	Rodents	Caucasus to Iraq	Caucasian tick-borne relapsing fever
B. latyschewii	*O. tartakowskyi*	Rodents	Iran, central Asia	Caucasian tick-borne relapsing fever
B. hermsii	*O. hermsi*	Rodents, chipmunks, tree squirrels	Western United States	American tick-borne relapsing fever
B. turicatae	*O. turicata*	Rodents	Southwestern United States	American tick-borne relapsing fever
B. parkeri	*O. parkeri*	Rodents	Western United States	American tick-borne relapsing fever
B. mazzottii	*O. talaje* (*O. dugesi*?)	Rodents	Southern United States, Mexico, Central and South America	American tick-borne relapsing fever
B. venezuelensis	*O. rudis* (*syn. O.*) *venezuelensis*	Rodents	Central and South America	American tick-borne relapsing fever
B. brasiliensis	*O. brasiliensis*	?	South America (Brazil)	?*
B. graingeri	*O. graingeri*	?	East Africa (Kenya)	One laboratory case*
B. tillae	*O. zumpti*	Rodents	South Africa	?*
B. queenslandica	*O. gurneyi*	Rodents	Australia	?*
B. armenica	*O. alactagalis*	Rodents	Armenia	?*

* Spirochete-tick association of unknown or little health significance in humans.

capable of transmitting them to humans (see table 1). Most of these ticks and their spirochetes were available in Dr. Davis' laboratory. He and his capable technician, Mr. Anthony J. Mavros, maintained colonies of 13 species of *Ornithodoros* and somehow managed to cultivate, in their natural tick vectors, 35 strains of spirochetes representing 14 species of *Borrelia.*

Throughout the 1940s and still in the early 1950s, tick-borne relapsing fever and its spirochetes were of interest to public health authorities. Although not deadly, relapsing fever was considered a serious and debilitating disease that appeared to be spreading in the southern and western parts of the country. It was felt therefore that public health officials, practicing physicians, and even specialists should have a thorough knowledge of this disease and of the means by which its causative agent is disseminated. Thus, the research activities of Dr. Davis were well supported. One of the many projects we tackled concerned the search for biologic criteria that would allow us to classify and to identify the spirochetes. On the basis of studies carried out since 1936, Davis [17] developed the theory that in the United States each species of *Ornithodoros* which is a vector of relapsing fever spirochetes carries a spirochete that is tick-host specific, i.e., in no instance has one of the three tick species—*O. hermsi, O. turicata, or O. parkeri*—transmitted the spirochete recovered from either of the other two. On the other hand, a species from one locality never failed to transmit the spirochetes of the same species from another locality.

Although with few exceptions this vector specificity held true for North America, it no longer did for African or Asian tick/spirochete combinations. In fact, in many of these countries, we encountered local specificity to the extent that, for instance, *Ornithodoros tholozani* from one part of Iran failed to transmit *Borrelia persica* from another part of that country [18]. Thus, we looked for additional classification criteria, such as the behavior or pathogenicity of spirochetes in newborn animals (mice, rats, voles, guinea pigs, rabbits), only to find that this approach did not work either.

RML was not the only laboratory in which intensive research on the relationship of relapsing fever spirochetes to tick vectors was conducted. To name a few, there were the Pasteur Institute of Iran in Teheran, where Dr. Baltazard [19], in collaboration with Dr. Davis, tried to solve the classification problem; the Swiss Tropical Institute in Basel, where Professor Geigy together with Professor Dr. Hans Mooser from Zurich, Switzerland, expanded studies that I initiated as a graduate student and showed that continuous transovarian passage of the relapsing fever spirochete *B. duttonii* in its tick vector without occasional reactivation in a susceptible host will lead to a partial or even complete loss of pathogenicity [20]; the London School of Tropical Medicine and Hygiene, where Dr. Raja Varma [21] studied spirochetes in *Ornithodoros* with emphasis on the mechanism(s) of transmission to a host; the Tropical Institute in Hamburg, where Dr. Haberkorn [22] dealt with the relationship of tick-borne spirochetes (*Borrelia crocidurae*) to the body louse; U.S. Naval Medical Research Unit No. 3 in Cairo, Egypt, where Drs. Davis and Harry Hoogstraal [23] searched the Egyptian deserts for foci of *Ornithodoros erraticus* and spirochetes; and finally, several laboratories in the USSR, where Dr. Pospelova-Shtrom [24] and colleagues worked intensively with *O. tholozani* and *Ornithodoros tartakowskyi* and their respective spirochetes, *B. persica* and *Borrelia latyschewii.*

Needless to say, I enjoyed my work with Dr. Davis. In fact, I enjoyed it so much that I applied for a second-year fellowship and, when that came to an end, for a position as a visiting scientist. Unfortunately, by that time (December 1953), administrative interest in and support for research on relapsing fevers and tick-borne spirochetes had completely vanished. I never will forget a discussion I had with Dr. Victor Haas, the director of the National Microbiological Institute (as we were then called). "Relapsing fever," he said, "is a disease of the past; it no longer represents a public health problem. We cannot justify financial support for conducting research on an illness that each year may affect a handful of people who can be treated effectively with antibiotics. Considering your plans to stay at RML, I strongly urge you to change to a different field of research." Thus, work on tick-borne spirochetes, for me at least, became a moonlighting job. When Dr. Davis retired in 1956, I inherited his technician, and together we managed to keep going some of the normal as well as spirochete-infected tick colonies. This enabled us through the past 30 years to provide outside agencies with normal or spirochete-infected *O. hermsi, O. turicata, O. parkeri,* or even *O. moubata.*

Periodically, as expected, nature reminded us that tick-borne relapsing fevers were not historical diseases but, rather, the rewards for those sharing the ticks' biotopes. Thus, in March 1968, I received a call

from Dr. Robert Thompson, a Centers for Disease Control-Epidemiology Intelligence Service (CDC-EIS) officer assigned to the Washington State Health Department, about an outbreak of a febrile illness among boy scouts that he thought might be Colorado tick fever. With a lot of snow still on the ground, I questioned his diagnosis, especially after he told me that the scouts had camped out at Browne Mountain (elevation 3,100 feet) in wooded country about seven miles southwest of Spokane, Washington. At the campsite were two old, poorly kept, and rodent-infested cabins. The older scouts and scoutmasters planned to teach the younger scouts the virtues of roughing it in cold weather; they spent the nights in the cabins while the younger scouts had to sleep in tents. Ten of 20 scouts camping inside and one of 22 sleeping in a tent became ill with fever that in some instances relapsed as many as three times. While one scout was still in the hospital, I suggested that blood smears be made and examined for relapsing fever spirochetes. They were positive. During a follow-up on-site visit, we collected rodent nesting material from the walls of one cabin and found 18 *O. hermsi*, two of which were positive for spirochetes [25].

The largest outbreak of tick-borne relapsing fever ever to occur in the Western Hemisphere took place in the summer of 1973 on the North Rim of the Grand Canyon [26]. Sixty-two visitors and Park Service employees who spent one or several nights in log cabins scattered throughout the North Rim Park area contracted the disease. Some investigators believed that this epidemic was closely related to a plague epizootic that had occurred in the area one year earlier and had led to a die-off of the natural rodent hosts of the tick vector *O. hermsi*.

This may be an ideal point at which to review the number of relapsing fever cases reported since 1959. As summarized in table 2, a total of 345 cases within the distributional area of *O. hermsi* and 37 cases within that of *O. turicata* came to the attention of the various state health departments. These figures certainly do not represent a true picture of relapsing fever in the United States. Because in most patients the disease is eventually self-limited, many cases go unrecognized [27].

Many of the above-mentioned institutions, such as the Pasteur Institute of Iran, the London School of Tropical Medicine and Hygiene, the Tropical Institute in Hamburg, among others, eventually followed RML's decision to "get out of the relapsing fever and spirochete business" (to use a phrase often heard in discussions with administrators). Indeed, for many years, there was little research activity on these subjects. By the end of the 1960s, however, new laboratories with interests not in vector/spirochete relationships but in the immune mechanisms underlying the typical relapsing pattern of the disease had emerged. It had long been speculated that this pattern was related to antigenic phase variations of the spirochetes, which appeared to adapt themselves repeatedly to host antibodies by altering their antigenic profiles.

The exciting research that has been forthcoming during the past years on relapsing fever and tick-borne spirochetes was based on the pioneering works of Drs. Coffey and Eveland [28, 29], who, for the

Table 2. Cases of tick-borne relapsing fever in the United States, 1959–1983.

	No. of cases during period indicated				
Borellia species, state	1959–1963	1964–1968	1969–1973	1974–1978	1979–1983
B. hermsii					
California	20	13	17	53	58
Arizona	1	0	62	3	4
Oregon	0	14	5	20	20
Washington	0	12	0	4	5
Colorado	0	0	0	4	20
New Mexico	0	0	0	3	3
Idaho	0	0	0	1	3
B. turicatae					
Texas	12	2	1	3	15
Kansas	0	1	0	1	0
Oklahoma	0	0	0	2	0

NOTE. Data are from reports of state health departments.

first time, applied indirect immunofluorescence techniques to the identification of *Borrelia hermsii* serotypes; of Dr. Oscar Felsenfeld [30] and co-workers, who successfully used the indirect immunoenzyme tests for the detection of antibodies against borreliae in animals and humans; of Dr. Russell Johnson [31], who developed a research department to study the physiology and biochemistry of tick-borne spirochetes; and, finally, of Dr. Richard Kelly [32], who found a complex medium – now known as Kelly's medium – that supported growth and development of various species of *Borrelia*. I am happy to state that for most of these investigators, our laboratory provided the strains of spirochetes, some of which had been maintained since Dr. Davis' time.

Interested in the immune response in tick-borne relapsing fever, our former director, Dr. Herbert G. Stoenner, initiated a study of antigenic variations of *B. hermsii* and was able to identify at least 24 different serotypes originating from a single spirochete. Each of these 24 serotypes were also shown to change to seven or more other serotypes. Conversions occurred constantly and were independent of relapses [33].

In a follow-up study headed by Dr. Alan Barbour, also of RML, each serotype was found to have a protein of different molecular weight, and it was speculated and subsequently proved that a change from the specific protein to another represents the basis for antigenic variation of *Borrelia* species during relapsing fever [34].

Dr. Kelly's development of an artifical culture medium for continuous serial passages of certain tick-borne borreliae deserves special mention, for it provided large quantities of spirochetes for immunochemical, molecular, and genetic analyses as well as for serodiagnostic procedures that previously had been hampered by difficulties in obtaining sufficiently large quantities of spirochetes from infected animals. Today, both the IFA and ELISA with cultured spirochetes as antigen appear to be useful in the diagnosis of tick-borne spirochetoses, even though antigenic cross-reactions with other spirochetes may occur, especially in low serum dilutions.

Lyme Disease

Our discovery in the fall of 1981 of a tick-borne spirochete as the long-sought cause of Lyme disease in the United States and of related disorders in Europe signaled the beginning of a new era in the research of tick-borne spirochetoses [35, 36]. All of a sudden, clinical investigators, microbiologists, epidemiologists, ecologists, entomologists, and even administrators scrambled for a spot in the "lymelight." No longer did we hear "get out of the spirochete business," for now we had discovered a tick-borne spirochete that at the site of tick-bite causes an expanding annular skin lesion known as erythema chronicum migrans (ECM) in Europe since the beginning of this century [37]. This lesion may be accompanied by fever, headache, stiff neck, and myalgia, now we had discovered a spirochete that causes neurologic disorders such as aseptic meningitis, encephalitis, and neuritis that has been known in Europe since 1922 as tick-borne meningopolyneuritis [38] or Bannwarth's syndrome [39] and is often accompanied by paralysis of the facial muscles (Bell's palsy); now we had discovered a spirochete that, within a few weeks to two years after onset of illness, causes migrating musculoskeletal pain in joints, tendons, bursae, muscles, or bones, and arthritis with joint swelling that usually begins months after onset and is characterized by intermittent attacks of swelling and pain, especially in the knees [40]; now we had found a spirochete that, in about 10% of patients and from as early as four days to three months after onset, causes fluctuating degrees of atrioventricular block and acute myocarditis, ventricular dysfunction, and cardiomegaly [41]; now we had found a spirochete capable of spreading transplacentally to the organs of the fetus, causing congenital heart disease and possible death of the infant [42]; now we had found a spirochete that in Europe, following tick bite, may cause lymphocytoma (lymphadenitis benigna cutis) or acrodermatitis chronica atrophicans [43].

Many of these clinical manifestations have occurred in Europe for years as entities of unknown cause until we discovered the causative spirochete in 1981.

Lyme disease is a complex, multisystem spirochetosis that affects both children and adults [40]. It was named after the Connecticut community of Lyme, where outbreaks of arthritis had occurred in 1974 and 1975 that were diagnosed as juvenile rheumatoid arthritis. Thanks to two persistant housewives, Mrs. Polly Murray and Mrs. Judith Mensch of Old Lyme, who questioned this diagnosis, the rheumatology department of Yale University Medical School conducted detailed clinical and epidemi-

ologic investigations that eventually led to the description of a new disease entity called Lyme arthritis or Lyme disease. Shortly after the causative spirochete—now called *Borrelia burgdorferi* [44]—was discovered, however, it became apparent that ECM, tick-borne meningoradiculitis, and acrodermatitis chronica atrophicans of Europe are caused by the same, or at least closely related, spirochetes [45–47] and that these clinical entities may represent various stages of the more complex disease entity called Lyme disease. Even though this term is a misnomer and not appreciated by European investigators because of a specific geographic reference, it does refer to a complex spirochetosis rather to specific clinical manifestations, such as erythema (chronicum) migrans, tick-borne polyneuritis, and lymphadenitis benigna cutis.

In the United States from 1975 through 1979, 512 cases of Lyme disease were diagnosed in 14 predominantly northeastern and midwestern states [48]. In 1982, 491 cases came to the attention of CDC. This number increased to 599 cases in 1983 and to 1,498 cases in 1984 [49]. The number of states reporting this disease has also increased significantly, from 14 in 1979 to 20 in 1984, although more than 90% of all cases were acquired in Connecticut, Massachusetts, Minnesota, New Jersey, New York, Rhode Island, and Wisconsin. Connecticut and New York, with 483 and 446 cases, respectively, reported the largest number of cases in 1984. As yet, it is not known whether the increase in numbers and widening geographic distribution of cases reflect increased recognition or reporting rather than increased incidence or spread of the vectors and/or spirochetes.

Ticks of the genus *Ixodes* have been suspected and proved to be vectors. In the United States, the deer tick, *Ixodes dammini*, from which the initial strain of *B. burgdorferi* was discovered and isolated, serves as a vector in the northeastern and midwestern states. In some areas in New York, for instance, up to 100% of adult ticks collected from vegetation have been found to harbor spirochetes (W. B. and J. L. Benach, unpublished observations). In the western part of the country, the western black-legged tick, *Ixodes pacificus*, has been incriminated as a potential vector. In a recently completed tick/spirochete survey with Dr. Robert Lane from the University of California, Berkeley, and Dr. Robert Gresbrink from the Oregon State Health Division, we were able to confirm this assumption. Of 715 adult ticks from Oregon, 14 (1.9%) were infected, whereas 11 (1.1%) of 972 ticks from Marin, Sonoma, and Mendocino counties in Northern California harbored spirochetes indistinguishable from *B. burgdorferi* [50]. These figures correlate well with the occurrence of Lyme disease in humans. So far, few cases have been reported from the western United States, whereas in the Northeast and Midwest the disease is considerably more prevalent.

Spirochetes indistinguishable from *B. burgdorferi* have been detected also in *Amblyomma americanum* [51], *Dermacentor variabilis* [52], *Rhipicephalus sanguineus* [53], *Haemaphysalis leporispalustris* [52], and *Ixodes scapularis* (J. A. Rawlings, personal communication). Of these, only *A. americanum* has been claimed to serve as a potential vector of *B. burgdorferi* in the northeastern state of New Jersey.

In Europe, the sheep tick, *Ixodes ricinus*, is the vector. It had been associated with ECM as early as 1908, and since then with the various clinical entities, such as tick-borne meningoradiculitis, lymphocytoma, and acrodermatitis chronica atrophicans. Its infection with spirochetes remained elusive until soon after we discovered the Lyme disease agent in *I. dammini*.

In 1978, I spent a one-year sabbatical at the University of Neuchâtel in Neuchatel, Switzerland, to conduct a tick/rickettsial survey. I found up to 10% of *I. ricinus* infected with a *Rickettsia* that was eventually shown to represent a new spotted fever group agent [53]. At the end of my sabbatical, I returned to RML, taking along as reference material the smears of 135 *I. ricinus* that had been collected in the Seewald Forest on the Swiss plateau, where ECM cases had previously been reported. I remembered these slides and wondered whether they could still be examined. After three years of storage, the Gimenez stain had completely faded. A restaining with Giemsa, however, proved moderately successful and allowed a reexamination. Thirteen (17%) of the ticks contained spirochetes. In the spring of 1982, we obtained live ticks from Neuchatel. Of 210 individually examined adult ticks 73 (36.3%) were infected with spirochetes. Morphologically, this spirochete appeared indistinguishable from the *I. dammini* organism, and antigenic similarities between these two spirochetes were apparent by direct immunofluorescence and SDS-PAGE protein profiles as well as by indirect immunofluorescence and western blot analyses of sera from ECM and Lyme disease patients [36].

As yet, little is known about the natural history

of the Lyme disease spirochete, particularly its source for infecting ticks. So far, spirochetes have been recovered from the blood of white-tailed deer (*Odocoileus virginianus*) [54], a raccoon (*Procyon lotor*) [55], white-footed mice (*Peromyscus leucopus*) [54–56], and from the liver of a passerine bird (*Cadtharus fuscescens*) [57]. The white-footed mouse appears to be a preferred host of immature *I. dammini* and is considered a potential spirochetal reservoir [58]. Although these animals, as fas as we know, are not adversely affected by the Lyme disease spirochete, dogs have been shown to be susceptible and will suffer lameness from inflammation in one or more joints [59–61]. Spirochetes identical to *B. burgdorferi* have been isolated from the blood of a Doberman Pinscher suffering stiffness in all four limbs [59].

Present Research

The discovery of the causative agent of Lyme disease and related disorders in 1981 has opened the doors for intensive clinical, epidemiologic, and ecologic research as attested to by the plethora of papers published during the past two years. With the help of sophisticated immunochemical and molecular technology, it suddenly has become possible to gain insight into the complex biology of tick-borne spirochetes. Relapsing fevers and their causative agents also have again become a prime target for research, and, as one discovery follows another, new fields to our vision are opened. To exemplify this statement, expressed many years ago by Louis Pasteur, I would like to finish my lecture by referring to still another exciting finding that my colleagues and I have made during our investigations on the ecology of Lyme disease in California. The relatively small percentage (1.9%) of *Ixodes pacificus* harboring *B. burgdorferi* led to the question of whether other species of ticks, such as the argasid tick, *Ornithodoros coriaceus*, which primarily feeds on deer and cattle, is a carrier of spirochetes. In a study with Dr. Lane, we collected *O. coriaceus* with dry ice–baited pitfall traps from chaparral and woodland-grass habitats at the University of California Hopland Field Station from July to September 1984 and examined them by direct immunofluorescence. Spirochetes were detected in 5 (0.9%) of 520 larvae, 10 (8.2%) of 121 nymphs, and 31 (24%) of 129 adults. Immunochemical and molecular studies with one isolate from these ticks revealed that this spirochete is a *Borrellia*, but it differs from the hitherto-described relapsing fever spirochetes or the Lyme disease agent [62].

Ornithodoros coriaceus is considered the vector of an as yet unknown agent causing epizootic bovine abortion (EBA) in rangeland cattle within the distributional area of *O. coriaceus* [63]. In California alone annual losses from EBA vary from 5% to 60% in individual herds, at a cost of $5 to $15 million. Chlamydiae have been proposed as the cause of this disease [64], but vaccines prepared from this agent did not protect cattle in areas where EBA is enzootic [65].

In a recent paper we suggest that the *O. coriaceus* spirochete may be causally related to EBA because of the high percentage of infected ticks in recognized EBA areas [62]. Also, the fact that prophylactic treatment of cattle with chlortetracycline reduces the abortion rates under field conditions indicates that an antibiotic-sensitive organism, such as a spirochete, may be the abortifacient agent. Finally, it is well known [66] that pregnant woman infected with relapsing fever frequently abort—a phenomenon known to occur also in Lyme disease, as discussed previously.

In 1948, I started my career as a medical entomologist with a study of the development of *B. duttonii* spirochetes in *O. moubata* ticks [67]. Although during the past 37 years I ventured into various fields of arthropod-borne pathogens, I always managed to keep up my interest in tick-borne spirochetoses. The discovery of the Lyme disease agent undoubtedly has led to a renaissance of interest in this subject. Having had the privilege to contribute to this exciting development is a most rewarding feeling as I am about to join the ranks of retired persons.

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