# Dogs as Sentinels for Human Lyme Borreliosis in The Netherlands

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Serum samples from hunters (*n* = 440), their hunting dogs (*n* = 448), and hunters without dog ownership (*n* = 53) were collected in The Netherlands at hunting dog trials and were tested for antibodies against *Borrelia burgdorferi* by a whole-cell enzyme-linked immunosorbent assay. Additionally, 75 healthy pet dogs were tested. The results of this study indicate that the seroprevalence among hunting dogs (18%) was of the same order as the seroprevalence among pet dogs (17%) and hunters (15%). The seropositivity of a hunting dog was not a significant indicator of increased risk of Lyme borreliosis for its owner. No significant rise in seroprevalence was found in dogs older than 24 months. This indicated that seropositivity after an infection with *B. burgdorferi* in dogs is rather short, approximately 1 year. In humans this is considerably longer but is also not lifelong. Therefore, the incidence of *B. burgdorferi* infections among dogs was greater than that among hunters, despite a similar prevalence of seropositivity among hunters and their hunting dogs. Because no positive correlation was observed between the seropositivity of a hunter and the seropositivity of the hunter's dog, direct transfer of ticks between dog and hunter does not seem important and owning a dog should not be considered a risk factor for Lyme borreliosis.

Lyme borreliosis (LB) is a zoonotic disease caused by the spirochete *Borrelia burgdorferi* (5, 41). An animal reservoir of approximately 40 mammals and birds has been established (15) in Europe. The disease is transmitted primarily by ticks feeding on mammals and birds, with the most common vector in Europe being the tick *Ixodes ricinus* (1). In humans, LB in its early stages is characterized by influenza-like symptoms, followed in 60 to 80% of the cases by erythema migrans (40), a skin lesion that spreads outward from around the site of a tick bite. If untreated, the disease may proceed to a second or a third stage in which neurological disorders and arthritis are common symptoms (42). Much less is known about LB in animals than is known about the disease in humans. The most common symptom of LB in dogs is migratory arthritis (30) without divergent radiographic findings. Other but less common symptoms reported in dogs are carditis (25), glomerulonephritis (17), and neuritis (2; B. M. Feder, R. J. Joseph, S. D. Moroff, et al., Abstr. Proc. 9th ACVIM, p. 892, 1991). *B. burgdorferi* infections or serologic evidence of *B. burgdorferi* infections have been reported in dogs in the United States (3, 7, 26, 29, 30). In Europe, relatively few reports exist on LB in animals. In Sweden (13), Denmark (18), Germany (20, 21, 35, 45, 47), The Netherlands (19), the United Kingdom (32), Belgium (33), France (9, 11, 12, 14), Switzerland (37), Slovakia (43), Slovenia (34), and Spain (10), antibodies to *B. burgdorferi* and/or clinical symptoms of LB have been found in dogs. However, in Europe, the use of dogs as sentinel animals for the estimation of the risk of Lyme borreliosis for humans in that region has not been examined. Moreover, it has been suggested that in the United States pet ownership increases the risk of getting Lyme disease (K. L. Curran and D. Fish, Letter, N. Engl. J. Med. **320:**183,

1989), yet in Europe the relationship of dog ownership and an increased risk of Lyme disease for the dog owners has not been studied.

People recreating or working in tick-infested areas like forests show an increased prevalence of antibodies to *B. burgdorferi* compared to that for controls (22, 23, 36). Parallel to the findings for people with high levels of outdoor activity, a higher seroprevalence of antibodies *B. burgdorferi* could be expected for hunting dogs compared to that for controls. As dogs could be an intermediary source for human tick infestation, the risk of human Lyme disease could be increased by dog ownership. The aims of the study described here were to evaluate if high levels of outdoor activity can be related to an increased prevalence of antibodies to *B. burgdorferi* in both hunter and hunting dog populations, to search if dogs in an area of endemicity for LB pose a risk factor for LB for their owners, and to investigate if in The Netherlands the risk for LB in humans can be deduced from the seroprevalence of antibodies against *B. burgdorferi* among the dog population in the same area.

## MATERIALS AND METHODS

In the autumn of 1989 at trials for hunting dogs, blood samples were collected from hunters (*n* = 440) and their dogs (*n* = 448). Blood samples from an additional group of hunters who did not own a dog (*n* = 53) were also included. All participants in the study were asked to fill in a questionnaire about age, tick infestations, and clinical symptoms of LB for both the hunter and the dog. The ages of the 448 hunting dogs ranged from 4 to 120 months, with a mean age of 38 months, and the dogs were of various breeds. In the same year of the trial, blood samples were collected from 75 healthy dogs of various breeds that lived in the countryside, that had no clinical signs of Lyme disease, and that presented at veterinary clinics for their regular vaccinations. The ages of the 75 dogs ranged from 6 to 97 months, with a mean age of 35 months. None of the animals included in this study were vaccinated against LB. No vaccine against LB is available in The Netherlands. All sera were stored at −70°C until assayed. Serological testing was used to determine the prevalence of Lyme antibodies in the hunters, hunting dogs, and nonhunting dogs. To exclude differences related to test technology, both human and dog sera were tested in an enzyme immunoassay (EIA) system by using the same antigen batch.

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**ELISA for human and canine sera.** The sera of the hunters were retested for immunoglobulin G (IgG) antibodies to *B. burgdorferi*, and the results were compared to the previously reported results (36). For the in-house enzyme-linked immunosorbent assay (ELISA), the *B. burgdorferi* B31 strain (ATCC 35210) was used as an antigen. The human and dog sera were tested in an ELISA as described by Craft et al. (8), with minor modifications. Briefly, the spirochetes were grown for 5 to 7 days at 35°C in BSK-II medium (modified Barbour-Stoenner-Kelly medium). The culture was centrifuged ($10,000 \times g$, 30 min, 4°C), and the pellets were washed twice in phosphate-buffered saline (PBS; pH 7.2) with 0.005 M $MgCl_2$ ($10,000 \times g$, 30 min, 4°C), resuspended in PBS, and sonicated 20 times for 15 s each time on ice water in a Branson sonicator-ultrasonic processor at the maximum microtip setting. The sonic extract was centrifuged ($10,000 \times g$, 30 min, 4°C), and the protein content of the supernatant was determined by a protein assay (Bio-Rad Laboratories, Munich, Germany). The supernatant was divided into aliquots and was kept at $-70$°C. Immunoplates (Polysorp; Nunc, Roskilde, Denmark) were coated with 100 µl of sonicated antigen (2 µg/ml) that was diluted in 0.05 M carbonate buffer (pH 9.6) (15 h, 4°C). Nonspecific binding was blocked with 200 µl of 1% fish gelatin (Sigma, St. Louis, Mo.) in PBS (1 h, 22°C). Test and control sera were diluted 1:100 and 1:250 in PBS with 0.05% Tween 20 and in 0.5% fish gelatin for human and canine sera, respectively, and were tested in duplicate (100 µl per well). After 1 h of incubation at 37°C, 100-µl volumes of peroxidase-conjugated goat anti-human IgG (Kirkegaard & Perry Laboratories, Inc., Gaithersburg, Md.) and peroxidase-conjugated protein G (Sigma) were added at a dilution of 1:8,000 (in PBS–Tween 20) for human sera and a dilution of 1:10,000 (in PBS–Tween 20) for canine sera, respectively, and the solutions were incubated at 37°C for 30 min. Between all steps, the plates were washed in a Microplate washer (Flow Laboratories, Glasgow, Scotland) on a three-wash cycle with PBS–Tween 20 used as a washing buffer. As a substrate, 100 µl of ready-to-use tetramethylbenzidine (D-tek, Mons, Belgium) was used. The optical density (OD) at 405 nm was read in a Titertek Multiskan apparatus (ICN Pharmaceuticals Inc., Irvine, Calif.). The time of the substrate reaction was set to 15 min and was stopped with tetramethylbenzidine stop solution (D-tek).

**Standardization of the human and canine Lyme disease EIA.** For the human Lyme disease EIA, 25 serum samples from patients with clinically defined late Lyme disease, 100 serum samples from blood donors, and 100 serum samples from patients with diseases that clinically mimic Lyme disease were used to determine the cutoff, which was 0.300 OD unit. For the canine Lyme disease EIA, sera from 105 dogs from an experimental animal facility that had never been exposed to ticks (5 of which, however, had been hyperimmunized against leptospirosis) were used to determine the cutoff for a positive reaction. A mean OD and standard deviation (SD) of the mean were calculated for the 105 negative canine serum samples and were used to determine the cutoff value, which was 0.250 OD unit. In the *B. burgdorferi* ELISAs, commonly 2 times (8) or 3 times (28) the SD above the mean for a group of negative controls is used as a cutoff value (31). This might, however, vary between laboratories. To determine the cutoff levels for a positive canine Lyme disease test result, a mean OD ratio and SD of the mean were calculated for the 105 negative serum samples which had the same serum dilution as the test sera. To ensure the reproducibility of the test, all the sera included in the serosurvey were tested with the same batch of antigen. The best reproducibility was obtained when 3 SDs was used as the cutoff, because 98% of the canine serum samples were consistently either positive or negative by both tests. If, on the other hand, a 2-SD cutoff was used, only 86% of the canine serum samples were repeatedly positive or negative. Of the canine sera, which additionally became positive when the cutoff was lowered, 82% were borderline sera; i.e., when the same sera were tested repeatedly, they gave various results, either positive or negative. This led to a much poorer reproducibility of the test. On the basis of these results, the cutoff between a positive test result and a negative test result was set at 3 SDs above the mean OD for the negative canine control serum samples, and a seropositive animal was defined as one that had an OD ratio above this calculated cutoff value.

**Control sera.** For the human Lyme disease EIA, sera with negative, cutoff, and positive values were tested in duplicate on each plate. For the canine Lyme disease EIA, a pool of sera from three dogs hyperimmunized with sonicated *B. burgdorferi* ATCC 35210 antigen was used as a positive control. These dogs had been immunized subcutaneously with LB antigen in an adjuvant mixture of water in the mineral oil Specol (4) (ID-DLO, Zelystad, The Netherlands) and were boostered after 4 weeks with *B. burgdorferi* antigen in PBS. The antibody response against LB was confirmed by Western blotting. One week after the last immunization, blood was collected from the animals and the serum was stored at $-70$°C until it was assayed. The immunized animals had an antibody titer of 51,200 (reciprocal dilution) in the ELISA and were pooled for use as positive control serum. No background reaction was observed for the positive control

TABLE 1. Prevalence of IgG antibodies to *B. burgdorferi* in hunters, by age, with or without ownership of hunting dogs

| Age (yr) | No. (%) of hunters | | | |
|---|---|---|---|---|
| | Hunters with hunting dogs | | Hunters without hunting dogs | |
| | Total | Seropositive | Total | Seropositive |
| 9–30 | 86 | 6 (7) | 16 | 1 (6) |
| 31–40 | 145 | 18 (12) | 10 | 1 (10) |
| 41–50 | 128 | 26 (20) | 11 | 2 (18) |
| >50 | 81 | 18 (22) | 16 | 3 (19) |
| Total | 440 | 68 (15) | 53 | 7 (13) |

serum in control wells, which were blocked with 1% fish gelatin (Sigma) in PBS. Sera taken before and after immunization of these dogs were also tested for antibodies against *Leptospira interrogans* serovar hardjo (macroscopic agglutination test, internal house test) and *L. interrogans* serovar icterohaemorrhagiae (macroscopic agglutination test, internal house test) and for *Treponema pallidum* antibodies (Fujirebio, Tokyo, Japan); all sera were negative.

A pool of sera from 10 experimental dogs negative for *B. burgdorferi* antibodies (Vet Lyme Borreliosis EIA; Genzyme-Virotech, Ruesselsheim, Germany) was used as a negative control.

To eliminate plate-to-plate variation, the ELISA result was expressed as an OD ratio, i.e., the ratio of the mean OD for a test serum sample to the mean OD for the serum sample with the cutoff value on the same plate. While testing the dog sera these positive and negative samples and a diluted positive control serum sample with the predefined cutoff value were tested on each plate. The mean OD value was calculated for each duplicate serum sample. Human or canine sera were retested if the OD values for the duplicates differed by more than 10% from the mean.

**Statistical Analysis.** Paired data were compared by McNemar's test, assuming a binomial distribution of the data. Nonpaired data were compared by using the chi-square test.

## RESULTS

The results of the testing of the hunters, as previously described by Nohlmans et al. (36), showed no significant differences compared to those of the current tests. Briefly, the prevalence of IgG antibodies against *B. burgdorferi* among owners of working hunting dogs ($n = 440$) was significantly higher (15%) than that among healthy blood donors ($n = 1,052$) matched for the same age (9%). In both groups the prevalence of seropositivity increased with age, but in hunters older than 40 years it remained relatively constant, as shown in Table 1. Only 3% of the hunting dog owners could recall having had symptoms most likely to be due to LB. Of the 68% seropositive hunters, 64 (94%) were asymptomatic. As shown in Table 1, the rate of seropositivity among the hunters increased with increasing age: from 7% for those <31 years of age to 20% for those >40 years of age ($P < 0.005$). Among the hunters older than 40 years, the seroprevalence no longer rose significantly and remained constant at approximately 20%.

As listed in Table 2, antibodies against *B. burgdorferi* were detected in 18% (95% confidence interval, 14.4 to 21.4) of the hunting dogs and 17% (95% confidence interval, 8.5 to 25.5) of the pet dogs. Hunting dogs older than 24 months appeared to have a greater risk of being exposed (22%) than younger hunting dogs (9 to 11%) ($P < 0.05$), but the seroprevalence among hunting dogs remained stable at approximately 22% among animals over 24 months of age (Table 2). In a comparison of the age distribution of seropositive hunting dogs and the total hunting dog population, no significant differences were ob-

TABLE 2. Prevalence of antibodies to *B. burgdorferi* among hunting
and nonhunting dogs, by age

| Age (mo) | No. (%) of dogs | | | |
|---|---|---|---|---|
| | Hunting dogs | | Nonhunting dogs | |
| | Total | Seropositive | Total | Seropositive |
| 6–12 | 56 | 5 (9) | 11 | 1 (9) |
| 13–24 | 125 | 15 (11) | 19 | 3 (16) |
| 25–36 | 85 | 19 (22) | 11 | 2 (18) |
| 37–48 | 73 | 16 (22) | 15 | 3 (20) |
| 49–120 | 109 | 25 (23) | 19 | 4 (21) |
| Total | 448 | 80 (18) | 75 | 13 (17) |

served except among the hunting dogs ages 60 to 70 months and younger than 12 months ($P < 0.05$).

When we compared the seroprevalence of antibodies against *B. burgdorferi* for the hunting dog population with that for the nonhunting dog population, no significant differences were seen for all age groups listed. Eleven (14%) of the 80 seropositive hunting dogs showed signs of lameness and were older than 24 months, with a mean age of 46 months. Eight (72%) of the 11 hunting dogs that had been suffering from migratory lameness had a history of regular tick infestations, whereas ticks had seldom been spotted on the other three dogs by their owners. Ticks had regularly been removed from 53 (66%) of the 80 seropositive hunting dogs and 217 (59%) seronegative hunting dogs. Most of the seropositive hunting dogs (86%) had not shown any clinical symptoms that could be attributable to LB, and only 11 (14%) had recently suffered from intermittent lameness, a clinical symptom that could be attributed to LB. Of the 217 seronegative hunting dogs, 36 (17%) had recently shown signs of lameness. All seropositive pet dogs were healthy, without any clinical signs pointing to LB. As shown in Tables 1 and 2, the prevalences of seropositive hunters (15%; 95% confidence interval, 11.7 to 18.3) and hunting dogs (18%; 95% confidence interval, 14.4 to 21.4) were not significantly different. However, if the results of the EIAs were matched between the dog and the dog owner, the prevalence of seropositivity among the hunters was significantly different ($P < 0.001$) from the prevalence of seropositivity among their hunting dogs. In only 12% of the hunter-dog pairs was a match of seropositivity observed. The seroprevalence among hunters with or without dog ownership was not significantly different.

## DISCUSSION

**Outdoor activity as a risk factor for Lyme disease?** The seroprevalence of antibodies against *B. burgdorferi* among hunting dogs and hunters in this study is higher than that among healthy blood donors (9%) in The Netherlands but is of the same order as the seroprevalence among Dutch forestry workers (20 to 24%), as described by Kuiper et al. (22). In contrast, a significantly lower seroprevalence in Dutch soldiers (0.9%) conducting predominantly outdoor activities in areas of endemicity for ticks has been reported (44). The most likely explanation for the lower seroprevalence among Dutch soldiers is the fact that soldiers must wear a special uniform during field training: long sleeves, long pants, and high boots. This uniform is different from and much more protective against

tick infestations than the clothes worn by most other people involved in recreational or occupational outdoor activities, especially during warm weather conditions. However, despite the observed similar seroprevalence among dogs and hunters in this study, the hypothesis of Eng et al. (T. R. Eng, M. L. Wilson, A. Spielman, and C. C. Lastavica, Letter, J. Infect. Dis. **158:**1410–1411, 1988) that dogs have a greater risk of *B. burgdorferi* infection than people is endorsed by the results of this study, as dogs stay seropositive for a much shorter period of time after an infection with *B. burgdorferi*. Because seropositivity seemed to last for only approximately 1 year, the seroprevalence in dogs in fact is more or less identical to the yearly incidence of infections with *B. burgdorferi* in dogs. Surprisingly, although it was supposed that hunting dogs have an increased risk of tick infestation compared to the risk for other dogs, no significant differences in seroprevalences between the hunting dog and the pet dog populations were found. These findings are in contrast to the seroprevalence among hunting dogs (40%) in the Slovak Republic (43), which was significantly higher than the seroprevalence among service dogs (12%). The lower seroprevalence among Slovakian service dogs could be explained by the residence of watchdogs in more strictly home environments and the rate of outdoor walking compared to the rate of outdoor walking of house dogs in The Netherlands, where it is higher. The breed of dog supposed as a proxy for occupational or recreational exposure did not influence the seroprevalence in our study, as the biotopes for the dog populations examined could be considered the same.

**Dynamic of antibody response to *B. burgdorferi* in humans and dogs.** Age as a proxy for the cumulative duration of exposure was demonstrated in this study by the increasing rate of seropositivity with the increasing age of the dogs, but after an age of 24 months no significant increase in age-specific seropositivity was found, although a continuous risk of exposure to *B. burgdorferi* exists. In contrast to the human immunological response, in whom IgG antibodies to *B. burgdorferi* can persist for several years, the findings of the present study are in concordance with previous findings that the seroprevalence in dogs remains relatively stable after 2 years of age (27, 38). Our study also strengthens the view of Hovius et al. (19) that a yearly reinfection is necessary to maintain seropositivity. Also in humans, seropositivity is certainly not lifelong, as shown by the incidence rates in hunters of different age groups. Because the period of seropositivity in humans after an infection with *B. burgdorferi* is much longer than that in dogs, the incidence of infection of the dogs in this study is certainly higher than that in humans, as was to be expected. Furthermore, these findings could be considered the same for test systems with isolates other than B31. The use of isolates representative of *B. burgdorferi* sensu lato in European Lyme disease serology showed no improvement of test performance but indicated only a predictive value for human clinical cases (6, 16, 46).

**Dogs and their validity as sentinel animals.** The dog has been proposed for use as a sentinel animal for detection of the risk of *B. burgdorferi* infection in humans. Dogs exposed to infected ticks develop antibodies to the spirochete, and dogs are more likely than people to be exposed to infected ticks because their behavior brings them into direct and closer contact with tick habitats like brush. Moreover, ticks can easily hide in the hair coats of dogs and dogs are not protected

against tick infestation by clothing like hunters are. Although it was expected that dogs were frequently bitten by ticks more often than hunters were, the seroprevalence of antibodies against *B. burgdorferi* in hunters and hunting dogs was of the same order in the present study. This indicated that estimates of seroprevalence among hunting dogs are predictive of the risk of LB in humans. This finding was supported not only by the overall seroprevalence but also by the fact that no significant variation was seen when the seroprevalences for hunters and hunting dogs from the same regions were compared (data not shown). The use of dog sera to detect and quantify the risk of Lyme disease for humans in a certain region is more sensitive than the use of reports of incident human clinical cases but is not more sensitive than the use of seroprevalence in humans. The use of dog sera, however, has the advantage that the seroprevalence among dogs is more likely to reflect the actual environmental risk of Lyme disease because of the short half-life of canine antibodies against *B. burgdorferi*. This study shows that the risk factors identified for dogs may directly or indirectly illuminate certain aspects of the epidemiology of human Lyme disease. Nonetheless, one should be aware that it is very difficult to standardize canine Lyme disease tests due to the lack of indisputable clinically defined cases of Lyme disease. Most studies use panels of canine sera reactive by other tests as a reference, but this is not a real "gold standard." A serum sample can be regarded as a gold standard when clinically it is indisputably related to Lyme disease and when the presence of *B. burgdorferi* has been demonstrated. Therefore, to circumvent the problem of disputable reference sera, this study used the sera of dogs vaccinated with *B. burgdorferi* for the tuning of the linear response range of the test. For the cutoff determination, the mean OD for a dog population considered negative for Lyme disease and a population considered possibly cross-reactive to Lyme disease (hyperimmunized against leptospirosis) was used. Although this method is acceptable for seroepidemiological studies, this is not the ideal way and panels of an acceptable number of indisputably defined sera from dogs with Lyme disease should be made available for future test development. Parallel to the findings for human Lyme disease serology, that exclusion of diseases that mimic Lyme disease is a better approach than confirmation of Lyme disease by Western blotting (16), such an approach should be taken into consideration for future multiple test approaches for canine Lyme disease serology.

**Dog ownership as a risk factor for Lyme disease?** In contrast to a single publication that cat ownership (two case reports) seemed to increase the risk of Lyme disease (Curran and Fish, letter, 1989), the seropositivity of the hunting dogs was not an indicator for an increased risk of *B. burgdorferi* infection for their owners. Only 12% of the seropositive hunters had hunting dogs which were also seropositive. Moreover, hunters without dog ownership showed no significantly lower rates of seropositivity. Therefore, on the basis of the findings of our study, ownership of dogs with increased risk of infection could not be associated with a higher risk of human Lyme disease, as described for dogs living in regions of endemicity by Eng et al. (Eng et al., letter, 1988) and Cimmino et al. (M. A. Cimmino and D. Fumarola, Letter, JAMA **262:**2997–2998, 1989). Humans and dogs seem to be independently infected.

**Conclusion.** The evolution of a Lyme disease focus might occur quickly (24, 39), which causes the need for a surveillance method capable of detecting changes in exposure to the pathogen. Dog serum samples can be used for this purpose, but they are not more sensitive than those of people with comparable exposures, such as hunters and forestry workers. However, because of the shorter period of seropositivity after infection, the seroprevalence among dogs is more indicative of recent exposure than the observed prevalence among humans. Dog ownership causes no increased risk for human Lyme disease.

## REFERENCES

1. **Ackermann, R., J. Kabatzki, H. P. Boisten, A. C. Steere, R. L. Grodzicki, S. Hartung, and U. Runne.** 1984. Ixodes ricinus spirochete and European erythema chronicum migrans disease. Yale J. Biol. Med. **57:**573–580.
2. **Azuma, Y., K. Kawamura, H. Isogai, and E. Isogai.** 1993. Neurologic abnormalities in two dogs suspected Lyme disease. Microbiol. Immunol. **37:**325–329.
3. **Barthold, S. W., S. A. Levy, E. Fikrig, L. K. Bockenstedt, and A. L. Smith.** 1995. Serologic responses of dogs naturally exposed to or vaccinated against Borrelia burgdorferi infection. J. Am. Vet. Med. Assoc. **207:**1435–1440.
4. **Bokhout, B. A., C. Van Gaalen, and P. J. Van der Heijden.** 1981. A selected water-in-oil emulsion: composition and usefulness as an immunological adjuvant. Vet. Immunol. Immunopathol. **2:**491–500.
5. **Burgdorfer, W., A. G. Barbour, S. F. Hayes, J. L. Benach, E. Grunwaldt, and J. P. Davis.** 1982. Lyme disease: a tickborne spirochetosis? Science **216:**1317–1319.
6. **Busch, U., C. Hizoteufel, R. Boehmer, V. Fingerle, H. Nitschko, B. Wilske, and V. Preacmursic.** 1996. Three species of Borrelia burgdorferi sensu late (*B. burgdorferi* sensu stricto, *B. afzelii*, and *B. garinii*) identified from cerebrospinal fluid isolates by pulsed-field gel electrophoresis and PCR. J. Clin. Microbiol. **34:**1072–1078.
7. **Cohen, N. D., C. N. Carter, M. A. Thomas, Jr., A. B. Angulo, and A. K. Eugster.** 1990. Clinical and epizootiologic characteristics of dogs seropositive for Borrelia burgdorferi in Texas: 110 cases (1988). J. Am. Vet. Med. Assoc. **197:**893–898.
8. **Craft, J. E., R. L. Grodzicki, and A. C. Steere.** 1984. Antibody response in Lyme disease: evaluation of diagnostic tests. J. Infect. Dis. **149:**789–795.
9. **Davoust, B., and M. Boni.** 1998. Lyme-disease in dogs—seroepidemiological survey in the south-east of France. Med. Mal. Infect. **28:**408–409.
10. **Delgado, S., and P. Carmenes.** 1995. Seroepidemiological survey for Borrelia burgdorferi (Lyme disease) in dogs from northwestern of Spain. Eur. J. Epidemiol. **11:**321–324.
11. **Doby, D. M., S. Chevrier, and A. Couatarmanach.** 1988. Tickborne Borrelia burgdorferi infection in dogs in western France. Systematic serological survey of 806 hunting dogs and 88 military dogs in 14 departments. Rec. Med. Vet. **164:**367–374.
12. **Doby, J., S. Chevrier, and A. Couatarmanach.** 1988. La spirochetose a tiques par Borrelia burgdorferi chez les chiens dans louest de la France. Rec. Med. Vet. **164:**367–374.
13. **Egenvall, A., B. N. Bonnett, A. Gunnarsson, A. Hedhammar, M. Shoukri, S. Bornstein, and K. Artursson.** 2000. Sero-prevalence of granulocytic Ehrlichia spp. and Borrelia burgdorferi sensu lato in Swedish dogs 1991–94. Scand. J. Infect. Dis. **32:**19–25.
14. **Euzeby, J. P., and A. Raffi.** 1988. Demonstration of antibodies to Borrelia burgdorferi in dogs: epidemiologica survey in the central Pyrenees region. Rev. Med. Vet. **139:**589–593.
15. **Gern, L., A. Estrada-Pena, F. Frandsen, J. Gray, T. Jaenson, F. Jongejan, O. Kahl, E. Korenberg, R. Mehl, and P. Nuttall.** 1998. European reservoir hosts of *Borrelia burgdorferi* sensu lato. Zentbl. Bakteriol. Parasitenkd. Infektkrankh. Hyg. Abt. 1 Orig. **287:**196–204.
16. **Goossens, H. A. T., A. E. van den Bogaard, and M. K. E. Nohlmans.** 1999. Evaluation of fifteen commercially available serological tests for diagnosis of Lyme borreliosis. Eur. J. Clin. Microbiol. Infect. Dis. **18:**551–560.
17. **Grauer, G. F., E. C. Burgess, A. J. Cooley, and J. H. Hagee.** 1988. Renal lesions associated with *Borrelia burgdorferi* infection in a dog. J. Am. Vet. Med. Assoc. **193:**237–239.
18. **Hansen, K., and H. Dietz.** 1997. Serosurvey for antibodies to *Borrelia burgdorferi* in Danish dogs. APMIS **97:**281–285.
19. **Hovius, K. E., S. G. Rijpkema, P. Westers, B. A. M. van der Zeijst, F. J. A. M. van Asten, and D. J. Houwers.** 1999. A serological study of cohorts of young dogs, naturally exposed to *Ixodes ricinus* ticks, indicates seasonal reinfection by *Borrelia burgdorferi* sensu lato. Vet. Q. **21:**16–20.
20. **Kasbohrer, A., G. Liebisch, A. Schonberg, and A. Liebisch.** 1994. Serodiagnosis of Lyme borreliosis development and evaluation of a test system for epidemiological studies in the dog. DTW. Dtsch. Tierarztl. Wochenschr. **101:**476–481.
21. **Kasbohrer, A., and A. Schonberg.** 1990. Serologic studies of the occurrence

of *Borrelia burgdorferi* in domestic animals in Berlin (West). Berl. Munch. Tierarztl. Wochenschr. **103:**374–378.

22. **Kuiper, H., B. M. de Jongh, A. P. Nauta, H. Houweling, L. G. Wiessing, A. W. van Charante, and L. Spanjaard.** 1991. Lyme borreliosis in Dutch forestry workers. J. Infect. **23:**279–286.

23. **Kuiper, H., A. P. van Dam, A. W. Moll van Charante, N. P. Nauta, and J. Dankert.** 1993. One year follow-up study to assess the prevalence and incidence of Lyme borreliosis among Dutch forestry workers. Eur. J. Clin. Microbiol. Infect. Dis. **12:**413–418.

24. **Lastavica, C. C., M. L. Wilson, V. P. Berardi, A. Spielman, and R. D. Deblinger.** 1989. Rapid emergence of a focal epidemic of Lyme disease in coastal Massachusetts. N. Engl. J. Med. **320:**133–137.

25. **Levy, S. A., and P. H. Duray.** 1988. Complete heart block in a dog seropositive for *Borrelia burgdorferi.* Similarity to human Lyme carditis. J. Vet. Intern. Med. **2:**138–144.

26. **Levy, S. A., and L. A. Magnarelli.** 1992. Relationship between development of antibodies to *Borrelia burgdorferi* in dogs and the subsequent development of limb/joint borreliosis. J. Am. Vet. Med. Assoc. **200:**344–347.

27. **Lindenmayer, J. M., D. Marshall, and A. B. Onderdonk.** 1991. Dogs as sentinels for Lyme disease in Massachusetts. Am. J. Public Health **81:**1448–1455.

28. **Magnarelli, L. A., and J. F. Anderson.** 1989. Class-specific and polyvalent enzyme-linked immunosorbent assays for detection of antibodies to *Borrelia burgdorferi* in equids. J. Am. Vet. Med. Assoc. **195:**1365–1368.

29. **Magnarelli, L. A., J. F. Anderson, A. F. Kaufmann, L. L. Lieberman, and G. D. Whitney.** 1985. Borreliosis in dogs from southern Connecticut. J. Am. Vet. Med. Assoc. **186:**955–959.

30. **Magnarelli, L. A., J. F. Anderson, A. B. Schreier, and C. M. Ficke.** 1987. Clinical and serologic studies of canine borreliosis. J. Am. Vet. Med. Assoc. **191:**1089–1094.

31. **Magnarelli, L. A., J. M. Meegan, J. F. Anderson, and W. A. Chappell.** 1984. Comparison of an indirect fluorescent-antibody test with an enzyme-linked immunosorbent assay for serological studies of Lyme disease. J. Clin. Microbiol. **20:**181–184.

32. **May, C., S. Carter, A. Barnes, S. Bell, and D. Bennett.** 1991. Serodiagnosis of Lyme disease in U. K. dogs. J. Small Anim. Pract. **32:**170–174.

33. **McKenna, P., J. Clement, D. Van Dijck, M. Lauwerys, D. Carey, T. Van den Bogaard, and G. Bigaignon.** 1995. Canine Lyme disease in Belgium. Vet. Rec. **136:**244–247.

34. **Mehle, J.** 1996. Lyme borreliosis in animals. Vet. Nov. **22:**179–183.

35. **Muller, E.** 1994. Borreliosis bei Hunden Klinische und serologische Befunde. Kleintierpraxis **39:**375–380.

36. **Nohlmans, M. K., A. E. van den Bogaard, A. A. Blaauw, and C. P. van Boven.** 1991. Prevalence of Lyme borreliosis in The Netherlands. Ned. Tijdschr. Geneeskd. **135:**2288–2292.

37. **Pfister, K., B. Bigler, J. Neswadba, L. Gern, and A. Aeschlimann.** 1989. *Borrelia burgdorferi* infections of dogs in Switzerland. Zentbl. Bakteriol. Parasitenkd. Infektkrankh. Hyg. Abt. 1 Orig. **18:**26–31.

38. **Schulze, T. L., E. M. Bosler, J. K. Shisler, I. C. Ware, M. F. Lakat, and W. E. Parkin.** 1986. Prevalence of canine Lyme disease from an endemic area as determined by seroservey. Zentbl. Bakteriol. Parasitenkd. Infektkrankh. Hyg. Abt. 1 Orig. Reihe A **263:**427–434.

39. **Schulze, T. L., J. K. Shisler, E. M. Bosler, M. F. Lakat, and W. E. Parkin.** 1986. Evolution of a focus of Lyme disease. Zentbl. Bakteriol. Parasitenkd. Infektkrankh. Hyg. Abt. 1 Orig. Reihe A **263:**65–71.

40. **Steere, A. C.** 1989. Lyme disease. N. Engl. J. Med. **321:**586–596.

41. **Steere, A. C., R. L. Grodzicki, A. N. Kornblatt, J. E. Craft, A. G. Barbour, W. Burgdorfer, G. Schmid, E. Johnson, and S. E. Malawista.** 1983. The spirochetal etiology of Lyme disease. N. Engl. J. Med. **308:**733–739.

42. **Steere, A. C., S. E. Malawista, N. H. Bartenhagen, P. N. Spieler, J. H. Newman, D. W. Rahn, G. J. Hutchinson, J. Green, D. R. Snydman, and E. Taylor.** 1984. The clinical spectrum and treatment of Lyme disease. Yale J. Biol. Med. **57:**453–464.

43. **Stefancikova, A., I. Skardova, B. Pet'ko, D. Janovska, and V. Cyprichova.** 1996. IgG antibodies to Borrelia in dogs in the area of Kosice. Vet. Med. Praha **41:**83–86.

44. **Vos, K., A. P. Van Dam, H. Kuiper, H. Bruins, L. Spanjaard, and J. Dankert.** 1994. Seroconversion for Lyme borreliosis among Dutch military. Scand. J. Infect. Dis. **26:**427–434.

45. **Weber, A., U. Heim, and R. Schafer.** 1991. Incidence of antibodies to *Borrelia burgdorferi* in dogs in small animal practice in North Bavaria. Berl. Munch. Tierarztl. Wochenschr. **104:**384–386.

46. **Wilske, B., U. Busch, H. Eiffert, V. Fingerle, H. W. Pfister, D. Rossler, and V. Preacmursic.** 1996. Diversity of OspA and OspC among cerebrospinal fluid isolates of *Borrelia burgdorferi* sensu lato from patients with neuroborreliosis in Germany. Med. Microbiol. Immunol. **184:**195–201.

47. **Wittenbrink, M. M., K. Failing, and H. Krauss.** 1996. Enzyme-linked immunosorbent assay and immunoblot analysis for detection of antibodies to *Borrelia burgdorferi* in dogs. The impact of serum absorption with homologous and heterologous bacteria. Vet. Microbiol. **48:**257–268.