Incidence of *Coccidioides* infection among dogs residing in a region in which the organism is endemic

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Objective—To determine the incidence of *Coccidioides* infection among dogs residing in a region in which the organism is endemic (Pima and Maricopa counties, Arizona) and estimate the rate of clinical illness.

Design—Community-based longitudinal and cross-sectional studies.

Animals—124 healthy 4- to 6-month-old seronegative puppies (longitudinal study) and 381 4- to 18-month-old dogs with unknown serostatus (cross-sectional study).

Procedure—Dogs in the longitudinal study were tested at 6-month intervals for at least 1 year for anticoccidioidal antibodies. Dogs that became ill were evaluated for coccidioidomycosis. Dogs in the cross-sectional study were tested for anticoccidioidal antibodies once, and clinical abnormalities were recorded.

Results—28 of the 104 (27%) dogs that completed the longitudinal study developed anticoccidioidal antibodies. Thirty-two of the 381 (8%) dogs in the cross-sectional study had anticoccidioidal antibodies. Five seropositive dogs in the longitudinal study and 13 seropositive dogs in the cross-sectional study had clinical signs of disease. The remaining seropositive dogs were otherwise healthy and were classified as subclinically infected. Survival analysis indicated that the cumulative probability of infection by 2 years of age was 28%, and the cumulative probability of clinical infection by 2 years of age was 6%. Titers for clinically and subclinically infected dogs overlapped.

Conclusions and Clinical Relevance—Results suggested that young dogs living in the study area had a high likelihood of becoming infected with *Coccidioides* spp, but few developed clinical illness. Serologic testing alone was insufficient for a diagnosis of clinical disease because of the overlap in titers between clinically and subclinically infected dogs. (*J Am Vet Med Assoc* 2005;226:1846–1850)

Coccidioides immitis and *Coccidioides posadasii* (sp nov), which cause coccidioidomycosis in humans and other animals, are dimorphic soil fungi endemic to the lower Sonoran life zone of the southwestern United States and Mexico. *Coccidioides immitis* occurs in central and southern California, whereas *C posadasii* occurs in the remainder of the region,[1] but to date, no differences have been reported in the diseases caused by the 2 species or the diagnostic requirements for detecting coccidioidomycosis. Animal hosts include a broad range of mammals, all of which become infected primarily by inhalation,[2-4] but clinically, the 2 most important species are humans and dogs.

The CDC classified coccidioidomycosis as a reemerging infectious disease in the wake of the 1991 to 1993 epidemic in California and the steady increase in human cases in Arizona since 1993.[5-7] Recent estimates are that approximately 150,000 people become clinically or subclinically infected in the United States each year, with more than half of these individuals living in Arizona.[8] In contrast, to our knowledge, the only report of the incidence of coccidioidomycosis in dogs was published in 1966,[9] and this study involved a small, experimental population of animals confined to a single location in Pima County. The purposes of the study reported here, therefore, were to determine the incidence of *Coccidioides* infection among dogs residing in the community in a region in which the organism is endemic (Pima and Maricopa counties, Arizona) and to estimate the rate of clinical illness. Longitudinal and cross-sectional study designs were used to recruit sufficient dogs for analysis.

Materials and Methods

Longitudinal study—Between May 2001 and May 2002, healthy 4- to 6-month-old puppies living in Pima or Maricopa county were enrolled in the study. Various means were used to inform the public of the study and encourage participation, including contacting private practitioners in the region, holding educational seminars, distributing flyers, and advertising in the local media. Candidates for enrollment in the study were examined at study sites in Phoenix and Tucson or by their primary veterinarians. Owners completed a questionnaire regarding housing and environment to evaluate possible infection risks of their dogs and were required to provide informed consent before dogs were enrolled in the study.

For dogs considered for inclusion in the study, a venous blood sample (6 to 12 mL) was collected for initial screening. Approximately 2 mL was placed in an evacuated tube containing EDTA, and the remainder was placed in a serum sep-

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arator tube. Blood in the serum separator tube was allowed to clot for 1 to 2 hours, and serum was collected following centrifugation. The anticoagulated blood sample and approximately 200 to 500 µL of serum were sent to a commercial laboratory[a] for a CBC and serum biochemical profile. The remaining serum was frozen and submitted to the Arizona Veterinary Diagnostic Laboratory by overnight shipment (Phoenix) or courier (Tucson), where it was stored at –80°C until assayed for anticoccidioidal antibodies. All samples were assayed within 1 week of receipt, with most samples assayed within 24 hours.

Dogs for which results of the screening serologic assay were positive were considered to already be infected and were ineligible for enrollment in the study. In addition, dogs with clinically important hematologic or serum biochemical abnormalities were excluded from the study. Seronegative puppies for which results of the screening CBC and serum biochemical profile were within reference limits were enrolled in the study. Owners agreed to return twice more at 6-month intervals for follow-up serologic testing. During each follow-up visit, owners again completed the questionnaire regarding housing and environmental conditions, and a blood sample was collected. After the 1-year follow-up visit, owners were invited to continue testing at 6-month intervals as long as the study was in operation.

Dogs that developed signs of illness during the course of the study were examined by their veterinarian, and samples were submitted for a CBC, serum biochemical profile, and serologic testing. Clinical signs were recorded, and additional diagnostic testing was performed as necessary. Samples for the CBC and serum biochemical profile were submitted to the study's designated laboratory,[a] and serum for serologic testing was picked up by study personnel within 24 hours or was shipped overnight for immediate testing. Because of cost constraints, radiography was not required by the study protocol. However, if radiographs were obtained at the discretion of the owner or primary care veterinarian, they were made available to study personnel.

Dogs that developed anticoccidioidal antibodies but did not have any clinical signs of illness were considered to be subclinically infected. Dogs were considered to be clinically infected if they developed anticoccidioidal antibodies and one or more of the following clinical signs: rectal temperature ≥ 39.4°C (103°F), cough, anorexia and lethargy of > 1 week's duration, and typical radiographic abnormalities (eg, interstitial or alveolar infiltrates, enlargement of thoracic lymph nodes, lung nodules, and lytic and proliferative bone lesions[3]). Dogs in which results of serologic testing were negative but that were suspected to have coccidioidomycosis on the basis of clinical signs were considered clinically infected only if the organism was identified during cytologic examination, histologic examination, or fungal culture of specimens.

For all dogs enrolled in the study, results of all CBCs, serum biochemical profiles, serologic assays, cytologic and histologic examinations, and fungal cultures were reported directly to study veterinarians as well as to the primary care veterinarians. All pertinent clinical findings collected by primary care veterinarians evaluating ill dogs were forwarded to study veterinarians for determination of whether dogs fit case definitions.

Cross-sectional study—Between March 2002 and March 2003, primary care veterinarians in Pima and Maricopa counties were encouraged to submit serum samples from dogs between 4 months and 18 months old, regardless of the dog's health status. The age range was selected to overlap with the age of dogs enrolled in the longitudinal study. Informed consent was obtained from owners at the time of sample collection. A questionnaire concerning housing and environmental conditions was administered by the primary care veterinarian or by study personnel via telephone. For dogs that were ill at the time of sample submission, a report of the clinical signs and physical findings was also requested, although failure to submit this information did not preclude enrollment.

Serum samples were placed in polypropylene cryovials by the primary care veterinarians and frozen. Samples from clinically ill dogs were picked up by courier (Tucson) within 24 hours or shipped overnight (Phoenix) to the Arizona Veterinary Diagnostic Laboratory and assayed immediately upon receipt. Samples from healthy dogs were shipped in batches and assayed within 2 weeks of receipt. Dogs were considered to be clinically infected if results of serologic testing for anticoccidioidal antibodies were positive and the dog had clinical signs typical of coccidioidomycosis.[3] Seropositive dogs that were otherwise healthy were considered to be subclinically infected.

Serologic testing—Agar gel immunodiffusion (AGID) assays for IgG and IgM against *Coccidioides* spp were performed as described.[10] Commercial-grade gellan gum[b] was used to prepare the AGID plates; IgG was detected with F antigen,[c] and IgM was detected with TP antigen.[d] If results of the AGID assay for IgG were positive, samples were diluted and retested, and titer was expressed as the reciprocal of the highest dilution that still yielded a positive result. For dogs in which results of the IgG assay were positive when undiluted serum was used but negative when diluted serum was used, titer was reported as < 1:2.

For dogs enrolled in the longitudinal study for which results of the AGID assay for IgG were positive, subsequent samples were tested in combination with the most recent prior sample to control for interassay variation.

Statistical analyses—Data were collected on scannable forms and read with a document scanner.[e] Proportions and distributions of positive serologic test results and clinical illness were calculated for dogs in the longitudinal and cross-sectional portions of the study. Annual incidences of all *Coccidioides* infections and clinically apparent infections among dogs in the longitudinal and cross-sectional portions of the study were estimated by means of Weibull survival analysis[11] extending from birth to 720 days of age.[f] Date of birth, recorded as month and year, was considered the earliest possible date of exposure for analysis purposes. Time of potential exposure was considered to be from approximate date of birth until time of examination for dogs in the cross-sectional portion of the study and until last examination date or date of seroconversion for dogs in the longitudinal portion of the study. Data from the 2 groups were combined to obtain final estimates of incidence because analyses showed no significant difference between the 2 groups of dogs.

Results

Longitudinal study—One hundred thirty-five dogs were screened for enrollment in the longitudinal study. Eleven dogs were determined to be ineligible for participation because results of the screening serologic assay were positive (n = 6) or hematologic or biochemical abnormalities (5) were detected. Four dogs were positive for IgG against *Coccidioides* spp, and 2 were positive for IgM against *Coccidioides* spp. The other 5 dogs had one or more of the following: leukocytosis, thrombocytopenia, hypoalbuminemia, lymphocytosis, and monocytosis.

The final cohort consisted of 124 dogs (90 in Pima County and 34 in Maricopa County). Of these, 69 (56%) were female and 55 (44%) were male. Ninety-

three (75%) were purebred, and 44 (35%) were neutered prior to enrollment in the study.

Of the 124 dogs enrolled in the study, 20 were lost to follow-up after the initial screening or after the 6-month recheck. Thus, 104 dogs were available for the 12-month evaluation. In addition, 37 of the 104 dogs returned for an 18-month evaluation and 7 of those returned for a final evaluation 24 months after initial enrollment.

For calculation of infection rates, information only for the 104 dogs that completed at least 1 year of testing was evaluated so that the denominator would not have to be weighted. However, information for all 124 enrolled dogs was considered in the Weibull survival analysis for incidence of infection. Twenty-eight of the 104 (27%) dogs developed antibodies against *Coccidioides* spp at some time during the follow-up period. Only IgG was detected, with titers ranging from < 1:2 to 1:16 (**Table 1**). Five of the 28 (18%) seropositive dogs were classified as clinically infected, and 23 (82%) were classified as subclinically infected.

All 5 clinically infected dogs had primary pulmonary disease, with coughing (4 dogs) and lethargy (3) being the most frequently reported signs. Two dogs had thoracic radiographic evidence of coccidioidomycosis[3]; thoracic radiographs were not obtained from the other 3 dogs. Neutrophilia was identified in 4 dogs, and monocytosis was present in all 5. None of the dogs developed evidence of disseminated infection throughout the course of the study. One other dog was evaluated extensively after it became lame between the time of initial screening and the 6-month evaluation. The dog had a titer of < 1:2, but results of a CBC and serum biochemical profile were normal, no radiographic abnormalities were observed, and no other clinical abnormalities (eg, coughing, lethargy, lack of appetite, and fever) were reported by the primary care veterinarian. The lameness was unresponsive to treatment with antifungal medication for several months, and sequential blood tests and radiography failed to reveal abnormalities, although the dog's titer was persistently < 1:2 or 1:2. The dog was ultimately classified as subclinically infected.

Cross-sectional study—A total of 381 dogs were enrolled in the cross-sectional portion of the study. Median age was 8 months (range, 4 to 18 months), with 153 (40%) being between 4 and 6 months of age. One hundred five dogs were from Pima County, and 276 were from Maricopa County. Overall, 209 (55%) dogs were female and 172 (45%) were male; 250 (66%) were neutered, and 270 (71%) were purebred.

Dogs in the cross-sectional portion of the study were tested for anticoccidioidal antibodies only once. For all dogs, results of the AGID assay for IgM were negative, but for 32 of the 381 (8%) dogs, results of the AGID assay for IgG were positive, with titers ranging from < 1:2 to 1:32 (Table 1). Thirteen of the 32 (41%) seropositive dogs were classified as clinically infected because they had physical findings supportive of a diagnosis of coccidioidomycosis. The remaining 19 (59%) seropositive dogs were reportedly healthy at the time of sample collection and were classified as subclinically infected.

Clinical signs were reported for 12 of the 13 dogs classified as clinically infected. Abnormalities included coughing (9 dogs), lethargy (5), anorexia (3), weight loss (2), radiographic evidence of a thoracic lesion (2), and radiographic evidence of a bone lesion (1). Specific clinical signs were not reported for the remaining dog, but the primary care veterinarian reported that the dog was ill.

Clinical abnormalities were reported for 28 of the dogs that were seronegative. Although clinical signs in some of these dogs could have been considered typical of clinical coccidioidomycosis, no cytologic, culture, or histologic results supportive of a diagnosis of coccidioidomycosis were reported for any of these 28 dogs. Thus, these seronegative dogs were not classified as clinically infected, despite their clinical signs.

Estimated incidence of infection—Probabilities that dogs raised since birth in Pima and Maricopa counties would become infected with *Coccidioides* spp during their first and second years of life were estimated to be 11% and 17%, respectively (**Figure 1**). The cumulative probability of infection by 2 years of age was 28%.

Probabilities that dogs raised since birth in Pima and Maricopa counties would develop clinically apparent coccidioidomycosis during their first and second years of life were estimated to be 2% and 4%, respectively. The cumulative probability of clinical infection by 2 years of age was 6%.

Table 1—Serum anticoccidioidal antibody titers among 124 dogs enrolled in a longitudinal study and 381 dogs enrolled in a cross-sectional study of the incidence of coccidioidomycosis among dogs in Pima and Maricopa counties, Arizona. Titers are from 60 seropositive dogs.

	Longitudinal study		Cross-sectional study	
Titer	Clinically infected	Subclinically infected	Clinically infected	Subclinically infected
< 1:2	0	13	2	7
1:2	2	4	3	3
1:4	3	1	0	4
1:8	0	3	2	3
1:16	0	2	3	2
1:32	0	0	3	0

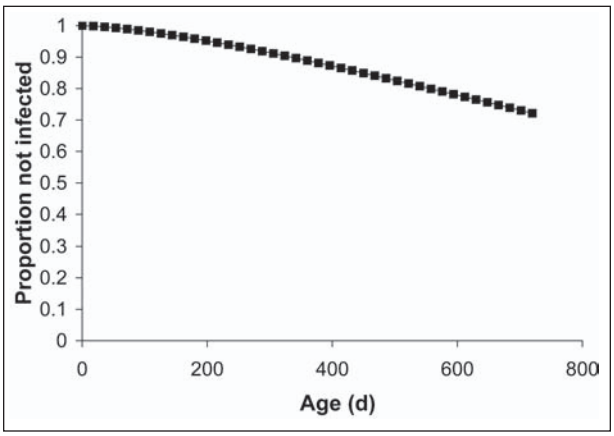

Figure 1—Weibull survival analysis of the probability of infection with *Coccidioides* spp from birth to 2 years of age among dogs in Pima and Maricopa counties, Arizona.

Discussion

Results of the present study suggest that dogs raised in Pima and Maricopa counties have a high risk (28%) of being infected with *Coccidioides* spp by the time they reach 2 years of age. Our findings also suggest that dogs had almost twice the risk of infection during the second year of life (17%), compared with the first year of life (11%). This was higher than the estimated rate of infection among human residents (3%/y),[12] but similar to results of early skin test studies,[13,14] which showed that 23% to 50% of military personnel newly immigrated to a region in which the organism was endemic became infected during the first year of residence. Exposure to dust has been shown to significantly affect the rate of infection in the military population,[15] and proximity to dust was concluded to be the difference between infectivity rates of monkeys and dogs housed outdoors on dirt or in cages 4 feet off the ground.[9] On the basis of these findings, we propose that dogs as a species have a high annual risk of infection because they naturally engage in activities that raise dust.

It was not clear why, for dogs in the present study, the risk of infection was higher during the second year of life than during the first year of life. It may be that younger animals spend more time indoors with less exposure to dust.[9,15,16] Because dogs < 4 months old were not included in the study, it is possible that infection rate data for the first year of life were skewed. However, because 40% of the dogs in the cross-sectional portion of the study were between 4 and 6 months old, we do not believe that missed infections that occurred during the first 4 months of life could account for the difference in infection rates between the first and second years of life.

In the present study, most infected dogs (42/60 [70%]) were subclinically, rather than clinically, infected. Similarly, it is estimated that 60% of infected humans are asymptomatic.[17] However, the fate of subclinically infected dogs is less clear than the fate of asymptomatic humans because there have been no long-term studies involving dogs. Because of the relatively short duration of the longitudinal portion of the present study, we were not able to determine whether dogs with subclinical infection would develop manifestations of illness, especially disseminated disease, in the future or were immune to reinfection and would never develop clinical signs of coccidioidomycosis.

Although we were unable to obtain data for dogs beyond 2 years of age, we predict that the infection rate among young adult dogs will remain approximately 17% per year, after which the rate will decrease as the number of susceptible dogs in the population decreases. This assumes that infected dogs become immune to reinfection, as is the case in humans.[17] The primary support for long-term immunity in dogs comes from a necropsy study[18] of 100 dogs with coccidioidomycosis. In that study, 90% of the dogs that died of coccidioidomycosis were ≤ 4 years old. The low death rate after 4 years of age, along with results of the present study showing a high annual rate of infection among young dogs, implies that most dogs develop a lasting immunity following infection. Studies should be conducted to test this hypothesis by following a cohort over several years or surveying dogs in a wider age bracket.

The AGID assay is the most widely used serologic test for anticoccidioidal antibodies. Other serologic assays for anticoccidioidal antibodies include a latex particle agglutination assay for IgM and ELISAs to detect IgG and IgM. Whereas these assays are considered more sensitive for detection of anticoccidioidal antibodies, they are less specific, and confirmation of positive results with the AGID assay is recommended because of high false-positive rates.[19] The biological progression of antibody development is such that IgM develops first and often disappears within weeks to a few months, whereas IgG develops slightly later and persists longer.[19]

In the present study, IgM was identified in only 2 dogs, both of which were considered ineligible for the longitudinal portion of the study because results of the initial screening test were positive. For all other dogs in which assay results were positive, only IgG was detected. Two possible explanations for this are the basic insensitivity of the assay and the possibility that early infections were missed. The concentration of IgM in serum is lower than the concentration of IgG; therefore, IgM may be missed because of testing limitations. Concentrating serum samples prior to assaying with the AGID assay for IgM can enhance detection,[19] but serum was not routinely concentrated in the present study, and the 5 samples that were concentrated approximately 6-fold and retested were still found to be negative for IgM. Because the design of the study made missing all early infections unlikely, it is believed that insensitivity of the assay combined with low serum concentrations of IgM led to the paucity of positive test results.

In humans, the anticoccidioidal IgG titer is often associated with extent of clinical coccidioidomycosis, with higher titers generally associated with more severe disease.[20] However, physicians are advised against using titer as the sole criterion for determining extent of disease in people,[17] and results of the present study suggest that a similar precaution should be applied to dogs. For example, titers for clinically infected dogs in the present study ranged from < 1:2 to 1:32, but titers for subclinically infected dogs ranged from < 1:2 to 1:16. Thus, clinical infection cannot be discriminated from subclinical infection on the basis of titer alone. Others have also recently shown that titers are highly variable among dogs with clinical coccidioidomycosis, ranging from 1:2 to 1:128 in a series of 24 cases.[21] Thus, because titers in clinically and subclinically infected dogs can overlap, additional diagnostic testing (ie, physical examination, CBC, serum biochemical analyses, radiography, and cytologic and histologic examination) is necessary to establish that an ill dog has coccidioidomycosis.

In the cross-sectional portion of the present study, because only a single serum sample was analyzed and limited information was available, some dogs classified as clinically infected may have been misclassified and did not truly have clinical coccidioidomycosis. Seronegative dogs with consistent clinical signs may

also have been misclassified because of insufficient data to establish a diagnosis of clinical coccidioidomycosis. In both parts of the study, it is possible that some dogs classified as subclinically infected would have been found to develop clinical signs of disease if followed up longer. These possible misclassifications represent limitations of the study design and are inherent to short-term longitudinal and survey studies.

Results of our study indicate a high annual risk of coccidioidal infection among dogs raised in counties in which the organism is endemic, but a minority of infections (30%) resulted in clinical illness, whereas the remainder were inapparent. Serologic titers overlapped among subclinically and clinically infected dogs such that additional tests were needed to establish the diagnosis of clinical coccidioidomycosis.

a. Antech Diagnostics Inc, Phoenix, Ariz.
b. Gelrite gellan gum, Sigma Chemical Co, St Louis, Mo.
c. Gibson Laboratories Inc, Lexington, Ky.
d. Meridian Diagnostics Inc, Cincinnati, Ohio.
e. DSMobile USB scanner, Pentax, Golden, Colo.
f. SAS, version 9.0, SAS Institute Inc, Cary, NC.

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New Veterinary Biologic Products

Product name	Species and indications for use	Route of administration	Remarks
Flavobacterium Columnare Vaccine, Avirulent Live Culture (Intervet Inc, US Vet Lic No. 286)	As an aid in the prevention of disease caused by *Flavobacterium columnare* for use in 7-days posthatch or older catfish	IM	USDA licensed 3/24/05
Bronchitis Vaccine, Georgia Type, Live Virus (Intervet Inc, US Vet Lic No. 286)	For the vaccination of healthy chickens one day of age or older as an aid in the prevention of infection due to the Georgia-type infectious bronchitis virus by coarse spray administration	Coarse spray	USDA licensed 4/11/05