ORIGINAL RESEARCH

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Risk Factors for *Bartonella* Seroreactivity Among Veterinary Workers in the Pacific Northwest

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Abstract

Background: Exposure to zoonotic diseases is a significant occupational risk in veterinary medicine. In this study, we characterized personal protective equipment use, injury frequency, and *Bartonella* seroreactivity in Washington State veterinary workers.

Methods: Using a risk matrix developed to reflect occupational risk factors for exposure to *Bartonella* and multiple logistic regression, we explored determinants of risk for *Bartonella* seroreactivity.

Results: Depending on the titer cutoff used, *Bartonella* seroreactivity was between 24.0% and 55.2%. No significant predictors of seroreactivity were found, although the relationship between high-risk status and increased seroreactivity for some *Bartonella* species approached significance. Serology for other zoonotic and vector borne pathogens did not identify consistent cross reactivity with *Bartonella* antibodies.

Conclusion: The predictive power of the model was likely limited by the small sample size and high level of exposure to risk factors for most participants. Given the high proportion of veterinarians seroreactive to one or more of the three *Bartonella* spp. known to infect dogs and cats in the United States, as well as seroreactivity to other zoonoses, and the unclear relationship between occupational risk factors, seroreactivity, and disease expression, more research is needed in this area.

Keywords: *Bartonella henselae*, *Bartonella vinsonii*, *Bartonella koehlerae*, risk matrix, zoonotic disease epidemiology, veterinarian occupational health

Introduction

V ETERINARY WORKERS REGULARLY face occupational exposure to zoonotic pathogens. While zoonotic infections can be subclinical and self-limiting, they can also be severe or significantly impact quality of life. In a survey of Oregon Veterinary Medicine Association members, nearly half (47%) of respondents reported contracting a zoonotic disease during their career (Jackson and Villarroel, 2012). In a 2012 study of Canadian veterinarians, 17% reported that they were diagnosed with or treated for a zoonotic disease in the past 5 years (Epp and Waldner, 2012). A recent system-

atic review and meta-analysis of veterinary occupational hazards found a pooled proportion estimate of zoonotic disease infection of 17% among veterinarians with proportions up to 31%, 26%, and 24% for specific infections such as bartonellosis, Q fever, and viral infection, respectively (Adebowale et al., 2021).

Despite these risks, surveys have reported low use of personal protective equipment (PPE) and lack of comprehensive infection prevention and control planning in veterinary workplaces (Attard et al., 2012; Lipton et al., 2008; Murphy et al., 2010). According to a survey of over 2000 veterinarians in the United States, almost all (92–99%) engage in needle

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recapping; less than one-quarter reported using appropriate PPE when handling patients with dermatologic (17.9%), gastrointestinal (21.4%), respiratory (6.3%), or neurologic symptoms (16.5%); and just over half (55%) always wash their hands before eating or drinking at work (Wright et al., 2008). As a result, veterinary workers remain vulnerable to zoonotic diseases, although the magnitude of the risk remains poorly understood.

Bartonella is a zoonotic pathogen associated with occupational veterinary exposures (Lantos et al., 2014; Oliveira et al., 2010; Oteo et al., 2017). *Bartonella* is relevant to veterinary workers because of the presence of these bacteria in blood, tissues, and effusions in companion animals and livestock (Bradley et al., 2014; Chomel et al., 2006; Okaro et al., 2017). *Bartonella* is particularly common in domestic cats—studies have documented 30–40% seroreactivity for *Bartonella henselae*, the presence of several other *Bartonella* species, and up to 75% bacteremic prevalence (Álvarez-Fernández et al., 2018; Fabbi et al., 2004). Human *Bartonella* infection can cause a wide range of illness. *B. henselae* infections are typically characterized by self-limited, regional lymphadenopathy but can also cause severe disease, particularly in immunocompromised individuals (Mascarelli et al., 2011; Mosepele et al., 2012).

Because of the expanding number of *Bartonella* species, the spectrum of disease they can cause, and their presence in companion animals and livestock, *Bartonella* has been proposed as an underrecognized threat, particularly to veterinary workers (Breitschwerdt, 2015). Because bloodborne infection with *Bartonella koehlerae* and *vinsonii* based on culture, PCR amplification, and DNA sequencing has been implicated in rheumatic disease manifestations, neurologic symptoms, and musculoskeletal conditions, further research on these species is critical (Breitschwerdt et al., 2010a; Breitschwerdt et al., 2010b; Breitschwerdt et al., 2008; Maggi et al., 2012; Maggi et al., 2011; Mozayeni et al., 2018). We sought to address this gap in the literature by including these species in this study.

Sequential and lifetime studies are needed to correlate the occupational risk of zoonotic exposure to actual health outcomes. Many point-in-time surveys of zoonotic disease in veterinary workers rely on self-reported symptoms, making misclassification of infection likely. In the current study, we measured seroreactivity to *B. henselae*, *B. koehlerae*, and *B. vinsonii* subsp. *berkhoffii* in a sample of 97 veterinarians at a Washington Veterinary Medical Association conference. To assess for serological cross reactivity, we also tested for exposure to other zoonotic and vector borne pathogens. Using a risk matrix developed from a survey, we investigated occupational risk factors for exposure to *Bartonella* to explore determinants of risk for *Bartonella* seroreactivity.

Methods

This study is a cross-sectional convenience survey of veterinarians in the Pacific Northwest. A self-administered survey of veterinary practice characteristics, work practices, exposure to potentially infectious materials, injuries, and health outcomes was completed by 97 veterinary professionals at the 2019 Pacific Northwest Veterinary Conference. Blood samples were collected from each participant and analyzed by immunofluorescent antibody assay (IFA) for antibodies specific to *B. henselae*, *B. koehlerae*, *B. vinsonii* subsp. *berkhoffii*, *Brucella abortus*, *Coxiella burnetii*, *Fran-*

cisella tularensis, *Anaplasma phagocytophilum*, *Ehrlichia chaffeensis*, *Rickettsia conorii*, and *Rickettsii typhi*. This study was approved by UW human subjects research under STUDY00000042: GAZER.

Laboratory methods

B. vinsonii subsp. *berkhoffii*, *B. henselae*, and *B. koehlerae* antibodies were determined in the Intracellular Pathogens Research Laboratory (IPRL) at North Carolina State University (Raleigh, NC) using cell culture grown bacteria as antigens and following standard immunofluorescent antibody assay (IFA) techniques as previously described. A canine isolate of *B. vinsonii* subsp. *berkhoffii* genotype II (NCSU 95CO-08, Winnie), and feline isolates of *B. henselae* SA2 strain (NCSU 95FO-099, Missy) and *B. koehlerae* (NCSU 09FO-01, Trillium), were passed from agar plate grown cultures into *Bartonella*-permissive cell lines, that is, the DH82 (a canine monocytoid) cell line for strains *B. henselae* SA2 and *B. koehlerae* and Vero cells (a mammalian fibroblast cell line) for *B. vinsonii* subsp. *berkhoffii* genotype II, for IFA testing. For each antigen, heavily infected cell cultures were spotted onto 30-well Teflon-coated slides (Cell-Line/Thermo Scientific), air-dried, acetone-fixed, and stored frozen.

Fluorescein conjugated goat anti-human IgG (Cappel, ICN) was used to detect bacteria within cells using a fluorescent microscope (Carl Zeiss Microscopy, LLC, Thornwood, NY). Serum samples diluted in a phosphate-buffered saline (PBS) solution containing normal goat serum, Tween-20, and powdered nonfat dry milk to block nonspecific antigen-binding sites were first screened at dilutions of 1:16 to 1:64. All sera that were reactive at a reciprocal titer of 64 were further tested with two-fold dilutions to an endpoint titer. To avoid confusion with possible nonspecific binding found at low dilutions, cutoffs of 1:64 and 1:128 were selected as seroreactive titers.

A 1:64 IFA titer was considered the minimal seroreactive titer based upon testing sera of 32 healthy volunteers from a local medical school, in which there was no seroreactivity to *B. koehlerae*, no seroreactivity to *B. vinsonii* subsp. *berkhoffii* genotypes I and III, only one individual was *B. henselae* seroreactive (at an IFA titer of 1:64), but for reasons that remain unclear, nearly half of these individuals were seroreactive to *B. vinsonii* subsp. *berkhoffii* genotype II (Breitschwerdt et al., 2010).

Indirect fluorescent antibody testing to assess cross reactivity to *Bartonella* spp. antigens was performed using previously frozen, blinded serum samples at Fuller Laboratories, a research testing (FDA Registration No. 3004036192) and Medical Device Manufacturing Laboratory, licensed by the state of California (Fuller Laboratories, Fullerton, CA). All sera were screened by the company's Quality Control Supervisor at a 1:64 dilution in phosphate-buffered saline, incubated for 30 min, then washed, and incubated for 30 min with an affinity purified goat anti-human IgG (Fc-specific) with Alexa Fluor 488 conjugation (Jackson ImmunoResearch Laboratories, Inc., West Grove, PA) for 30 min (all at 37°C). A senior investigator with 30 years of IFA reading experience reassessed seroreactivity at 1:64 and 1:256 endpoint dilution. A 1:64 dilution was considered a positive result for all five genera for assessing cross reactivity to *Bartonella* species.

Risk matrix

A risk matrix is a common semiquantitative tool in occupational health research and risk management, which considers the probability of exposure to a hazard and the likelihood of an adverse outcome, allowing assignment of individuals or tasks into ordered categories characterizing the risk of an adverse outcome (Arnetz et al., 2014; Jensen et al., 2022; Sieber et al., 1991). To consider the likelihood of exposure to *Bartonella*, we combined frequency of PPE use across tasks and reported animal-related injury collected on the survey, as these measures would most impact whether *Bartonella* has a port of entry into an individual.

Frequency use score for PPE was determined by assessing reported glove, surgical mask, eye shield, and other PPE use for nine tasks where exposure to blood, saliva, needle sticks, or animal bites and scratches could occur, on a 0–4 frequency scale (0 = never use, 4 = always use). Scores on tasks were summed to create a total PPE use score with a maximum of 144 points. High PPE use was defined as ≥ 37 points (average of > 4 points per task, *e.g.*, multiple pieces of PPE sometimes or one piece of PPE always), moderate PPE use as 19–36 points (average of > 2 and ≤ 4 points per task, *e.g.*, no more than multiple pieces of PPE rarely or one piece of PPE often), and low PPE use as 0–18 points (average of ≤ 2 points per task, *e.g.*, no more than two pieces of PPE rarely or one piece of PPE sometimes).

Score for occupational injury was assigned by assessing frequency of animal injury and needle stick injury in the past year on a scale of 0–5 (0 = never, 5 = daily). Scores were summed for a total injury score with a maximum of 10 points. A low injury score was defined as ≤ 3 points (*e.g.*, no more than monthly for one type of injury or every 6 months for two types), moderate injury score as 4–6 points (*e.g.*, daily for one type of injury or monthly for two types), and high injury score as ≥ 7 points (*e.g.*, at least weekly for one type of injury and monthly for the other).

To create an overall risk score, PPE use scores were reverse coded, with high use assigned a value of 1, moderate use assigned a value of 2, and low use assigned a value of 3. Low injury was assigned a value of 1, moderate injury a value of 2, and high injury was assigned a value of 3. The two categories (PPE use and injury) were summed to create the overall risk score, with the range of scores being 2–6. Low level of exposure risk was defined as 2–3 total points (high PPE use and low injury), moderate level as 4 total points, and high level as 5–6 points (low PPE use and high injury). The resultant risk matrix and variables are outlined in Appendix Tables A1–A3.

Logistic regression model

We generated a logistic regression model, including total risk, career length, cat ownership, and dog ownership, as possible predictors of overall *Bartonella* seroreactivity at the 1:128 cutoff [Logit(p) = $\beta 0 + \beta 1 X_{risklevel} + \beta 3 X_{careerlength} + \beta 4 X_{petcat} + \beta 4 X_{petdog}$]. The same model was used for the outcomes *B. henselae* seroreactivity, *B. koehlerae* seroreactivity, and *B. vinsonii* subsp. *berkhoffii* seroreactivity. A chi-squared test was used to assess the relationship between *Bartonella* seroreactivity and general health rating.

Results

Participant characteristics

Most of the 97 participants were veterinarians, although veterinary technicians, practice managers, and students were also included (Table 1). The sample was mostly female and of white race/ethnicity. Categories for jobs and race were not mutually exclusive. Age ranged from 23 to 71 years (mean age = 48.2). The mean career length for participants was 22.3 years (Table 2). As reported in Tables 1 and 2, exposure to cats and dogs was high for the majority of the sample. Scratches were the most common occupational injury. Cats were the most common animal source of injury.

Most participants (93.8%) reported being in excellent or good health (Table 3). However, many participants also reported being diagnosed with a condition such as allergies, arthritis, or a chronic musculoskeletal disorder (Table 3). Only one participant reported diagnosis with bartonellosis.

Bartonella *seroreactivity*

At the 1:64 titer cutoff, 54.2% (53) of participants were seroreactive to at least one *Bartonella* species 32.3% (31) for *B. henselae*, 36.5% (35) for *B. koehlerae*, and 23.7% (23) for *B. vinsonii* subsp. *berkhoffii*. At the 1:128 cutoff, 24.0% of participants were seroreactive to at least one *Bartonella* species (11.5% for *B. henselae*, 15.6% for *B. koehlerae*, and 8.3% for *B. vinsonii* subsp. *berkhoffii*). Twenty-six (27.1%), 17 (17.7%), and 10 (10.4%) participants were reactive to 1, 2, or 3 *Bartonella* species, respectively. Forty-four (46.0%) participants were not seroreactive to any of the three *Bartonella* species at 1:16 and 1:32 screening dilutions.

Assessment of Bartonella *cross-reactivity*

Table 4 compares *Bartonella* spp. seropositivity to seropositivity to other zoonotic bacteria. For all but one pathogenic organism, there was no statistical association with *Bartonella* seropositivity. However, there was a statistically

TABLE 1. DEMOGRAPHIC CHARACTERISTICS

Demographic characteristics	n (%)	Mean	SD
Age		46.6	13.1
Gender			
Female	82 (85.4)		
Male	12 (12.5)		
Other	2 (2.1)		
Race/ethnicity[a]			
White	82 (84.4)		
Black	0		
Hispanic	2 (2.1)		
Asian	3 (3.1)		
American Indian/Alaska Native	0		
Native Hawaiian/Pacific Islander	1 (1.0)		
Other	1 (1.0)		
Pet ownership[a]			
Cat	71 (74.0)		
Dog	72 (75)		

[a]Participants could check more than one category; some participants did not answer.

SD, standard deviation.

TABLE 2. OCCUPATIONAL CHARACTERISTICS

Occupational characteristics	n (%)	Mean	SD
Length of career (years)		22.3	12.6
Job title[a]			
Owner	27 (28.1)		
Veterinarian	76 (79.2)		
Veterinary technician	9 (9.4)		
Veterinary assistant	0		
Veterinary student	1 (1.0)		
Practice manager	3 (3.1)		
Other[b]	6 (6.3)		
Practice type[a]			
Small animal	81 (84.4)		
Large animal	3 (3.1)		
Mixed practice	13 (13.5)		
Other[b]	11 (11.5)		
Occupational cat/dog exposure[a]			
Cat	94 (97.9)		
Dog	92 (95.8)		
Most common injury type[a]			
Bite	8 (8.3)		
Scratch	70 (72.9)		
Kick	5 (5.2)		
Needle stick	16 (16.7)		
Other	6 (6.3)		
Most common animal injury source[a]			
Cat	50 (52.1)		
Dog	29 (30.2)		
Other	16 (16.7)		

[a]Participants could check more than one category.
[b]Other jobs included technical services vet, state/army vet, department chair/instructor, public health vet; other practice types included exotic animals, zoos.

significant correlation between *F. tularensis* antibodies and Bartonella antibodies, but this was based on a low total number of *F. tularensis*-positive samples ($N = 19/97$). Of the 15 study participants with titers ranging from 1:256 to 1:1024 to 1 or more of the *Bartonella* spp. antigens, 7 were not

TABLE 3. REPORTED HEALTH STATUS

Self-reported health	n (%)
Health rating	
Excellent	35 (36.5)
Good	55 (57.3)
Fair	6 (6.3)
Poor	0
Diagnoses[a]	
Allergies	42 (43.8)
Chronic Musculoskeletal Disorder	34 (35.4)
Arthritis	27 (28.1)
Zoonotic infection[b]	18 (18.8)
Asthma	16 (16.7)
Dermatitis	12 (12.5)
Immunocompromising Disorder	6 (6.3)
Other	10 (10.4)

[a]Participants could check more than one category.
[b]Zoonotic infections included ringworm, cryptosporidiosis, salmonellosis, psittacosis, roundworms, and bartonellosis.

seroreactive to any of the 6 other genera tested. Of the remaining eight of these *Bartonella* spp. seroreactors, three had antibodies only to *A. phagocytophilum* and two only to *F. tularensis*. Seroreactivity to individual and combinations of *Bartonella* spp. antigens is summarized in Table 5. The highest geometric mean titers were to *B. henselae* and *B. koehlerae*, respectively.

Correlation of Bartonella *seroreactivity and risk factors*

No significant predictors of seroreactivity were found using the initial logistic regression model, likely because of the small sample size, lack of variability in risk factors, and limited sensitivity of *Bartonella* IFA (seronegative infection). In a model comparing high risk to low and moderate risk instead of all risk categories to each other, values approaching or achieving significance were found for the relationship between high risk and general *Bartonella* seroreactivity, as well as *B. koehlerae* seroreactivity (Table 6). A significant inverse relationship between career length and general *Bartonella* seroreactivity was observed in this high-risk model (odds ratio [OR] = 0.51 [0.27–0.98], $p = 0.043$). No significant relationship between *Bartonella* seroreactivity and general health rating was found.

Discussion

This study emphasizes that *Bartonella* exposure, as assessed by IFA testing of incompletely defined specificity, is likely frequent. Because few serosurveys of *Bartonella* in veterinary workers have been conducted, it is difficult to compare our findings to existing literature. However, our seroreactivity findings are comparable to a 2017 serosurvey of *Bartonella* in veterinary workers by Oteo et al. This serosurvey, like ours, was conducted at a conference of veterinary medicine professionals. At the 1:64 cutoff point, we found that 32.7% of participants were seroreactive to *B. henselae* and 36.5% were seroreactive to *B. koehlerae*, similar to Oteo's findings of 37.1% and 41.6%. Our results differed for *B. vinsonii* subsp. *berkhoffii*.

We found that 24.0% of participants were seroreactive to *B. vinsonii* subsp. *berkhoffii*, while Oteo found a higher percentage of 56.2. This may be due to Oteo's use of *B. vinsonii* subsp. *berkhoffii* genotype III, a genotype found more frequently in Europe, versus our use of *B. vinsonii* subsp. *berkhoffii* genotype II, the most prevalent subsp. in dogs and humans in the United States. At the 1:128 cutoff, we found similar seroreactivity to *B. henselae* (11.5% vs. 10.1%), higher seroreactivity to *B. koehlerae* (15.6% vs. 10.1%), and lower seroreactivity to *B. vinsonii* subsp. *berkhoffii* (8.3% vs. 12.4%), suggesting that *B. koehlerae* exposure may occur more frequently in the northwestern United States (Osikowicz et al., 2021).

In another study of veterinary workers, 42 of 97 (44%) veterinary personnel had detectable *Bartonella* antibodies with an IFA titer of 1:64 or greater to at least one *Bartonella* species antigen (Lantos et al., 2014). While seroprevalence was not reported by species, detection of *Bartonella* DNA using enrichment culture and molecular amplification showed that 56% of participants with detectable species *Bartonella* DNA were infected with *B. henselae*, 26% with *B. vinsonii*, and 22% with *B. koehlerae*, suggesting that exposure to *Bartonella* species varies by region.

TABLE 4. SEROLOGY RESULTS FOR 97 VETERINARY WORKERS TESTED FOR *BARTONELLA* SPP. ANTIBODIES AND FOR ANTIBODIES TO OTHER ZOONOTIC OR VECTOR-BORNE INFECTIOUS DISEASES

	Total (≥1:64) seroreactive	Bartonella seroreactive (≥1:64)	Bartonella nonseroreactive (≤1:32)	p[a]
Brucella abortus	1	1	0	0.360
Coxiella burnetii Phase I	3	1	2	0.451
Coxiella burnetii Phase II	9	4	5	0.519
Francisella tularensis	19	15	4	**0.018**
Anaplasma phagocytophilum	22	16	6	0.053
Ehrlichia chaffeensis	9	5	4	0.954
Rickettsia rickettsii	7	5	2	0.354
Rickettsia typhi	4	3	1	0.849

Significant values are in bold.
[a]Association evaluated by chi-squared test.

Published findings indicate that seroreactivity to *Bartonella* may be higher in veterinarians than the general population, although seroreactivity can only be directly compared for *B. henselae* in most studies, due to the lack of human serosurveys of *B. koehlerae* and *B. vinsonii* subsp. *berkhoffii*. A serosurvey of healthy adults in Korea found a *B. henselae* prevalence of 15.0% (1:64 cutoff) and a serosurvey of children in Jordan found a prevalence of 11% (1:64 cutoff) (Al-Majali and Al-Qudah, 2004; Kwon et al., 2017). However, a serosurvey of healthy students in Germany found that 30% (1:64 cutoff) were seroreactive to *B. henselae*, similar to the 32.3% prevalence in our sample (Sander et al., 1998).

Further research is necessary for more definitive estimates of seroprevalence, particularly for different regions and study populations before a confident comparison can be made. However, seroprevalence appears to be highest in populations with extensive animal and arthropod exposures (Breitschwerdt et al., 2007).

Importantly, in our study, 27.8% of the individuals tested were seroreactive to only one *Bartonella* sp. antigen when assessed at the 1:128 titer, and 17.7% were only reactive to two of the IFA antigens. When dogs infected with *B. koehlerae* were experimentally infected with *B. henselae* or *B. vinsonii* subsp. *berkhoffii*, seroreactivity was only detected to *B. koehlerae* and the other infecting *Bartonella* sp. (Balakrishnan et al., 2013). Although it was not unusual for study participants to have had seroreactivity to one, two, or all three of the IFA antigens, we acknowledge that IFA cannot definitively determine the infecting species or if the individual has been exposed to more than one species, as a result of repeat exposures. Coinfection with more than one *Bartonalla*

spp. has been documented in veterinary workers based upon PCR amplification and DNA sequence confirmation (Maggi et al., 2011).

Overall, relationships between hypothesized risk factors and seroreactivity were not significant in our original logistic regression model. However, there was a trend toward increasing seroreactivity with increasing risk level. This trend was more visible when comparing high exposure risk participants to all other participants and significant or near-significant relationships were found between high exposure risk level and general *Bartonella* seroreactivity (OR = 2.95, $p = 0.052$) as well as *B. koehlerae* seroreactivity (OR = 3.35, $p < 0.05$). Cat and dog ownership were not significant predictors of seroreactivity. Because veterinary workers have regular exposure to cats and dogs in both their training and career, this is not unexpected. Exposure to a small number of cats or dogs at home would not likely affect most veterinary workers' overall exposure.

The extent to which there is serological cross-reactivity between *Bartonella* and other known pathogens to which veterinary workers are exposed remains unclear. Interestingly, as the genus *Brucella* is phylogenetically most closely related to the genus *Bartonella* and therefore would most likely share immunogenic cross-reactive antigens, only one study participant was seroreative to *B. abortus* antigens. In contrast, *Francisella*, which is a distantly related genus, showed a statistical association with *Bartonella* spp. antibodies. Using a microagglutination assay and a 1:128 cutoff value, Telford and colleagues found landscapers working on Martha's Vineyard to be at occupational risk of *Francisella* exposure (Feldman et al., 2003). To our knowledge, there are

TABLE 5. TOTAL, INDIVIDUAL, AND COMBINATION REACTIVITY AT THE 1:64 CUTOFF TO *BARTONELLA* SPP. ANTIGENS

	Reactivity to antigen total (%)	GMT	Range	Reactivity to antigen only (%)
Any *Bartonella* antigen	53 (54.6)	—	—	—
Bartonella henselae	14 (14.4)	196.6	64–1024	6 (6.2)
Bartonella koehlerae	9 (9.3)	92.4	64–256	7 (7.2)
Bartonella vinsonii berkhoffii	3 (3.1)	64	64	0 (0)
Bh and *Bk*	6 (6.2)	—	—	—
Bh and *Bvb*	1 (1.0)	—	—	—
Bk and *Bvb*	10 (10.3)	—	—	—
Bh, *Bk*, and *Bvb*	10 (10.3)	—	—	—

GMT, geometric mean titer.

TABLE 6. ASSOCIATION BETWEEN HIGH TOTAL RISK
STATUS AND *BARTONELLA* STATUS

Species	OR	95% CI	p
All *Bartonella*	2.95	0.99–8.79	**0.052**
Bartonella henselae	2.03	0.49–8.32	0.33
Bartonella koehlerae	3.35	1.01–11.18	**0.049**
Bartonella vinsonii subsp. *berkhoffii*	2.00	0.41–9.84	0.39

Significant values are in bold.
CI, confidence interval; OR, odds ratio.

no studies that specifically address *Francisella* spp. exposure risks in veterinary workers, but it is a recognized hazard in this occupational group, and our findings suggest the need for further exploration of this occupational risk.

Despite the statistical association, the low number of *F. tularensis*-positive samples means that cross-reactivity to this pathogen would not explain the high rate of *Bartonella* seropositivity in our study. Also, the lack of cross-reactivity in six sera with the highest *Bartonella* antibody titers obtained in this study to all other tested genera provides additional support for the specificity of *Bartonella* spp. IFA, when testing human sera.

Limitations to the study include the small sample size and homogeneity of risk factors in the sample, which likely limited our ability to identify significant risk factors for *Bartonella* seroreactivity. Using a more heterogenous sample and including practice type or frequency of occupational exposure to cats and dogs in future analyses could help clarify these relationships. Similarly, a larger sample size would allow us the degrees of freedom to investigate individual risk factors in a multiple logistic regression model instead of combining individual risk factors into a risk matrix, which could help to identify specific work practices that may relate to *Bartonella* seroreactivity.

This study supports previous studies that document veterinary occupational exposure to *Bartonella* species, particularly species with pets as reservoir hosts. As an emerging infectious disease, bartonellosis should be further explored and monitored in this population. While reducing illness from *Bartonella* is worthwhile in itself, *Bartonella* can also be used as an indicator of risk posed by other emerging infectious diseases and to evaluate the effectiveness of PPE use and injury prevention against blood- and saliva-borne zoonotic infections in general. In human medicine, research has shown that some of the main impediments to PPE are usability, availability, and clear communication, and that addressing these issues in hospital-based interventions can be effective in increasing compliance (Williams et al., 2019). Veterinary medicine faces similar impediments and interventions similar to those effective in human medicine could be considered for future implementation and evaluation (Robin et al., 2017).

Future research that includes multiple *Bartonella* species, uses serology in addition to self-report or PCR testing, and compares veterinary workers with a wide range of work practices and animal exposures will hopefully clarify the role of *Bartonella* in human and animal health, inform interventions that improve the safety of veterinary workplaces, and ultimately decrease the burden of *Bartonella* in this population.

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(Appendix follows →)

Appendix

APPENDIX TABLE A1. DEVELOPMENT OF THE RISK MATRIX: VARIABLES COMBINED INTO THE TOTAL PERSONAL PROTECTIVE EQUIPMENT SCORE

Task	Glove use	Surgical mask use	Eye shield use	Other PPE use	PPE score
Cystocentesis	0 = Never 1 = Rarely 2 = Sometimes 3 = Often 4 = Always	0–4	0–4	0–4	0–16
Drawing blood					
Prepping blood work					
Restraining patient					
Placing/removing IV					
Setting up/examining ear or skin cytology					
Cleaning surgical suites/instruments					
Performing dentistry					
Monitoring anesthetized patients					
Total PPE score					0–144

PPE, personal protective equipment.

APPENDIX TABLE A2. VARIABLES COMBINED INTO THE TOTAL INJURY SCORE

Injury type	Daily	Weekly	Monthly	Every 6 months	Once a year	Never	Injury score
Animal injury	5	4	3	2	1	0	0–5
Sharps injury							
Total injury score							0–10

APPENDIX TABLE A3. RISK MATRIX COMBINING FREQUENCY OF PERSONAL PROTECTIVE EQUIPMENT USE AND INJURY TO DETERMINE LIKELIHOOD OF EXPOSURE TO BARTONELLA DUE TO JOB PRACTICES

		Total injury score[a]		
		Low (1)	Medium (2)	High (3)
Total PPE score[b]	Low (3)	4 Moderate	5 High	6 High
	Medium (2)	3 Low	4 Moderate	5 High
	High (1)	2 Low	3 Low	4 Moderate

[a]Based on self-reported frequency (daily, weekly, monthly, every 6 months, once a year, never) of both animal and sharps injuries.
[b]Based on self-reported frequency (never, rarely, always, sometimes, often) of PPE (glove, surgical mask, eye shield, other) use.
  Colored cells refer to risk for exposure to *Bartonella* with those in the *light gray* cells having a low risk, those in the *medium gray* cells having a moderate risk, and those in the *dark gray* cells having a high risk.