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Rabies exposures and pre-exposure vaccination practices among individuals with an increased risk of rabies exposure in the United States

Jesse D. Blanton DrPH
Emily Colwell
Cynthia L. Walden
Lessie M. Davis
Christine Hoang DVM, MPH
Julie A. Legred CVT
Emily G. Pieracci DVM, MPH
Ryan M. Wallace DVM, MPH
Mark H. Ebell MD, MS
Zhen F. Fu DVM, PhD
Stephanie A. Shwiff PhD
Joel M. Lee DrPH

From the College of Public Health (Blanton, Ebell, Lee) and the Department of Pathology, College of Veterinary Medicine (Fu), University of Georgia, Athens, GA 30602; the National Animal Care and Control Association, 40960 California Oaks Rd #242, Murrieta, CA 92562 (Colwell, Walden); the National Wildlife Rehabilitators Association, 2625 Clearwater Rd #110, St Cloud, MN 56301 (Davis); AVMA, 1931 N Meacham Rd, Schaumburg, IL 60173 (Hoang); the National Association of Veterinary Technicians in America, PO Box 1227, Albert Lea, MN 56007 (Legred); the CDC, 1600 Clifton Rd, Atlanta, GA 30333 (Pieracci, Wallace); and the National Wildlife Research Center, Wildlife Services, APHIS, USDA, 4101 LaPorte Ave, Fort Collins, CO 80521 (Shwiff). Dr. Blanton's present address is CDC, 1600 Clifton Rd, Atlanta, GA 30333.

Address correspondence to Dr. Blanton (asi5@cdc.gov).

OBJECTIVE
To identify knowledge and practices related to rabies vaccination and serologic monitoring among animal care workers in the United States.

DESIGN
Cross-sectional survey.

SAMPLE
2,334 animal care workers (ie, veterinarians, veterinary technicians, animal control workers, and wildlife rehabilitators).

PROCEDURES
Participants were contacted through relevant professional organizations to participate in an anonymous web-based survey. The survey collected demographic and occupational information, animal handling and potential rabies exposure information, and individual rabies vaccination and serologic monitoring practices. Comparisons of animal bite and rabies exposure rates were made between occupational groups. Multiple logistic regression was used to evaluate factors associated with rabies vaccination status and adherence to serologic monitoring recommendations.

RESULTS
Respondents reported 0.77 animal bites/person-year or 0.10 bites/1,000 animals handled. The overall rate of postexposure prophylaxis due to an occupational rabies exposure was 1.07/100 person-years. Veterinarians reported the highest rabies vaccination rate (98.7% [367/372]), followed by animal control workers (78.5% [344/438]), wildlife rehabilitators (78.2% [122/156]), and veterinary technicians (69.3% [937/1,352]). Respondents working for employers requiring rabies vaccination and serologic monitoring were 32.16 and 6.14 times, respectively, as likely to be vaccinated or have a current serologic monitoring status as were respondents working for employers without such policies.

CONCLUSIONS AND CLINICAL RELEVANCE
Results suggested that, given the high reported rates of animal bites and potential rabies exposures among animal care workers, improvements in rabies vaccination and serologic monitoring practices are needed. (*J Am Vet Med Assoc* 2018;252:1491–1502)

Individuals with occupational contact with animals have an inherently higher risk of exposure to zoonotic diseases than do members of the general population, with between 35% and 64% of veterinarians reporting having acquired a zoonotic infection over the course of their career.[1,2] In addition, animal bites are one of the most common injuries received by animal care workers. For example, > 60% of veterinarians in studies[3–7] from the Americas, Australia, and Europe reported a history of having an animal bite over the course of their career. Similarly, a 1984 study[8] found that 40% of animal control workers in New Mexico had a history of an animal bite, receiving approximately 1.8 bites/1,000 animals handled, for a bite rate 175 to 500 times that for the general population. Bites were reported among 98% of veterinary nurses and technicians at an international conference in Australia,[9] and bites resulting in an

ABBREVIATIONS

ACIP	Advisory Committee for Immunization Practices
CI	Confidence interval

infection were reported among 44% of technicians working in clinical practices in Minnesota.[10] In comparison, a national survey[11] conducted between 2001 and 2003 found that approximately 1.5% of the US population is a victim of dog bites annually, with 19% of those bitten seeking some kind of medical care. Most studies estimating national rates of animal bites have focused on bites from a single species (eg, dog bites), with bites from all animals in total accounting for approximately 125 to 135 of every 100,000 emergency room visits.[12,13] Fewer studies have examined risk factors for animal-related injuries, but being older and having more experience working with animals have generally been identified as inversely associated with bite rates among all occupational groups.[3,8,14]

Although animal bites may result in physical trauma and localized bacterial infection requiring medical attention, they also constitute potential rabies exposures in endemic areas, with nearly 21% of veterinarians reporting contact with an animal suspected to be rabid.[15,16] The ACIP categorizes individuals as having a continuous, frequent, infrequent, or rare risk of exposure to rabies,[17] with animal care workers categorized in the frequent or infrequent category depending on whether rabies is endemic in terrestrial animals in the region where they work. Individuals in the frequent and infrequent exposure risk categories are recommended to receive primary rabies vaccination, and individuals in the frequent exposure risk category are also recommended to undergo routine serologic monitoring for anti-rabies antibodies.[17] Primary rabies vaccination consists of 3 doses of rabies vaccine administered on days 0, 7, and 21 or 28. Although prior vaccination does not preclude the need for additional care in the event of a rabies exposure, it simplifies the postexposure prophylaxis regimen, requiring only 2 booster vaccine doses, on days 0 and 3, and no human rabies immune globulin, compared with human rabies immune globulin and 4 or 5 doses of vaccine for individuals who have not been vaccinated previously.[17] Serologic monitoring every 2 years is recommended for those in the frequent exposure risk category to ensure the presence of a primed immune response. Although no rabies neutralizing antibody titer has been identified as protective in persons who have been previously vaccinated against rabies, complete neutralization at a serum dilution of 1:5 with the rapid fluorescent focus inhibition test, equivalent to a titer of 0.1 to 0.2 U/mL, has been identified by the ACIP as minimum evidence of an immunologic response.[17] If the rabies neutralizing antibody titer is less than this when serologic monitoring is conducted, a single dose of rabies vaccine is administered to boost the immune response.

Despite the inherent risks of rabies exposure, adherence to the ACIP's recommendations is variable among animal care workers. Although veterinarians have been reported to have relatively high (eg, > 80%) rabies vaccination rates,[10,16] lower rates generally are reported among other occupational groups with frequent and infrequent rabies exposure risks. For example, lower rates of vaccination (typically around 30% to 50%) have been reported among veterinary technicians,[10,18] and generally, less than a third of staff members at any veterinary facility have reportedly undergone rabies antibody titer testing within the past 2 years. Beyond this, veterinary facility policies may not encourage adherence to the ACIP's recommendations. A survey[18] of veterinary facilities in West Virginia found that only 45% of all facilities (52% of facilities in counties where raccoon rabies was endemic and 38% of facilities in counties considered free from terrestrial rabies) had a policy requiring that veterinarians receive primary rabies vaccination, and only 15% of facilities (24% of facilities in counties where raccoon rabies was endemic and 7% of facilities in counties considered free from terrestrial rabies) had an identical policy for veterinary technicians. Similarly, only 25% of facilities in counties where raccoon rabies was endemic had a policy regarding serologic monitoring for veterinarians, compared with 15% of facilities that had a similar policy for veterinary technicians.

Developing methods to improve compliance with the ACIP's recommendations for primary rabies vaccination and serologic monitoring among US animal care workers requires a better understanding of knowledge gaps regarding rabies exposure risks in various animal care worker populations and of current attitudes toward vaccination and monitoring. Therefore, the purpose of the study reported here was to assess rabies knowledge, attitudes, and practices of individuals in 4 distinct occupational groups in the United States—namely, veterinarians, veterinary technicians, animal control workers, and wildlife rehabilitators—considered to have a higher rabies exposure risk than individuals in the general US population.

Materials and Methods

Study design

The study was designed as a descriptive cross-sectional survey of persons with occupational activities that could reasonably be expected to put them at a higher risk of rabies exposure (ie, veterinarians, veterinary technicians, animal control workers, and wildlife rehabilitators) than members of the general population. The study protocol was reviewed and approved by the Institutional Review Board of the University of Georgia (IRB #3431).

Four professional organizations (AVMA, National Association of Veterinary Technicians in America, National Animal Control and Care Association, and National Wildlife Rehabilitators Association) were contacted to assist with recruitment from their membership. The survey was provided for review

to subject matter experts at each organization, and suggestions were incorporated into the survey before the final web-based version was developed.[a]

The survey consisted of 5 sections. The first section collected information on respondents' age, sex, state of residence, level of education, and household income. The second section collected information on respondents' knowledge of rabies and rabies vaccination recommendations. The third section collected information on respondents' type and duration of employment, frequency of working with animals, and potential rabies exposures. The fourth section collected information on respondents' rabies vaccination history and serologic monitoring practices. The fifth section collected information on respondents' willingness to pay for rabies vaccination and serologic monitoring and attitudes toward various rabies exposure risks. The present report focused only on findings from the first 4 sections.

Occupational groups were self-identified by respondents. Although some occupational groups were formally recognized (eg, veterinarians) through educational and licensure requirements, other occupational groups were more subjective (eg, wildlife rehabilitators), with requirements for working in that occupation differing from state to state. Veterinary technicians participating in the survey were considered to have most likely been licensed or certified in the state where they worked; however, the survey did not explicitly exclude veterinary assistants or noncertified technicians in states without license requirements.

A recruitment letter and web link to the survey were provided to each professional organization, which then distributed the information to its members through its email distribution list or an electronic newsletter. Recruitment letters were distributed in May 2016, and the survey remained open until July 31, 2016. One reminder announcement was distributed by all organizations approximately 5 to 6 weeks after the initial recruitment notice.

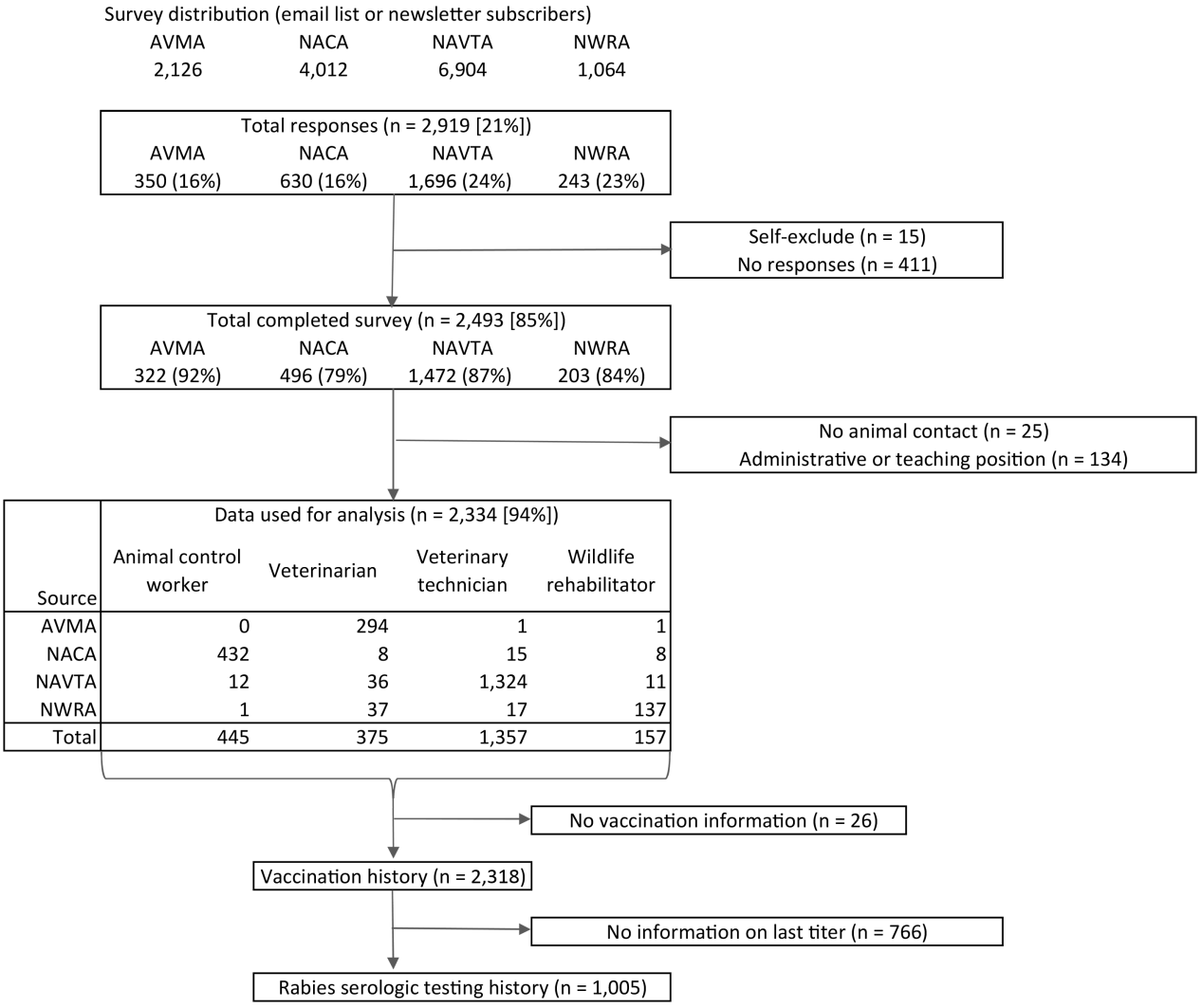
Data analysis

All data were exported from the survey software and entered into a database for cleaning and analysis with standard statistical software.[b] Variables were compared among the 4 occupational groups (veterinarians, veterinary technicians, animal control workers, and wildlife rehabilitators), between persons who had and had not been vaccinated against rabies, and between persons who did or did not adhere to the ACIP rabies serologic monitoring guidelines. Respondents' state of residence was compared with national surveillance designations[19] to determine the rabies reservoir region in which they lived. Respondents were questioned about the number of animals they had contact with each week and the number of animals suspected to have neurologic disorders they had contact with each month to limit recall bias. These rates were annualized for additional calculations. A hypothetical gamble scenario was used to assess individual risk attitudes. A set of nested questions was presented regarding an individual's willingness to accept a new employment opportunity. The alternatives presented options reflective of a high-risk, high-reward scenario versus a low-risk, low-reward scenario. The second set of options presented the same scenario, but with risks and rewards adjusted on the basis of previous responses. A risk aversion category from 1 (most risk averse) to 4 (least risk averse) was assigned on the basis of individual responses.[20]

Continuous variables were evaluated for normality by means of visual inspection of histograms and normal probability plots. Variables were log-transformed if substantial deviations from normality were observed, and normality was reassessed in the same manner. Frequencies were calculated for categorical variables, and means and SD were calculated for continuous variables. Geometric means and SD factors were calculated for continuous variables that were log-transformed. A χ^2 test was used as appropriate to identify differences between groups for categorical variables. Analysis of variance was used to evaluate differences between group means. Incidence rates and 95% CIs were calculated by group for animal bites, suspect animal handling, and postexposure prophylaxis. In addition, mean bite rates/1,000 animals handled were calculated. Univariate odds ratios were calculated for rabies vaccination (yes vs no) and serologic monitoring (yes vs no) groups. Any variables from this univariate analysis with a P value ≤ 0.1 were entered in a multiple logistic regression model along with all potential 2-way interactions. Final models were selected by means of a stepwise process based on the likelihood-ratio statistic and individual evaluations for confounding. Multicollinearity was evaluated visually with a correlation matrix between variables and a weighted regression model to generate eigenvalues and conditional indices. Variables with conditional indices > 10 were considered to represent potential collinearity. For all final statistical tests, values of $P < 0.05$ were considered significant.

Results

A total of 2,919 responses were received through the web-based survey. Estimated survey distribution numbers provided by the participating professional organizations suggested that the survey was distributed to approximately 14,106 individuals; thus, the estimated response rate was 21% (2,919/14,106). Of the 2,919 respondents, 426 were excluded because they did not complete the survey, and an additional 159 were excluded because they indicated they had no animal contact in their position or indicated they were in an administrative or teaching position with very limited animal contact. Data for the remaining 2,334 respondents, representing an estimated survey response rate of 18%, were used in analyses **(Figure 1)**.



Source	Animal control worker	Veterinarian	Veterinary technician	Wildlife rehabilitator
AVMA	0	294	1	1
NACA	432	8	15	8
NAVTA	12	36	1,324	11
NWRA	1	37	17	137
Total	445	375	1,357	157

Figure 1—Flow diagram illustrating responses to a survey of animal care workers (ie, veterinarians, veterinary technicians, animal control workers, and wildlife rehabilitators) in the United States regarding knowledge and practices related to rabies vaccination and serologic monitoring of rabies antibody titers. NACA = National Animal Care and Control Association. NAVTA = National Association of Veterinary Technicians in America. NWRA = National Wildlife Rehabilitator Association.

Of the 2,334 respondents, 375 self-identified as a veterinarian, 1,357 self-identified as a veterinary technician, 445 self-identified as an animal control worker, and 157 self-identified as a wildlife rehabilitator **(Table 1)**. Mean age for all respondents was 41.8 years (SD, 12.5 years), but veterinary technicians were significantly ($P < 0.001$) younger (mean, 38.7 years; SD, 11.3 years) than individuals in the other 3 occupational groups. Overall, most respondents were female (86.8% [2,025/2,334]), with veterinary technicians and wildlife rehabilitators having higher proportions of women, compared with veterinarians and animal control workers. Of the 2,328 respondents who indicated a state of residence, 1,125 (48.3%) resided in a state where the raccoon rabies virus variant was the primary rabies reservoir. Except for animal control workers, > 85% of respondents in each group reported holding an associate's degree or higher. Mean time respondents had worked in their current position was 10.8 years (SD, 9.8 years), with veterinarians and wildlife rehabilitators having reportedly worked significantly longer times in their current position than veterinary technicians and animal control workers. Percentage of respondents previously vaccinated against rabies varied across occupational groups, with veterinarians reporting the highest rate (98.7% [367/372]), followed by animal control workers (78.5% [344/438]), wildlife rehabilitators (78.2% [122/156]), and veterinary technicians (69.3% [937/1,352]). For respondents who reported a history of rabies vaccination, the percentage who reported adherence to serologic monitoring according to ACIP recommendations (ie, rabies antibody titer testing within the past 2 years) was only 61.0% (613/1,005), with veterinarians having the lowest

Table 1—Demographic characteristics of animal care workers (ie, veterinarians [n = 375], veterinary technicians [1,357], animal control workers [445], and wildlife rehabilitators [157]) in the United States who responded to a survey on knowledge and practices related to rabies vaccination and serologic monitoring of rabies antibody titers.

Variable	Animal control worker	Veterinarian	Veterinary technician	Wildlife rehabilitator	All	*P* value*
Age (y)	44.4 (12.0)	47.0 (12.9)	38.7 (11.3)	49.5 (13.5)	41.8 (12.5)	< 0.001
Gender						< 0.001
Female	297 (66.7)	294 (78.4)	1,285 (94.7)	149 (94.9)	2,025 (86.8)	
Male	148 (33.3)	81 (21.6)	72 (5.3)	8 (5.1)	309 (13.2)	
Rabies reservoir region (n = 2,328)						< 0.001
Raccoon	179 (40.3)	193 (51.6)	679 (50.2)	74 (47.1)	1,125 (48.3)	
Skunk, fox, or mongoose	213 (48.0)	132 (35.3)	466 (34.4)	60 (38.2)	871 (37.4)	
Bat only or rabies free	52 (11.7)	49 (13.1)	208 (15.4)	23 (14.6)	332 (14.3)	
Education (n = 2,327)						< 0.001
High school or less	163 (36.8)	0 (0)	77 (5.7)	22 (14.1)	262 (11.3)	
Associate's or bachelor's degree	259 (58.5)	4 (1.1)	1,207 (89.2)	96 (61.5)	1,566 (67.3)	
Veterinary degree	0 (0)	363 (96.8)	2 (0.1)	3 (1.9)	368 (15.8)	
Graduate degree (eg, MS or PhD)	21 (4.7)	8 (2.1)	67 (5)	35 (22.4)	131 (5.6)	
Household income (n = 2,254)						< 0.001
≥ $50,000	258 (59.3)	330 (93.5)	677 (51.4)	109 (73.2)	1,374 (61.0)	
< $50,000	177 (40.7)	23 (6.5)	640 (48.6)	40 (26.8)	880 (39.0)	
Years in current position	10.3 (8.2)	15.1 (12.9)	9.6 (9.0)	12.1 (10.4)	10.8 (9.8)	< 0.001
Previously vaccinated against rabies (n = 2,318)						< 0.001
Yes	344 (78.5)	367 (98.7)	937 (69.3)	122 (78.2)	1,770 (76.4)	
No	94 (21.5)	5 (1.3)	415 (30.7)	34 (21.8)	548 (23.6)	
Current titer per ACIP recommendations (n = 1,005)						0.014
Yes	120 (69.0)	143 (55.2)	300 (60.0)	50 (69.4)	613 (61.0)	
No	54 (31.0)	116 (44.8)	200 (40.0)	22 (30.6)	392 (39.0)	

Values are given as number of respondents (%), except that values for age and years in current position are given as mean (SD). Not all respondents answered all questions; for each variable, number in parentheses represents total number of respondents.

*The χ^2 test was used for categorical variables, and ANOVA was used for continuous variables.

percentage with a current monitoring status (55.2% [143/259]).

With the exception of wildlife rehabilitators, > 85% of respondents indicated they worked with companion animals (eg, cats and dogs; **Table 2**). High proportions of animal control workers and wildlife rehabilitators indicated they worked with wildlife, and > 60% of respondents in both groups reported working with rabies reservoir species (eg, raccoons, skunks, foxes, or bats). The geometric mean number of animals handled annually for all respondents was 1,908 animals/y (SD factor, 2.8). Although both animal control workers and wildlife rehabilitators handled significantly ($P < 0.001$) fewer animals on an annual basis than did veterinarians and veterinary technicians, these 2 groups had higher average rates of animal bites/1,000 animals handled, compared with veterinarians and veterinary technicians. Overall, the animal bite rate was 0.77 animal bites/person-year or, after adjusting for the number of animals handled, 0.10 animal bites/1,000 animals handled, with wildlife rehabilitators reporting the highest animal bite rates. Most (56.0% [1,304/2,329]) respondents reported a history of handling an animal suspected or confirmed to be rabid while in their current position. Animal control workers (71.9% [320/445]) and veterinarians (60.8% [226/372]) were most likely to have handled an animal suspected or confirmed to be rabid. However, animal control workers and wildlife rehabilitators had the highest rates of contact with animals suspected or confirmed to be rabid (1.24 and 0.54 rabid animals/1,000 animals handled, respectively). Overall, 26.6% (343/1,290) of respondents reported having been exposed to rabies during their last contact with an animal suspected or confirmed to be rabid, and 20.9% (271/1,295) reported receiving postexposure prophylaxis because of potential rabies exposure while in their current position. Wildlife rehabilitators had the highest percentage of respondents who received postexposure prophylaxis (47.4% [37/78]). The overall rate of postexposure prophylaxis due to an occupational rabies exposure was 1.07/100 person-years (95% CI, 0.95 to 1.21). Cats were the most frequently reported animal involved in potential rabies exposures that resulted in postexposure prophylaxis, followed by raccoons, bats, dogs, and livestock.

Knowledge of rabies and ACIP rabies vaccination recommendations differed significantly among occupational groups. Recognition of saliva as a potentially infectious substance was high (> 96%) among all groups **(Table 3)**. However, recognition

Table 2—Animal contact, bite rates, and rabies exposure risks for study participants in Table 1.

Variable	Animal control worker	Veterinarian	Veterinary technician	Wildlife rehabilitator	All	*P* value*
Animals with which respondents worked (n = 2,310)						
Companion animals	441 (99.1)	322 (85.9)	1,287 (94.8)	35 (22.3)	2,085 (89.3)	
Large animals or livestock	229 (51.5)	95(25.3)	223 (16.4)	10 (6.4)	557 (23.9)	
Exotic pets, birds, or reptiles	171 (38.4)	97 (25.9)	429 (31.6)	22 (14.0)	719 (30.8)	
Birds	213 (47.9)	74 (19.7)	289 (21.3)	87 (55.4)	663 (28.4)	
Reptiles	163 (36.6)	58 (15.5)	231 (17.0)	58 (36.9)	510 (21.9)	
Feral cats	358 (80.4)	111 (29.6)	436 (32.1)	17 (10.8)	922 (39.5)	
Wildlife	235 (52.8)	49 (13.1)	158 (11.6)	125 (79.6)	567 (24.3)	
Rabies reservoir species	284 (63.8)	33 (8.8)	96 (7.1)	109 (69.4)	522 (22.4)	
Animals handled annually (n = 2,312)†	1,006.9 (2.8)	2,314.0 (2.8)	2,415.5 (2.3)	972.2 (4.0)	1,908.0 (2.8)	< 0.001
Animal bites (n = 2,302)						< 0.001
Bites/person-year‡	0.45 (0.44–0.47)	1.00 (0.98–1.01)	0.66 (0.65–0.68)	1.66 (1.60–1.70)	0.77 (0.77–0.79)	
Bites/1,000 animals handled†	0.11 (13.3)	0.08 (11.7)	0.09 (9.8)	0.29 (18.9)	0.10 (11.4)	
Ever handled a suspected or confirmed rabid animal (n = 2,329)						< 0.001
Yes	320 (71.9)	226 (60.8)	679 (50.1)	79 (50.3)	1,304 (56.0)	
No or don't know	125 (28.1)	146 (39.2)	676 (49.9)	78 (49.7)	1,025 (44.0)	
Suspected or confirmed rabid animals handled (n = 1,268)						< 0.001
Rabid animals/person-year‡	3.68 (3.62–3.70)	0.67 (0.65–0.69)	1.21 (1.20–1.23)	0.76 (0.72–0.79)	1.50 (1.49–1.52)	
Rabid animals/1,000 animals handled†	1.24 (9)	0.14 (8.7)	0.13 (8.6)	0.54 (8.0)	0.25 (10.7)	
Potentially exposed to rabies during last contact with a suspected or confirmed rabid animal (n = 1,290)§						0.007
Yes	60 (19.1)	66 (29.3)	194 (28.8)	23 (29.5)	343 (26.6)	
No or don't know	254 (80.9)	159 (70.7)	479 (71.2)	55 (70.5)	947 (73.4)	
In current position, received rabies PEP owing to potential exposure (n = 1,295)						< 0.001
Yes	68 (21.7)	56 (24.8)	110 (16.2)	37 (47.4)	271 (20.9)	
No or don't know	246 (78.3)	170 (75.2)	567 (83.8)	41 (52.6)	1,024 (79.1)	
Incidents/100 person-years‡	1.47 (1.15–1.86)	0.99 (0.75–1.27)	0.84 (0.69–1.01)	1.95 (1.29–2.66)	1.07 (0.95–1.21)	
Source of potential rabies exposure for which PEP was received (n = 269)						
Cat	20 (29.4)	24 (42.9)	56 (50.9)	1 (2.7)	101 (37.3)	
Dog	5 (7.4)	6 (10.7)	22 (20.0)	0 (0)	33 (12.2)	
Livestock	0 (0)	13 (23.2)	8 (7.3)	1 (2.7)	22 (8.1)	
Bat	9 (13.2)	2 (3.6)	6 (5.5)	17 (45.9)	34 (12.5)	
Fox	5 (7.4)	0 (0)	1 (0.9)	2 (5.4)	8 (3.0)	
Raccoon	16 (23.5)	4 (7.1)	10 (9.1)	13 (35.1)	43 (15.9)	
Skunk	7 (10.3)	4 (7.1)	2 (1.8)	0 (0)	13 (4.8)	
Other or multiple species	5 (7.4)	2 (3.6)	5 (4.5)	3 (8.1)	15 (5.5)	

Unless otherwise indicated, values represent number (%) of respondents.
†Data are given as geometric mean (SD factor). ‡Values in parentheses represent 95% CI. §Restricted to persons reporting having ever handled a suspected or confirmed rabid animal.
PEP = Postexposure prophylaxis.
See Table 1 for remainder of key.

of nervous tissue as a potentially infectious material was low among all groups, but particularly among animal control workers and wildlife rehabilitators. Furthermore, the percentage of respondents who incorrectly indicated that blood was potentially infectious for rabies ranged from 39.7% (veterinarians [149/375]) to 53.6% (veterinary technicians [728/1,357]). Greater than 78% (1,797/2,294) of respondents recognized that appropriate pre-exposure vaccination against rabies consisted of 3 doses of vaccine. However, only 15.1% (veterinary technicians [205/1,355]) to 35.3% (wildlife rehabilitators [55/156]) of respondents correctly indicated that appropriate postexposure prophylaxis for a previously vaccinated person consisted of 2 booster doses of vaccine. Overall, only 41.4% (967/2,334) of respondents correctly indicated that rabies antibody titer testing every 2 years is recommended for persons who work with animals in rabies-endemic areas. Most respondents (67.8% [1,583/2,334]) indicated they did not know what titer is the recommended cutoff for indicating when a rabies vaccine booster is necessary. Even when an appropriate titer cutoff was indicated, nearly twice as many participants in each occupational group identified the World Health Organization–recommended titer[21] versus the ACIP-recommended titer.[17] Knowledge of an existing employer policy requiring rabies vaccination or routine serologic monitoring was low across all groups. Veterinary technicians were the least likely to report an employer requirement to receive rabies vaccination (18.2% [245/1,343] of veterinary technicians), whereas animal control workers and wildlife rehabilitators had the highest reported rates (38.9% [169/435] and 37.9% [58/153], respectively).

Of the 1,770 respondents who had previously been vaccinated against rabies, 56.8% (1,005/1,770) were categorized as meeting the ACIP criteria for frequent rabies exposure risk and would be recommended to undergo serologic monitoring every 2 years. Of these, 61.0% (613/1,005) were considered to have a current serologic monitoring status (ie, rabies neutralizing antibody titer measured within past 2 years). Univariate analysis identified several factors significantly associated with having both a history of vaccination and a current serologic monitoring status: age, household income, years in cur-

Table 3—Knowledge of rabies vaccination and serologic monitoring recommendations for study participants in Table 1.

Variable	Animal control worker	Veterinarian	Veterinary technician	Wildlife rehabilitator	Total	*P* value*
Indicated substance as potential rabies infectious material						
Saliva	431 (96.9)	374 (99.7)	1,334 (98.3)	154 (98.1)	**2,293 (98.2)**	
Nervous tissue	248 (55.7)	325 (86.7)	959 (70.7)	88 (56.1)	**1,620 (69.4)**	
Urine	70 (15.7)	68 (18.1)	319 (23.5)	34 (21.7)	**491 (21.0)**	
Blood	200 (44.9)	149 (39.7)	728 (53.6)	68 (43.3)	**1,145 (49.1)**	
Don't know	5 (1.1)	0 (0)	16 (1.2)	2 (1.3)	**23 (1.0)**	
No. of vaccine doses for pre-exposure vaccination (n = 2,294)						< 0.001
< 3 doses	40 (9.1)	67 (18.1)	226 (16.9)	7 (4.8)	**340 (14.8)**	
3 doses	353 (80.2)	290 (78.2)	1,029 (76.9)	125 (86.2)	**1,797 (78.3)**	
> 3 doses	47 (10.7)	14 (3.8)	83 (6.2)	13 (9.0)	**157 (6.8)**	
What is administered after a rabies exposure for a person who is previously vaccinated against rabies (n = 2,331)						< 0.001
2 doses of vaccine	83 (18.7)	132 (35.2)	205 (15.1)	55 (35.3)	**475 (20.4)**	
4 doses of vaccine	18 (4.0)	9 (2.4)	27 (2.0)	3 (1.9)	**57 (2.4)**	
Rabies immunoglobulin and vaccine	207 (46.5)	162 (43.2)	582 (43.0)	67 (42.9)	**1,018 (43.7)**	
Nothing	24 (5.4)	4 (1.1)	52 (3.8)	4 (2.6)	**84 (3.6)**	
Don't know	113 (25.4)	68 (18.1)	489 (36.1)	27 (17.3)	**697 (29.9)**	
How often should previously vaccinated people have their titer checked if they work with animals in a rabies-endemic area?						< 0.001
Every 5 y	84 (18.9)	96 (25.6)	298 (22.0)	11 (7.0)	**489 (21.0)**	
Every 2 y	200 (44.9)	171 (45.6)	515 (38.0)	81 (51.6)	**967 (41.4)**	
Yearly	82 (18.4)	52 (13.9)	284 (20.9)	44 (28.0)	**462 (19.8)**	
Every 6 mo	12 (2.7)	2 (0.5)	30 (2.2)	10 (6.4)	**54 (2.3)**	
Never	2 (0.4)	1 (0.3)	2 (0.1)	0 (0)	**5 (0.2)**	
Don't know	65 (14.6)	53 (14.1)	228 (16.8)	11 (7.0)	**357 (15.3)**	
According to US recommendations, people should receive a rabies vaccine booster when their titer drops below this level						< 0.001
Correct to ACIP recommendations	40 (9.0)	45 (12.0)	99 (7.3)	30 (19.1)	**214 (9.2)**	
Correct to WHO recommendations	87 (19.6)	134 (35.7)	210 (15.5)	35 (22.3)	**466 (20.0)**	
Incorrect response	16 (3.6)	11 (2.9)	39 (2.9)	5 (3.2)	**71 (3.0)**	
Don't know	302 (67.9)	185 (49.3)	1,009 (74.4)	87 (55.4)	**1,583 (67.8)**	
Does your employer have a policy requiring you to be vaccinated against rabies? (n = 2,298)						< 0.001
Yes	169 (38.9)	83 (22.6)	245 (18.2)	58 (37.9)	**555 (24.2)**	
No or don't know	266 (61.1)	284 (77.4)	1,098 (81.8)	95 (62.1)	**1,743 (75.8)**	
Does your employer have a policy requiring you to have your rabies titer checked periodically? (n = 2,296)						< 0.001
Yes	112 (25.7)	47 (12.8)	194 (14.5)	54 (35.5)	**407 (17.7)**	
No or don't know	323 (74.3)	320 (87.2)	1,148 (85.5)	98 (64.5)	**1,889 (82.3)**	

Values represent number (%) of respondents. Not all respondents answered all questions; for each variable, number in parentheses represents total number of respondents.

*The χ^2 test was used to test for differences across groups.

WHO = World Health Organization.

rent position, occupational group, history of working with rabies reservoir species, number of animals handled annually, history of handling an animal suspected or confirmed to be rabid, and employer policies requiring vaccination and serologic monitoring **(Table 4)**. Veterinarians were 32.51 times as likely to be vaccinated as were veterinary technicians, and persons with an employer policy requiring vaccination were 24.20 times as likely to be vaccinated as were those whose employer did not have such a policy. Respondents with an employer policy requiring serologic monitoring were 5.47 times as likely to have a current serologic monitoring status as were those whose employer did not have such a policy. An increase in age category was associated with higher odds of having been vaccinated against rabies but with lower odds of having a current serologic monitoring status.

Multivariable logistic regression models were fit to identify factors associated with the likelihood of having been vaccinated against rabies **(Table 5)** and the likelihood of having a current serologic monitoring status **(Table 6)**. No substantial collinearity among variables in either final model was observed.

Controlling for other factors, respondents residing in states where the raccoon rabies virus variant was present were 3.17 times as likely to be vaccinated as were those living in states free from terrestrial rabies (ie, rabies present only in bats; Table 5). Having an associate's degree or graduate degree was associated with a higher likelihood of being vaccinated, compared with having only a high school degree or less, and veterinarians and animal control workers were substantially more likely to be vaccinated than were veterinary technicians. Respondents working for an employer that had a policy requiring vaccination were 32.16 times as likely to be vaccinated as were those working for an employer without such a policy. Respondents' risk aversion score had a significant ($P < 0.001$) impact on model fit, and ORs for other factors changed by > 10% if risk aversion score was removed. Therefore, this variable was retained in the final model. Respondents who were less risk averse (ie, had a higher risk aversion score) were more likely

Table 4—Results of univariate analysis of factors potentially associated with having been vaccinated against rabies and having a current serologic monitoring status for study participants in Table 1.

	Rabies vaccination					Current titer				
Category	**Yes (n = 1,770)**	**No (n = 548)**	**OR**	**95% CI**	***P* value**	**Yes (n = 613)**	**No (n = 392)**	**OR**	**95% CI**	***P* value**
Age					< 0.001					0.001
6–31 y	362	207	Referent	NA		104	37	Referent	NA	
32–50 y	853	235	2.08	(1.66–2.59)		322	206	0.56	(0.36–0.84)	
51–78 y	555	106	2.99	(2.29–3.92)		187	149	0.45	(0.29–0.69)	
Gender					0.012					0.385
Female	1,519	493	Referent	NA		540	338	Referent	NA	
Male	251	55	0.68	(0.49–0.91)		73	54	0.85	(0.58–1.24)	
Rabies reservoir region					< 0.001					0.080
Raccoon	938	179	3.78	(2.88–4.97)		404	237	1.26	(0.97–1.64)	
Skunk, fox, or mongoose	637	230	2	(1.53–2.61)		209	155	Referent	NA	
Bat only or rabies free	187	135	Referent	NA		NA	NA	NA	NA	
Education					< 0.001					0.119
High school or less	182	78	Referent	NA		60	35	Referent	NA	
Associate's or bachelor's degree	1,116	440	1.09	(0.81–1.44)		368	221	0.97	(0.62–1.52)	
Veterinary degree	360	5	30.71	(13.07–87.23)		139	114	0.71	(0.44–1.15)	
Graduate degree (eg, MS or PhD)	106	24	1.89	(1.14–3.21)		44	21	1.22	(0.63–2.40)	
Household income					< 0.001					0.011
< $50,000	672	285	Referent	NA		399	283	Referent	NA	
≥ $50,000	1,098	263	1.77	(1.45–2.16)		191	93	1.46	(1.09–1.95)	
Years in current position					< 0.001					0.029
0–3	485	211	Referent	NA		127	74	Referent	NA	
4–8	299	135	0.96	(0.74–1.25)		112	51	1.28	(0.82–1.99)	
9–16	481	118	1.77	(1.37–2.30)		181	112	0.94	(0.65–1.36)	
> 16	505	84	2.61	(1.98–3.48)		193	155	0.72	(0.51–1.04)	
Occupation category					< 0.001					0.014
Veterinarian	367	5	32.51	(13.35–79.16)		143	116	0.82	(0.61–1.11)	
Veterinary technician	937	415	Referent	NA		300	200	Referent	NA	
Animal control worker	344	94	1.62	(1.26–2.09)		120	54	1.48	(1.03–2.15)	
Wildlife rehabilitator	122	34	1.59	(1.08–2.39)		50	22	1.51	(0.89–2.62)	
Work with rabies reservoir species					< 0.001					0.003
Yes	440	77	2.04	(1.56–2.65)		180	83	1.56	(1.16–2.12)	
No	1,311	467	Referent	NA		424	306	Referent	NA	
Animals handled annually					0.013					0.012
52–1,040	388	91	Referent	NA		146	70	Referent	NA	
1,041–2,600	799	252	0.74	(0.57–0.97)		278	171	0.78	(0.55–1.10)	
2,601–3,900	193	56	0.81	(0.56–1.18)		72	45	0.77	(0.48–1.23)	
> 3,900	390	149	0.61	(0.46–0.82)		117	106	0.53	(0.36–0.78)	
Animal bites/1,000 animals handled					0.121					0.089
< 0.05	496	143	Referent	NA		170	124	Referent	NA	
0.05–0.45	844	248	0.98	(0.78–1.24)		296	196	1.1	(0.82–1.48)	
> 0.45	430	157	0.79	(0.61–1.02)		147	72	1.49	(1.03–2.15)	
Ever handled a suspected rabid animal					< 0.001					0.004
Yes	1,070	219	2.30	(1.89–2.80)		441	248	1.5	(1.14–1.96)	
No or don't know	697	328	Referent	NA		171	144	Referent	NA	
Risk group					0.389					0.048
4 (least risk averse)	152	38	Referent	NA		58	20	Referent	NA	
3	185	63	0.73	(0.46–1.16)		54	41	0.46	(0.23–0.87)	
2	294	78	0.94	(0.61–1.95)		109	60	0.63	(0.34–1.14)	
1 (most risk averse)	1,022	318	0.80	(0.54–1.16)		362	246	0.51	(0.29–0.86)	
Employer policy requiring vaccination or periodic titer checks					< 0.001					< 0.001
Yes	545	10	24.20	(12.84–45.61)		276	51	5.47	(3.93–7.70)	
No or don't know	1,207	536	Referent	NA		335	339	Referent	NA	

NA = Not applicable.

to be vaccinated against rabies, although not significantly so.

The interaction between rabies reservoir region and occupational group was associated with the likelihood of having a current serologic monitoring status (Table 6). The primary effect of this interaction was that wildlife rehabilitators living in states in which the raccoon rabies virus variant was endemic were substantially less likely to have a current serologic monitoring status (OR, 0.13; 95% CI, 0.04 to 0.47) than were those living in states in which other terrestrial rabies virus variants (ie, skunk, fox, or mongoose) were endemic. Significant, but moderate, effects were observed for income and history of handling animals suspected or confirmed to be rabid, with both factors associated with an increased likelihood of having a current serologic monitoring status. Respondent age and reported number of animals handled annually were negatively associated with likelihood of having a current serologic monitoring status. Respondents working for an employer that had a policy requiring serologic monitoring were 6.14 times as likely to have a current serologic monitoring status as were respondents working for an employer without such a policy. As was the case for the vaccination status model, risk aversion score had a significant ($P < 0.001$) impact on model fit.

Table 5—Results of multivariate analysis of factors associated with having been vaccinated against rabies for study participants in Table 1.

Parameter	OR	95% CI
Rabies reservoir region (referent: bat only or rabies-free region)		
Raccoon	3.17	(2.30–4.36)
Skunk, fox, or mongoose	1.70	(1.24–2.34)
Education (referent: high school or less)		
Associate's or bachelor's degree	1.81	(1.24–2.65)
Veterinary degree	1.98	(0.22–17.63)
Graduate degree (eg, MS or PhD)	2.77	(1.48–5.18)
Years in current position	1.04	(1.02–1.05)
Occupational group (referent: veterinary technician)		
Animal control worker	1.51	(1.07–2.12)
Veterinarian	33.24	(3.18–347.65)
Wildlife rehabilitator	1.10	(0.68–1.80)
Handled suspected rabid animal (referent: no)	1.64	(1.30–2.08)
Risk aversion group*	1.07	(0.95–1.20)
Employer policy requiring vaccination (referent: no)	32.16	(14.18–72.94)

*Increase in odds for each whole-number increase in risk aversion score.

Table 6—Results of multivariate analysis of factors associated with having a current serologic monitoring status for study participants in Table 1.

Parameter	OR	95% CI
Age	0.98	(0.96–0.99)
Raccoon reservoir region (referent: skunk, fox, or mongoose region and veterinary technician)		
Animal control worker	1.73	(0.82–3.67)
Veterinarian	1.50	(0.85–2.64)
Wildlife rehabilitator	0.13	(0.04–0.47)
Income (referent: < $50,000)	1.52	(1.06–2.16)
Occupational group (referent: raccoon region and veterinary technician)		
Animal control worker	1.21	(0.64–2.28)
Veterinarian	1.36	(0.88–2.12)
Wildlife rehabilitator	0.37	(0.16–0.89)
Number of animals handled annually*	0.80	(0.68–0.94)
Handled suspected rabid animal (referent: no)	1.47	(1.07–2.02)
Risk aversion group†	1.10	(0.94–1.28)
Employer policy requiring titer check (referent: no)	6.14	(4.18–9.02)

*Logarithmically transformed. †Increase in odds for each whole-number increase in risk aversion score.

Discussion

To our knowledge, the present study represented the first attempt to collect information on a national scale related to animal bites, rabies exposure, and adherence to ACIP rabies vaccination recommendations across multiple occupational risk groups. Importantly, the present study included animal control workers and wildlife rehabilitators, 2 groups that have rarely been surveyed in previous studies examining rabies exposure risks and vaccination practices. Identifying factors potentially associated with adherence to current ACIP recommendations may be important in developing interventions that reduce risk in a cost-effective manner.

Animal bite rates reported by survey respondents in the present study (0.77 animal bites/person-year and 0.10 animal bites/1,000 animals handled) were approximately 50 to 165 times the estimated national bite rate for dogs alone. Although inclusion of bites from multiple species likely accounts for some of this higher observed rate, an increased risk of rabies exposure was also documented. For all respondents in the present study, the overall rate of postexposure prophylaxis due to an occupational rabies exposure was 1.07/100 person-years. The current estimated rate of postexposure prophylaxis in the United States is 0.012/100 person-years,[22] making the risk among animal care workers more than 90 times the risk for the general population.

A major focus of the ACIP and National Association of State Public Health Veterinarians rabies recommendations is mitigating rabies exposure risks for persons with an inherently increased risk of exposure. However, basic knowledge of rabies transmission, infectivity, and vaccination recommendations were lacking overall in all occupational groups in the present study. Nearly all respondents correctly recognized infectious substances, but nearly half also incorrectly identified urine and blood as infectious substances. These incorrect response rates were lower than similar response rates reported for the general population[23]; however, they were still worryingly high for occupational cohorts that would be expected to be familiar with rabies exposure risks. In addition, only 20.4% of respondents knew the correct number of rabies vaccine doses for postexposure prophylaxis in persons who had previously been vaccinated, and familiarity with serologic monitoring recommendations was mixed. Awareness of these clinical recommendations is important in making informed medical decisions with an individual's health-care providers. A previous study[24] documented instances of inap-

propriate postexposure prophylaxis administration in the clinical setting, and confusion regarding appropriate titer cutoffs exists even in the scientific literature.[25] Given the documented increased risk of rabies exposure among animal care workers, improved knowledge may be critical to ensure that they are able to take a more proactive role in obtaining appropriate health care in the event of an exposure.

Rabies vaccination rates were significantly different between occupational groups in the present study. Nearly all veterinarians were vaccinated against rabies, a finding consistent with results of a previous study.[25] Rabies vaccination rates ranged between 70% and 80% in other studies, which have also found the lowest rabies vaccination rates among veterinary technicians, as was the case in the present study. Although veterinary technicians also had lower bite and rabies exposure rates, these rates were not significantly different from rates for veterinarians, for whom vaccination is typically required to complete their academic training or enter the workforce. However, likelihood of vaccination was also associated with years working in a respondent's current position. This association might be attributable to a stronger incentive to be vaccinated as individuals become more familiar with the risks in their positions, but it may also have represented a cohort effect, whereby the individual likelihood of being vaccinated or receiving postexposure prophylaxis increases over time as a result of occupational exposures. An opposite effect appeared in relation to serologic monitoring, with adherence to ACIP monitoring recommendations decreasing as respondent age increased. Rabies antibody titers often do not change substantially over time,[26] so this decrease in adherence with age may have represented fatigue in maintaining regular monitoring when no change was noticed over time.

In the present study, serologic monitoring rates were low across all occupational groups, and 21% of respondents reported that titers should be monitored only every 5 years. Very few cases of rabies have been reported among persons with a history of pre-exposure vaccination, and those that have been reported typically involved unusual exposure routes (eg, laboratory exposures) or coadministration of the vaccine with drugs that might affect the immune response (eg, chloroquine).[27–29] In addition, at least 1 study[30] has suggested that the duration of immunity following rabies pre-exposure vaccination may exceed 10 years.

Confusion also appeared to persist regarding what an adequate titer may be during serologic monitoring, with most respondents in the present study unaware of current antibody titer recommendations. Also, when respondents did indicate a valid recommendation, the World Health Organization guidelines were more frequently recognized than those of the ACIP. This confusion may have been aggravated by the lack of a clear protective rabies antibody titer,[31] as opposed to known protective antibody titers for other vaccine-preventable diseases. A better understanding of the protective role of rabies vaccination against unrecognized exposures is needed as well as information on the effectiveness of booster vaccination following a potential exposure. Cost-effectiveness analyses should be considered to evaluate current recommendations for serologic monitoring and whether different monitoring frequencies might be considered.

Although workplace policies requiring rabies vaccination or serologic monitoring appeared to have a significant effect on adherence to ACIP recommendations in the present study, < 25% of respondents reported such policies at their place of employment. Instituting vaccination requirements for veterinary students appears to have been a successful strategy for ensuring high vaccination rates. A similar tactic requiring rabies vaccination might be considered for training programs focused on animal control workers, veterinary technicians, and wildlife rehabilitators. However, outreach to academic and training programs and employers is warranted to encourage policies reinforcing ACIP recommendations. More work is needed to understand why rabies vaccination policies are not implemented more consistently. In the interim, consideration should be given to adding additional guidance regarding workplace policies in the ACIP and National Association of State Public Health Veterinarians recommendations.[32,33]

Several limitations of the present study should be noted. As with any cross-sectional survey, recall bias was a concern when seeking information on prior exposures. Shorter recall periods for information with high numbers of events (eg, number of animals handled weekly) were used in an attempt to minimize recall bias. Generally, more heaping (ie, responses ending in units of 0 or 5) was observed for questions that involved high-frequency events, compared with less frequent events such as bites, suggesting that respondents provided more generalized responses for high-frequency events. In addition, the recruitment process through professional organizations likely resulted in some selection bias, in that participation in a professional organization is likely to select for persons who are more engaged in their profession and may receive more information, education, and communication, compared with those not involved in a professional organization. Survey demographics were compared with occupational data available in the 2015 American Community Survey to evaluate representativeness of the samples of animal control workers, veterinarians, and veterinary technicians. Age and sex distributions were similar to national estimates for each occupational group, but tended to skew slightly toward older and more female respondents. However, education and income levels were significantly higher than national estimates, consistent with the speculation that sampling from members of professional associations may result in some bias. The greatest deviations were observed among veterinary technicians (**Supplementary Table S1**, available at avmajournals.avma.org/doi/suppl/10.2460/

javma.252.12.1491). The method of recruitment also made it impossible to determine an exact response rate. The estimated response rate of 18% was low, but was comparable to rates reported for some previous studies.[16,34] Furthermore, response rates were consistent across occupational groups, which would suggest comparisons between groups were not impacted by unequal sampling concerns.

Additional research is needed to further explore factors that may influence rabies vaccination practices and adherence to serologic monitoring recommendations. Specifically, the costs associated with pre-exposure vaccination and routine serologic monitoring are likely to impact adherence reports, but were not covered in the present study. Out-of-pocket costs for rabies pre-exposure vaccination can exceed $900, more than a week's net pay for those at or below the median household income level,[35,36] and pre-exposure vaccination may not be covered by a person's health insurance policy. One study[18] found that about half as many employers covered pre-exposure vaccination as covered postexposure prophylaxis in the event of an exposure. Our findings also suggested that additional training on rabies transmission routes and current recommendations for animal care workers is warranted. A study[18] in West Virginia found that < 30% of veterinary clinics had a copy of or online access to the ACIP or National Association of State Public Health Veterinarians recommendations. Methods to increase access to and familiarity with these documents in work settings should be considered. Similarly, the factor most strongly associated with adherence to rabies vaccination and serologic monitoring recommendations was the presence of employer policies supporting these recommendations. Educational outreach on rabies recommendations should include providing guidance and encouragement to employers on developing policies for rabies vaccination and serologic monitoring. The veterinary standard precautions recommendations published by the National Association of State Public Health Veterinarians[33] cover serologic monitoring of employees, but similar recommendations could be strengthened and reinforced in other rabies recommendation documents, including those from the ACIP and the National Association of State Public Health Veterinarians.

Footnotes

a. SurveyMonkey, Palo Alto, Calif.
b. SAS, version 9.4, SAS Institute Inc, Cary, NC.

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