Canine Heartworm Infection and Prophylaxis Use among Pet Caretakers from the Cumberland Gap Region of Tennessee, USA

Authors: Cappiello, Briana, Brehm, Autumn, Wisnieski, Lauren, Gruszynski, Karen, Spangler, Dawn, et al.

Source: Journal of Parasitology, 109(3) : 225-232

Published By: American Society of Parasitologists

URL: https://doi.org/10.1645/22-112

Journal of Parasitology 2023 109(3) 225–232

Published 20 June 2023

DOI: 10.1645/22-112

Contents and archives available through www.bioone.org or www.jstor.org

Journal of Parasitology

journal homepage: www.journalofparasitology.org

CANINE HEARTWORM INFECTION AND PROPHYLAXIS USE AMONG PET CARETAKERS FROM THE CUMBERLAND GAP REGION OF TENNESSEE, USA

Briana Cappiello[1,2], Autumn Brehm[2], Lauren Wisnieski[2], Karen Gruszynski[2], Dawn Spangler[2], and Charles Faulkner[2]

[1] Walworth Animal Hospital, 1711 Walworth Penfield Rd, Walworth, New York 14568.
[2] Richard A. Gillespie College of Veterinary Medicine, Lincoln Memorial University, Harrogate, Tennessee 37752.
Correspondence should be sent to Charles Faulkner (https://orcid.org/0000-0003-0062-6460) at: *charles.faulkner@lmunet.edu*

KEY WORDS

Dirofilaria immitis
Canine heartworm
Prophylaxis

ABSTRACT

The prevalence of infection with canine heartworm (CHW), *Dirofilaria immitis*, continues to increase across the United States, regardless of the availability of effective and affordable prophylactic products. Current reports of CHW prevalence as estimated by the Companion Animal Parasite Council (CAPC) are thought to under-represent the true magnitude of the issue because pet dogs that do not receive regular veterinary care are often excluded. This study estimated the prevalence of CHW in pet dogs and associated prophylaxis use in pet dogs in the Cumberland Gap Region with a combined doorstep diagnostic testing approach and caretaker survey. Dogs tested (n = 258) during the summers of 2018 and 2019 revealed a 2.3% (6/258) prevalence in the pet dog population with 33% (2/6) being microfilaremic. Questionnaire data from caretaker interviews revealed that 41.8% (108/258) of the dogs were not receiving CHW prophylaxis. Significant predictors of CHW prophylaxis use identified through logistic regression included pet caretaker awareness of CHW as an important health issue and the use of veterinary services in the year preceding participation in the survey. These results underscore the importance of veterinary-mediated client interaction to create risk awareness of CHW disease and association with prophylaxis compliance.

Canine heartworm (CHW), *Dirofilaria immitis*, has been recognized worldwide as an increasingly important parasitic infection in small animal practice (Bowman et al., 2016). Untreated, it is an insidious infection and a potential cause of life-threatening pulmonary disease and right-sided heart failure in companion animals including dogs, cats, and ferrets (Bowman et al., 2016). It is also a source of emotional anguish and financial burden for pet caretakers confronted with the reality that the health of a beloved family member is threatened by a preventable infectious disease. Within the United States, the veterinary profession spends millions annually to promote awareness, prevention, and treatment of CHW. However, the prevalence of CHW infection continues to increase, despite the widespread availability of educational messaging and effective CHW prophylaxis (Drake and Wiseman, 2018).

The Companion Animal Parasite Council (CAPC) and American Heartworm Society (AHS) reported an average 15% to 22% increase in reported CHW cases per veterinary clinic in the United States between the years 2013 and 2016 (Drake and Wiseman, 2018). In the southern regions of the United States higher averages predominate because of environmental temperatures, vector availability, and sufficient reservoirs of infection that coincide to facilitate high rates of transmission (Brown et al., 2012; Drake and Wiseman, 2018). Although these reports reflect significant increases in CHW infection and annual incidence, the CAPC acknowledges that their maps represent only 30% of test results in the United States but provide a strong indication of CHW activity in local areas. Accordingly, if these estimates are valid, approximately 50–70 million dogs in the United States went untested in 2013, and the actual prevalence of CHW is likely much higher than reported (Drake and Wiseman, 2018).

Veterinarians surveyed in 2019 by the American Heartworm Society (AHS) attributed the increased incidence of CHW in their communities to the failure of pet owners to administer prophylactic products on time and year round (American Heartworm Society, 2020). Veterinary practice dispensing data for the entire United States suggested that although the number of dogs receiving prophylactic medications increased between 2013 and 2016, the overall proportion of dogs on prophylactic programs has decreased (Drake and Wiseman, 2018). Compliance with AHS recommendations for the prevention of CHW has been a persistent challenge for veterinarians; however, few studies have been undertaken to identify characteristics influential in the use of CHW prophylactic products. Variation in CHW prophylaxis use has been explained as a multifactorial web of factors including (1) available economic resources for pet health care (Gates and Nolan, 2010), (2) pet caretaker knowledge and perceptions of CHW severity (Rohrbach et al., 2011a, 2011b), (3) community

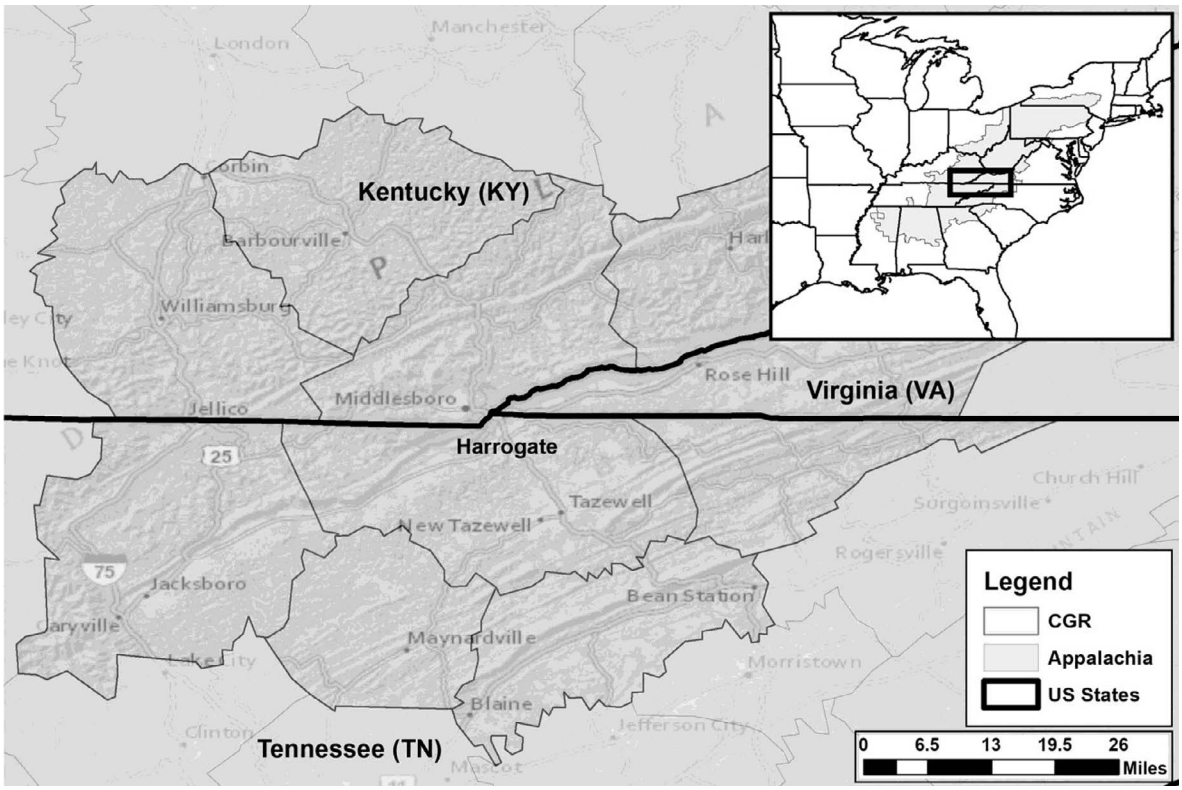

Figure 1. Map of the study location, Harrogate, Tennessee, located in Claiborne County shown relative to the counties comprising the Cumberland Gap Region (CGR), the state boundaries of Kentucky, Tennessee, and Virginia, and the Appalachian region of the United States. Map created using ArcGIS Desktop 10.8.2 (ESRI, Redlands, California). Sources: National Geographic, Environmental Systems Research Institute, Inc., Garmin, HERE Technologies, United Nations Environment Programme World Conservation Monitoring, United States Geological Survey, National Aeronautics and Space Administration, Ministry of Economy, Trade and Industry, Natural Resources Canada, General Bathymetric Chart of the Oceans, National Oceanic and Atmospheric Administration, Increment P Corporation.

prevalence and perceived mosquito activity (Ledesma et al., 2019), and (4) familiarity and use of veterinary services (Bir et al., 2020).

In a study of CHW prevalence and prophylaxis use in pet dogs participating in wellness clinics for human-pet pairs in the Cumberland Gap Region (CGR), no dogs were identified during serologic screening for CHW antigen despite the anecdotal evidence that nearly 50% of owners reported non-use or inconsistent use of monthly prophylactic compounds (Watlington, 2018). This finding was surprising given the CHW seropositivity in approximately 5% of dogs confined in local animal shelters and rescues and its correspondence with the CAPC-mapped prevalence for dogs seen in veterinary clinics in Claiborne County, Tennessee (Watlington, 2018; Patterson et al., 2020).

The current study was undertaken to investigate the relevance of household economic factors and caretaker awareness of CHW in a rural Tennessee community and to address the disparity in these prevalence estimates. Diagnostic testing carried out in conjunction with a survey of pet caretakers was undertaken to estimate the prevalence of CHW infection, as determined by seropositivity for *D. immitis* antigen, and to test the hypothesis that community CHW prevalence would be comparable to estimates derived from sheltered canines and pet dogs presenting at veterinary clinics with subclinical and clinically apparent infection (Self et al., 2019). Likewise, we estimated that CHW prophylaxis use by pet caretakers would be consistent with our previous observations. This research was expected to contribute to a greater understanding of the motives that underlie pet caretaker adoption of CHW prophylaxis and compliance in the pet dog population.

MATERIALS AND METHODS

Study design and location

This study was designed to investigate the occurrence of infection with *Dirofilaria immitis* in pet dogs residing in households of neighborhood communities in Harrogate, Tennessee, located near the Cumberland Gap (36°36′13.68″N, 83°40′27.12″W), an iconic geophysical landmark where the state lines of Tennessee, Kentucky, and Virginia are contiguous (Fig. 1). Pet dog-owning households were enrolled in the study by convenience sampling during a pedestrian survey conducted in summer 2018–2019. Investigators visited community households to collect blood samples from dogs for the detection of canine heartworm antigen with commercially available diagnostic assays. Qualitative data to characterize the knowledge, attitudes, and practices underlying the use of CHW prophylaxis were also collected by administering written questionnaires completed during the visit. Additional pet caretakers opportunistically encountered during the door-to-door sampling effort were also invited to participate. The sample size required to detect 5% CHW serologic prevalence in a pet dog population with 50%

owner-reported compliance with CHW prophylaxis ($P = 0.05$, $\beta = 0.80$) was estimated to fall between 233 and 290 animal subjects based on calculation methods of Kelsey (1996) and Fleiss et al. (1980). Enrolled pet caregivers were surveyed with a standardized questionnaire to obtain information relevant to describing the relationship between heartworm infection status, use of CHW prophylaxis, frequency and use of veterinary services, number of pets in the household, home ownership and income, and other characteristics. Analytical units for the investigation were pet dogs residing in households.

CHW prophylaxis use was hypothesized to be explainable within a context of economic and non-economic variables operative at the household unit of analysis. Variables that informed the economic context were household income, the number of household dogs, and to a lesser extent how the household dog(s) was acquired. Non-economic variables hypothesized as important predictors of CHW prophylaxis use were operationalized with questions that affirmed pet caretaker awareness of CHW as an important health concern and the belief that prophylaxis is important for the prevention of disease. Information on the indoor/outdoor residency of pet family members and pet restriction or confinement was also collected as nominal measures of human-pet attachment, protection, or safety. Variables that informed on the caretaker commitment to pet health included vaccination status, reproductive alteration, and use of vet services in the year preceding participation in the study.

Blood sample collection and laboratory testing

Blood samples (2 to 3 cc) were collected by venipuncture from a cephalic, lateral saphenous, or jugular vein into an EDTA tube at the owner's doorstep. Samples were screened on site to detect canine heartworm antigen with commercially available tests (see below) according to manufacturer instructions. The remaining sample was placed in a cooler with cold-chain transport to the laboratory for additional serologic and microfilaria testing. Pet caretakers with animals that tested positive were provided with literature from the AHS, advised to seek local veterinary care for clinical evaluation and treatment of the affected animal, and received follow-up consultation with the study principal investigator to answer any additional questions and concerns.

In the laboratory, all samples were repeat tested for CHW antigen for confirmation of the residential on-site testing. Field and laboratory assay of samples collected in 2018 was based on the ZippTest Canine Heartworm (Centaur Animal Health, Olathe, Kansas). Samples collected in 2019 were assayed with the VETSCAN Heartworm Rapid Test (ABAXIS, Union City, California) and SNAP Heartworm RT (IDEXX, Westbrook, Minnesota). Published sensitivity and specificity for these tests are comparable (Barr et al., 2011; Henry et al., 2018). Serologically positive samples were examined for microfilarial stages of *D. immitis* using the modified Knott's test and identified according to established morphologic characteristics (Knott, 1939; Newton and Wright, 1956; Magnis et al., 2013).

Statistical analysis

Data were cataloged in a relational database constructed with the Epi Info version 7.2 statistical software package (Dean et al., 2011). For all descriptive analyses, the chi-square test and Student's *t*-test were used to test the association of CHW seropositivity and prophylaxis with dog signalment characteristics, pet caretaker and household characteristics, and pet husbandry characteristics. In cases of expected cell counts <5 for categorical variables, Fisher's exact test was substituted for the chi-square test. Dog signalment characteristics including age, gender, and reproductive status were evaluated for association with pet dog prophylaxis. Likewise, pet caretaker, household, and pet husbandry characteristics were tested for association with household CHW test status and household adoption of CHW prophylaxis. Pet caretaker and household characteristics included owner gender, age, household income, number of resident dogs in the household, household utilization of veterinary services in the preceding year, awareness of CHW as a health concern, and belief in the importance of CHW prophylaxis. Pet husbandry characteristics included vaccination status, utilization of veterinary services in the preceding year, source of pet acquisition, indoor/outdoor status, and pet confinement (i.e., leash walk, fenced-in yard, or allowed to roam freely). Statistical significance for all analyses was $P < 0.05$. Bonferroni corrected significance levels were used to assess non-random association for comparisons with ≥ 3 categorical independent variables.

Statistically significant associations resulting from the descriptive analysis were further evaluated in a multivariable model to identify factors associated with CHW prophylaxis use. A generalized linear mixed model (GLMM) was constructed using the GENLINMIXED command in SPSS (IBM SPSS Statistics for Windows, ver. 28) with a logit link and binomial distribution. Significant variables were retained in the model using backward selection where statistical significance was set at $P < 0.05$. A random intercept for household was used to adjust for the shared variance of individual dogs from the same household.

RESULTS

Descriptive analyses

As part of the current study, 258 dogs residing in 165 households were tested for CHW antigen (Table I). CHW prevalence was 2.3% (6/258; 95% CI, 0.1–5.0%) among tested dogs, and 2 antigen-positive dogs were microfilaremic for *Dirofilaria immitis*. Female dogs were more likely to have been reproductively altered compared to males (Table I). Most of the dogs tested received CHW prophylaxis (57%, 148/258) as affirmed by their caretakers, and this percentage was comparable for male and female dogs (Table I). CHW prophylaxis use was associated with reproductive status; neutered male (76%, 51/67) and spayed female dogs (85%, 67/79) were more likely ($P < 0.05$) to be given CHW prophylaxis compared to their intact counterparts (Table II).

Pet caretakers from households with dogs tested for CHW antigen (n =165 households) also provided questionnaire data (Tables III, IV). Pet caretakers were predominately female (62%, 103/165) and younger ($P < 0.05$) than their male counterparts (Table III). Household income was consistent with the economic profile for Claiborne County, Tennessee (U.S. Census Bureau, 2022), and 47% (78/165) of informants reported annual household income >$30K (Table IV). Seropositivity for CHW antigen was unrelated to household income ($P = 0.66$) or the number of resident pet dogs ($P = 0.17$) (Table III). Regular use of CHW prophylaxis was reported by participants in 61% (100/165)

Table I. Pet dogs tested for canine heartworm antigen (n = 258) and use of heartworm prophylaxis by sex, mean age, and reproductive status.

Dogs tested (n = 258)	Mean age, years (SD)*	Reproductive status†		Canine heartworm antigen		Heartworm prophylaxis‡	
		Intact	Altered	Negative	Positive	Yes	No
Male (n = 124)	5.91 (3.97)	47§	77	119	5	67	57
Female (n = 134)	5.27 (3.95)	28	102§	133	1	81	51
Total	248	75	179	252	6	148	108

* Age not recorded for 3 male, and 7 female dogs.
† Reproductive status not recorded for 4 female dogs.
‡ Heartworm prophylaxis status not recorded for 2 female dogs.
§ Statistically significant non-random association ($P < 0.05$).

of households tested (Table IV). Although 42% (70/165) of participants reported income less than $30K per year, this was not associated with CHW prophylaxis use ($P = 0.16$) (Table IV). Likewise, CHW prophylaxis use was not associated with the number of resident dogs ($P = 0.66$) (Table IV).

When asked about how their pet dogs were acquired, caretakers reported that their dog was acquired from friends or family, adopted from local animal shelters and rescues, or taken in when found loose or "just showed up" (Table V). CHW prophylaxis use was associated with pet acquisition ($P < 0.05$), pet residence in the household ($P < 0.05$), and pet confinement or restriction ($P < 0.05$) (Table V). Pet dogs receiving CHW prophylaxis were more likely to be vaccinated ($P < 0.01$) and visited a veterinarian in the preceding year ($P < 0.01$) (Table V). Awareness of CHW as a health concern for dogs and the associated belief that the use of prophylaxis was important for protection was widespread among interviewed pet caretakers with 81% (126/165) and 94% (135/165) answering affirmatively (Table IV). Although CHW awareness was associated with household prophylaxis use ($P < 0.01$), supporting data were insufficient to evaluate specific details underlying pet owners' decision to adopt a program of CHW prophylaxis for canine protection. Self-reported reasons for the non-use of prophylaxis were obtained from the response of 33 pet caretakers to an open-ended query as to why their animal was not receiving CHW prophylaxis. The cost of prophylaxis was the most frequently cited self-reported reason for non-use by pet caretakers (Table IV). Other reasons in descending order were not being aware of infection risk, failure to maintain a current prescription, forgetting to provide, and not being aware of CHW as a health issue (Table IV).

Multivariable analysis

In the GLMM analysis of CHW prophylaxis use among pet dogs in surveyed households 12 potential predictor variables that were identified from the descriptive analysis ($P < 0.05$) were eligible for inclusion in the full logistic regression model. In the final model, only awareness of CHW as a significant health issue and use of veterinary services in the preceding year were retained ($P < 0.01$) following the elimination of insignificant variables (Table VI). Household respondents unaware of CHW as a health concern had 0.097 lower odds (95% CI, 0.028–0.335) of prophylaxis use with their pet dogs compared to respondents answering affirmatively. Similarly, dogs that had not been to the veterinarian in the preceding year had 0.141 lower odds (95% CI, 0.052–0.384) of prophylaxis use. Alternatively stated, the odds of CHW prophylaxis use were 90% greater among pet caretakers acknowledging CHW as a significant health issue, and nearly 86% greater for pet caretakers acknowledging the use of veterinary services in the previous year. These relationships are depicted graphically by comparison of the estimated mean probability for CHW prophylaxis use with each of the associated variables (Fig. 2).

DISCUSSION

This study aimed to investigate the prevalence of canine heartworm (CHW) infection and the use of prophylaxis in pet dogs from neighborhood communities in Harrogate, Claiborne County, Tennessee. Pet dogs and their caretakers were identified by convenience sampling for inclusion in the study during 2018 and 2019. The estimated serologic prevalence of CHW infection was 2.3% based on testing of blood samples collected from dogs

Table II. Heartworm prophylaxis for pet dogs (n = 252) by sex and reproductive status.

	Heartworm prophylaxis†					Probability of non-random association		
	Yes		No					
Dog reproductive status*	Male	Female	Male	Female	Total	Male	Female	Overall
Intact	16	12	31	15	74	$P < 0.01$	$P = 0.046$	$P < 0.01$
Altered	51	67	26	34	178			
Total	67	79	57	49	252			

* Reproductive status not recorded for 4 female dogs.
† Heartworm prophylaxis status not recorded for 2 female dogs.

Table III. Pet caretaker and household characteristics by canine heartworm test results in participating households (n = 165).

Pet caretaker and household characteristics†	Household infection status*	
	Canine heartworm (CHW) antigen positive (n = 5)	Canine heartworm (CHW) antigen negative (n = 160)
Pet caretakers		
Female, no. (%)	4 (2.4)	99 (61)
Mean age (SD)‡	39.75 (12.7)	43.38 (18.64)
Male, no. (%)	1 (0.6)	58 (35)
Mean age (SD)‡	36 (n.a.)§	53.14 (18.38)
Household income, no. (%)		
Income <$30K	3 (2)	67(45)
Income >$30K	2 (1)	76 (51)
Pet dog in household, no. (%)		
1–2 pet dogs	3 (2)	136 (82)
≥3 pet dogs	2 (1)	24 (14)
Household CHW prophylactic use, no. (%)		
Yes	4 (2)	98 (59)
No	1 (1)	62 (38)

* Based on seropositivity of at least 1 dog residing in household.
† Gender not recorded for pet caretaker of 3 households, pet caretaker age not recorded for 11 households, estimated income not provided for 17 households.
‡ Statistically significant difference in mean age.
§ n.a. = Not applicable.

Table IV. Pet caretaker and household characteristics by canine heartworm prophylaxis use in participating households (n = 165).

Pet caretaker and household characteristics†	Household prophylaxis use*	
	Yes (n = 100)	No (n = 65)
Pet caretakers		
Female, no. (%)	62 (38)	41 (25)
Mean age (SD)‡	38.75 (12.7)	49.58 (17.08)
Male, no. (%)	38 (23)	21 (13)
Mean age (SD)‡	55.18 (19.13)	48 (16.07)
Household income, no. (%)		
Income <$30K	42 (28)	28 (19)
Income >$30K	56 (38)	22 (15)
Pet dog in household, no. (%)		
1–2 pet dogs	87 (53)	52 (31)
≥ 3 pet dogs	15 (9)	11 (7)
Household veterinary visit in last year, no. (%)§		
Yes	88 (69)	39 (31)
No	6 (21)	23 (79)
Awareness of CHW as health concern, no. (%)‖		
Yes	86 (55)	40 (26)
No	7 (4)	23 (15)
Believe CHW prophylaxis is important, no. (%)		
Yes	92 (64)	43 (30)
No	0	9 (6)
Self-described reason for prophylaxis non-use		
Cost of prophylaxis		13
Not aware of CHW risk		8
Not up to date with prescription		5
Forgot to provide		5
Not aware of CHW as a health issue		2

* Based on canine heartworm prophylaxis use in at least 1 dog residing in household.
† Gender not recorded for pet caretaker of 3 households, pet caretaker age not recorded for 11 households, estimated income not provided for 17 households.
‡ Statistically significant difference in mean age ($P < 0.05$).
§ Statistically significant non-random association ($P < 0.05$).
‖ Statistically significant non-random association ($P < 0.05$).

using commercially available antigen detection methods. This estimate is comparable to the mapped prevalence based on dogs seen at local veterinary practices 3.57%, (19/532) during the same period (Companion Animal Parasite Council, 2018). However, the 1.27 % greater prevalence difference depicted by the CAPC maps (averaged data 2018–2019) likely reflects a bias of clinically ill animals presented for treatment compared with the asymptomatic animals sampled in the survey (Self et al., 2019). The prevalence estimates are not statistically different (Fisher's exact test, $P = 0.395$), despite the difference in sample populations, and affirm the relevance of the CAPC maps as a reasonable depiction of CHW in the community.

Pet caretakers participating in our study also completed a standardized questionnaire to provide additional information about their pet dog(s) and the use of CHW prophylactic medications in their households. Nearly 60% of the dogs tested were receiving CHW prophylaxis at the time of the survey. Pet owner spending for CHW prophylaxis can range between $75 and $300 annually per individual dog depending on the drug product and frequency of its administration (Gates and Nolan, 2010; Bir et al., 2020). As Gates and Nolan (2010) discovered, the economic breakpoint at which the adoption of CHW and flea/tick medications reached their highest use (>75%) occurred in households with income between $40K and $80K. Their study was conducted with caretakers of pets served by the veterinary teaching hospital associated with the University of Pennsylvania, where the median household income for the metropolitan Philadelphia area was approximately $58K. For our study, we hypothesized that a similar economic breakpoint for CHW prophylaxis use occurred at approximately 20% of the median household income ($38K) for Claiborne County, Tennessee. Moreover, it was anticipated that CHW prophylaxis use was associated with the number of pet dogs in the household given the cumulative expense of their care. However, such an association was not supported in the survey despite the mention of the "cost of prophylaxis" as a self-described reason for the non-use of CHW prophylaxis. Purchased pet dogs, despite their economic investment value, were just as likely to receive CHW prophylaxis as stray neighborhood dogs that "just showed up" to become household pets. The elimination of these variables from the multivariable logistic regression model demonstrates their diminished importance as predictors of CHW prophylaxis use.

Expenditures for veterinary health care have been characterized as discretionary spending within household budgets where funds allocated for pet family members often compete with other expenses like rent/mortgage, utilities, groceries, childcare, and unplanned medical issues. Although the median household income for the communities sampled in the study area is

Table V. Husbandry characteristics and canine heartworm prophylaxis use for pet dogs (n = 258) from participating households.

Husbandry characteristics*	Pet prophylaxis use, no. (%)	
	Yes (n = 149)	No (n = 109)
Pet wellness		
Vaccinated[a]	144 (56)	86 (34)
Not vaccinated[a]	4 (1)	22 (9)
Veterinary visit in last year (yes)[b]	132 (52)	58 (23)
Veterinary visit in last year (no)[b]	15 (6)	49 (19)
Pet acquisition		
Purchase	55 (59)	40 (41)
Friend or family[c]	42 (47)	45 (53)
Adopted shelter/rescue	31 (80)	8 (20)
Found loose/just showed up[c]	20 (61)	13 (39)
Pet residence in household		
Indoor[d]	90 (35)	43 (17)
Indoor/outdoor	41 (16)	40 (15)
Outdoor[d]	17 (7)	25 (10)
Pet confinement/restriction		
Leash walk[e]	36 (69)	15 (31)
Fenced in yard[f]	79 (66)	42 (34)
Allowed to roam freely[e,f]	30 (38)	50 (62)

* Statistically significant non-random association ($P < 0.05$) denoted by same superscripts.

approximately $38K, residential per capita income is $22.5K, and nearly 19% of the population lives at or below the poverty level (U.S. Census Bureau, 2022), it appears that decisions to provide CHW prophylaxis are not wholly influenced by economic factors. These observations are supported by nationwide consumer spending trends that indicate pet-related expenditures including food, medicines, and veterinary services are often prioritized above other household expenditures (Henderson, 2013).

It is of interest, however, that pet dogs acquired from family or friends demonstrated an increased use of CHW prophylaxis when compared to neighborhood dogs that "just showed up" and were adopted into caretaker's families. This association may indicate continuity in shared preventive health beliefs regarding the use or adoption of CHW prophylaxis among caretakers inheriting or acquiring pet dogs from friends and family members.

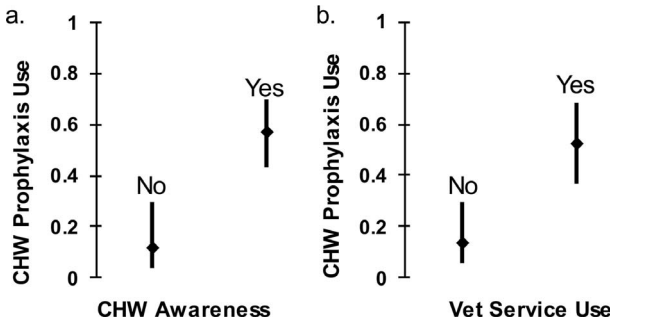

Figure 2. Model-adjusted probability with 95% confidence intervals for canine heartworm (CHW) prophylaxis use according to household respondents' awareness of canine heartworm as a health concern (**a**) and use of veterinary services for their pet dog in the year preceding participation in this study (**b**), as determined from a mixed-effects logistic regression model (n = 241 dogs, n = 154 households).

The effect of caretaker behavioral attachment to their pets and its relation to veterinary preventive health has been poorly investigated. Shore et al. (2005) were unable to demonstrate associations in basic levels of pet care based on owner attachment. In our study, pet dog residence indoors and restricted neighborhood roaming behavior were operationalized as proxies for caretaker attachment. Pet dogs residing exclusively indoors were proportionally more likely to receive CHW prophylaxis compared to those living exclusively outdoors. Likewise, pet dogs allowed to roam freely in their neighborhood were less likely to receive CHW prophylaxis. However, the significance of these associations in the bivariable analysis was not retained in the multi-variable model, which may be due to the difficulty of relating pet-caretaker behaviors and interactions to patterns of veterinary care. The susceptibility of the forgoing bivariable analyses to Type 1 error and inflated significance associated with multiple uncorrected single-degree-of-freedom tests merits acknowledgment. Further investigation of human-pet attachment and its relation to heartworm prophylaxis use with a validated scale for measurement is necessary to fully evaluate the significance of such an association.

Table VI. Summary table for binomial logistic regression of canine heartworm (CHW) prophylaxis use and association with pet caretaker awareness of CHW as a health concern and use of veterinary services in the year preceding the household survey (n = 241 dogs, n = 154 households).

	Fixed coefficients								
Model term					95% confidence interval			95% confidence interval	
	Coeff.	Std error	t*	P value	Lower	Upper	Odds ratio	Lower	Upper
Intercept	1.270	0.2546	4.986	<0.001	0.768	1.771	3.560	2.2156	5.879
CHW awareness as health concern									
No	−2.328	0.6264	−3.717	<0.001	−3.563	−1.094	0.97	0.028	0.335
Yes†	0								
Veterinary service use									
No	−1.960	0.5083	−3.855	<0.001	−2.961	−0.958	0.141	0.052	0.384
Yes†	0								

* Student's t statistic.
† Coefficient for reference category set to 0.

In the logistic regression analysis, only CHW awareness as an important pet health issue and the use of veterinary services in the preceding year were retained in the final model. The co-occurrence of these 2 variables in the final model suggests the importance of the caretaker-veterinarian relationship as a source of information about CHW and its prevention. Our results support the conclusion that although CHW awareness is a motivating factor in prophylaxis use, it is not unequivocally associated with the belief that it is important for the prevention of disease. Indeed, this is realized in the observation that only 64% of pet caretakers nationwide have their dogs enrolled in CHW prophylactic programs (Drake and Wiseman, 2018).

Although reasons for the non-use of CHW prophylaxis were only collected in a small subsample in our study (n = 33 households) and emphasized expense, an association with household economics was not supported. Further research is necessary to fully explore pet caretaker beliefs and perceptions that underlie their decisions not to use CHW prophylaxis even though they may be aware of its adverse impact on pet health. Such research has broader implications for understanding the failure of persons to adopt various disease prevention and early disease detection strategies often associated with positive health outcomes.

Our study is subject to limitations including the limited generalizability resulting from the identification of study participants by convenience sampling and sampling from a single residential population in Harrogate, Tennessee. The degree to which the study participants represent all pet owners living in the tri-state Cumberland Gap region, Claiborne County, and its peripheries beyond the sample radius is unclear. The limited scope of the study population is especially relevant to characterizing pet-care takers who declined participation. Data collected did not specifically address reasons why study participants chose not to use CHW prophylaxis, the perceived risk of CHW infection in the community, or their acknowledged emotional attachment to the health and well-being of their pet dogs. Despite these limitations, the study as presented contributes to understanding patterns of CHW prevalence and prophylaxis in pet dogs. Moreover, the study affirms the relevance of the mapped CHW prevalence presented by CAPC as a reasonable representation of infection risk in local communities. Similar studies conducted at the community scale of resolution and combined with vector prevalence data may be useful for understanding CHW transmission and infection risk in the absence of prophylaxis use.

ACKNOWLEDGMENTS

The authors assert all applicable international, national, and/or institutional guidelines for the care and use of animals were followed and that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1964, as revised in 2013. Blood collection activities for the animal subjects, questionnaire administration, and informed consent protocols for human pet-caretaker participation were approved by the Lincoln Memorial University (LMU) Institutional Animal Care and Use Committee (IACUC), and Institutional Review Board (IRB) for research activities with human subjects under protocol numbers LMU-IACUC 1803 CLIN and LMU-IRB 681 V.1, respectively. Intramural funding from the Lincoln Memorial University College of Veterinary Medicine supported student research internships for the field study and laboratory analyses. We thankfully acknowledge the efforts of Ariel Hudson, Tyler Goldberg, Stephanie Soltis, and others who assisted with animal restraint, blood collection, and questionnaire administration during the pedestrian survey. The final preparation and submission of the manuscript were reviewed by all authors and benefited from the comments and suggestions of our colleagues Dr. Vina Faulkner and Stacie Williams.

LITERATURE CITED

American Heartworm Society. 2020. No state is heartworm free: AHS announces findings of 2019 Heartworm Incidence Survey. Available at: www.heartwormsociety.org/in-the-news/558-ahs-announces-findings-of-2019-heartworm-incidence-survey. Accessed 12 October 2022.

Barr, M. C., E. P. Boynton, P. L. Schmidt, F. Bossong, and G. R. Johnston. 2011. Diagnosis of canine heartworm infection. Today's Veterinary Practice 1: 30–37.

Bir, C., M. Ortez, N. J. Olynk Widmar, C. A. Wolf, C. Hansen, and F. B. Ouedraogo. 2020. Familiarity and use of veterinary services by US resident dog and cat owners. Animals 10: 483. doi:10.3390/ani10030483.

Bowman, D. D., Y. Liu, C. S. McMahan, S. K. Nordone, M. J. Yabsley, and R. B. Lund. 2016. Forecasting United States heartworm *Dirofilaria immitis* prevalence in dogs. Parasites & Vectors 9: 540. doi:10.1186/s13071-016-1804-y.

Brown, H. E., L. C. Harrington, P. E. Kaufman, T. McKay, D. D. Bowman, C. T. Nelson, D. Wang, and R. Lund. 2012. Key factors influencing canine heartworm, *Dirofilaria immitis*, in the United States. Parasites & Vectors 5: 245. doi:10.1186/1756-3305-5-245.

Companion Animal Parasite Council. 2018. Parasite prevalence maps: Claiborne County Tennessee. Available at: https://capcvet.org/maps/#/2018/all-year/heartworm-canine/dog/united-states/tennessee/2441-claiborne-county. Accessed 12 October 2022.

Dean, A. G., T. G. Arner, G. G. Sunki, R. Friedman, M. Lantinga, S. Sangam, J. C. Zubieta, K. M. Sullivan, K. A. Brendel, Z. Gao, et al. 2011. Epi Info™ ver 7.2.3.1, a database and statistics program for public health professionals. Centers for Disease Control and Prevention (CDC), Atlanta, Georgia. Available at: https://www.cdc.gov/epiinfo. Accessed 10 January 2019.

Drake, J., and S. Wiseman. 2018. Increasing incidence of *Dirofilaria immitis* in dogs in USA with focus on the southeast region 2013–2016. Parasites & Vectors 11: 39. doi:10.1186/s13071-018-2631-0.

Fleiss, J. L., A. Tytun, and H. K. Ury. 1980. A simple approximation for calculating sample sizes for comparing independent proportions. Biometrics 36: 343–346.

Gates, M. C., and T. J. Nolan. 2010. Factors influencing heartworm, flea, and tick preventative use in patients presenting to a veterinary teaching hospital. Preventive Veterinary Medicine 93: 193–200.

Henderson, S. 2013. Spending on pets: "Tails" from the Consumer Expenditure Survey. Beyond the Numbers: Prices and Spending, vol. 2, no. 16 U.S. Bureau of Labor Statistics, Washington, DC. Available at: https://www.bls.gov/opub/

btn/volume-2/pdf/spending-on-pets.pdf. Accessed 13 October 2022.

Henry, L. G., K. J. Brunson, H. S. Walden, N. Wenzlow, S. E. Beachboard, K. L. Barr, and M. T. Long. 2018. Comparison of six commercial antigen kits for detection of *Dirofilaria immitis* infections in canines with necropsy-confirmed heartworm status. Veterinary Parasitology 254: 178–182.

IBM Corporation. 2021. IBM SPSS statistics for Windows, version 28.0. Software distributed by IBM Corp, Armonk, New York.

Kelsey, J. L., A. S. Whittemore, A. S. Evans, and W. D. Thompson. 1996. Methods in Observational Epidemiology, Monographs in Epidemiology and Biostatistics. 2nd ed. Oxford University Press, New York, New York, 448 p.

Knott, J. 1939. A method for making microfilarial surveys on day blood. Transactions of the Royal Society of Tropical Medicine and Hygiene 33: 191–196.

Ledesma, N. A., P. E. Kaufman, R. D. Xue, C. Leyen, M. J. Macapagal, O. C. Winokur, and L. C. Harrington. 2019. Entomological and sociobehavioral components of heartworm (*Dirofilaria immitis*) infection in two Florida communities with a high or low prevalence of dogs with heartworm infection. Journal of American Veterinary Medical Association 254: 93–103.

Magnis, J., S. Lorentz, L. Guardone, F. Grimm, M. Magi, T. J. Naucke, and P. Deplazes. 2013. Morphometric analyses of canine blood microfilariae isolated by the Knott's test enables *Dirofilaria immitis* and *D. repens* species-specific and *Acanthocheilonema* (syn. *Dipetalonema*) genus-specific diagnosis. Parasites & Vectors 6: 48. doi:10.1186/1756-3305-6-48.

Newton, W. L., and W. H. Wright. 1956. The occurrence of a dog filariid other than *Dirofilaria immitis* in the United States. Journal of Parasitology 42: 246–258.

Patterson, G., M. Tanhauser, P. Schmidt, D. Spangler, C. Faulkner, V. Faulkner, D. Kish, K. Gruszynski, H. Naikare, M. D. Coarsey, et al. 2020. Serosurvey of arthropod-borne diseases among shelter dogs in the Cumberland Gap Region of the United States. BMC Veterinary Research 16: 221. doi:10.1186/s12917-020-02440-1.

Rohrbach, B. W., A. Lutzy, and S. Patton. 2011a. Attributes, knowledge, beliefs, and behaviors relating to prevention of heartworm in dogs among members of a national hunting dog club. Veterinary Parasitology 176: 324–332.

Rohrbach, B. W., A. Odoi, and S. Patton. 2011b. Survey of heartworm prevention practices among members of a national hunting dog club. Journal of the American Animal Hospital Association 47: 161–169.

Self, S. W., C. N. Pulaski, C. S. McMahan, D. A. Brown, M. J. Yabsley, and J. R. Gettings. 2019. Regional and local temporal trends in the prevalence of canine heartworm infection in the contiguous United States: 2012–2018. Parasites & Vectors 12: 380. doi:10.1186/s13071-019-3633-2.

Shore, E. R., D. K. Douglas, and M. L. Riley. 2005. What's in it for the companion animal? Pet attachment and college students' behaviors toward pets. Journal of Applied Animal Welfare Science 8: 1–11.

United States Census Bureau. 2022. QuickFacts: Claiborne County Tennessee. Updated 13 September. Available at: www.census.gov/quickfacts/fact/map/claibornecountytennessee. Accessed 12 October 2022.

Watlington, H. 2018. Genetic markers involved in macrocyclic lactone resistance in *Dirofilaria immitis* and estimation of heartworm prevalence in resident canine populations of the Cumberland Gap Region of Kentucky, Tennessee, and Virginia. M.S. Thesis. Lincoln Memorial University, Harrogate Tennessee, 67 p.