

# Detection of Gastrointestinal Parasitism at Recreational Canine Sites in the United States (the DOGPARCS study)

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## Research

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# Abstract

**Background:** The rapid growth in off-leash dog parks provides opportunity for canine socialization activities but carries risk of exposure to intestinal parasites. This study assessed the prevalence of these infections in dogs visiting dog parks.

**Methods:** Fresh defecations were collected from dogs visiting parks in 30 metropolitan areas across the United States. Samples were analyzed by coproantigen immunoassay (CAI) (FecalDx<sup>®</sup> and *Giardia* Test, IDEXX Laboratories) and zinc sulfate centrifugal flotation (CF). Owners responded to a questionnaire on their dog's signalment and use of heartworm/intestinal parasite control medications (HWCM).

**Results:** Samples were examined from 3,006 dogs, 87.9% aged at least 12 months, visiting 288 parks. At least one intestinal parasite was detected in 622 (20.7%) samples, nematodes in 263 (8.8%), with hookworm, whipworm, and ascarids in 7.1, 1.9, and 0.6% of samples, respectively. A sample positive for one or more intestinal parasites was found in 245 (85.1%) parks, with nematodes found in 143 (49.7%). Combined, CAI and CF detected 78.4% more intestinal nematode infections than CF alone. Hookworm and whipworm were detected in all age groups, but ascarids were only detected in dogs less than 4 years. Approximately 42% of dogs aged less than 1 year were positive for nematodes or *Giardia*. Based on owner reports, HWCM was current for 68.8% of dogs, dogs previously diagnosed with intestinal parasitism were more likely to be receiving a HWCM than those without such history, and a significantly lower ( $P = 0.0003$ ) proportion of dogs receiving a HWCM were positive for intestinal nematodes compared with those not on such medication.

**Conclusion:** Intestinal parasites, the most common of which were *Giardia*, *Ancylostoma caninum* and *Trichuris vulpis*, were found in 20% of dogs and 85% of dog parks across the United States. Optimal detection of canine intestinal parasitism was achieved by combining CF and CAI. Canine intestinal parasites are common across the United States, and dog health can be enhanced by regular testing of fecal samples and routine administration of medications effective against the most common infections.

## Background

Canine intestinal parasite infections are often subclinical but can become clinically apparent in puppies and in adults with heavy burdens [1, 2]. Subclinical infections may carry a health cost, and dogs with patent infections shed eggs or cysts that can contaminate the environment and act as a source of reinfection, infection of other dogs, and in some cases infection of humans [3, 4]. Stray and shelter dogs have higher rates of patent infections than dogs in the general population, and are often rescued and relocated across country and state borders [2, 5 -7].

Humane organizations care for and relocate shelter dogs, helping to address the demand for new pets, with pet dog ownership in the United States now the highest since measuring began in 1982 [8]. If newly-homed dogs are harboring intestinal parasites and left untreated, they can be a source of infection for other dogs in their new locations. Additionally, the relationship between dogs and owners has continued to evolve with more people incorporating their dogs into daily activities and travel than in previous generations, exposing the dog to environments potentially frequented by many other dogs [8 - 10]. Understanding the national risk of canine

intestinal parasite infection is therefore important to drive recognition of the need for effective testing and control measures.

Two published reports have provided insights into the national prevalence of intestinal parasite infection of dogs in the United States [2, 5]. In the first report, findings were based on centrifugal sucrose flotation of fecal samples collected from shelter dogs, while in the second the results were based on samples submitted by veterinary practices to a testing laboratory that utilized zinc sulfate centrifugal flotation (CF). Extrapolation of results of the former study to the pet dog population is limited because shelter dogs may not have received anthelmintic treatment, and 84% of sampled dogs were under 3 years of age. Nonetheless, the findings of intestinal parasite infection in those dogs provides an indication of the potential parasite transmission risk associated with the movement of shelter dogs. A limitation of the second study is that samples were submitted by veterinary practices and so would likely have come from dogs receiving consistent high-quality veterinary care. For both studies, another limitation is that while CF is more sensitive than the passive flotation technique commonly used in veterinary practices, in many cases it can provide negative results in dogs harboring common nematode or *Giardia* infections [11 - 15]. In 2014 a validated coproantigen immunoassay (CAI) became available and when used with CF enhances the detection of canine intestinal parasite infections [14 - 18]. Thus, with the interstate relocation of dogs that could be infected with intestinal parasites and the availability of improved testing methodologies, there is opportunity for an up-to-date assessment of intestinal parasitism in dogs in the United States.

Over the last ten years across the United States, the number of off-leash dog parks has increased dramatically, providing ideal locations to sample pet dogs [19]. A national study was initiated with the objective of determining the prevalence of canine intestinal parasite infections in dogs visiting dog parks. Other objectives were to provide insight into the complementary use of CF and CAI testing to diagnose these infections, and to assess the relationship between owner-reported use of heartworm control medication (HWCM) and intestinal parasite infection.

## Methods

### *Fecal samples*

Dog parks were selected in 30 major metropolitan areas across the United States. Investigators collecting samples were veterinary staff from the College of Veterinary Medicine at Oklahoma State University, and veterinary staff of Elanco Animal Health and IDEXX. For each metropolitan area, 10 parks were selected to represent the diversity of geographic, socioeconomic and neighborhood types available in the area, taking into account factors such as safety for those collecting samples and accessibility of the parks. The target was to collect 100 samples from each metropolitan area. Consistent with earlier national surveys, results were divided into four regional areas derived from a previously described segmentation [2, 5] (Table 1).

**Table 1.** Listing of cities (alphabetical order within region) for sample collection

Southeast	Northeast	Midwest	West
Atlanta	Boston	Chicago	Albuquerque
Austin	New York City	Cleveland	Bakersfield
Charlotte	Philadelphia	Detroit	Boise
Houston	Washington DC	Indianapolis	Denver
Miami/Ft Lauderdale		Kansas City	Los Angeles
Nashville		Minneapolis	Phoenix
New Orleans		St Louis	Portland
Oklahoma City/ Tulsa			Sacramento
Raleigh/Durham			Seattle
Tampa			

All dogs from which fecal samples were collected were owned by or under the care of dog park attendees and participation was voluntary. Immediately after defecation the dog's fecal sample was collected into a plastic bag. No samples were collected from dogs belonging to any employees of the companies supporting the study, their friends or family members, investigators or assistant investigators, or to any veterinary clinic staff. Dogs brought to the park by professional dog walkers were not eligible. For owners with multiple dogs, only one dog was sampled. The person responsible for the dog had to agree for the feces to be collected and verbally respond to a study questionnaire, which included the dog's signalment and the questions "Is your dog currently on a heartworm/intestinal worm preventive/medication?" and "Has your dog ever been diagnosed with intestinal worms?" Owners responding positively to the former question were asked whether the heartworm/intestinal worm control medication (HWCM) was administered orally, topically or by injection. Brand names were neither asked nor recorded if the owner volunteered the name.

All samples were processed at a single laboratory (IDEXX, 401 Industry Rd, Louisville, KY 40208) employing validated CAIs for hookworm, whipworm, and ascarids (FecalDx<sup>®</sup>, and *Giardia* Test, IDEXX Laboratories, Inc, Westbrook, Maine) and *Giardia* [-15 - 17]. A zinc sulfate CF (specific gravity 1.24) was also used to detect a variety of parasites, including but not limited to nematodes and protozoa [20].

## Analysis of results

The proportion of dogs testing positive for each parasite was determined according to signalment, metropolitan area, and region in which the dog was sampled, whether the dog's owner reported administering a HWCM, and if the dog had been previously diagnosed with intestinal parasites. A 2-proportion z-test was used to test whether the proportion of dogs returning positive fecal tests for hookworm, whipworm, or ascarids was lower when owners reported the use of a HWCM than when owners reported not using a HWCM. A 2-proportion z-test was also used to test whether dogs reporting a previous intestinal parasite infection were more likely to be currently receiving a HWCM than those without a previous infection.

Dogs were categorized by age grouping in alignment with recent American Animal Hospital Association guidelines, with consistent years applied to each category: <1 year, puppy; 1 to 3 years, young adult; 4 to 6 years, mature adult; and  $\geq 7$  years, senior [21]. A 4-sample test for equality of proportions was used to test whether the proportion of dogs testing positive for hookworm, whipworm, ascarid or *Giardia* varied between these age groups.

Holm's multiple comparison correction was used to control the family-wise error rate due to the large number of comparisons being made. Post hoc pairwise comparisons of the proportion of HWCM usage by region were performed using Holm's multiple comparison correction.

Throughout, 95% confidence intervals were calculated using the modified Wald method, except for the use of HWCMs by age and by region for which a multinomial approach was employed to model the individual probabilities of the response variable (age category x preventive) [22].

## Results

### *Demographics and questionnaire*

Samples were collected from 3,022 dogs in 288 dog parks during July and August 2019. Sixteen samples were disqualified because they were not accompanied by completed questionnaires or because insufficient feces were available for testing. Thus, fecal testing results and questionnaires were available from 3,006 dogs. The most commonly represented age group was young adult (1 to 3 years) ( $n = 1,371$ , 45.6% of 3,006 dogs), followed by senior ( $\geq 7$  years) (659, 21.9%), mature adult (4 - 6 years) (613, 20.4%) and puppy (< 12 months) (363, 12.1%). Within the latter group 72 dogs (2.4%) were less than 6 months of age. Of the 3,006 dogs, 1,317 (43.8%) were female, of which 1,183 (89.8%) had been spayed while 1,689 (56.2%) were male, of which 84.6% had been neutered. As reported by owners, the most commonly represented breeds were: Labrador Retriever (356, 11.8% of sampled dogs), German Shepherd Dog (187, 6.2%), Golden Retriever (137, 4.6%), Australian Shepherd (103, 3.4%), Siberian Husky (102, 3.4%), Chihuahua (83, 2.8%), and Boxer (64, 2.1%). The breeds of 547 dogs (18.2%) were described as mixed or were not specified.

In response to the question on nematode parasite control, 2,069 owners (68.8% of the total) stated that they were currently providing a HWCM for their dog. Of those owners, 1,847 (89.3%) reported using an oral formulation, 68 (3.3%) a topical formulation, and 144 (7.0%) an injection. Ten owners did not know how the HWCM was being administered (Table 2). The proportion of dogs reported to be currently receiving a HWCM was significantly higher ( $P < 0.0001$ ) in those previously infected with intestinal parasites (79.2%) (estimated difference of proportions 0.111; 95% CI, 0.075, 1), compared with those without known prior intestinal worm infection (68.1%). Regionally, owner-reported HWCM use in the West was significantly lower than in each other region ( $P < 0.0001$ ). No other between-region differences were significant. By dog age grouping, the frequency of use of a HWCM was similar at approximately 70% for puppies through mature adult dogs, while 63.6% of owners of senior dogs reported that they were providing a HWCM.

**Table 2.** Number of owners (%) reporting currently using a heartworm/intestinal parasite control medication, by region and formulation

Medication use	Southeast (n = 989)	Northeast (n = 400)	Midwest (n = 708)	West (n = 909)	National (n = 3006)
Yes	829 (83.8)	317 (79.3)	570 (80.5)	353 (38.8)	2069 (68.8)
95% CI	81.5, 86.1	75.3, 83.2	77.6, 83.4	35.7, 42.0	67.2, 70.5
No	14 (14.8)	68 (17.0)	135 (19.1)	536 (59.0)	885 (29.4)
95% CI	12.6, 17.0	13.3, 20.7	16.2, 22.0	55.8, 62.2	27.8, 31.1
Unknown	14 (1.4)	15 (3.8)	3 (0.4)	20 (2.2)	52 (1.7)
95% CI	0.7, 2.2	1.9, 5.6	0.1, 0.9	1.3, 3.2	1.3, 2.2
Formulation (n, % of dogs on heartworm/intestinal control medication)					
Oral	728 (87.8)	299 (94.3)	497 (87.2)	323 (91.5)	1847 (89.3)
95% CI	85.6, 90.0	91.8, 96.9	84.5, 89.9	88.6, 94.4	87.9, 90.6
Topical	23 (2.8)	8 (2.5)	27 (4.7)	10 (2.8)	68 (3.3)
95% CI	1.7, 3.9	0.8, 4.3	3.0, 6.5	1.1, 4.6	2.5, 4.1
Injectable	74 (8.9)	9 (2.8)	43 (7.5)	18 (5.1)	144 (7.0)
95% CI	7.0, 10.9	1.0, 4.7	5.4, 9.7	2.8, 7.4	5.9, 8.1

CI – confidence interval

### *Fecal test results*

Using CAI and CF, intestinal parasites were detected in 622 (20.7%) samples, with 8.8% positive for one or more of hookworm, whipworm, and ascarids (Table 3). Of the 288 parks, 245 (85.1%) provided samples positive for any intestinal parasites, with 49.7% positive for a nematode parasite. The most commonly detected parasite was *Giardia*, while hookworm was the most commonly detected nematode.

**Table 3.** Number (%; 95% confidence interval) of dogs and parks with  $\geq 1$  sample positive for intestinal parasites by coproantigen immunoassay or centrifugal flotation

	Dogs Number (%; 95% CI) (N = 3006)	Dog Parks Number (%; 95% CI) (N = 288)
Any parasitic species <sup>‡</sup>	622 (20.7; 19.3, 22.2)	245 (85.1; 80.5, 88.8)
Nematodes <sup>#</sup> and/or <i>Giardia</i>	609 (20.3; 18.9, 21.7)	243 (84.4; 79.7, 88.1)
<i>Giardia</i> spp.	391 (13.0; 11.9, 14.3)	213 (74.0; 68.6, 78.7)
Nematodes <sup>#</sup>	263 (8.8; 7.8, 9.8)	143 (49.7; 49.7, 55.4)
Hookworm	214 (7.1; 6.3, 8.1)	125 (43.4; 37.8, 49.2)
Whipworm	58 (1.9; 1.0, 1.8)	52 (18.1; 14.0, 22.9)
Ascarid	17 (0.6; 0.3, 0.8)	16 (5.6; 3.4, 8.9)
<i>Cystoisospora</i>	16 (0.5; 0.3, 0.9)	16 (5.6; 3.4, 8.9)
<i>Alaria</i>	1 (0.0; 0.0, 0.2)	1 (0.4; 0.0, 2.1)
Capillarids	2 (0.1; 0, 0.3)	1 (0.4; 0.0, 2.1)
<i>Spirometra</i>	2 (0.1; 0, 0.3)	2 (0.7; 0.0, 2.7)
Taeniid	1 (0.0; 0.0, 0.2)	1 (0.4; 0.0, 2.1)

<sup>‡</sup>Includes all parasitic species of nematodes, as well as *Alaria*, *Cystoisospora*, and *Spirometra* and taeniid.

<sup>#</sup>Nematodes: hookworm, whipworm, ascarid (includes coinfections)

Use of CF and microscopy allowed identification of hookworm and ascarid ova. Of 110 samples positive for hookworm ova, 108 (98.2%) were *Ancylostoma caninum*, 2 (1.8%) were *Uncinaria stenocephala*. Of 12 samples positive by CF for ascarids, 11 (91.7%) were *Toxocara canis* and 1 (8.3%) *Toxascaris leonina*.

A 4-sample test for equality of proportions of age groups with positive tests for one or more of hookworm, whipworm and ascarids was significant ( $P < 0.0001$ ), with the highest prevalence in dogs less than 12 months of age. Infection with hookworm, whipworm and *Giardia* was detected regardless of age group, while ascarid infection was only identified in samples from dogs under 4 years of age (Figs 1 and 2; Table 4). Dogs reported to be currently on a HWCM had a significantly lower proportion of positive test results for hookworm, whipworm or ascarid (7.5%) than those not receiving a HWCM (11.4%) ( $P = 0.0003$ ; estimated difference of proportions -0.039; 95% CI, -1, -0.018) (Table 5).

**Table 4:** Number (%) of dogs positive for intestinal parasites by coproantigen immunoassay or centrifugal flotation by age grouping



Demographic category	Nematodes/ <i>Giardia</i>	Nematodes	Hookworm	Whipworm	Ascarid	<i>Giardia</i>
12 months; puppy (n = 363)	152 (41.9)	50 (13.8)	35 (9.6)	14 (3.9)	11 (3.0)	121 (33.3)
95% confidence interval	36.9, 47.0	10.6, 17.7	7.0, 13.1	2.3, 6.4	1.6, 5.4	28.7, 38.3
3-6 years; young adult (n = 371)	307 (22.4)	132 (9.6)	108 (7.9)	30 (2.2)	6 (0.4)	195 (14.2)
95% confidence interval	20.3, 24.7	8.2, 11.3	6.6, 9.4	1.5, 3.1	0.2, 1.0	12.5, 16.2
7-13 years; mature adult (n = 13)	70 (11.4)	43 (7.0)	37 (6.0)	8 (1.3)	0 (0.0)	30 (4.9)
95% confidence interval	9.1, 14.2	5.2, 9.3	4.4, 8.2	0.6, 2.6	0.0, 0.8	3.4, 6.9
14-17 years; senior (n = 659)	80 (12.1)	38 (5.8)	34 (5.2)	6 (0.9)	0 (0.0)	45 (6.8)
95% confidence interval	9.9, 14.9	4.2, 7.8	3.7, 7.1	0.4, 2.0	0.0, 0.7	5.1, 9.0

Percentages based on the number of positive dogs in that age group as the numerator and total of dogs reported to be in that category as denominator

**Table 5:** Number (%<sup>a</sup>) of dogs positive for intestinal parasites by coproantigen immunoassay or centrifugal flotation according to owner-reported current use of a heartworm/intestinal parasite control medication <sup>a</sup>

Demographic characteristic	Nematodes/ <i>Giardia</i>					
	<i>Giardia</i>	Nematodes	Hookworm	Whipworm	Ascarid	<i>Giardia</i>
Dogs on medication: Yes (n = 2069)	404 (19.5)	155 (7.5)	125 (6.0)	31 (1.5)	11 (0.5)	276 (13.3)
95% confidence interval	17.9, 21.3	6.4, 8.7	5.1, 7.2	1.1, 2.1	0.3, 1.0	12.0, 14.9
Oral (n = 1847)	365 (19.8)	138 (7.5)	111 (6.0)	28 (1.5)	10 (0.5)	251 (13.6)
95% confidence interval	18.09, 21.6	6.4, 8.8	5.0, 7.2	1.0, 2.2	0.3, 1.0	12.1, 15.2
Topical (n = 68)	16 (23.5)	6 (8.8)	5 (7.4)	2 (2.9)	0 (0.0)	11 (16.2)
95% confidence interval	14.9, 35.0	3.8, 18.3	2.8, 16.5	0.2, 10.7	0.0, 6.4	9.1, 26.9
Injection (n = 144)	22 (15.3)	10 (6.9)	8 (5.6)	1 (0.7)	1 (0.7)	14 (9.7)
95% confidence interval	10.2, 22.1	3.7, 12.5	2.7, 10.7	0.0, 4.2	0.0, 4.2	5.8, 15.8
Medication formulation unknown (n = 10)	1 (10.0)	1 (10.0)	1 (10.0)	0 (0.0)	0 (0.0)	0 (0.0)
95% confidence interval	0.0, 42.6	0.0, 42.6	0.0, 42.6	0.0, 32.1	0.0, 32.1	0.0, 32.1
Dogs on medication: No (n = 885)	190 (21.5)	101 (11.4)	84 (9.5)	25 (2.8)	6 (0.7)	106 (12.0)
95% confidence interval	18.9, 24.3	9.5, 13.7	7.7, 11.6	1.9, 4.2	0.3, 1.5	10.0, 14.3
Medication status unknown (n = 52)	15 (28.9)	7 (13.5)	5 (9.6)	2 (3.9)	0 (0.0)	9 (17.3)
95% confidence interval	18.3, 42.4	6.4, 25.6	3.8, 21.0	0.3, 13.7	0.0, 8.2	9.2, 30.0

<sup>a</sup>Percentages based on the number of positive dogs in that demographic category as the numerator and total of dogs reported to be in that category as denominator

Coinfections were detected in 49 (1.6%) dogs. The most common coinfection was hookworm with *Giardia* in 24 dogs (0.8%), followed by hookworm and whipworm coinfection in 12 dogs (0.4%). Prevalence was also calculated by region (Table 6). In each region less than 1% of tests were positive for *Cystoisospora*. Details of the proportion of infected dogs and parks from which positive samples were collected in each of the 30 metropolitan areas are provided in supplemental Tables 1 and 2.

**Table 6.** Regional distribution: number (%) of dogs and parks with a positive test (coproantigen immunoassay or centrifugal flotation) for intestinal parasites

Positive tests		Nematodes/ <i>Giardia</i>	Nematodes	Hookworm	Whipworm	Ascarid	<i>Giardia</i>
From dogs	Southeast (n = 989)	270 (27.3)	169 (17.1)	151 (15.3)	27 (2.7)	5 (0.5)	129 (13.0)
	95% confidence interval	24.6, 30.2	14.9, 19.6	13.2, 17.7	1.9, 4.0	0.2, 1.2	11.1, 15.3
	Northeast (n = 400)	72 (18.0)	25 (6.3)	21 (5.3)	8 (2.0)	1 (0.3)	48 (12.0)
	95% confidence interval	14.5, 22.1	4.2, 9.1	3.4, 7.9	1.0, 4.0	0.0, 1.6	9.2, 15.6
	Midwest (n = 708)	131 (18.5)	44 (6.2)	28 (4.0)	15 (2.1)	6 (0.9)	98 (13.8)
	95% confidence interval	15.8, 21.5	4.7, 8.3	2.7, 5.7	1.3, 3.5	0.3, 1.9	11.5, 16.6
	West (n = 909)	136 (15.0)	25 (2.8)	14 (1.5)	8 (0.9)	5 (0.6)	116 (12.8)
	95% confidence interval	12.8, 17.4	1.9, 4.1	0.9, 2.6	0.4, 1.8	0.2, 1.3	10.7, 15.1
From parks	Southeast (n = 96)	86 (90.0)	73 (76.0)	69 (71.9)	25 (26.0)	5 (5.2)	70 (72.9)
	95% confidence interval	81.7, 94.4	66.6, 83.5	62.1, 79.9	18.3, 35.7	2.0, 11.9	81.7, 94.4
	Northeast (n = 39)	31 (79.5)	17 (43.6)	16 (41.0)	7 (18.0)	1 (2.6)	28 (71.8)
	95% confidence interval	64.2, 89.5	29.3, 59.0	27.1, 56.6	8.7, 33.0	0.0, 14.4	56.1, 83.6
	Midwest (n = 68)	59 (86.8)	33 (48.5)	26 (38.2)	12 (17.7)	5 (7.4)	50 (73.5)
	95% confidence interval	76.5, 93.1	37.1, 60.2	27.6, 50.1	10.2, 28.5	2.8, 16.5	61.9, 82.6
	West (n = 85)	67 (78.8)	20 (23.5)	14 (16.5)	8 (9.4)	5 (5.9)	65 (76.5)
	95% confidence interval	68.9, 86.3	15.7, 33.6	10.0, 25.9	4.6, 17.7	2.2, 13.4	66.4, 84.3

See supplementary tables for detailed numbers by metropolitan region

#### *Coproantigen immunoassay and centrifugal flotation*

In detection of hookworm, whipworm, or ascarids, 289 infections were found (Fig 3). Of those 289, 162 (56.1%) were detected using CF and 244 (84.4%) using CAI. Both methods were in positive agreement in 117 (40.5%) of these infections. The combination of CF and CAI detected 78.4% more infections than did CF alone. For hookworm, the methods were in positive concordance for 85 infections, CAI detected 104 infections when CF was negative, and for 25 infections the reverse was true. Of the 58 *Trichuris vulpis* infections, the findings

for each method were in positive concordance for 22, 18 infections detected by CAI were negative on CF, and 18 infections detected by CF were negative by CAI.

## Discussion

The present study is the first large-scale effort to determine the prevalence of intestinal parasites in dogs visiting dog parks throughout the United States. We documented parasites in over 20% of dogs and 85% of parks by testing fecal samples collected from more than one-third of the 810 dog parks in the United States [19]. The prevalence of parasite infection in dogs in the present study is higher than that seen in pet dogs with fecal samples submitted to national diagnostic laboratories (12.5%) but lower than reported from stray dogs upon arrival at municipal shelters (36%), a difference likely due, in part, to the fact that while dogs attending dog parks receive attention from their owners, not all benefit from routine veterinary care [2, 5].

*Giardia* was the most commonly identified intestinal parasite both in the present study (13.0%) and in an earlier national report of parasites in pet dogs (4.0%) [2]. In contrast, *Giardia* was only rarely detected (0.6%) in a national survey of shelter dogs in which samples were examined by sugar CF, presumably due to the lower sensitivity of this method for recovering the fragile cysts [5, 12]. Infections with *Giardia* are often subclinical, and cysts or trophozoites are shed intermittently from infected dogs, limiting the diagnostic sensitivity of CF as a stand-alone method. By combining CAI with CF, the present study may better estimate the true prevalence of infection. An earlier report using a similar strategy (CF + CAI) found a *Giardia* prevalence of 15.6% among dogs presenting to clinics with diarrhea or vomiting [23]. Dogs in shelters, breeding facilities, and kennels are more likely to be infected with *Giardia*, and an increased prevalence among dogs that visit dog parks has been reported [24].

Nematodes were also commonly detected, identified in 10% of the samples tested. As in other studies using CF alone, the hookworm *A. caninum* and whipworm *T. vulpis*, which present a risk to canine health throughout all life stages of a dog, were the most common intestinal nematodes identified [14, 25, 26]. Surprisingly, passive flotation remains the most commonly used technique in clinical practice despite multiple studies demonstrating that it fails to detect infection when compared to CF [12 - 15]. Combining CAI for nematode antigens with CF in the present study resulted in detection of nearly 80% (78.4%) more nematode infections than CF alone, likely due to the CAI detecting non-patent infections [16, 17]. These findings reinforce the previously demonstrated complementary value of combining CAI with CF to enhance intestinal nematode detection [27].

Cestodes were only rarely detected in the present study even though recent studies in the United States have shown that the prevalence of cestode infection is greater than that of nematodes in some populations of dogs and cats [14, 28]. Because cestode eggs are heavy and shed in proglottids, recovery by CF is poor [29]. Using a higher specific gravity sugar solution for CF in part addresses this limitation, enhancing recovery of taeniid eggs, but sensitivity remains very low for identifying *Dipylidium caninum* infection [14, 29]; CAI is not yet commercially available for canine cestodes.

As with earlier national reports, although parasites are found in every region, the present study indicates that the highest prevalence of nematode intestinal parasite infection, and in particular *A. caninum* infection, occurs

in the Southeast [2, 5]. This factor that, together with the very high prevalence of heartworm infection in the southeastern United States, likely explains the common owner-reported use of HWCM in this region. Other canine surveys from the region support that hookworm and whipworm are very common, identifying *A. caninum* in as many as 48% of shelter dogs and 17% of samples from dog parks, and *T. vulpis* in up to 39% of shelter dogs and 8.5% of samples from dog parks [14, 26, 30, 31].

In the present study, more than 15% of dogs visiting dog parks in the Southeast, and 4 to 5.3% of those in the Midwest and Northeast, were infected with hookworm, a finding that is particularly concerning given the recent reports of multiple drug-resistant hookworms in pet dogs, including Greyhounds [32 - 34]. Although we do not know the resistance status, 6 of the 12 Greyhounds sampled from dog parks in the present study were positive for hookworm, and 5 of those 6 were reported by the owner to be on a HWCM at the time they were sampled (data not shown). Hundreds of thousands of stray and rescue dogs, including retired Greyhounds, are commonly relocated from the southern United States to other regions, a practice that can facilitate movement of parasites [7, 35, 36].

Intestinal nematodes, particularly *A. caninum* and *T. vulpis*, but not all intestinal parasites (e.g. *Giardia*, *Cystoisospora* spp.), were less commonly detected in samples from dogs reportedly receiving HWCM in the present study, providing evidence that implementing broad-spectrum parasite control measures reduces infections and limits environmental contamination with eggs. This finding has long been suspected and is supported by other regional surveys [26, 37]. However, hookworm, whipworm, or ascarid infections were still detected in some dogs reportedly receiving HWCM in the present study, perhaps due to the earlier detection afforded by antigen testing, the short (2-3 week) prepatent period of hookworm, and the fact that not all HWCMs are effective against whipworm or other intestinal nematodes [16, 17, 27, 38]. For example, injectable products are not effective against either whipworm or ascarids, and are not FDA-label approved for efficacy against new hookworm infections beyond the time of initial administration [39, 40]. Detection of nematode infections and other parasites in dogs reported to be receiving HWCMs in the present study indicates that regular testing is warranted for all dogs even when these medications are used.

Interestingly, a majority (68.8%) of owners in the present study reported current use of a HWCM, similar to other recent papers surveying dog owners in Oklahoma and Florida [26, 41]. This high owner-reported prevalence of use contrasts with other data indicating that, even in areas where heartworm infection is common, only a minority of pet dogs receive a HWCM [42, 43]. Factors that may bias owner-reported use of HWCM include forgetfulness, guilt about not following veterinary recommendations, and confusion about a given product's efficacy for heartworm versus external parasites. Additionally, the study was conducted in the summer months, when mosquitoes are most active, a timing that may have resulted in a higher proportion of owners reporting current use of HWCM. Routine use of HWCM is critically important because many of the products can limit environmental contamination with zoonotic parasites like *A. caninum* and *T. canis* which cause cutaneous larva migrans and toxocariasis, respectively. Other strategies such as reducing the number of stray or free-roaming animals, prompt removal of all pet feces, wearing shoes to avoid skin contact with contaminated soil, and avoiding geophagy in children can also reduce infection risk [44].

## Summary And Conclusion

Dog parks and other areas in which dogs are walked (e.g., neighborhood walking paths, apartment complexes) provide valuable human and animal socialization opportunities, but also may increase the risk of exposure to intestinal parasite infection. Maintaining dogs on broad spectrum parasite control products with efficacy against hookworm, whipworm, and ascarids helps mitigate this risk, decreasing the health risks to dogs and the potential for zoonotic infections, particularly as the owner-pet relationship and interaction grow ever closer. Indeed, in the present study reported use of HWCM reduced but did not eliminate infection with intestinal nematodes (Table 5). Canine cestode infection prevalence remains unclear but recent work suggests that tapeworms are common in dogs and that routine treatment for tapeworms may also be warranted [14]. The CAI used in the present study detected more infections than did CF alone, although using the two tests in concert allowed the greatest number of infections to be identified (Fig 3). Regular fecal testing for parasites by CF and CAI is recommended to safeguard canine health by identifying infections early and as a means of monitoring product use and continued efficacy

## Abbreviations

CAI Coproantigen immunoassay; CF Centrifugal flotation; CI Confidence interval; FDA Food and Drug Administration; HWCM Heartworm/intestinal parasite control medication

## Declarations

### Ethics approval

The protocol was approved by Elanco Privacy and Consumer Information Review Board. No animals were handled, and no treatments were administered.

### Consent for publication

Not applicable

### Availability of data and material

Data from this study are available for review on reasonable request to Elanco Animal Health, IDEXX or Oklahoma State University

### Competing interests

KS, TMK, CHL and AJR are employees of Elanco. SH, TG and SS are employees of IDEXX. WGR has received payments for clinical research and consulting fees from Elanco; SL and KTD have received honoraria, expense reimbursement, or research support from several companies that manufacture parasite control and diagnostic products.

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### Authors' contributions

All authors participated in the design and implementation of the study and all revised and approved the final version of the manuscript.

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## Figures

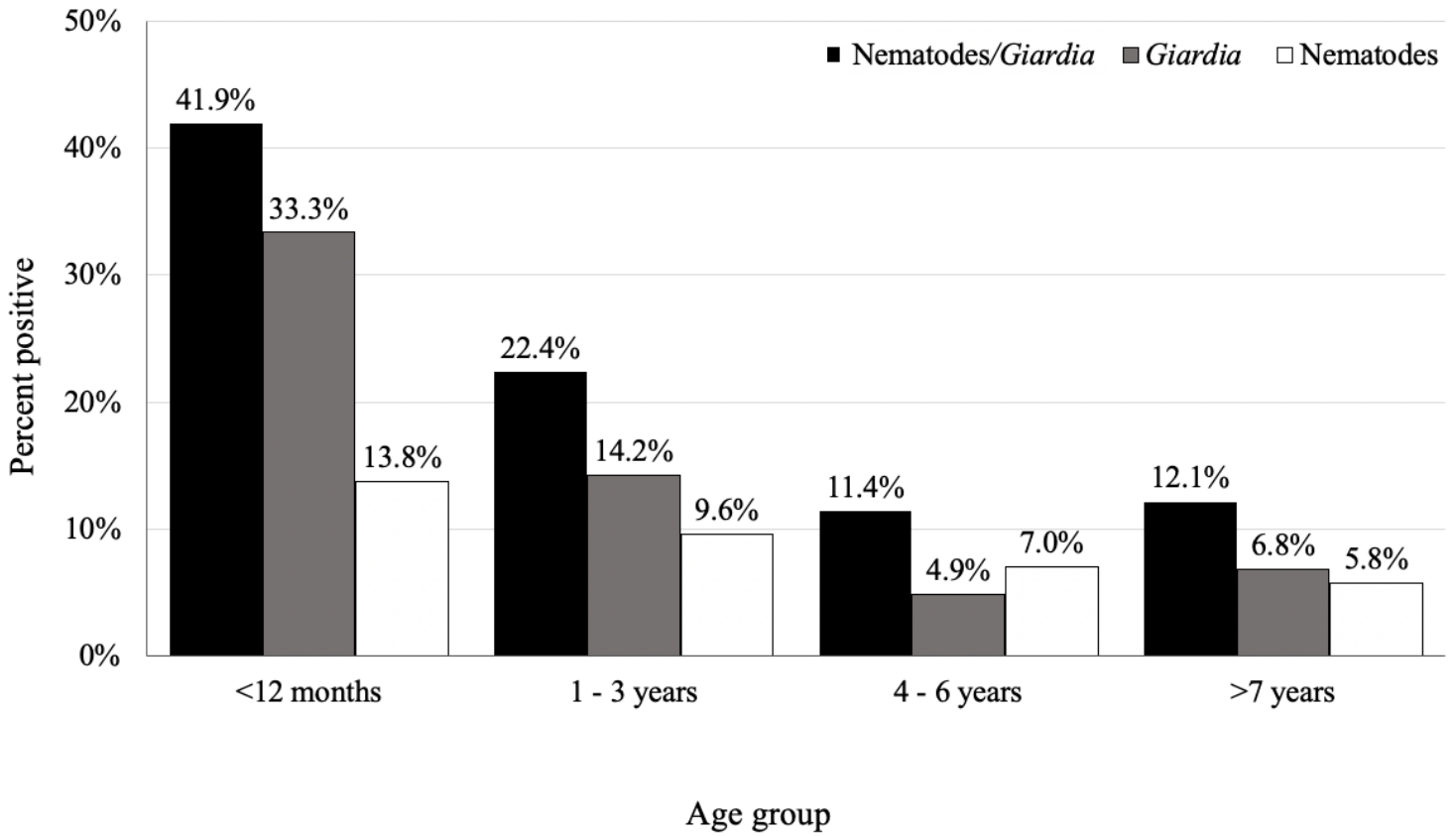
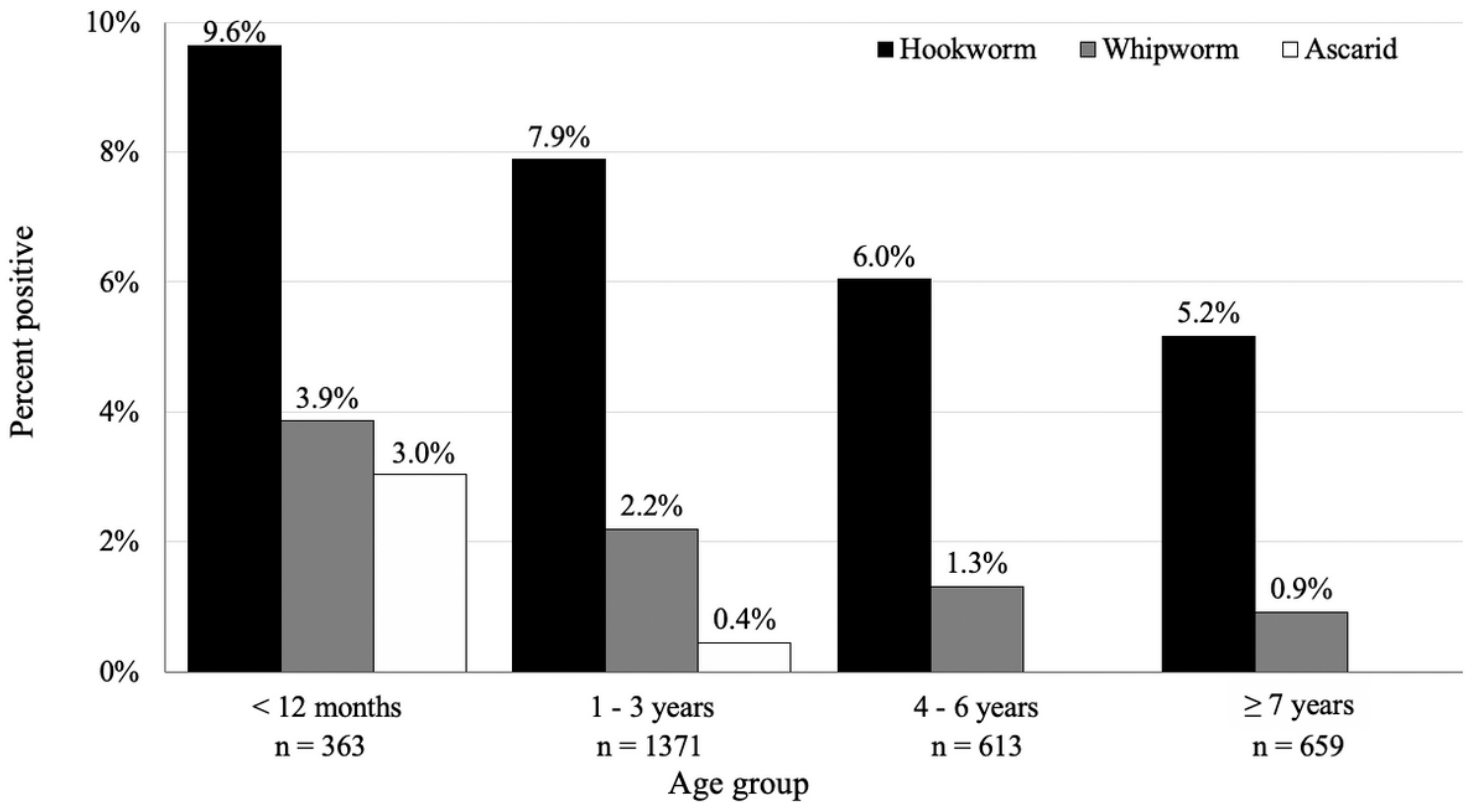


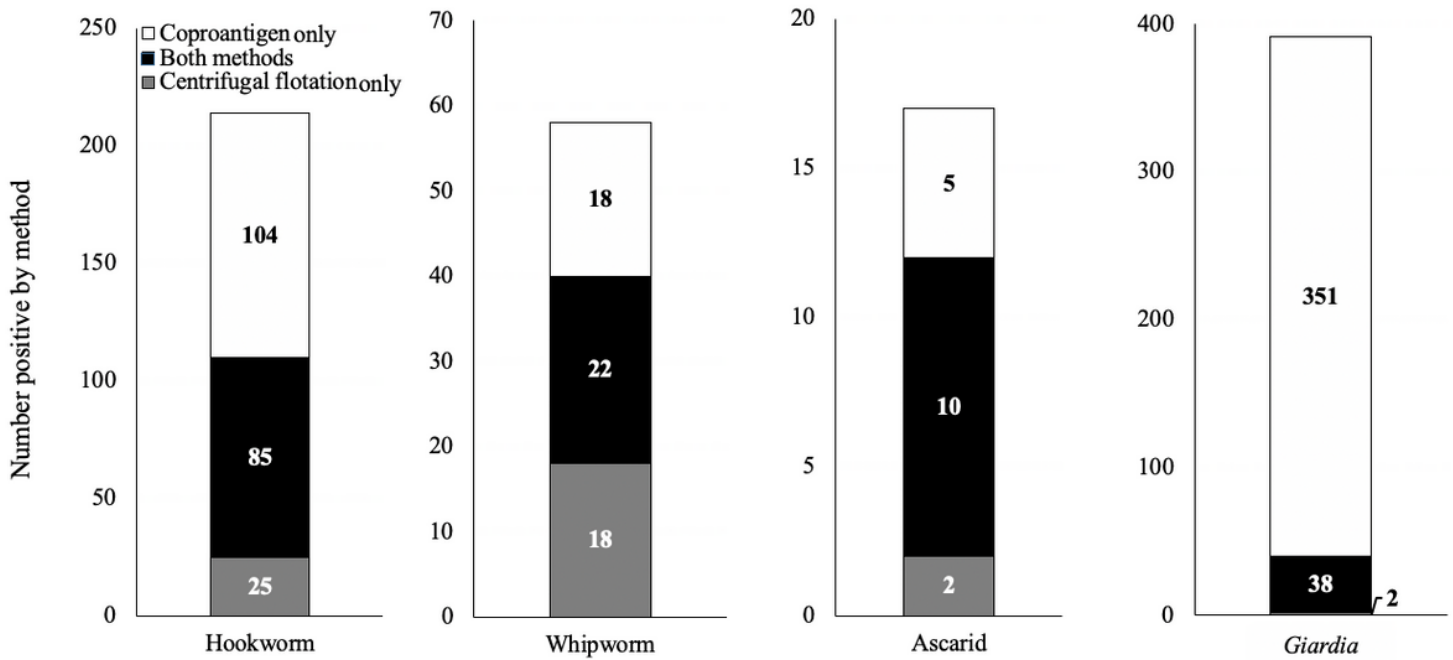
Figure 1

Percent of dogs in each age group positive for intestinal parasites



**Figure 2**

Percent of dogs in each age group positive for a nematode parasite. Ascarids were not detected in dogs >3 years of age



**Figure 3**

Number of infections identified by centrifugal flotation only, both methods, and coproantigen immunoassay only

## Supplementary Files

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- [SupplementalTable1Dogsbycity.docx](#)
- [SupplementalTable2Parksbycity.docx](#)