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The prevalence of *Giardia* infection in dogs and cats, a systematic review and meta-analysis of prevalence studies from stool samples

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ABSTRACT

Giardia has a wide range of host species and is a common cause of diarrhoeal disease in humans and animals. Companion animals are able to transmit a range of zoonotic diseases to their owners including giardiasis, but the size of this risk is not well known. The aim of this study was to analyse giardiasis prevalence rates in dogs and cats worldwide using a systematic search approach. Meta-analysis enabled to describe associations between *Giardia* prevalence and various confounding factors. Pooled prevalence rates were 15.2% (95% CI 13.8–16.7%) for dogs and 12% (95% CI 9.2–15.3%) for cats. However, there was very high heterogeneity between studies. Meta-regression showed that the diagnostic method used had a major impact on reported prevalence with studies using ELISA, IFA and PCR reporting prevalence rates between 2.6 and 3.7 times greater than studies using microscopy. Conditional negative binomial regression found that symptomatic animals had higher prevalence rates ratios (PRR) than asymptomatic animals 1.61 (95% CI 1.33–1.94) in dogs and 1.94 (95% CI 1.47–2.56) in cats. *Giardia* was much more prevalent in young animals. For cats >6 months, PRR = 0.47 (0.42–0.53) and in dogs of the same age group PRR = 0.36 (0.32–0.41). Additionally, dogs kept as pets were less likely to be positive (PRR = 0.56 (0.41–0.77)) but any difference in cats was not significant. Faecal excretion of *Giardia* is common in dogs and slightly less so in cats. However, the exact rates depend on the diagnostic method used, the age and origin of the animal. What risk such endemic colonisation poses to human health is still unclear as it will depend not only on prevalence rates but also on what assemblages are excreted and how people interact with their pets.

1. Introduction

Giardia is a common cause of acute gastroenteritis in humans and many animal species across the globe. *Giardia* is one of the most important protozoan pathogens causing diarrhoeal disease, in both developed and developing countries. In the USA, *Giardia* incidence ranges from 7.4 to 7.6 cases per 100,000 populations (Geurden et al., 2008) and in the United Kingdom, an incidence of 5.5 cases per 100,000 people was reported in 2005 (Feng and Xiao, 2011). However, these figures are almost certainly an underestimate and about 2.8×10^8 new cases are likely to occur in humans per annum (Lane and Lloyd, 2002). Furthermore, chronic giardiasis can lead to malabsorption and failure to thrive in children increasing the disease burden due to this infection (Cotton et al., 2011). Although *Giardia* does cause disease, it can also be asymptomatic in humans and animals (Ballweber et al., 2010). A recent large scale

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case–control study in developing countries by Kotloff and colleagues found no association between *Giardia* infection and moderate to severe diarrhoea in infants and young children (Kotloff et al., 2013). Interestingly, the authors reported higher *Giardia* prevalence rates in the control group. This is in accordance with the findings of Veenemans and colleagues who reported that *Giardia* infection can be associated with a protective effect against diarrhoea in developing countries (Veenemans et al., 2011). However, the mechanisms of this protection are not fully understood.

The fact that *Giardia* can infect both human and animals has raised concerns about the risk to public health from companion animals (Thompson et al., 2008). The level of risk depends on prevalence rates and excretion patterns. However, this risk is only linked to the presence of human infective *Giardia* assemblages (A and B) (Caccio et al., 2005). In an excellent review of *Giardia* in cats and dogs, Ballweber and colleagues noted that reported prevalence of *Giardia* in stools varied from one study to another and in part this variation was associated with geography, detection method, age of animal, whether or not symptomatic and where the animal was housed (Ballweber et al., 2010). However, the authors did not formally test these observations and so we are not yet able to fully quantify the impact that such factors have on reported animal prevalence. In order to better define the prevalence of *Giardia* in cats and dogs, we performed a systematic review and meta-analysis. In addition, we undertook a series of regression analyses to further investigate and so quantify the impact certain factors would have on apparent prevalence.

2. Methods

2.1. Search strategy

The Ovid/Medline and CAB abstracts databases were searched for studies that reported on the prevalence of *Giardia* in either dogs or cats. All studies that reported on cats or dogs were included, providing that the authors stated how many samples were tested, how many were positive and the detection method. To remove potential bias for historical studies that may have not used modern detection methods; we restricted our search to papers published from 2001 onward. The initial search using the exploded MESH search terms in Ovid "*Giardia*" and "prevalence" and "cats" or "dogs" was run in September 2011 and updated in October 2014. The more agricultural and veterinary focused database CAB abstracts was searched in October 2014 using the following search terms: "dog or dogs or canine or canines" and" *Giardia*" and "prevalence" for dogs and "cat" or "cats" or "canine or "canines" and" *Giardia*" and "prevalence" for cats. The retrieved papers were screened using title and abstract and all eligible papers were retained for full text analysis.

2.2. Data extraction

For each prevalence study, the following were recorded: (1) host species, (2) location of study, (3) clinical signs, (4) age range and origin (pet or other), (5) method of detection, (6) total number of faecal samples, and (7) number of *Giardia* positive samples

2.3. Data analysis

Data was initially recorded on Microsoft Excel. For the calculation of pooled prevalence, data was transferred into Stats Direct^{TM} (http://www.statsdirect.co.uk/). Random effects pooled prevalence and heterogeneity were calculated and Forest plots generated. Publication bias was assessed by means of funnel plots and Harbord's bias index. Where a paper presented subgroup analyses, these were combined for the initial meta-analysis except where these subgroups were based on whether or not the animals tested were known to be symptomatic or asymptomatic. Where prevalence results for sub-groups were presented in the original paper (in terms of age group and animal origin), subsequent analyses treated these as separate study arms to assess the effect of these variables on prevalence rates.

The impact of predictors of prevalence was tested using STATA version 13.0. For the two predictors that were known for all studies (region and diagnostic method), random effects negative binomial regression was performed, with region and diagnostic method as confounding variables. For those parameters that were only extractable for a limited number of studies (symptoms, age group and whether or not the animals were pets), we used conditional negative binomial regression. In this regression, only those studies that had reported each subgroup in the same paper were included and so this was effectively a matched analysis (Cummings and McKnight, 2004).

3. Results

The database searches retrieved 594 papers. Title and abstract scanning enabled us to exclude 123 studies (Fig. 1). 374 studies were retained for investigation. During data extraction, further 205 papers were excluded because of one of the following reasons: do not satisfy inclusion criteria including other host species, present the same results as another paper published by the same author (generally same year of publication), inability of access full length article and language of publication. One paper was identified through reference lists and was included. Therefore 169 papers were retained for analysis. Details of all included studies are given in Table 1. Out of these 169 papers, 127 had data on dogs and 68 on cats. Table 2 summarises the characteristics of the included studies according to the detection method and geographical region. All further analyses were done separately on dogs and cats.

3.1. Prevalence in dogs

Amongst the 127 papers in dogs (150 study arms), samples were obtained from 4,309,451 animals, of which 112,513 (2.61%) were positive. Fig. 2 shows the forest plot for all included studies ordered by detection method and reducing prevalence. The random effects

Table 1
Characteristic of included studies used for *Giardia* prevalence meta-analysis from dogs and cats.

Host species	Location	Clinical signs	Age groups and origin	Detection method	Total	Positives	Prevalence rate	Collection period	Publication year	Reference
Dogs	Egypt	Mixed	3 age groups (pet and police dogs)	Microscopy	180	21	0.12	2012–2013	2014	(Ahmed et al., 2014)
Dogs	Brazil	Symptomatic	No age groups (pets)	PCR	104	14	0.13	Not stated	2014	(Gizzi et al., 2014)
Dogs	Brazil	Asymptomatic	No age groups (pets)	PCR	43	2	0.05	Not stated	2014	(Gizzi et al., 2014)
Dogs	Brazil	Unknown	2 age group (shelter and pet shop)	Microscopy	80	34	0.43	2011–2012	2014	(Mota et al., 2014)
Dogs	Portugal	Symptomatic	4 age groups (pets)	Microscopy	193	30	0.16	2008–2010	2014	(Neves et al., 2014)
Dogs	Portugal	Asymptomatic	4 age groups (pets)	Microscopy	175	13	0.07	2008–2010	2014	(Neves et al., 2014)
Dogs	Spain	Unknown	No age group (shelter and hunting)	Microscopy	169	64	0.38	Not stated	2014	(Ortuno et al., 2014)
Dogs	Italy	Symptomatic	6 age groups (pets and kennels)	Microscopy	435	124	0.29	2007–2010	2014	(Pipia et al., 2014)
Dogs	Italy	Asymptomatic	6 age groups (pets and kennels)	Microscopy	220	48	0.22	2007–2010	2014	(Pipia et al., 2014)
Dogs	Canada	Unknown	2 age groups (pets)	ELISA	251	16	0.06	2009	2014	(Procter et al., 2014)
Dogs	Cambodia	Unknown	No age group (pets)	PCR	94	2	0.02	2012	2014	(Schar et al., 2014)
Dogs	Canada	Unknown	2 age group (pets)	IFA	251	62	0.25	2010	2014	(Smith et al., 2014)
Dogs	Taiwan	Unknown	No age groups (strays)	PCR	118	11	0.09	2010–2011	2014	(Tseng et al., 2014)
Dogs	Iran	Unknown	2 age groups (strays)	Microscopy	100	9	0.09	2013	2014	(Yagoob and Bahman, 2014)
Dogs	Iran	Asymptomatic	2 age group (pets)	Microscopy	210	2	0.01	2010	2014	(Gharekhani, 2014)
Dogs	USA	Mixed	No age group (shelter)	IFA	672	196	0.29	2006–2009	2014	(Johansen et al., 2014)
Dogs	China	Unknown		ELISA	318	51	0.16	Not stated	2014	(Yang et al., 2014)
Dogs	Italy	Mixed	2 age groups (pets)	ELISA	208	42	0.20	2010–2011	2014	(Zanzani et al., 2014)
Dogs	Venezuela	Unknown	3 age group (pets)	Microscopy	98	14	0.14	2007	2013	(Cazorla Perfetti and Morales Moreno, 2013)
Dogs	Brazil	Unknown	No age groups (pets)	Microscopy	195	33	0.17	2009–2012	2013	(Farias et al., 2013)
Dogs	China	Unknown	2 age group (farm and police)	PCR	205	27	0.13	2011	2013	(Li et al., 2013)

Table 1 (*Continued*)

Host species	Location	Clinical signs	Age groups and origin	Detection method	Total	Positives	Prevalence rate	Collection period	Publication year	Reference
Dogs	Trinidad and Tobago	Unknown	2 age groups (kennel and stray)	Microscopy	104	26	0.25	2010–2011	2013	(Mark-Carew et al., 2013)
Dogs	USA	Mixed	4 age groups (pets)	Microscopy	2,468,359	10,843	0.00	2003–2009	2013	(Mohamed et al., 2013)
Dogs	Brazil	Asymptomatic	6 age groups (strays)	Microscopy	357	19	0.05	2011–2012	2013	(Quadros et al., 2013)
Dogs	Italy	Mixed	No age group (pets)	Microscopy	239	9	0.04	2008–2010	2013	(Riggio et al., 2013)
Dogs	India	Symptomatic	3 age group (pets)	ELISA	120	49	0.41	2010–2011	2013	(Shikha et al., 2013)
Dogs	Peru	Symptomatic	4 age groups (pets)	Microscopy	180	21	0.12	2009–2010	2013	(Sotelo et al., 2013)
Dogs	Peru	Asymptomatic	4 age groups (pets)	Microscopy	120	29	0.24	2009–2010	2013	(Sotelo et al., 2013)
Dogs	Canada	Unknown	1 age group (mixed)	IFA	209	61	0.29	2006	2013	(Uehlinger et al., 2013)
Dogs	Brazil	Mixed	No age group (mixed origin)	Microscopy	300	48	0.16	2007–2009	2012	(Paz e Silva et al., 2012)
Dogs	Ivory Coast	Unknown	No age group (free roaming domestic animals)	PCR	11	6	0.55	Not stated	2012	(Berrilli et al., 2012)
Dogs	Romania	Unknown	2 age groups (mixed origin)	ELISA	416	144	0.35	2008–2009	2012	(Mircean et al., 2012)
Dogs	USA	Unknown	No age category (pets)	Microscopy	129	5	0.04	2009–2010	2012	(Wang et al., 2012)
Dogs	Germany	Unknown	2 age groups (stray)	ELISA	341	39	0.11	2006–2007	2012	(Becker et al., 2012)
Dogs	Spain	Unknown	No age group (shelter)	Microscopy	604	99	0.16	Not stated	2012	(Dado et al., 2012)
Dogs	China	Symptomatic	3 age group (pets)	PCR	57	15	0.26	2010–2011	2012	(Li et al., 2012)
Dogs	China	Asymptomatic	3 age group (pets)	PCR	152	8	0.05	2010–2011	2012	(Li et al., 2012)
Dogs	Peru	Unknown	4 age groups (pets)	Microscopy	130	19	0.15	2008	2012	(Pablo et al., 2012)
Dogs	Canada	Unknown	No age group (pets)	IFA	231	48	0.21	2009–2011	2012	(Schurer et al., 2012)
Dogs	Poland	Asymptomatic	>12 months Sled dogs	IFA	108	31	0.29	2009–2010	2011	(Bajer et al., 2011)
Dogs	USA	Asymptomatic	No age category (pets)	Microscopy	519,585	35,172	0.07	2009	2011	(Covacin et al., 2011)
Dogs	Japan	Asymptomatic	≤3 months (pet shop puppies)	ELISA	1794	420	0.23	2007–2009	2011	(Itoh et al., 2011a)
Dogs	Japan	Symptomatic	2 age groups (pets)	ELISA	128	19	0.15	2008–2010	2011	(Itoh et al., 2011b)

Dogs	Japan	Asymptomatic	2 age groups (pets)	ELISA	2237	177	0.08	2008–2010	2011	(Itoh et al., 2011b)
Dogs	Germany	Mixed	6 age categories (pets)	ELISA	24,677	4591	0.19	2003–2011	2011	(Barutzki and Schaper, 2011)
Dogs	Costa Rica	Mixed	No age group (pets)	IFA	58	5	0.09	2009	2011	(Scorza et al., 2011)
Dogs	Canada	Unknown	No age category (pets)	IFA	75	10	0.13	2007	2011	(Bryan et al., 2011)
Dogs	Portugal	Unknown	No age category (household and kennels)	Microscopy	126	31	0.25	2007–2008	2011	(Ferreira et al., 2011)
Dogs	Canada	Unknown	3 age groups (household and shelter)	Microscopy	619	50	0.08	2008–2009	2011	(Joffe et al., 2011)
Dogs	Romania	Unknown	4 age group (pets)	Microscopy	1500	45	0.03	2008–2010	2011	(Amfim et al., 2011)
Dogs	Spain	Unknown	No age group (shelter)	Microscopy	544	221	0.41	2005–2008	2011	(Ortuño and Castellà, 2011)
Dogs	European countries	Symptomatic	4 age categories (pets)	ELISA	6683	1827	0.27	2005–2006	2010	(Epe et al., 2010)
Dogs	European countries	Asymptomatic	4 age categories (pets)	ELISA	1915	305	0.16	2005–2006	2010	(Epe et al., 2010)
Dogs	European countries	Unknown	4 age categories (pets)	ELISA	87	20	0.23	2005–2006	2010	(Epe et al., 2010)
Dogs	Galapagos Islands	Asymptomatic	No age groups (pets)	IFA	97	5	0.05	Not stated	2010	(Gingrich et al., 2010)
Dogs	USA	Mixed	No age group (racing dogs)	IFA	120	10	0.08	2008	2010	(McKenzie et al., 2010)
Dogs	Japan	Mixed	Exact age given (pets)	Microscopy	77	2	0.03	2006–2010	2010	(Yoshiuchi et al., 2010)
Dogs	Canada	Symptomatic	5 age group but no prevalence info (vet clinic)	ELISA	1871	241	0.13	2006	2010	(Olson et al., 2010)
Dogs	Canada	Unknown	No age group (unknown origin as environmental samples)	Microscopy	155	95	0.61	Not stated	2010	(Himsworth et al., 2010)
Dogs	Brazil	Unknown	No age group (strays)	Microscopy	46	1	0.02	2005	2010	(Klimpel et al., 2010)
Dogs	South Africa	Unknown	No age group (strays)	Microscopy	240	13	0.05	2008–2009	2010	(Mukaratirwa and Singh, 2010)

Table 1 (*Continued*)

Host species	Location	Clinical signs	Age groups and origin	Detection method	Total	Positives	Prevalence rate	Collection period	Publication year	Reference
Dogs	Poland	Unknown	No age group (shelter or privately owned)	Microscopy	148	3	0.02	Not stated	2010	(Solarczyk and Majewska, 2010)
Dogs	Argentina	Unknown	No age group (unknown origin)	Microscopy	1944	25	0.01	2005–2008	2010	(Soriano et al., 2010)
Dogs	London	Unknown	2 age groups (strays)	ELISA	878	87	0.10	2006–2007	2010	(Upjohn et al., 2010)
Dogs	Mexico	Unknown	6 age group (shelter)	Microscopy	147	10	0.07	2006–2007	2010	(Jiménez-Cardoso et al., 2010)
Dogs	Iran	Unknown	2 age groups (stray)	Microscopy	98	7	0.07	2009	2010	(Mirzaei, 2010)
Dogs	Iran	Symptomatic	3 age groups (pets)	ELISA	27	5	0.19	2007–2010	2010	(Mosallanejad et al., 2010b)
Dogs	Iran	Asymptomatic	3 age groups (pets)	ELISA	123	1	0.01	2007–2010	2010	(Mosallanejad et al., 2010b)
Dogs	Belgium	Symptomatic	No age group (diagnostic lab)	IFA	351	64	0.18	2004–2007	2009	(Claerebout et al., 2009)
Dogs	Belgium	Asymptomatic	No age group (dog schools, owners, kennels)	IFA	808	199	0.25	2004–2007	2009	(Claerebout et al., 2009)
Dogs	Netherlands	Asymptomatic	No age group (household dogs)	ELISA	92	16	0.17	2007	2009	(Overgaauw et al., 2009)
Dogs	Italy	Symptomatic	2 age groups (kennels)	PCR	22	13	0.59	2005–2006	2009	(Scaramozzino et al., 2009)
Dogs	Italy	Asymptomatic	2 age groups (kennels)	PCR	105	13	0.12	2005–2006	2009	(Scaramozzino et al., 2009)
Dogs	USA	Unknown	No age group (vet clinic)	Microscopy	6555	216	0.03	1997–2007	2009	(Gates and Nolan, 2009)
Dogs	Japan	Unknown	No age group (household dogs)	Microscopy	1105	137	0.12	1997, 2002, 2007	2009	(Itoh et al., 2009)
Dogs	USA	Unknown	5 age groups (vet clinic)	Microscopy	1,199,293	48,353	0.04	Not stated	2009	(Little et al., 2009)
Dogs	Romania	Symptomatic	2 age groups (pets)	Microscopy	153	24	0.16	2006–2007	2009	(Coman et al., 2009)
Dogs	Spain	Unknown	No age group (shelter and pets)	Microscopy	505	31	0.06	1999–2000	2009	(Gracenea et al., 2009)
Dogs	Italy	Unknown	No age groups (pets)	PCR	143	44	0.31	2008	2009	(Papini et al., 2009)
Dogs	Brazil	Unknown	No age group (pets)	Microscopy	81	9	0.11	2006–2007	2009	(Prates et al., 2009)
Dogs	Iran	Unknown	No age group (pet and farm)	Microscopy	174	1	0.01	2006–2007	2009	(Razmi, 2009)

Dogs	Thailand	Unknown	No age group (semi-domesticated in temples)	PCR	104	73	0.70	2004	2009	(Traub et al., 2009)
Dogs	Belgium	Symptomatic	No age group (pets)	IFA	141	42	0.30	Not stated	2008	(Geurden et al., 2008)
Dogs	Belgium	Asymptomatic	No age group (pets)	IFA	272	34	0.13	Not stated	2008	(Geurden et al., 2008)
Dogs	South Korea	Symptomatic	3 age categories (kennels)	ELISA	42	20	0.48	2008	2008	(Liu et al., 2008)
Dogs	South Korea	Asymptomatic	3 age categories (pets)	ELISA	430	33	0.08	2008	2008	(Liu et al., 2008)
Dogs	Serbia	Asymptomatic	One age group (>1 year) pets, strays and military dogs	Microscopy	151	22	0.15	Not stated	2008	(Nikolic et al., 2008)
Dogs	UK	Symptomatic	7 age groups in a graph (household dogs)	Microscopy	4526	380	0.08	2003–2005	2008	(Batchelor et al., 2008)
Dogs	Brazil	Unknown	2 age groups (strays and pets)	Microscopy	254	39	0.15	2004–2005	2008	(Katagiri and Oliveira-Sequeira, 2008)
Dogs	Brazil	Unknown	3 age categories (housed and shelter)	Microscopy	200	33	0.17	Not stated	2008	(Meireles et al., 2008)
Dogs	Australia	Unknown	No age group (refuge and vet clinic)	Microscopy	1400	130	0.09	2004–2005	2008	(Palmer et al., 2008)
Dogs	Italy	Unknown	No age category (faecal samples)	ELISA	415	32	0.08	2005	2008	(Rinaldi et al., 2008)
Dogs	Brazil	Symptomatic	4 age group (pets)	ELISA	228	23	0.10	2006–2007	2008	(Labarthe et al., 2008)
Dogs	Brazil	Asymptomatic	4 age group (pets)	ELISA	1609	156	0.10	2006–2007	2008	(Labarthe et al., 2008)
Dogs	Argentina	Unknown	2 age group (shelter and pets)	Microscopy	46	5	0.11	2004	2008	(Lavallén et al., 2011)
Dogs	UK	Symptomatic	No age group (to be hearing dogs)	Microscopy	59	6	0.10	Not stated	2007	(Guest et al., 2007)
Dogs	UK	Asymptomatic	No age group (to be hearing dogs)	Microscopy	549	46	0.08	Not stated	2007	(Guest et al., 2007)

Table 1 (*Continued*)

Host species	Location	Clinical signs	Age groups and origin	Detection method	Total	Positives	Prevalence rate	Collection period	Publication year	Reference
Dogs	Finland	Asymptomatic	2 age groups (pets)	IFA	150	8	0.05	2003–2004	2007	(Rimhanen-Finne et al., 2007)
Dogs	Spain	Mixed	4 age groups (housed and homeless)	Microscopy	251	1	0.00	Not stated	2007	(Martinez-Carrasco et al., 2007)
Dogs	Czech Republic	Unknown	No age category (faecal samples from city and rural)	Microscopy	4320	49	0.01	1998–2001	2007	(Dubna et al., 2007)
Dogs	Norway	Unknown	4 age categories (pets)	IFA	290	60	0.21	1999–2002	2007	(Hamnes et al., 2007)
Dogs	Thailand	Unknown	No age group (pets)	Microscopy	229	18	0.08	Not stated	2007	(Inpankaew et al., 2007)
Dogs	Spain	Unknown	4 age groups (housed and homeless)	Microscopy	1800	18	0.01	Not stated	2007	(Martinez-Moreno et al., 2007)
Dogs	Spain	Unknown	No age group (strays)	Microscopy	1161	82	0.07	Not stated	2007	(Miro et al., 2007)
Dogs	Brazil	Unknown	2 age groups (strays)	Microscopy	410	119	0.29	Not stated	2007	(Mundim et al., 2007)
Dogs	Greece	Unknown	2 age groups (shepherd and hunting)	Microscopy	281	12	0.04	2003–2004	2007	(Papazahariadou et al., 2007)
Dogs	Brazil	Unknown	5 age group (pets)	Microscopy	1473	392	0.27	2002–2004	2007	(Lorenzini et al., 2007)
Dogs	Brazil	Unknown	2 age groups (pets)	Microscopy	53	16	0.30	2006	2007	(Pinto et al., 2007)
Dogs	Brazil	Symptomatic	4 age groups (pets)	Microscopy	150	14	0.09	2004–2005	2007	(Santos et al., 2007)
Dogs	Brazil	Asymptomatic	4 age groups (pets)	Microscopy	50	3	0.06	2004–2005	2007	(Santos et al., 2007)
Dogs	Slovakia	Unknown	3 age groups (mixed origin)	Microscopy	752	12	0.02	2006	2007	(Szabová et al., 2007)
Dogs	Hungary	Unknown	9 age groups (pets and kennels)	ELISA	187	110	0.59	2004–2006	2007	(Szénási et al., 2007)
Dogs	Brazil	Unknown	No age group (pets)	PCR	10	7	0.70	2003–2005	2007	(Volotão et al., 2007)
Dogs	USA	Symptomatic	No age category (pets)	ELISA	16,064	2506	0.16	Not stated	2006	(Carlin et al., 2006)
Dogs	Italy	Symptomatic	4 age groups (pets, kennels and strays)	Microscopy	91	22	0.24	2001–2003	2006	(Capelli et al., 2006)
Dogs	Italy	Asymptomatic	4 age groups (pets, kennels and strays)	Microscopy	158	20	0.13	2001–2003	2006	(Capelli et al., 2006)

Dogs	Canada	Asymptomatic	No age group (pets visiting hospitals)	ELISA	102	7	0.07	2004	2006	(Lefebvre et al., 2006)
Dogs	Chile	Symptomatic	2 age groups (pets)	Microscopy	972	211	0.22	1996–2003	2006	(Lopez et al., 2006)
Dogs	Argentina	Unknown	4 age groups (pets)	Microscopy	2193	195	0.09	2003–2004	2006	(Fontanarrosa et al., 2006)
Dogs	Canada	Unknown	2 age categories (pets)	Microscopy	70	5	0.07	2004	2006	(Shukla et al., 2006)
Dogs	Costa Rica	Unknown	No age group (pets	Microscopy	1136	227	0.20	2002–2004	2006	(Arguedas Zeledón et al., 2006)
Dogs	Brazil	Unknown	No age group (pet)	Microscopy	95	8	0.08	2001	2006	(Labruna et al., 2006)
Dogs	Poland	Asymptomatic	No age group (city and rural dogs)	ELISA	86	46	0.53	Not stated	2005	(Gundlach et al., 2005)
Dogs	Brazil	Asymptomatic	2 age groups and 2 dog origins	Microscopy	166	52	0.31	Not stated	2005	(Huber et al., 2005)
Dogs	Japan	Symptomatic	2 age groups (kennels)	ELISA	64	24	0.38	2003–2004	2005	(Itoh et al., 2005)
Dogs	Japan	Asymptomatic	2 age groups (kennels)	ELISA	297	111	0.37	2003–2004	2005	(Itoh et al., 2005)
Dogs	USA	Symptomatic	No age group (shelter)	IFA	49	18	0.37	2002	2005	(Sokolow et al., 2005)
Dogs	USA	Asymptomatic	No age group (shelter)	IFA	49	18	0.37	2002	2005	(Sokolow et al., 2005)
Dogs	Italy	Mixed	2 age groups (shelter)	ELISA	183	101	0.55	2004	2005	(Papini et al., 2005)
Dogs	Mexico	Unknown	No age group (strays)	Microscopy	200	93	0.47	1997–1998	2005	(Ponce-Macotela et al., 2005)
Dogs	Brazil	Unknown	No age group (pets and stray)	Microscopy	434	6	0.01	2001–2002	2005	(Alves et al., 2005)
Dogs	Germany	Asymptomatic	No age group (shelter)	ELISA	264	78	0.30	Not stated	2004	(Cirak and Bauer, 2004)
Dogs	Japan	Unknown	No age group (pets)	Microscopy	772	22	0.03	1979, 1991, 2001	2004	(Asano et al., 2004)
Dogs	Canada	Asymptomatic	No age group (research facility)	Microscopy	107	11	0.10	2002	2004	(Anderson et al., 2004)
dogs	Italy	Symptomatic	2 age groups (pets and strays)	ELISA	8	3	0.38	2003	2004	(Bianciardi et al., 2004)
Dogs	Italy	Asymptomatic	2 age groups (pets and strays)	ELISA	97	17	0.18	2003	2004	(Bianciardi et al., 2004)
Dogs	USA	Symptomatic	No age group (pets)	IFA	71	4	0.06	1997–1998	2003	(Hackett and Lappin, 2003)

Table 1 (*Continued*)

Host species	Location	Clinical signs	Age groups and origin	Detection method	Total	Positives	Prevalence rate	Collection period	Publication year	Reference
Dogs	USA	Asymptomatic	No age group (pets)	IFA	59	3	0.05	1997–1998	2003	(Hackett and Lappin, 2003)
Dogs	Germany	Unknown	No age group (pets)	ELISA	8438	1400	0.17	1999–2002	2003	(Barutzki and Schaper, 2003)
Dogs	India	Unknown	No age group (dogs in close contact with humans)	PCR	101	20	0.20	Not stated	2003	(Traub et al., 2003)
Dogs	Brazil	Mixed	2 age group (kennel)	Microscopy	100	41	0.41	Not stated	2003	(Mundim et al., 2003)
Dogs	Brazil	Asymptomatic	2 age groups (pets and strays)	Microscopy	271	33	0.12	1999–2000	2002	(Oliveira-Sequeira et al., 2002)
Dogs	Serbia	Asymptomatic	No age groups (pets, stray, farm)	Microscopy	167	24	0.14	Not stated	2002	(Nikolić et al., 2002)
Dogs	Brazil	Unknown	No age group (pets)	Microscopy	250	49	0.20	2002–2001	2002	(Rufino et al., 2002)
Dogs	Japan	Symptomatic	4 age groups (pets)	Microscopy	407	88	0.22	Not stated	2001	(Itoh et al., 2001)
Dogs	Japan	Asymptomatic	4 age groups (pets)	Microscopy	628	63	0.10	Not stated	2001	(Itoh et al., 2001)
Dogs	japan	Symptomatic	No age group (presumably pets as sampled from animal hospitals)	ELISA	71	35	0.49	2000	2001	(Mochizuki et al., 2001)
Dogs	Japan	Asymptomatic	No age group (presumably pets as sampled from animal hospitals)	ELISA	10	4	0.40	2000	2001	(Mochizuki et al., 2001)
Dogs	Canada	Mixed	4 age groups (pets)	ELISA	1216	93	0.08	1999	2001	(Jacobs et al., 2001)
Dogs	Brazil	Asymptomatic	No age group (stray)	Microscopy	140	4	0.03	Not stated	2001	(Carollo et al., 2001)
Cats	Iran	Unknown	No age group (stray)	Microscopy	140	15	0.11	2012	2014	(Khademvatan et al., 2014)
Cats	Albania	Unknown	No age group (pet)	ELISA	58	17	0.29	2008–2011	2014	(Knaus et al., 2014)
Cats	UK	Symptomatic	3 age groups (pets)	PCR	1088	225	0.21	2010–2012	2014	(Paris et al., 2014)
Cats	USA	Symptomatic	No age group (cat sanctuary)	PCR	68	38	0.56	2009–2012	2014	(Polak et al., 2014)
Cats	Italy	Asymptomatic	No age group (pets)	PCR	146	11	0.08	Not stated	2014	(Mancianti et al., 2014)

Cats	Italy	Mixed	2 age groups (pets)	ELISA	127	35	0.28	2010–2011	2014	(Zanzani et al., 2014)
Cats	Hungary	Unknown	No age group (pets)	ELISA	115	43	0.37	2011	2013	(Capari et al., 2013)
Cats	Brazil	Unknown	5 age groups (pets)	Microscopy	191	8	0.04	2011	2013	(Pivoto et al., 2013)
Cats	Italy	Mixed	No age group (pets)	Microscopy	81	1	0.01	2008–2010	2013	(Riggio et al., 2013)
Cats	Italy	Unknown	No age groups (strays)	ELISA	139	4	0.03	Not stated	2013	(Spada et al., 2013)
Cats	Canada	Mixed	4 age group (pets)	IFA	283	28	0.10	1998–2008	2013	(Hoopes et al., 2013)
Cats	USA	Symptomatic	No age group (pets and shelter)	ELISA	219	18	0.08	2007–2009	2012	(Queen et al., 2012)
Cats	USA	Asymptomatic	No age group (pets and shelter)	ELISA	54	1	0.02	2007–2009	2012	(Queen et al., 2012)
Cats	Finland	Unknown	No age group (pets)	ELISA	402	13	0.03	2009–2010	2012	(Nareaho et al., 2012)
Cats	Germany	Unknown	2 age groups (stray)	ELISA	584	40	0.07	2006–2007	2012	(Becker et al., 2012)
Cats	Spain	Unknown	No age group (shelter)	Microscopy	144	6	0.04	Not stated	2012	(Dado et al., 2012)
Cats	Romania	Symptomatic	3 age categories (pets)	ELISA	50	16	0.32	2007–2009	2011	(Mircean et al., 2011)
Cats	Romania	Asymptomatic	3 age categories (pets)	ELISA	67	11	0.16	2007–2009	2011	(Mircean et al., 2011)
Cats	Japan	Asymptomatic	3 age categories (cat cafes)	Microscopy	321	26	0.08	2003–2010	2011	(Suzuki et al., 2011)
Cats	Germany	Mixed	6 age categories (pets)	ELISA	8560	1082	0.13	2003–2010	2011	(Barutzki and Schaper, 2011)
Cats	Costa Rica	Mixed	No age group (pets)	IFA	7	4	0.57	2009	2011	(Scorza et al., 2011)
Cats	Portugal	Unknown	No age category (household and kennels)	Microscopy	22	3	0.14	2007–2008	2011	(Ferreira et al., 2011)
Cats	Poland	Unknown	No age category (vet clinic)	Microscopy	160	6	0.04	2006–2007	2011	(Jaros et al., 2011)
Cats	Canada	Unknown	3 age groups (household and shelter)	Microscopy	153	0	0.00	2008–2009	2011	(Joffe et al., 2011)
Cats	Egypt	Unknown	No age groups (strays)	Microscopy	113	2	0.02	2010	2011	(Khalafalla, 2011)

Table 1 (*Continued*)

Host species	Location	Clinical signs	Age groups and origin	Detection method	Total	Positives	Prevalence rate	Collection period	Publication year	Reference
Cats	Italy	Unknown	Exact age given (pets and strays)	PCR	181	11	0.06	2006–2009	2011	(Paoletti et al., 2011)
Cats	Norway	Mixed	2 age groups (show cats)	IFA	52	4	0.08	2009	2011	(Tysnes et al., 2011)
Cats	European countries	Symptomatic	4 age categories (pets)	ELISA	3331	765	0.23	2005–2006	2010	(Epe et al., 2010)
Cats	European countries	Asymptomatic	4 age categories (pets)	ELISA	871	89	0.10	2005–2006	2010	(Epe et al., 2010)
Cats	European countries	Unknown	4 age categories (pets)	ELISA	12	2	0.17	2005–2006	2010	(Epe et al., 2010)
Cats	New Zealand	Mixed	No age group (show cats)	ELISA	22	7	0.32	2006	2010	(Kingsbury et al., 2010)
Cats	Japan	Mixed	Exact age given (pets)	Microscopy	55	1	0.02	2006–2010	2010	(Yoshiuchi et al., 2010)
Cats	Canada	Symptomatic	6 age group but no prevalence info (vet clinic)	ELISA	389	16	0.04	2006	2010	(Olson et al., 2010)
Cats	USA	Unknown	No age groups (shelter and foster homes)	Microscopy	1629	145	0.09	2006–2010	2010	(Lucio-Forster and Bowman, 2011)
Cats	Romania	Unknown	2 age groups (pets)	Microscopy	414	3	0.01	2007–2009	2010	(Mircean et al., 2010)
Cats	Brazil	Mixed	No age groups (pets)	Microscopy	166	58	0.35	Not stated	2010	(Dall'Agnol et al., 2010)
Cats	Iran	Symptomatic	3 age groups (pets)	ELISA	23	4	0.17	2008–2010	2010	(Mosallanejad et al., 2010a,b)
Cats	Iran	Asymptomatic	3 age groups (pets)	ELISA	127	1	0.01	2008–2010	2010	(Mosallanejad et al., 2010a,b)
Cats	UK	Asymptomatic	No age category (pets)	ELISA	55	3	0.05	2006–2007	2009	(Gow et al., 2009)
Cats	Netherlands	Asymptomatic	No age group (household cats)	ELISA	22	3	0.14	2007	2009	(Overgaauw et al., 2009)
Cats	Australia	Mixed	No age group (cattery and shelter)	ELISA	149	15	0.10	2006–2007	2009	(Bissett et al., 2009)
Cats	Brazil	Unknown	No age group (cats for euthanasia)	Microscopy	51	3	0.06	2007	2009	(Coelho et al., 2009)
Cats	USA	Unknown	No age group (vet clinic)	Microscopy	1566	36	0.02	1997–2007	2009	(Gates and Nolan, 2009)
Cats	Iran	Unknown	No age group (strays)	Microscopy	113	1	0.01	2004–2005	2009	(Mohsen and Hossein, 2009)
Cats	Iran	Unknown	No age group (stray)	Microscopy	113	1	0.01	2004–2005	2009	(Arbabi and Hooshyar, 2009)

Cats	USA	Mixed	No age group (pets)	IFA	250	34	0.14	Not stated	2009	(Ballweber et al., 2009)
Cats	Romania	Symptomatic	2 age groups (pets)	Microscopy	23	6	0.26	2006–2007	2009	(Coman et al., 2009)
Cats	Spain	Unknown	No age group (shelter)	Microscopy	50	2	0.04	1999–2000	2009	(Gracenea et al., 2009)
Cats	UK	Symptomatic	2 age groups (pets)	Microscopy	1403	76	0.05	2003–2007	2008	(Tzannes et al., 2008)
Cats	Iran	Unknown	No age group (pets)	Microscopy	147	1	0.01	Not stated	2008	(Jafari Shoorijeh et al., 2008)
Cats	Australia	Unknown	No age group (refuge and vet clinic)	Microscopy	1063	22	0.02	2004–2005	2008	(Palmer et al., 2008)
Cats	Brazil	Symptomatic	4 age group (pets)	ELISA	124	22	0.18	2006–2007	2008	(Labarthe et al., 2008)
Cats	Brazil	Asymptomatic	4 age group (pets)	ELISA	338	50	0.15	2006–2007	2008	(Labarthe et al., 2008)
Cats	USA	Symptomatic	No age group (shelters)	IFA	177	24	0.14	Not stated	2007	(Mekaru et al., 2007)
Cats	USA	Asymptomatic	No age group (shelters)	IFA	177	10	0.06	Not stated	2007	(Mekaru et al., 2007)
Cats	Italy	Symptomatic	3 age groups (strays and pets)	ELISA	24	6	0.25	2004	2007	(Papini et al., 2007)
Cats	Italy	Asymptomatic	3 age groups (strays and pets)	ELISA	242	36	0.15	2004	2007	(Papini et al., 2007)
Cats	USA	Mixed	5 age groups (pets)	IFA	250	34	0.14	Not stated	2007	(Vasilopulos et al., 2007)
Cats	Brazil	Unknown	5 age group (pets)	Microscopy	288	59	0.20	2002–2004	2007	(Lorenzini et al., 2007)
Cats	Italy	Unknown	4 age group (stray)	Microscopy	76	2	0.03	2005–2006	2007	(Natale et al., 2007)
Cats	Brazil	Unknown	No age group (pets)	PCR	1	1	1.00	2003–2005	2007	(Volotão et al., 2007)
Cats	Japan	Symptomatic	4 age groups (pets)	ELISA	132	57	0.43	2003–2005	2006	(Itoh et al., 2006)
Cats	Japan	Asymptomatic	4 age groups (pets)	ELISA	468	183	0.39	2003–2005	2006	(Itoh et al., 2006)
Cats	USA	Mixed	5 age groups (pets)	Microscopy	211,105	1223	0.01	2003–2004	2006	(De Santis-Kerr et al., 2006)
Cats	USA	Symptomatic	No age category (pets)	ELISA	4977	538	0.11	Not stated	2006	(Carlin et al., 2006)
Cats	Chile	Symptomatic	2 age groups (pets)	Microscopy	230	44	0.19	1996–2003	2006	(Lopez et al., 2006)

Table 1 (*Continued*)

Host species	Location	Clinical signs	Age groups and origin	Detection method	Total	Positives	Prevalence rate	Collection period	Publication year	Reference
Cats	Colombia	Unknown	3 age groups (strays or unwanted)	PCR	46	3	0.07	2005	2006	(Santin et al., 2006)
Cats	Canada	Unknown	2 age categories (pets)	Microscopy	41	1	0.02	2004	2006	(Shukla et al., 2006)
Cats	Germany	Asymptomatic	No age group (shelter)	ELISA	98	22	0.22	Not stated	2004	(Cirak and Bauer, 2004)
Cats	USA	Mixed	No age group (show cats from catteries)	ELISA	117	36	0.31	2001	2004	(Gookin et al., 2004)
Cats	Italy	Symptomatic	2 age groups (pets and strays)	ELISA	6	0	0.00	2003	2004	(Bianciardi et al., 2004)
Cats	Italy	Asymptomatic	2 age groups (pets and strays)	ELISA	42	2	0.05	2003	2004	(Bianciardi et al., 2004)
Cats	Germany	Unknown	No age group (pets)	ELISA	3167	399	0.13	1999–2002	2003	(Barutzki and Schaper, 2003)
Cats	Australia	Unknown	No age group (not pets)	PCR	40	32	0.80	Not stated	2003	(McGlade et al., 2003)
Cats	Brazil	Unknown	No age group (stray)	Microscopy	66	8	0.12	Not stated	2003	(Serra et al., 2003)
Cats	USA	Mixed	No age group (shelter)	Microscopy	50	16	0.32	Not stated	2002	(Zajac et al., 2002)
Cats	Serbia	Asymptomatic	2 age groups (pets)	Microscopy	81	18	0.22	Not stated	2002	(Nikolić et al., 2002)
Cats	USA	Mixed	<1 year old cats (pets and shelter)	Microscopy	263	19	0.07	1998–1999	2001	(Spain et al., 2001)

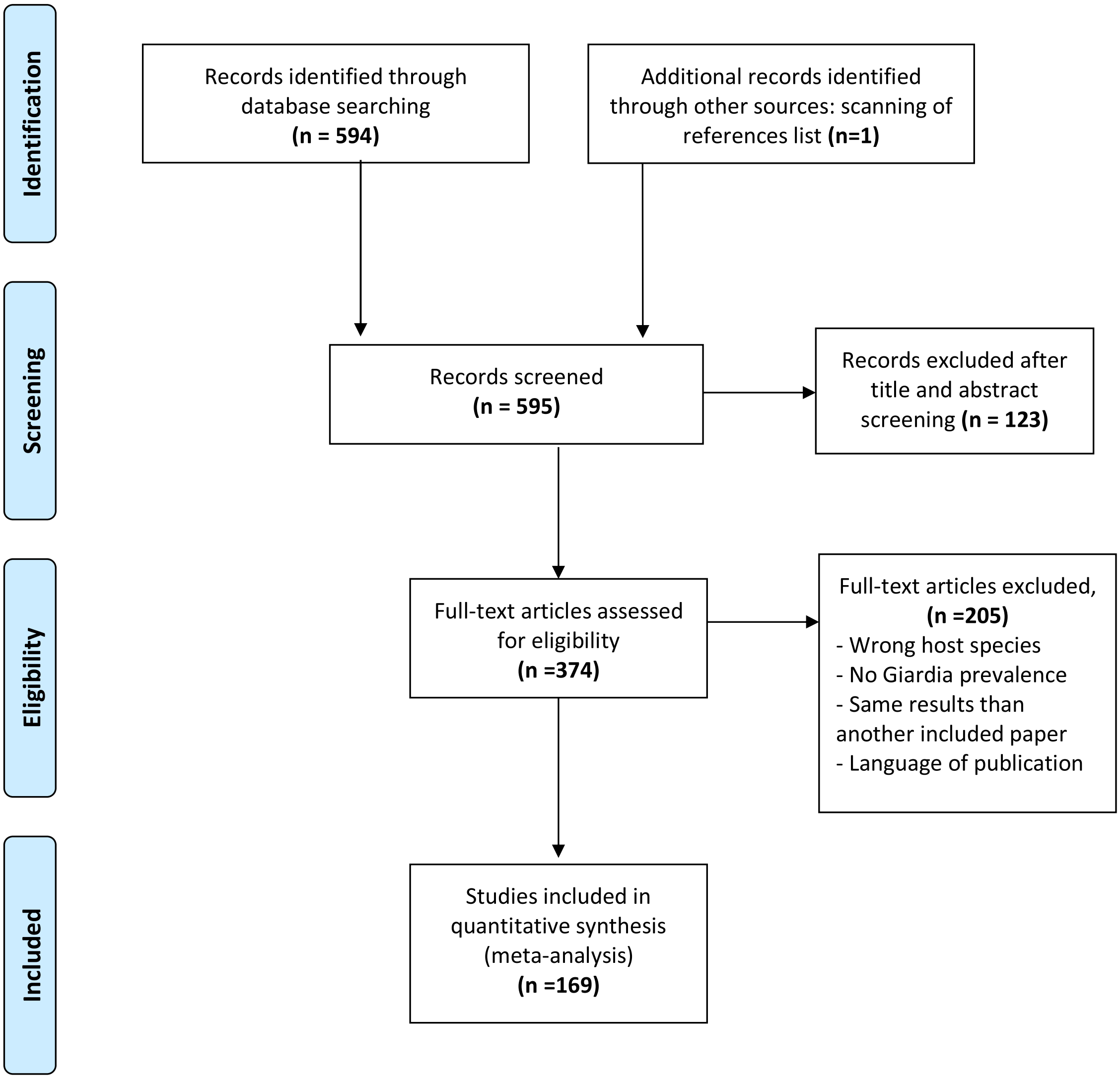

Fig. 1. Flow diagram describing paper selection and inclusion/exclusion process according to PRISMA guidelines.

Table 2
Region and diagnostic method for included studies.

Characteristic	Dogs		Cats	
	N = 127	%	N = 68	%
Region				
Africa	3	2.4	1	1.5
Asia	23	18.1	8	11.8
Australasia	1	0.8	4	5.9
Europe	43	33.9	29	42.6
North America	22	17.3	16	23.5
South America	35	27.6	10	14.7
Diagnostic method				
ELISA	28	22.0	24	35.3
IFA	15	11.8	6	8.8
Microscopy	73	57.5	31	45.6
PCR	11	8.7	7	10.3

pooled prevalence of all studies for canines was 15.2% (95% CI 13.8–16.7%). Heterogeneity was, however, very high I^2 = 99.9%. As can be seen in the funnel plot (supplementary file 1A), there is a strong suggestion of publication bias towards publication of high prevalence studies (Harbord: bias = 20.9 (92.5% CI = 15.1–26.7) $P < 0.0001$).

3.2. Prevalence in cats

Amongst the 68 papers (78 study arms) on cats, 248,195 samples were tested of which 5,807 (2.33%) were positive. The forest plot for the cat studies is shown in Fig. 3. The random effects pooled prevalence is 12% (95% CI 9.2–15. 3%). Once again there was very high heterogeneity I^2 = 99.3%. As with the data from dogs, there is a strong suggestion of publication bias towards publication of high prevalence studies (Harbord: bias = 15.6 (92.5% CI = 10.8–20.3) $P < 0.0001$) (supplementary file 1B).

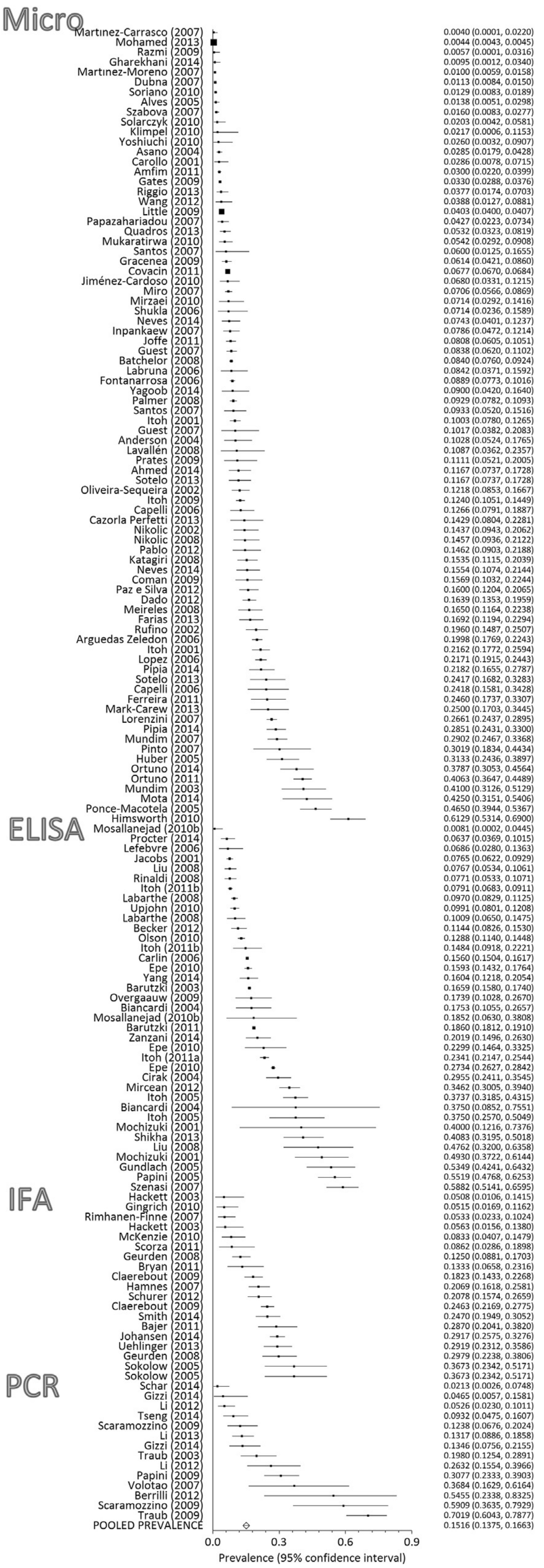

Fig. 2. Forest plot for prevalence studies in dogs ordered by detection method and reducing prevalence.

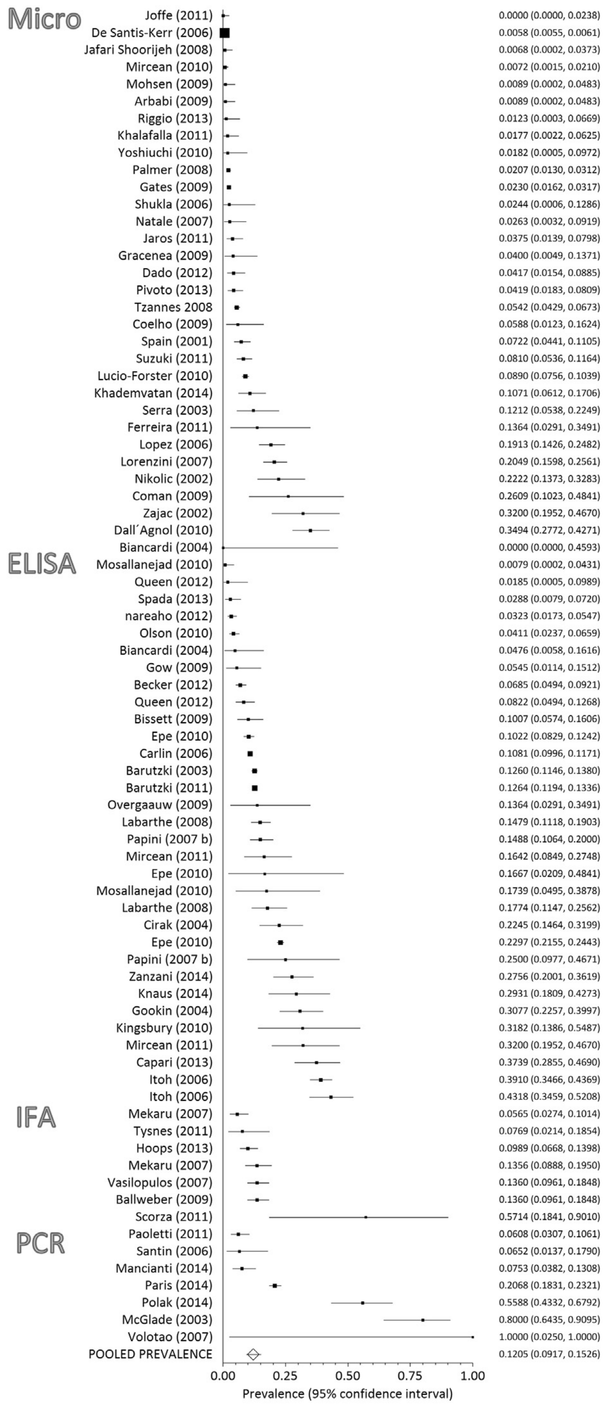

Fig. 3. Forest plot for prevalence studies in cats ordered by detection method and reducing prevalence.

3.3. *Predictors of prevalence in cats and dogs*

Table 3 gives the estimates of the impact of key study characteristics on *Giardia* prevalence in dogs and cats. Region and diagnostic method were tested together in a single random effects model. Given that data on the other predictors (origin of animal (Kennel/stray or pet),

Table 3
Predictors of *Giardia* prevalence rates in dogs and cats using panel negative binomial regression.

Characteristic	Dogs					Cats				
	No. groups conditional regression	Prevalence rate ratio	Lower 95% CI	Upper 95% CI	P	No. groups conditional regression	Prevalence rate ratio	Lower 95% CI	Upper 95% CI	P
Region[a]										
Europe		1			0.046		1			0.022
Africa		1.68	0.56	5.02			0.71	0.09	5.42	
Asia		0.77	0.48	1.24			0.87	0.40	1.89	
Australasia		1.46	0.29	7.28			1.37	0.52	3.61	
North America		0.82	0.51	1.32			0.78	0.42	1.47	
South America		1.61	1.06	2.45			2.73	1.40	5.30	
Diagnostic method[b]										
Microscopy		1			<0.0001		1			0.0001
ELISA		2.26	1.49	3.42			2.68	1.60	4.48	
IFA		2.48	1.47	4.19			3.75	1.65	8.48	
PCR		2.42	1.32	4.45			3.51	1.58	7.78	
Clinical signs[c]										
Asymptomatic	22	1			<0.0001	9	1			<0.0001
Symptomatic		1.61	1.33	1.94			1.94	1.47	2.56	
Origin of animals[d]										
Strays/Kennels		1			0.0004		1			0.21
Pets		0.56	0.41	0.77			0.91	0.53	1.55	
Age group[c]										
<6 months	15	1			<0.0001	12	1			<0.0001
>6 months		0.36	0.32	0.41			0.47	0.42	0.53	

[a] Random effects negative binomial regression adjusted for diagnostic method.
[b] Random effects negative binomial regression adjusted for region.
[c] Conditional negative binomial regression.
[d] Random effects negative binomial regression adjusted for region and diagnostic method.

diagnostic method and age group) were obtainable in only a minority of studies, these were treated as matched data and used for conditional negative binomial regression.

It can be seen that the major predictor for prevalence rate is the diagnostic method used, with standard microscopy being very poor compared to ELISA (226% higher), IFA (248%) and PCR (242%) in dogs. In cats, the relative advantage of these other methods appears to be even greater than is the case for dogs, ELISA (268%), IFA (375%), and PCR (351%). There is no convincing impact of region on *Giardia* prevalence in dogs, though in cats there is some impact, with prevalence being greater in more tropical countries, especially in South America than in the industrial North. In further analyses, prevalence was greater in symptomatic compared to asymptomatic individuals (161% for dogs and 194% for cats) and lower in animals >6 months old compared to animals <6 months (64% less for dogs and 53% less for cats). Domestic pets were also less likely to be positive than strays or animals kept in kennels (44% less for dogs and 9% less for cats), although for cats this was not statistically significant.

Given the important effect of detection method on estimated prevalence, we recalculated the random effects pooled prevalence for two subgroups: microscopy for one subgroup and the other three methods combined (ELISA, IFA and PCR) for the other subgroup. For dogs the pooled prevalence for microscopy was 11.6% (95% CI 10–13.2%) and for the other detection methods was 19.8% (95% CI 17.9–21.7%). The respective pooled prevalence results for cats were 6.5% (95% CI 4.2–9.2%) and 15.9% (95% CI 13.5–18.4%), respectively.

4. Discussion

We have shown that *Giardia* prevalence rate in the faeces of both dogs and cats varies substantially from one study to another. The pooled prevalence rates were 15.2% and 12% for dogs and cats, respectively. However, there was substantial heterogeneity in both datasets. There was also evidence of publication bias that may lead to overestimated pooled prevalence. The age of the animal, whether or not it is a domestic pet and whether or not it was symptomatic for diarrhoea also affected the prevalence. The geographical continent had some effect with the industrial northern regions of Europe and North America having lower prevalence than the rest of the world, but this was not particularly significant.

When we further investigated the data, it was clear that the major factor driving reported prevalence rates was the detection method used. In particular, we have shown that microscopy performs poorly compared to other detection methods. However, we acknowledge that microscopy is not as standardised as the other methods and preparation/concentration steps can dramatically influence the sensitivity of the technique. For example, it has been shown that zinc sulphate flotation followed by microscopy can have similar performance as molecular detection methods (Paz e Silva et al., 2012). For this investigation, including all the variants of microscopy would have increased the number of variables in the regression, thus preventing meaningful analyses. Therefore, we have chosen to group detection methods together irrespective of their methodological variation. Another issue related to comparing prevalence data is that different laboratories could apply distinct cut-off limits, particularly relevant for ELISA and IFA. This could potentially mean that discordant results can be obtained from two laboratories. For molecular targets, PCR sensitivity also depends on gene abundance (single versus multi-copy genes). Another aspect, that is relevant to all detection methods, is the quantity and quality of the pathogen material in the sample (Bouzid et al., 2008). All these limitations make a direct comparison of the performance of diagnostic tests a tricky task. This has been addressed through standardised protocols for the detection of pathogens of public health importance including *Giardia*.

Our conclusions on the relative sensitivity of the main diagnostic approaches are similar to those found by direct comparison showing that microscopy performed the poorest (Geurden et al., 2008). Like Geurden and colleagues, we found that IFA was more sensitive than ELISA for cats, however, the difference was marginal for dogs. The very different sensitivities of the newer diagnostic tests compared to microscopy raise the question of whether or not these more sensitive tests give a better indication of zoonotic risk to humans. This is not an easy question to answer even though the greater prevalence derived from the more sensitive tests would suggest greater risk, the additional positives would be expected to excrete fewer cysts and so pose less of a risk. In any event, the epidemiological evidence is that companion animals are not a major source of human giardiasis (Hunter and Thompson, 2005). Furthermore, given that dogs and cats often carry non-human infective *Giardia* assemblages, one has to be very cautious about extrapolating risk to humans based solely on prevalence data in animals (Ballweber et al., 2010).

Meta-regression is becoming more common in meta-analysis of randomised controlled trials and can provide valuable insights when there are no direct comparisons (Salanti et al., 2008). However, meta-regression techniques do not provide as strong evidence because they are observational rather than experimental in design. This criticism of the approach would not apply in regard to the analyses presented here, in part because the primary studies were all observational in nature. Another criticism could be the potential for confounding factors affecting the estimates of the impact of predictors on prevalence rates. Whilst this may have affected the estimates of the relative sensitivity of the different analytical methods to some degree, this is unlikely to have a particularly large impact. For the other predictors (symptoms, age group and origin), such confounding will have largely been eliminated by the conditional regression analysis.

In conclusion, we have shown that *Giardia* is common in dogs and to a lesser extent in cats. Studies based on direct microscopy will significantly underestimate prevalence compared to immune-based or PCR detection methods. This does not necessarily imply a major risk of zoonotic disease as many of the strains found in dogs and cats will be of assemblages that do not pose a particular risk of human illness, however, this would need to be assessed by typing of positive samples.

Acknowledgements

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vetpar.2014.12.011.

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