Global prevalence and epidemiology of *Strongyloides stercoralis* in dogs: a systematic review and meta-analysis

Aida Vafae Eslahi1†, Sima Hashemipour2†, Meysam Olfatifar1†, Elham Houshmand3, Elham Hajialilo4,5, Razzagh Mahmoudi1, Milad Badri1* and Jennifer K. Ketzis6*

**Abstract**

**Background:** *Strongyloides stercoralis*, a soil-transmitted helminth, occurs in humans, non-human primates, dogs, cats and wild canids. The zoonotic potential between these hosts is not well understood with data available on prevalence primarily focused on humans. To increase knowledge on prevalence, this review and meta-analysis was performed to estimate the global status of *S. stercoralis* infections in dogs.

**Methods:** Following the PRISMA guidelines, online literature published prior to November 2020 was obtained from multiple databases (Science Direct, Web of Science, PubMed, Scopus and Google Scholar). Prevalence was calculated on a global and country level, by country income and climate, and in stray/animal shelter dogs versus owned dogs. Statistical analyses were conducted using R-software (version 3.6.1).

**Results:** From 9428 articles, 61 met the inclusion criteria. The estimated pooled global prevalence of *S. stercoralis* in dogs was 6% (95% CI 3–9%). Infection was found to be the most prevalent in low-income countries with pooled prevalence of 22% (95% CI 10–36%). The highest pooled prevalence of *S. stercoralis* in dogs was related to regions with average temperature of 10–20 °C (6%; 95% CI 3–11%), an annual rainfall of 1001–1500 mm (9%; 95% CI 4–15%) and humidity of 40–75% (8%; 95% CI 4–13%). Prevalence was higher in stray and shelter dogs (11%; 95% CI 1–26%) than in owned dogs (3%; 95% CI 1–7%).

**Conclusions:** As with *S. stercoralis* in humans, higher prevalence in dogs is found in subtropical and tropical regions and lower-income countries, locations which also can have high dog populations. While this study presents the first estimated global prevalence of *S. stercoralis* in dogs, it is potentially an underestimation with 15 of 61 studies relying on diagnostic methods of lower sensitivity and a paucity of data from most locations. Standardized protocols (e.g. quantity of feces and number of samples for a Baermann) in future studies could improve reliability of results. More prevalence studies and raising veterinary awareness of *S. stercoralis* are needed for a One Health approach to protect humans and dogs from the impact of the infection.

**Keywords:** *Strongyloides stercoralis*, Canine, Neglected tropical disease, Soil transmitted helminth, Systematic review
[1–4]. One of these zoonotic pathogens is *Strongyloides stercoralis*, a soil-transmitted helminth that affects 100–370 million people globally and is classified as a neglected tropical disease [5, 6]. The main manifestations of *S. stercoralis* infection are gastrointestinal and cutaneous signs. However, *S. stercoralis* infections can be asymptomatic but, in the other extreme, can cause severe pulmonary pathology with auto- and hyperinfection [7–9]. The life cycle of *S. stercoralis* involves homogonic and heterogonic stages. In the homogonic cycle, only females exist in the host and eggs are produced via parthenogenesis. First-stage larvae (L1) and occasionally in some hosts eggs containing L1 are excreted via the host's feces into the environment where the heterogonic cycle occurs. Male and female molts into free-living adult worms through four larval stages with female larvae also being able to molt into infectious third-stage larvae (L3) without further development until entering a host [8]. The most common techniques to detect larvae of *S. stercoralis* in human feces are direct smear, Kato-Katz, flotation, sedimentation, Baermann and Koga agar plate culture with the latter three being the more sensitive for larvae. Indirect fluorescent antibody tests (IFATs), enzyme-linked immunosorbent assays (ELISAs) and molecular methods also can be used for diagnosis but are more frequently used in research versus clinical settings [10–12]. The primary treatment for *S. stercoralis* infection in humans is ivermectin [9].

*Strongyloides stercoralis* also is capable of infecting canids and a range of other vertebrate hosts such as felids and non-human primates [6, 13]. Canine *S. stercoralis* infection occurs most frequently in puppies and young dogs under 1 year of age and in puppies living in breeding kennels with poor sanitary conditions during hot and humid seasons [14–18]. Infection in dogs can be asymptomatic, but also can be life-threatening with clinical signs ranging from diarrhea and malabsorption to bronchopneumonia. Extraintestinal disseminations such as the nasal cavities, lungs, stomach and cranial cavity associated with severe clinical signs have been documented in immunocompromised canids as in humans (e.g. due to other pre-existing conditions or administration of immunosuppressive medicines) [19–21]. The methods for detection of *S. stercoralis* in dog feces are the same as those in humans with treatments including not only ivermectin but also fenbendazole, albendazole and selamectin although no products are registered for this use in dogs [22].

Dogs and humans share certain *S. stercoralis* genotypes. Although there are few reports of transmission from dogs to humans, experimental infections illustrate that *S. stercoralis* from human origin can infect dogs, suggesting dogs can be a reservoir for human infection [6, 13, 23, 24]. While there have been recent studies estimating regional and global prevalence of *Strongyloides* for humans and associated risk factors [5, 7, 12, 25], these data are not available for infections in dogs. In a one health context, better knowledge on the prevalence of *S. stercoralis* infection in dogs and the risk of zoonotic transmission to humans is needed. Therefore, this review and meta-analysis aimed to estimate the global prevalence of *S. stercoralis* in dogs and assess some variables that might influence prevalence.

**Methods**

**Search strategy**

This systematic review and meta-analysis followed PRISMA guidelines (http://www.prisma-statement.org/). A systematic literature search was carried out on multiple general science databases to identify all publications reporting *S. stercoralis* in dogs across the world published prior to November 2020. Science Direct, Web of Science, PubMed, Scopus and Google Scholar were explored using the following search terms: *Strongyloides stercoralis*, *S. stercoralis*, strongyloidiasis, dogs, puppies, gastrointestinal helminths, soil-transmitted helminths, worldwide and prevalence using AND and/or OR Boolean operators. Two independent authors involved in the search evaluated titles and abstracts and reviewed the full-text papers. After removing duplicates and irrelevant records, reference lists of full texts were examined for potential eligibility of citations not found in the database search.

**Inclusion and exclusion criteria and data extracted**

Literature was eligible for inclusion if it met the following priori criteria: (1) peer-reviewed articles containing original data, (2) cross-sectional studies reporting the prevalence of strongyloidiasis in dogs, (3) accessible full text and abstract and (4) numerator and denominator data available to confirm prevalence values. Literature that did not satisfy the aforementioned criteria, such as review articles with no original data, letters, editorials, articles with fecal material collected from the ground and lack of clarity about whether there were repeated samples and articles with ambiguous/undetermined conclusions, were excluded. Articles that reported *S. stercoralis* in humans, animals other than dogs and soil were excluded.

Using a Microsoft Excel® spreadsheet, the following information was retrieved from the included articles: first author name, year of publication, country where the study was conducted, continent, sample size and number of positive cases, diagnostic method(s) used, income level (https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups), humidity (https://www.timeanddate.com/weather/iran/tehran/climate), annual rainfall (https://en.clima
te-data.org/), average temperature (https://en.climate-data.org/), latitude, (https://www.geodatos.net/en/coordinates/) and climate (https://www.britannica.com/science/Koppen-climate-classification). Antibody seroprevalence studies were excluded, since they cannot confirm current infection. Experimental antigen methods also were excluded. In studies where more than one method was used to analyze a single sample (e.g. Baermann and flotation), the total number of positive samples was determined and used in the analysis.

Quality assessment
The Newcastle-Ottawa Scale was used to assess the quality of the included articles [26]. A maximum score of 9 was assigned to each article based on subject selection (0–4 points), comparability of subjects (0–2 points) and exposure (0–3 points). A total score of 0–3, 4–6 and 7–9 points was considered poor, moderate and high quality, respectively [27–29].

Data synthesis and statistical analysis
The pooled prevalence of *S. stercoralis* in dogs reported globally and by continent was calculated with 95% confidence intervals (CIs). In addition, prevalence for stray and shelter dogs was compared to that of owned dogs with owned dogs defined as household owned, those in pet stores and breeding dogs but excluding those with only breeding kennel data. Sub-group analysis included country income level, humidity, annual rainfall, average temperature and latitude. The probability of publication bias was surveyed using Egger’s regression test and Begg’s test. A meta-regression analysis was conducted to evaluate the impact of the year of publication on prevalence. All statistical analyses were performed using the meta-package in *R* (version 3.6.1). The pooled prevalence estimates were computed using the alpha method for the random-effects model, based on the inverse variance approach for measuring weight. Cochrane’s Q test and inconsistency index (I² statistics) were used to assess the magnitude of heterogeneity among included studies, with I² values of <25%, 25–75% and <75% considered as low, moderate and high heterogeneity, respectively. A *P* value < 0.05 was considered statistically significant.

Results

Literature search, selection and data extraction
Our systematic search yielded a total of 9428 publications. One hundred thirty-two full-text articles were chosen for eligibility assessment. There were 16 studies with an unspecified sample size and 55 studies with no original data, including reviews, case reports and case series, letters, theses and workshops. Finally, 61 studies were included in the meta-analysis based on critical appraisal criteria (Fig. 1; Table 1 with full list of references in Additional file 1: References S1). The included studies utilized parasitology techniques comprising microscopic methods (flotation with and without concentration, sedimentation, Baermann, Kato-Katz and other direct smear methods, and necropsy), culture methods (Harada-Mori and agar plate culture), molecular techniques [conventional polymerase chain reactions (PCR) and real-time PCR] and serological methods (IFAT and ELISA). Of the 61 articles, 15 used only direct smears and/or flotation with most studies using sedimentation and/or Baermann often in combination with flotation or direct smears. Four studies used culture, three of which were combined with other methods. Only eight of the included articles used diagnostic methods other than microscopy and culture: three used immunological methods in addition to microscopic or culture methods; one used serology, PCR, microscopic and culture methods; one used PCR and microscopic methods; and one used only PCR methods.

Pooled prevalence
The estimated pooled global prevalence for *S. stercoralis* in dogs was 6% (95% CI 3–9%) with a higher estimated pooled prevalence in stray/shelter dogs (11%, 95% CI 1–26%) than in owned dogs (3%, 95% CI 1–7%) (Figs. 2; 3). Based on the manuscripts included in the analysis, *S. stercoralis* infection in dogs has been documented in 29 countries (Fig. 4; Additional file 2: Figure S1). The pooled prevalence on different continents ranged from 21 to 2%, with 21% (95% CI 10–34%) in Africa, 6% (95% CI 0–100%) in Oceania, 5% (95% CI 0–14%) in Asia, 2% (95% CI 0–10%) in North America, 2% (95% CI 0–7%) in South America and 2% (95% CI 0–5%) in Europe (Fig. 2; Additional file 3: Table S1).

The largest number of studies was conducted in Ethiopia (8 studies), followed by Japan (6 studies). Analyses based on countries showed that Cambodia had the highest pooled prevalence (85%, 95% CI 78–91%) (Additional file 2: Figure S1). The estimated pooled prevalence based on country-level income groups ranged from 22 to 2%, with the highest rate in low-income countries (22%, 95% CI 10–36%) (Additional file 3: Table S1).

Our analyses revealed that regions with average temperatures of 10–20 °C had the highest prevalence of *S. stercoralis* (6%, 95% CI 3–11%) (Additional file 3: Table S1). Furthermore, the infection was more prevalent in regions with humidity of 40–75% (8%, 95% CI 4–13%), annual rainfall of 1001–1500 mm (9%, 95% CI 4–15%) and a tropical wet and dry climate (12%, 95% CI 5–21%). In addition, we found that the highest prevalence rate was at a latitude of 1°–25° (11%, 95% CI 5–19%).
Publication bias
As demonstrated by funnel plot asymmetry, a highly significant publication bias was observed in our study using Egger’s test ($t = 4.12$, $P = 0.0001$) and Begg’s test ($P = 0.001$) (Fig. 5A, B). Meta-regression analysis demonstrated that there was a significant heterogeneity between studies regarding the year of publication (regression slope = 0.0055, $P = 0.0116$) (Fig. 6). Evaluation of study quality revealed that, among 61 studies, 36 had a total score of 7–9 points (high quality) and 25 had a total score of 4–6 points (moderate quality). No included studies were considered poor quality (Table 1).

Discussion
Dogs are among the most popular companion animals with a considerable positive impact on the psychological and physiological conditions of their owners [30, 31]. This close relationship with dogs, however, can pose
Table 1  Main characteristics of the included studies reporting the prevalence of *Strongyloides stercoralis* in dogs

| No. | First author                      | Publication year | Country | Continent | Diagnostic methods used                              | Quality assessment based on Newcastle–Ottawa Scale |
|-----|-----------------------------------|------------------|---------|-----------|------------------------------------------------------|---------------------------------------------------|
| 1   | Rizzo and Ricciardi               | 1978             | Italy   | Europe    | Unclear                                             | 5                                                 |
| 2   | Ugochukwu and Ejimadu             | 1985             | Nigeria | Africa    | Saturated solution flotation, formalin-ether sedimentation | 5                                                 |
| 3   | Tarish et al.                     | 1986             | Iraq    | Asia      | Necropsy                                            | 6                                                 |
| 4   | Stehr-Green et al.                | 1987             | USA     | North America | Formalin-ethyl acetate sedimentation         | 9                                                 |
| 5   | Epe et al.                        | 1993             | Germany | Europe    | Coproscopical examinations                           | 6                                                 |
| 6   | Bugg et al.                       | 1999             | Australia | Oceania  | Sedimentation, zinc sulfate (ZnSO₄) flotation       | 7                                                 |
| 7   | Itoh et al.                       | 2003             | Japan   | Asia      | Coproscopical examination                           | 7                                                 |
| 8   | Anosike et al.                    | 2004             | Nigeria | Africa    | Direct smear, concentration methods                 | 5                                                 |
| 9   | Asano et al.                      | 2004             | Japan   | Asia      | Direct smear, saturated salt (NaCl) flotation, ZnSO₄ flotation, sucrose flotation | 8                                                 |
| 10  | Ramirez-Barrios et al.            | 2004             | Venezuela | South America | NaCl flotation                                    | 8                                                 |
| 11  | Komtangi et al.                   | 2005             | Cameroon | Africa    | McMaster                                            | 5                                                 |
| 12  | Júnior et al.                     | 2006             | Brazil  | South America | Baermann, sedimentation, ELISA, IFAT      | 9                                                 |
| 13  | Gonçalves et al.                  | 2007             | Brazil  | South America | Baermann, sedimentation, ELISA, IFAT      | 8                                                 |
| 14  | Lorenzini et al.                  | 2007             | Brazil  | South America | Saturated NaCl flotation, ZnSO₄ flotation   | 6                                                 |
| 15  | Papazahariadou et al.             | 2007             | Greece  | Europe    | Telemann’s sedimentation                             | 8                                                 |
| 16  | Dillard et al.                    | 2007             | Finland | Europe    | Baermann                                            | 7                                                 |
| 17  | Ugbomoiko et al.                  | 2008             | Nigeria | Africa    | Kato-Katz thick smear                                 | 7                                                 |
| 18  | Das et al.                        | 2009             | India   | Asia      | Unclear                                             | 5                                                 |
| 19  | Claerebout et al.                 | 2009             | Belgium | Europe    | Sucrose flotation                                    | 8                                                 |
| 20  | Gates and Nolan                   | 2009             | USA     | North America | ZnSO₄ flotation, formalin-ethyl acetate sedimentation | 8                                                 |
| 21  | Itoh et al.                       | 2009             | Japan   | Asia      | Formalin-ethyl acetate sedimentation                | 7                                                 |
| 22  | Takano et al.                     | 2009             | Japan   | Asia      | Direct smear, agar plate culture (APC)              | 7                                                 |
| 23  | Leelayoova et al.                 | 2009             | Thailand | Asia      | Direct smear, formalin-ethyl acetate concentration   | 6                                                 |
| 24  | Razmi                             | 2009             | Iran    | Asia      | Mini Parasep® SF (sedimentation)                    | 7                                                 |
| 25  | Mariana et al.                    | 2010             | Bolivia | South America | Willis-Malloy flotation                  | 5                                                 |
| 26  | Zewdu et al.                      | 2010             | Ethiopia | Africa    | Necropsy                                            | 6                                                 |
| 27  | Awoke et al.                      | 2011             | Ethiopia | Africa    | Direct smear, flotation                             | 5                                                 |
| 28  | Jones et al.                      | 2011             | Ethiopia | Africa    | Necropsy                                            | 5                                                 |
| 29  | Itoh et al.                       | 2011             | Japan   | Asia      | Formalin-ethyl acetate sedimentation                | 8                                                 |
| 30  | Itoh et al.                       | 2011             | Japan   | Asia      | Formalin-ethyl acetate sedimentation                | 7                                                 |
| 31  | Paulos et al.                     | 2012             | Ethiopia | Africa    | Sedimentation and flotation                         | 5                                                 |
| 32  | Martins et al.                    | 2012             | Brazil  | South America | PARATEST® Diagnostek (sedimentation)        | 7                                                 |
| 33  | Getahun and Addis                 | 2012             | Ethiopia | Africa    | Sedimentation and NaCl flotation                    | 6                                                 |
| 34  | Mircean et al.                    | 2012             | Romania | Europe    | NaCl flotation                                       | 8                                                 |
| 35  | Mekbib et al.                     | 2013             | Ethiopia | Africa    | Direct smear, flotation and sedimentation            | 5                                                 |
| 36  | G/selasie et al.                  | 2013             | Ethiopia | Africa    | McMaster, sedimentation                             | 5                                                 |
| 37  | Abere et al.                      | 2013             | Ethiopia | Africa    | Direct smear, sedimentation and NaCl flotation      | 6                                                 |
| 38  | Perera et al.                     | 2013             | Sri Lanka | Asia      | NaCl flotation, Sheather’s sucrose flotation, direct smear | 6                                                 |
| 39  | Riggio et al.                     | 2013             | Italy   | Europe    | Flotation, Baermann                                  | 8                                                 |
| 40  | Ortuno et al.                     | 2014             | Spain   | Europe    | ZnSO₄ flotation                                      | 7                                                 |
| 41  | Alvarado-Esquível et al.          | 2015             | Mexico  | North America | Sheather’s and ZnSO₄ flotation        | 8                                                 |
certain risks with the potential of dogs transmitting a broad range of zoonotic pathogens, including viruses, bacteria, parasites and fungi [32–34]. Regarding *S. stercoralis*, some genotypes are dog specific while others can infect dogs and humans; hence, dogs could be reservoirs of zoonotic *S. stercoralis* [6, 13, 35]. In this review and meta-analysis, we estimated the global prevalence of *S. stercoralis* in dogs. Our findings show *S. stercoralis* in dogs being documented in 29 countries and that infections are not limited to dogs in tropical and subtropical regions, although these regions have the higher prevalence as is the general case for human infections [12].

Factors that potentially contribute to the higher prevalence in tropical regions include temperature and humidity, country income and presence of stray dogs. Similar to prior studies, the results of the meta-analysis herein presented indicate that climate conditions play a key role in the prevalence of *S. stercoralis* infection with the highest pooled prevalence in areas with a tropical wet and dry climate [12]. The higher humidity and temperature make favorable conditions for survival of heterogonic stages of *S. stercoralis* [36, 37]. While the climate plays a key role in prevalence, several studies have confirmed higher rates of helminthic infections in humans in low-income countries, attributed to sanitary conditions and limited access to health care [38–40]. This is similar to our results, with the highest prevalence of *S. stercoralis* in dogs in low-income countries. In these countries,
| Study | Prevalence | 95% CI |
|-------|------------|--------|
| Africa |            |        |
| Kentungi et al 2005 Cameroon | 0.1145 | [0.0764, 0.193] |
| Zewdu et al 2010 Ethiopia | 0.2541 | [0.1852, 0.330] |
| Anokye et al 2009 Ethiopia | 0.4029 | [0.3028, 0.508] |
| Jones et al 2011 Ethiopia | 0.4610 | [0.4042, 0.527] |
| Paulino et al 2012 Ethiopia | 0.5002 | [0.4544, 0.6247] |
| Gachon and Addis 2013 Ethiopia | 0.526 | [0.4779, 0.590] |
| Mehliti et al 2013 Ethiopia | 0.6012 | [0.5681, 0.6334] |
| saleh et al 2013 Ethiopia | 0.6398 | [0.5944, 0.6866] |
| Alencar et al 2013 Ethiopia | 0.3772 | [0.3194, 0.4376] |
| Eleso et al 2013 Nigeria | 0.0300 | [0.0103, 0.0645] |
| Ugwudike and Ejere 1995 Nigeria | 0.1096 | [0.0410, 0.1978] |
| Asemota et al 2004 Nigeria | 0.1665 | [0.0387, 0.1949] |
| Uglehumbnail et al 2006 Nigeria | 0.0379 | [0.0231, 0.0645] |
| Random effects model: | 0.2154 | [0.1903, 0.3405] |

| Asia |            |        |
|------|------------|--------|
| Jakina et al 2017 Cambodia | 0.5747 | [0.5765, 0.957] |
| Dave et al 2009 India | 0.4629 | [0.4020, 0.600] |
| Ruan 2008 Japan | 0.0287 | [0.0123, 0.465] |
| Badi and Furq 2016 Iraq | 0.0000 | [0.0000, 0.004] |
| Tafadhi et al 1985 Iraq | 0.0000 | [0.0000, 0.004] |
| Isih et al 2005 Japan | 0.0186 | [0.0129, 0.250] |
| Assen et al 2014 Japan | 0.0104 | [0.0067, 0.293] |
| Isih et al 2011 Japan | 0.0111 | [0.0072, 0.672] |
| Isih et al 2011 Japan | 0.0652 | [0.0122, 0.105] |
| Takahashi et al 2009 Japan | 0.0099 | [0.0000, 0.009] |
| Isih et al 2009 Japan | 0.0109 | [0.0062, 0.119] |
| Perera et al 2015 Sri Lanka | 0.1311 | [0.0387, 0.392] |
| Poosiriyanik and Tan 2016 Thailand | 0.0312 | [0.0052, 0.164] |
| Supa et al 2013 Thailand | 0.0417 | [0.0164, 0.083] |
| Lutschay and 2005 Thailand | 0.0653 | [0.0060, 0.224] |
| Random effects model: | 0.0545 | [0.0470, 0.1426] |

| Europe |            |        |
|--------|------------|--------|
| Chamreun et al 2009 Belgium | 0.0809 | [0.0489, 0.098] |
| Dilland et al 2007 Finland | 0.0662 | [0.0234, 0.156] |
| Epel et al 1999 Germany | 0.0005 | [0.0000, 0.003] |
| Pappas and Brewer 2007 Greece | 0.0178 | [0.0077, 0.180] |
| Riggi et al 2007 Italy | 0.0084 | [0.0043, 0.090] |
| Paradas et al 2017 Italy | 0.0321 | [0.0100, 0.143] |
| Sauda et al 2016 Italy | 0.0016 | [0.0003, 0.008] |
| Itra et al 2017 Italy | 0.3400 | [0.2772, 0.475] |
| Rizzo and Riccardi 1978 Italy | 0.0859 | [0.0490, 0.126] |
| Mischen et al 2002 Romania | 0.0058 | [0.0010, 0.020] |
| Mischen et al 2007 Romania | 0.0075 | [0.0052, 0.067] |
| Kutun et al 2019 Russia | 0.0097 | [0.0056, 0.040] |
| Sirkhunov et al 2017 Slovakia | 0.1302 | [0.0626, 0.230] |
| Sanduliu-Tomver et al 2019 Slovenia | 0.0134 | [0.0050, 0.045] |
| Cristante et al 2016 Spain | 0.0018 | [0.0003, 0.004] |
| Weight et al 2016 UK | 0.0373 | [0.0150, 0.072] |
| Darchenko et al 2013 France | 0.0275 | [0.0150, 0.048] |
| Random effects model: | 0.0255 | [0.0204, 0.050] |

| North America |            |        |
|----------------|------------|--------|
| Pedi et al 2015 Canada | 0.0026 | [0.0007, 0.072] |
| Aburandu-Esaguri et al 2015 Mariana | 0.1984 | [0.0990, 0.294] |
| Sohe-Green et al 1987 USA | 0.0140 | [0.0086, 0.046] |
| Gates and Nita 2009 USA | 0.0020 | [0.0003, 0.005] |
| Nagarani et al 2020 USA | 0.0020 | [0.0000, 0.010] |
| Random effects model: | 0.0022 | [0.0000, 0.006] |

| Oceania |            |        |
|---------|------------|--------|
| Bug et al 1999 Australia | 0.0024 | [0.0004, 0.020] |
| Behnhausen et al 2003 Australia | 0.2190 | [0.1741, 0.279] |
| Random effects model: | 0.0099 | [0.0000, 1.000] |

| South America |            |        |
|----------------|------------|--------|
| Mariano et al 2010 Bolivia | 0.0417 | [0.0163, 0.102] |
| Munita et al 2012 Brazil | 0.0252 | [0.0200, 0.330] |
| Ferreira et al 2016 Brazil | 0.0010 | [0.0000, 0.020] |
| Jensen et al 2006 Brazil | 0.0005 | [0.0000, 0.000] |
| Gagnon et al 2007 Brazil | 0.0001 | [0.0000, 0.000] |
| Lommerci et al 2007 Brazil | 0.0001 | [0.0000, 0.000] |
| Harada and Forero 2019 Colombia | 0.0001 | [0.0000, 0.000] |
| Garcia et al 2018 Venezuela | 0.0010 | [0.0001, 0.001] |
| Reisino-Bermudez et al 2004 Venezuela | 0.0001 | [0.0000, 0.000] |
| Random effects model: | 0.0045 | [0.0003, 0.003] |

| Random effects model: | 0.0618 | [0.0356, 0.0945] |

Test for subgroup differences: $I^2 = 23.83\%$, $df = 5$ ($p < 0.001$)
### Fig. 3

Forest plots for random-effects meta-analysis of the global prevalence of *Strongyloides stercoralis* in owned and stray/shelter dogs

| Study                                | Prevalence | 95% CI       |
|--------------------------------------|------------|--------------|
| **Owned dogs**                       |            |              |
| Rizzo and Ricciardi. 1978 Italy      | 0.0059     | [0.0010; 0.0326] |
| Stehr-Green et al. 1987 USA          | 0.0140     | [0.0038; 0.0496] |
| Bugg et al. 1999 Australia           | 0.0031     | [0.0066; 0.0174] |
| Itoh et al. 2003 Japan               | 0.0186     | [0.0129; 0.0268] |
| Aneke et al. 2004 Nigeria            | 0.1065     | [0.0835; 0.1349] |
| Asano et al. 2004 Japan              | 0.0104     | [0.0053; 0.0203] |
| Ramirez-Barrias et al. 2004 Venezuela| 0.0033     | [0.0007; 0.0158] |
| Komunyango et al. 2005 Cameroon      | 0.1145     | [0.0706; 0.1803] |
| Jujer et al. 2006 Brazil             | 0.0893     | [0.0026; 0.0333] |
| Goncalves et al. 2007 Brazil         | 0.2431     | [0.1864; 0.3105] |
| Papazahariadou et al. 2007 Greece    | 0.0178     | [0.0076; 0.0410] |
| Dillard et al. 2007 Finland          | 0.0652     | [0.0224; 0.1750] |
| Ugbonoiko et al. 2008 Nigeria        | 0.0379     | [0.0231; 0.0615] |
| Clecambre et al. 2009 Belgium        | 0.0012     | [0.0002; 0.0007] |
| Gates and Nolan. 2009 USA            | 0.0020     | [0.0012; 0.0034] |
| Itoh et al. 2009 Japan               | 0.0109     | [0.0062; 0.0189] |
| Razmi et al. 2009 Iran               | 0.0287     | [0.0123; 0.0655] |
| Takano et al. 2009 Japan             | 0.0909     | [0.0395; 0.1958] |
| Leclayseva et al. 2009 Thailand      | 0.0053     | [0.0009; 0.0294] |
| Mariana et al. 2010 Bolivia          | 0.0417     | [0.0163; 0.1021] |
| Itoh et al. 2011 Japan               | 0.0111     | [0.0072; 0.0172] |
| Itoh et al. 2011 Japan               | 0.0025     | [0.0012; 0.0055] |
| Getahun and Addis. 2012 Ethiopia     | 0.2161     | [0.1779; 0.2600] |
| Martins et al. 2012 Brazil           | 0.2632     | [0.2029; 0.3338] |
| Riggio et al. 2013 Italy             | 0.0084     | [0.0023; 0.0300] |
| Oruno et al. 2014 Spain              | 0.0227     | [0.0063; 0.0791] |
| Elom et al. 2015 Nigeria             | 0.0300     | [0.0163; 0.0845] |
| Wright et al. 2016 UK                | 0.0175     | [0.0060; 0.0503] |
| Pumidionming et al. 2016 Thailand    | 0.0152     | [0.0095; 0.0438] |
| Ferreira et al. 2016 Brazil          | 0.0010     | [0.0003; 0.0028] |
| Jaleta et al. 2017 Cambodia          | 0.8547     | [0.7996; 0.9073] |
| Kurnosova et al. 2019 Russia         | 0.0091     | [0.0056; 0.0148] |
| Hurtado and Forero. 2019 Colombia    | 0.0546     | [0.0367; 0.0806] |
| Sampoo et al. 2020 Thailand          | 0.0417     | [0.0179; 0.0938] |
| Nagamori et al. 2020 USA             | 0.0020     | [0.0012; 0.0033] |
| **Random effects model**             | 0.0389     | [0.0154; 0.0725] |
| Heterogeneity: $\hat{\tau}^2 = 97.7682\%$, $\tau^2 = 0.0454$, $p < .001$ |          |              |

| Study                                | Prevalence | 95% CI       |
|--------------------------------------|------------|--------------|
| **Stray / animal shelter dogs**      |            |              |
| Ng and Kelly. 1975 Australia         | 0.0022     | [0.0004; 0.0121] |
| Tarish et al. 1986 Iraq              | 0.0500     | [0.0089; 0.2361] |
| Das et al. 2009 India                | 0.0429     | [0.0210; 0.0860] |
| Zewdu et al. 2010 Ethiopia           | 0.4038     | [0.2816; 0.5393] |
| Jones et al. 2011 Ethiopia           | 0.4610     | [0.4024; 0.5297] |
| Abeke et al. 2013 Ethiopia           | 0.3913     | [0.2639; 0.5354] |
| Puebla et al. 2015 Cuba              | 0.0357     | [0.0098; 0.1212] |
| Alvarado-Esquivel et al. 2015 Mexico | 0.1584     | [0.0999; 0.2419] |
| Hadi and Faraj. 2016 Iraq            | 0.0500     | [0.0231; 0.1048] |
| Strikova et al. 2017 Slovakia        | 0.1000     | [0.0279; 0.3010] |
| Parades et al. 2017 Italy            | 0.0806     | [0.0349; 0.1751] |
| Sunda et al. 2018 Italy              | 0.0016     | [0.0003; 0.0088] |
| Iata et al. 2019 Italy               | 0.3600     | [0.2727; 0.4576] |
| Iata et al. 2019 Italy               | 0.3600     | [0.2727; 0.4576] |
| Dashchenko et al. 2020 Ukraine       | 0.0308     | [0.0120; 0.0764] |
| **Random effects model**             | 0.1294     | [0.0521; 0.2346] |
| Heterogeneity: $\hat{\tau}^2 = 97.9031\%$, $\tau^2 = 0.0580$, $p < .001$ |          |              |

Random effects model

Heterogeneity: $\hat{\tau}^2 = 97.9974\%$, $\tau^2 = 0.0540$, $p < .001$

Test for subgroup differences: $\chi^2 = 5.2672$, df = 1 ($p = .02$)
access to veterinary care, specifically access to or affordability of anthelmintics, might be limited, contributing to the higher prevalence. Also, in low-income countries, the number of stray dogs can be high with the prevalence of *S. stercoralis* infection being greater than that in owned dogs, based on the data from the meta-analysis herein presented [41, 42].

Cambodia, where the highest prevalence was found in our analysis, serves as a potential example of the interaction of climate, income and free-roaming (individually or community owned but not contained) or stray dogs. Cambodia is a lower middle-income country with a tropical climate and limited accessibility to improved sanitation services as well as safe drinking water [43]. In the human population, *S. stercoralis* is a public health concern with prevalence being > 40%, one of the higher levels in human populations that have been found [44–46]. Lastly, many dogs in the country are free-roaming or stray [47]. These potential interactions support the need for a One Health approach to addressing *Strongyloides* infections in humans and dogs.

There is no gold standard method for detecting *S. stercoralis* in dogs (or people), and the current techniques have limited sensitivity due to the low burden of parasites and intermittent larval shedding [21, 48]. The most commonly used methods for the diagnosis of *S. stercoralis* infection in humans are direct smear and Kato-Katz, both of which have low sensitivity [12, 46]. Sedimentation, the Baermann method and agar plate culture have higher sensitivity, but they are inconvenient, time-consuming and still underestimate infections [12, 49]. While these latter methods were used in most of the studies included in the meta-analysis, technical details were inconsistent and their implementation varied. For example, with the Baermann the quantity of fecal material and the number of samples analyzed (e.g. one or three from consecutive days) were not standardized across studies, thus resulting in varied sensitivity of the method across studies. In some of the included articles, the focus was on general parasite prevalence with flotation and smears used for fecal analysis, standard screening methods for parasites in dogs but methods with low sensitivity for *S. stercoralis*, potentially resulting in an underestimation of prevalence. Interpretation of results from serological and molecular-based techniques, which were used in a few of the included articles, must be made with caution because of the possibility of false-positive and/or negative results [21]. Given the high variation in how each diagnostic method was used in the studies, sensitivity ranges could not be assigned with confidence; hence, in the meta-analysis herein presented, prevalence was not adjusted based on the diagnostic method used with the resulting global prevalence likely underestimated.

In a clinical setting, *S. stercoralis* infections in dogs also are likely to be underestimated or overlooked because of the challenge of differentiating *S. stercoralis* larvae from other larvae that can occur in feces [i.e. *Angiostrongylus vasorum*, *Crenosoma vulpis*, *Filaroides (Oslerus) osleri*, *Filaroides hirti* and *Filaroides milksi*] [21]. Also, feces must be directly collected from the rectum or collected from the ground immediately after defecation to prevent fecal contamination with the larvae of free-living nematodes.
Most of the studies included in the meta-analysis were from tropical and subtropical regions, biasing the result towards higher prevalence in these regions. In other regions, within specific dog populations, prevalence might be higher than indicated in the meta-analysis with studies targeting *S. stercoralis* in susceptible dog populations (e.g. kennels, strays and shelter dogs) having prevalence similar to that seen in tropical and subtropical regions [16, 19, 50]. Hence, there is a need for more prevalence studies outside of tropical and subtropical regions to obtain a better understanding of the zoonotic risk.

**Conclusion**

The results of this systematic review and meta-analysis indicate the significant burden and current status of *S. stercoralis* infection in dogs in different parts of the world and highlight the need for studies in more geographical regions using methods with defined sensitivity. Paying attention to waste management systems, improving hygiene education and sanitary facilities in human populations as well as cleaning the environment of dog feces and establishing a preventive strategy for stray dogs could reduce the prevalence of the infection, especially in lower-income tropical and subtropical regions of the world. To decrease the burden of infective larvae in the environment contaminated with the feces of dogs, and in order to protect the canine and human population from the risk of infection, adequate deworming practices are essential. While few studies directly link infection of *Strongyloides* in humans to dogs, the shared genotypes and the similarity in where prevalence is higher support that the zoonotic potential of *S. stercoralis* infection is an important subject that should be reflected through raising awareness among dog owners and veterinarians. We recommend health authorities to organize efficient monitoring programs for protecting humans and dogs from the impact of the infection.
Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s13071-021-05135-0.

Additional file 1: References S1. List of articles used in the meta-analysis.
Additional file 2: Figure S1. Sub-group analysis of the prevalence of Strongyloides stercoralis in included studies based on country.
Additional file 3: Table S1. Sub-group analysis of the prevalence of Strongyloides stercoralis in included studies based on continent, income level, humidity, annual rainfall, average temperature, latitude and climate.

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Authors' contributions
MB, AVE and JKK designed the study. EH, EH and RM searched for primary publications, screened and appraised primary studies. AVE and MB extracted the data and, with JKK, wrote the study manuscript. MO, EH and SH contributed to data analysis and interpretation and edited the manuscript. All authors read the manuscript and participated in the preparation of the final version of the manuscript. All authors read and approved the final manuscript.

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Declarations
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Author details
1 Medical Microbiology Research Center, Qazvin University of Medical Sciences, Qazvin, Iran. 2 Metabolic Diseases Research Center, Research Institute
References

1. Zibaei M, Nosrati MRC, Shadnoosh F, Houshmand E, Karami MF, Rafsanjani MK, et al. Insights into hookworm prevalence in Asia: a systematic review and meta-analysis. Trans R Soc Trop Med Hyg. 2020;114(3):141–5.

2. Omidinia N, Zibaei M, Hosseini H, Pourrostami K, Eslahi AV, Badri M. Human hydatidosis in Alborz province: a 5-year retrospective epidemiological analysis of hospitalized cases. Ann Parasitol. 2020;66(4):587–92.

3. Cavelan S, Laurensen MK, Taylor LH. Diseases of humans and their domestic mammals: pathogen characteristics, host range and the risk of emergence. Philos Trans R Soc B Biol Sci. 2001;356:991–9.

4. Eslahi AV, Mowlavi G, Houshmand E, Abdoli A, Houshmand E, Majidiani H, Nahavandi KH, et al. Occurrence of Dicrocoelium dendriticum (Goeze, 1782) in road-killed canids of Iran and its public health implication. Vet Parasitol Reg Stud Rep. 2021;24:100568.

5. Eslahi AV, Badri M, Nahavandi KH, Houshmand E, Dalvand S, Riahi SM, et al. Prevalence of strongyloidiasis in the general population of the world: a systematic review and meta-analysis. Pathog Glob Health. 2021;115:7–20.

6. Ko PP, Suzuki K, Canales-Ramos M, Htwe MPPTH, Htike WW, Yoshida A, et al. Phylogenetic relationships of Strongyloides species in carnivore hosts. Parasitol Int. 2020;78:100215.

7. Barroso M, Salvador F, Sánchez-Montalvá A, Bosch-Nicolau P, Molina I. Strongyloides stercoralis infection in dogs in the Spanish Balearic Islands. Vet Parasitol. 2020;287:108573.

8. Viney ME. Strongyloides. Parasitology. 2017;144(3):259–62.

9. Nutman T. Human infection with Strongyloides stercoralis and other related Strongyloides species. Parasitology. 2017;144(3):263–73.

10. Buonfrate D, Requena-Mendez A, Angheben A, Cinquini M, Cruciani M, Fittipaldo A, et al. Accuracy of molecular biology techniques for the diagnosis of Strongyloides stercoralis infection—a systematic review and meta-analysis. PLoS Negl Trop Dis. 2018;12(2):e0006229.

11. Levshagen MA, Costa-Cruz JM. Update on immunologic and molecular diagnosis of human strongyloidiasis. Acta Trop. 2014;135:33–43.

12. Schar F, Trostorf U, Giardina F, Khieu V, Muth S, Marti H, et al. Strongyloides stercoralis: global distribution and risk factors. PLoS Negl Trop Dis. 2013;7(7):e2288.

13. Barratt JLN, Lane M, Talundzic E, Richins T, Robertsson G, Formenti F, et al. A global genotyping survey of Strongyloides stercoralis and Strongyloides fuelleborni using deep amplicon sequencing. PLoS Negl Trop Dis. 2019;13(9):e0007609.

14. Umut Ş, Meral Y, Bölükbaş CS, Güler AT, Aciž M. First clinical Strongyloides stercoralis case in a dog in Turkey. Turk J Vet Anim Sci. 2017;41(2):312–5.

15. Goncalves ALR, Machado GA, Gonçalves-Pires MRF, Ferreira-Junior A, Silva DAO, Costa-Cruz JM. Evaluation of strongyloidiasis in kennel dogs and keepers by parasitological and serological assays. Vet Parasitol. 2007;147(1–2):132–9.

16. Dillard KJ, Saari SAM, Amtila M. Strongyloides stercoralis infection in a Finnish kennel. Acta Vet Scand. 2007;49(1):1–6.

17. Júnior AF, Gonçalves-Pires MRF, Silva DAO, Gonçalves ALR, Costa-Cruz JM. Parasitological and serological diagnosis of Strongyloides stercoralis in domesticated dogs from southeastern Brazil. Vet Parasitol. 2006;136(2):137–45.

18. Eydel M, Skrimmison K. Strongyloides stercoralis found in imported dogs, household dogs and kennel dogs in Iceland. Icel Agric Sci. 2016;29:39–51.

19. Dashchenko S, Sotoka N, Semenko O. Distribution of Strongyloides stercoralis among dogs of different housing groups in Kyiv and Kyiv region, clinical manifestations and diagnostic methods. EUREKA Health Sci. 2020;5:99–107.

20. Basso W, Grandt L-M, Magrenat A-L, Gottstein B, Campos M. Strongyloides stercoralis infection in imported and local dogs in Switzerland: from clinical to molecular genetics. Parasitol Res. 2019;118(1):255–66.

21. Paradies P, Iarussi F, Sasanelli M, Capogna A, Lia RP, Zucca D, et al. Occurrence of strongyloidiasis in privately owned and sheltered dogs: clinical presentation and treatment outcome. Parasit Vectors. 2017;10(1):1–9.

22. Thamsborg SM, Ketjis J, Horn Y, Matthews JB. Strongyloides spp. infections of veterinary importance. Parasitology. 2017;144(3):274–84.

23. Faust EC, Kagi ES. Experimental studies on human and primate species of Strongyloides. I. The variability and instability of types. Am J Trop Med. 1933;13:47–65.

24. Lok JB, Community TCeR. Strongyloides stercoralis: a model for translational research on parasitic nematode biology. WormBook. 2007. https://doi.org/10.1895/wormbook.1.134.1.

25. Buonfrate D, Bisanzio D, Geioli G, Odermatt P, Fürst T, Greenaway C, et al. The global prevalence of Strongyloides stercoralis infection. Pathogens. 2020;9(6):468.

26. Wells G, Shea B, O’Connell D, Peterson J, Welch V, Losos M, et al. The Newcastle–Ottawa Scale (NOS) for assessing the quality if nonrandomized studies in meta-analyses. www.ohri.ca/programs/clinical_epidemiology/oxford.asp. Accessed 3 July 2021.

27. Badri M, Eslahi AV, Ofiatfar M, Dalvand S, Houshmand E, et al. Keys to unlock the enigma of ocular toxocariasis: a systematic review and meta-analysis. Ocul Immunol Inflamm. 2021;12:1–2.

28. Eslahi AV, Ofiatfar M, Abdoli A, Houshmand E, Johkool MG, Zarabadi-pour M, et al. The neglected role of Trichomonas tenax in oral diseases: a systematic review and meta-analysis. Acta Parasitol. 2021;66:715–32.

29. Mirzadeh M, Ofiatfar M, Eslahi AV, Abdoli A, Houshmand E, Majidiani H, et al. Global prevalence of Trichomonas vaginalis among female sex workers: a systematic review and meta-analysis. Parasitol Res. 2021;120(7):2311–22.

30. Kanat-Maymon Y, Antebi A, Zilcha-Mano S. Basic psychological need fulfillment in human–pet relationships and well-being. Piers Individ Diff. 2016;92:69–73.

31. Grafjoner D, Harte E, Potter LM, McGuigan N. The effect of dog-assisted intervention on student well-being, mood, and anxiety. Int J Environ Res Public Health. 2017;14(5):483.

32. Ritossa L, Viozzi G, Flores V. The state of knowledge on intestinal helminths in free-roaming dogs in southern South America. Canine Genet Health Med. 2021. https://doi.org/10.5772/inntechopen.96125.

33. Ghasemzadeh I, Namazi SH. Review of bacterial and viral zoonotic infections transmitted by dogs. J Med Life. 2015;8(Spec Iss 4):1.

34. Szabóvá E, Juríš P, Miterpáková M, Antolciová D, Papajová I, Šefčíková H. Prevalence of important zoonotic parasites in dog populations from the Slovak Republic. Helminthologia. 2007;44(4):170–6.

35. Jaleta TG, Zhou S, Bemm FM, Schar F, Khieu V, Muth S, et al. Different but overlapping populations of Strongyloides stercoralis in dogs and humans—dogs as a possible source for zoonotic strongyloidiasis. PLoS Negl Trop Dis. 2017;11(8):e0005752.

36. Viney ME, Lok JB. The biology of Strongyloides spp. WormBook. 2015;16:1–17.

37. Paula FM, Costa-Cruz JM. Epidemiological aspects of strongyloidiasis in Brazil. Parasitol Research. 2011;109(11):1319–40.

38. Sartorus B, Cano J, Simpson H, Tusting LS, Marczak LB, Miller-Petrie MK, et al. Prevalence and intensity of soil-transmitted helminth infections of children in sub-Saharan Africa, 2000–18: a geographical analysis. Lancet Glob Health. 2021;9(1):e52–60.

39. De Silva NR, Brooker S, Hotez PJ, Montresor A, Engels D, Savioli L. Soil-transmitted helminth infections: updating the global picture. Trends Parasitol. 2003;19(12):547–51.

40. Beknazarová M, Whiley H, Ross K. Strongyloides: a disease of socioeconomic disadvantage. Int J Environ Res Public Health. 2016;13(5):517.

41. Abulada OA. Prevalence of intestinal helminth infections of stray dogs of public health significance in Lagos metropolis, Nigeria. Int Ann Sci. 2019(9):1:24–32.

42. Orutano D, Dantas-Torres F, Mithalca AD, Traub RJ, Lappin M, Baneth G. Zoonotic parasites of sheltered and stray dogs in the era of the global economic and political crisis. Trends Parasitol. 2020;37:10:813–25.
43. Liao C-W, Chiu K-C, Chiang I-C, Cheng P-C, Chuang T-W, Kuo J-H, et al. Prevalence and risk factors for intestinal parasitic infection in schoolchildren in Battambang, Cambodia. Am J Trop Med Hyg. 2017;96(3):583.

44. Forrer A, Khieu V, Schindler C, Schär F, Marti H, Char MC, et al. Ivermectin treatment and sanitation effectively reduce Strongyloides stercoralis infection risk in rural communities in Cambodia. PLoS Negl Trop Dis. 2016;10(8):e0004909.

45. Khieu V, Schär F, Forrer A, Hattendorf J, Marti H, Duong S, et al. High prevalence and spatial distribution of Strongyloides stercoralis in rural Cambodia. PLoS Negl Trop Dis. 2014;8(6):e2854.

46. Eslahi AV, Olfatifar M, Karim MR, AbuOdeh R, Modirian E, Houshmand E, et al. Global incidence of helminthic contamination of vegetables, cucurbits and fruits: a systematic review and meta-analysis. Food Control. 2021. https://doi.org/10.1016/j.foodcont.

47. Chevalier V, Davun H, Som S, Ly P, Pov V, Ly S. Large scale dog population demography, dog management and bite risk factors analysis: a crucial step towards rabies control in Cambodia. PLoS ONE. 2021;16(7):e0254192.

48. Iatta R, Buonfrate D, Paradies P, Cavalera MA, Capogna A, Larussi F, et al. Occurrence, diagnosis and follow-up of canine strongyloidiasis in naturally infected shelter dogs. Parasitology. 2019;146(2):246–52.

49. Vafae Eslahi A, Olfatifar M, Houshmand E, Ghanbari Johkoold M, Zibaei M, Foroutan M, Hosseinie H, Badri M, et al. Prevalence of Strongyloides stercoralis in the immunocompetent and immunocompromised individuals in Iran: a systematic review and meta-analysis. Trans R Soc Trop Med Hyg. 2021. https://doi.org/10.1093/trstmh/trab104.

50. Gates MC, Nolan TJ. Endoparasite prevalence and recurrence across different age groups of dogs and cats. Vet Parasitol. 2009;166(1–2):153–8.

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