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Research Article

CLINICAL PATTERNS AND DIAGNOSTIC GAPS OF HUMAN DIROFILARIASIS: SCOPING REVIEW WITH IMPLICATIONS FOR INDONESIA

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Abstract

Human dirofilariasis is an emerging mosquito-borne zoonosis caused by *Dirofilaria* spp.. Increasing reports from Southern Europe and Southeast Asia contrast with the literature from other regions of Asia, which are underreported. Identifying patterns in clinical presentation, species distribution, and case management could expose diagnostic gaps and direct resources to target these deficiencies. This review conducted a scoping review to establish the clinical presentation and species distribution of human dirofilariasis cases worldwide and propose a preliminary conceptual framework correlating species with anatomical predilection to guide clinical suspicion. Searches in PubMed, Scopus, and Google Scholar were performed following the PRISMA-ScR on May 13, 2023, resulting in 15 case reports (1989–2022) with morphological and/or molecular species confirmation. Identified cases suggest that while *D. repens* infections lead to subcutaneous involvement, *D. immitis* infections are primarily pulmonary and ocular, with one report of *D. hongkongensis* causing an ocular infection. These findings suggest an association between species and anatomical predilection; however, this pattern should be interpreted cautiously because of the limited number of confirmed cases and potential publication bias. Molecular confirmation of species is sparse, and excision remains the primary mode of management. An important finding was the absence of reported human cases from Indonesia, despite cases in neighboring countries. Given the reported canine infections and suitable vector conditions, this may represent a potential underdiagnosis requiring verification through active surveillance. Our findings highlight persistent diagnostic challenges and support strengthened molecular diagnostics and One Health Surveillance.

Keywords: Human Dirofilariasis, One Health, Vector-Borne Disease, Zoonosis

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INTRODUCTION

Dirofilariasis is a serious zoonotic infection in humans caused by nematodes of the genus *Dirofilaria*, with limited understanding. The species most frequently reported in human infections include *D. repens* and *D. Immitis* (Choudhury et al., 2023; Simón et al., 2022). Recent studies have discussed their clinical and epidemiological relevance (Perles et al., 2024). Canids, including dogs, are the definitive hosts for these parasites, with mosquitoes from the genera *Culex*, *Aedes*, and *Anopheles* acting as biological vectors (Aung et al., 2023; Kondrashin et al., 2020; Momčilović et al., 2025). Humans contract the disease accidentally through the bite of a mosquito infected with third-stage (L3) larvae; however, because they cannot sexually mature inside a human host, no microfilariae are released into the bloodstream, and therefore, humans act as dead-end hosts (Choudhury et al., 2023; Genchi & Kramer, 2017; Hattendorf & Lühken, 2025). While this infection has been widely studied in animals, there continues to be limited understanding of dirofilariasis in humans, and knowledge is drawn from individual case reports (Simón et al., 2022).

The clinical manifestations appear to be influenced by the anatomical localization of adult parasites. Based on reported human cases, *D. immitis* has been frequently associated with pulmonary nodular lesions that may mimic neoplasms radiologically, whereas *D. repens* and *D. tenuis* have been predominantly reported in subcutaneous tissues, with occasional involvement of the ocular region (Capelli et al., 2018; Momčilović et al., 2025; Palicelli et al., 2022). However, these associations should be interpreted cautiously because the current evidence is largely derived from case reports and may not represent the complete clinical spectrum. This radiological mimicry of neoplasia may lead to unnecessary invasive procedures in some reported cases, including pulmonary resection performed for lesions initially suspected to be carcinomas (Momčilović et al., 2025; Simón et al., 2022)(Momčilović et al., 2025; Simón et al., 2022). However, the frequency of such events remains unclear.

The documentation of cases in greater numbers over the last 20 years from Southern Europe, South Asia, and Southeast Asia (minimum sampling of the other Asian regions) into the literature has warranted reports of dirofilariasis as an emerging zoonosis (Choudhury et al., 2023; Gabrielli et al., 2021; Momčilović et al., 2025; Thilakarathne et al., 2023). The likely causes are climate change, which allows for vector migration, urbanization, which leads to an increase in mosquito populations, and globalization of people and their companion animals (Capelli et al., 2018; Hattendorf & Lühken, 2025; Momčilović et al., 2025; Palicelli et al., 2022). Therefore, it can be concluded that dirofilariasis is expanding beyond endemic foci (Hattendorf & Lühken, 2025; Kondrashin et al., 2020).

The potential for transmission in Southeast Asia has been suggested by the presence of suitable ecological conditions and documented human cases in several countries within the region. Human cases have been reported in several countries, including Malaysia, Thailand, and Vietnam, involving different clinical presentations and *Dirofilaria* species (Dang et al., 2010; Rohela et al., 2009; Shekhar et al., 1996; Somsap et al., 2021; Sukudom et al., 2018). These regional patterns may support the surveillance hypothesis that countries with comparable ecological conditions, including Indonesia, could warrant further investigation. However, this regional evidence should not be interpreted as direct evidence of human transmission or disease burden in Indonesia, and population-based surveillance data are required to estimate the actual risk.

Seroprevalence studies of *D. immitis* in canines have demonstrated substantial infection levels in Indonesia, ranging from 10% in Aceh to 57% in Bali and Jakarta, with notable prevalence reported in Central Kalimantan (28.7%) and South Kalimantan (21%) (Dayanti et al., 2021). Potential vector species, including *Aedes albopictus*, *Culex pipiens*, and several *Anopheles* spp., are distributed across Indonesia (Aung et al., 2023; Hattendorf & Lühken, 2025; Szentivanyi et al., 2025). Together with reports of human cases from neighboring Southeast Asian countries, these findings indicate that Indonesia has ecological conditions compatible with potential zoonotic transmission; however, they do not provide evidence of human infection occurrence or disease burden in the country. However, the absence of confirmed human cases in the published literature does not establish whether human infections are absent or remain undetected.

The absence of clinical reports despite ecological suitability may reflect several possibilities, including limited clinical recognition, restricted diagnostic capacity, insufficient surveillance, or genuinely low occurrence of human infection. Therefore, the current evidence should be interpreted as an unresolved knowledge gap rather than a confirmation of undetected human transmission.

To date, efforts to understand dirofilariasis in Indonesia have been limited to the veterinary context. No review has synthesized animal-level prevalence data with global clinical trends to determine the possible risks to public health. This review aims primarily to characterize the clinical trends and species distribution of confirmed human dirofilariasis cases reported globally. The secondary objectives were to explore diagnostic approaches, anatomical predilection patterns, and evidence gaps relevant to human dirofilariasis detection, including the current knowledge gap in Indonesia. This review also sought to provide an initial framework for conceptualizing species distribution with anatomic predilection to increase diagnostic accuracy.

RESEARCH METHOD

Research Design

This scoping review focuses on published primary studies describing human dirofilariasis cases, including case reports and case series (Pollock et al., 2021; Simón et al., 2022).. This study was performed in adherence to the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines (Peters et al., 2021; Pollock et al., 2021, 2022, 2023). No protocol was registered prior to conducting this review, and no geographic filters were used during the search strategy; regional restriction was applied during the analysis and interpretation of the findings.

Research Questions

This scoping review sought to answer the following question: (1) What is the distribution of Dirofilaria species among human cases globally? (2) What is the association between the causative species and clinical presentation? (3) How are cases diagnosed to confirm the infection? (4) What are the data gaps between animal prevalence and human case reporting in Indonesia?

Search Strategy

A literature search was performed on May 13, 2023, as part of the original scoping review process. References published after the search period were not eligible for inclusion in the scoping review, but were used selectively as additional supporting literature to provide an updated context regarding dirofilariasis epidemiology, diagnosis, and One Health perspectives. Three electronic databases were searched, namely PubMed, Scopus, and Google Scholar. The search period was defined to capture published evidence available at the time the review was conducted. Subsequent references published after the search period were used only to provide contextual updates in the Introduction and Discussion sections and were not included in the evidence synthesis. The search strategy using keywords and logic symbols is presented below.

PubMed search terms: *("Dirofilaria"[Title/Abstract] OR "dirofilariasis"[Title/Abstract]) AND ("human"[Title/Abstract] OR "case report"[Title/Abstract]) AND ("zoonosis"[Title/Abstract]).*

Scopus search terms: TITLE-ABS-KEY (dirofilaria OR dirofilariasis) AND (human OR "case report") AND zoonosis.

Google Scholar search terms: *("Dirofilaria" OR "dirofilariasis") AND "human" AND "zoonosis"*

Justification for Google Limitation

Google Scholar was used to search for grey literature. The first 100 results were ranked by relevance. Potential selection bias was considered (Briscoe et al., 2023; Winn et al., 2024).

Inclusion and Exclusion Criteria

The included studies were limited to primary reports of human dirofilariasis, including individual case reports and case series. Both individual case reports and case series were eligible because human dirofilariasis is uncommon and evidence is predominantly derived from descriptive clinical reports, with the following criteria: (1) human infection with *Dirofilaria* species; (2) morphologic and/or molecular confirmation of *Dirofilaria* species; (3) English- or Indonesian-language full-text articles; (4) publications published between 1989 and 2022; and (5) sufficient clinical information regarding patient presentation and diagnosis. The unit of inclusion was a published article, rather than an individual patient. Each eligible publication was considered as one study, and patient-level clinical information was extracted when available. For the case series, individual patient data were extracted only when cases were separately reported or when aggregate clinical characteristics were available.

Studies excluded were: (1) case reports from animals with no clinical correlate; (2) review articles, editorials, or commentaries; (3) absence of confirmed species identification; (4) lack of clinical information; and (5) duplicate reports.

Justification for Case-Based Study Selection

Case-based studies (including case reports and case series) were included because human dirofilariasis is uncommon, and these study designs provide detailed clinical, diagnostic, and epidemiological information that is often unavailable in larger observational studies.

Article Selection

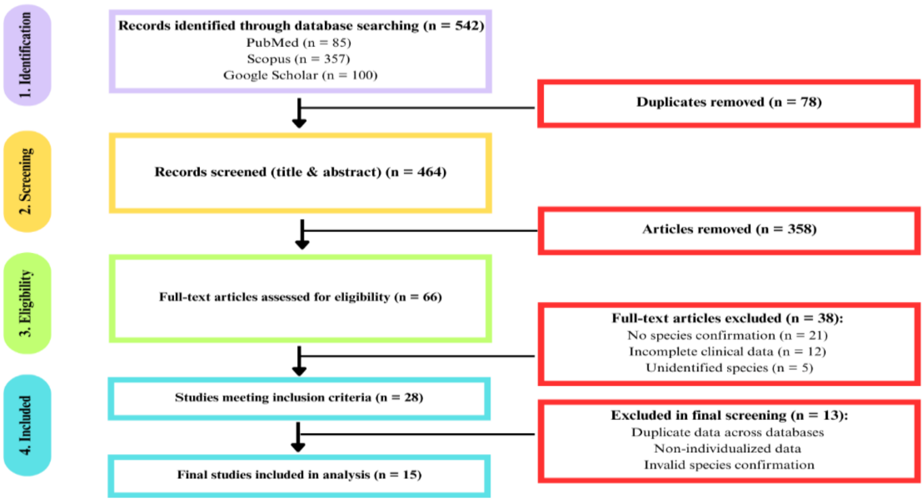

Figure 1. PRISMA-ScR Flow Diagram Illustrating the Systematic Study Selection Process.

A Total Of 542 records were identified, with 15 studies ultimately included after duplicate removal, screening, and full-text eligibility assessment, with the reasons for exclusion documented at each stage.

The selection process was conducted according to the PRISMA-ScR guidelines. Title and abstract screening was performed by one reviewer in a systematic manner, applying predetermined inclusion/exclusion criteria uniformly to minimize bias. Of the 542 articles identified through PubMed (n = 85), Scopus (n = 357), and Google Scholar (n = 100) search engines, 78 duplicates were removed using citation software. The remaining 464 articles were screened at the title and abstract stage.

Articles that fulfilled the exclusion criteria were removed from consideration. A total of 398 articles were excluded during the title and abstract screening phase of the review. After title and abstract screening, 66 articles were assessed for full-text eligibility. Articles that did not meet the inclusion criteria were removed from the pool. 38 articles were excluded after full-text review. Of the 28 articles that met the inclusion criteria, 13 were removed due to overlapping data between publications (duplicate case reporting), lack of separation of data by individual, or invalid species confirmation methods. Fifteen articles were included in the analysis. One of the included studies was a case series of 55 pediatric patients. This study was eligible because the case series were predefined as acceptable study designs based on the inclusion criteria. This study was retained because it provided individual-level clinical information and met the diagnostic confirmation criteria required for this review.

Data Extraction (Charting Process)

Data charting was conducted using a standardized form for data extraction, which was piloted and applied uniformly throughout. The following data were extracted from each study: 1) study characteristics (author/year/country); 2) patient characteristics (age/sex/risk factors); 3) clinical presentation/location; 4) species identified; 5) diagnostic modalities employed (imaging/histopathology/molecular); and 6) treatment modalities used. The prevalence data of animals used for comparison in Indonesia were obtained from a previous study (Dayanti et al., 2021). This information was used for comparative context and was not drawn from the articles identified in our systematic search. Standardized data extraction was performed with internal consistency checks.

Data Analysis

The description was used to analyze the patterns of species distribution and clinical variation. No quality assessment was performed on the studies included in this review. This is because scoping reviews aim to map evidence without assessing study quality or intervention effects. The results are presented as summary tables with descriptive narratives.

RESULTS AND DISCUSSION

Study Characteristics and Data Distribution

Of the included studies, 15 case reports and small case series were from Europe (Greece, Slovakia, Italy, Bulgaria, and Serbia), South Asia (India and Sri Lanka), Southeast Asia (Malaysia, Thailand, and Vietnam), the Middle East (Iran), and one imported case report was from Australia. Table 1 summarizes the study characteristics, including location, species, clinical presentation, and diagnostic techniques used.

Table 1. Summary of Included Studies on Human Dirofilariasis

Author (Year)	Country	Species	Clinical Manifestation	Diagnostic Methods	Intervention
(Falidas et al., 2016)	Greece	*D. immitis*	Right subcostal nodule	Ultrasonography; Microscopy; PCR	Surgical excision
(Miterpáková et al., 2022)	Slovakia	*D. immitis*	Solitary pulmonary nodule	CT scan; Histopathology; PCR	Surgical resection

Author (Year)	Country	Species	Clinical Manifestation	Diagnostic Methods	Intervention
(Palicelli et al., 2022)	Italy	*D. immitis*	Pulmonary nodule; fever	CT scan; Histopathology; PCR	Nodule excision
(Campana et al., 2022)	Italy	*D. repens*	Subcutaneous nodule (arm)	Ultrasonography; Microscopy	Excisional biopsy
(Stoyanova, 2018)	Bulgaria	*D. repens*	Temporal edema	Biomicroscopy; Histopathology	Surgical extraction
(Alam et al., 2021)	India	*D. repens*	Thigh swelling	Ultrasonography; MRI; ELISA; Histopathology	Cyst excision
(Momčilović et al., 2019)	Serbia	*D. repens*	Buccal edema	MRI; Histopathology; PCR	Maxillofacial surgery
(Suresh et al., 2022)	Iran	*D. repens*	Facial edema	Radiography; Histopathology	Lesion excision
(Shekhar et al., 1996)	Malaysia	*D. repens*	Lymphadenopathy nodule	Histopathology	Surgical removal
(Rohela et al., 2009)	Malaysia	*D. repens*	Conjunctival redness	Slit-lamp examination; Microscopy	Parasite extraction
(Somsap et al., 2021)	Thailand	*D. immitis*	Ocular pain; photophobia	Slit-lamp examination; PCR	Forceps extraction
(Sukudom et al., 2018)	Thailand	*D. hongkongensis*	Subconjunctival worm	Slit-lamp examination; PCR	Surgical removal
(Bennett et al., 1989)	Australia	*D. repens*	Breast lump	Cytology; Histopathology	Excisional biopsy
(Dang et al., 2010)	Vietnam	*D. repens*	Ocular pain; swelling	PCR	Surgical biopsy
(Wijekoon et al., 2022)	Sri Lanka	*D. repens*	Scrotal nodules (30.9%); back (14.5%); face (10.9%)	Ultrasonography (54.5%); Histopathology (56.6%)	Surgical removal

The number needed for treatment calculations was not possible because of insufficient data. In summary, Table 1 demonstrates that the majority of cases are caused by *D. repens* with subcutaneous involvement. Cases of pulmonary involvement were almost exclusively caused by *D. immitis*. Molecular confirmation was performed in only one-fourth of the cases. For most studies, histopathology of excised tissue was the sole diagnostic modality. This observation pattern suggests that reported case distributions may be influenced by detection and reporting systems, in addition to underlying infection patterns.

Detection is likely driven by differences in clinical suspicion, diagnostic capacity, and publication customs among countries and regions. Furthermore, the predominance of single case reports introduces selection bias, whereby atypical or otherwise medically interesting cases are published preferentially. The ages ranged from 5 to 67 years, with roughly equal male-to-female distribution. Dog ownership (6/15 studies), living in rural or waterfront regions, and reported insect bites were the most commonly described risk factors for acquiring cutaneous leishmaniasis. However, the reporting of risk factors was heterogeneous and incomplete, which prevents the synthesis of studies and the identification of population exposure risks.

Species Distribution and Epidemiological Interpretation

Of note, *Dirofilaria repens* was identified most frequently, being present in 11 of the 15 included studies (73.3%) and was represented in all regions where the studies were conducted. *D. immitis* was identified less frequently, being present in four of the 15 included studies (26.7%), including three studies from Southern Europe and one study from Thailand. Finally, *D. hongkongensis* has only been reported in a single ocular case in Thailand. Species identification was summarized according to the reported species, and percentages were calculated based on the total number of included studies. While this distribution is consistent with known biological characteristics, it may also be influenced by detection bias and differences in diagnostic accessibility, rather than representing the true distribution of human infections. Species-specific differences in reported frequencies may partly reflect differences in the detection probability between species. *Dirofilaria repens* develops within subcutaneous nodules that are readily accessible for biopsy. Meanwhile, lung nodules caused by *D. immitis* go unnoticed because they are asymptomatic or mistaken for carcinoma. These would only be detected if physicians ordered thoracic imaging, followed by excision and molecular confirmation. As a result, passive surveillance based on reported clinical cases may overrepresent *D. repens* and underrepresent *D. immitis* because species with more clinically apparent or accessible lesions are more likely to be detected and reported. However, the magnitude of this potential detection bias cannot be determined using case reports alone. This review concludes that caution should be exercised when interpreting case reports epidemiologically.

Patterns of Clinical Manifestations

Overall, the data suggest that there is a pattern in tissue tropism. Across studies and species, clinical manifestations were more heavily based on the location of larval development. Independently, *D. repens* presents as solitary or multiple subcutaneous nodules with erythema, edema, or pain in adjacent areas. Body location was inconsistently reported, but a case series of 55 pediatric patients with *D. repens* from Sri Lanka contributed significantly to this data (Wijekoon et al., 2022). Patients presented with multiple subcutaneous nodules with a predilection for the scrotal region (30.9%), back/abdomen (14.5%), and head/face (10.9%). However, due to the large proportion of cases included in this study, these data may be subject to data dominance bias, falsely centralizing the anatomical distribution. In contrast to *D. repens*, *D. immitis* was only detected as pulmonary nodules with mild respiratory symptoms. Eyes are involved with both *D. immitis* and *D. hongkongensis*, resulting in symptoms such as acute ocular pain, photophobia, or visible worms under the conjunctiva (Somsap et al., 2021; Sukudom et al., 2018). These clinical presentations should be used as a framework to prompt diagnostic suspicion but not as confirmation of etiology. As such, this review cannot use diagnostic patterns to infer species because they would be incomplete without further confirmation.

Diagnostic Approach

In nearly all studies, the diagnosis was confirmed through histopathological examination of the excised tissue (86.7%). In the included studies, molecular diagnosis using PCR was performed in 40% of the cases (Gabrielli et al., 2021; Labu et al., 2022; Thilakarathne et al., 2023). Recent publications outside the review period have also emphasized the importance of molecular confirmation for species identification (Franzò et al., 2026)

Diagnosis is almost exclusively performed after reactionary excision of the lesion rather than based on prospective clinical suspicion. Thus, there is potential for species misidentification, especially in degenerated or partial specimens. This will ultimately skew the reported epidemiological maps of each species. (Chocobar et al., 2024; Dimzas et al., 2024; Mus et al., 2025; Palicelli et al., 2022) Imaging and slit lamp examinations provide information on the presence of a lesion, but does not specify parasitic etiology. For these reasons, cases go undetected or are diagnosed only after significant progression. Limitations of current diagnostic methodologies reinforce the pattern of underdiagnosis by creating barriers to case recognition, especially at an early stage. This review found that the current diagnostic strategy fails to define the true clinical spectrum of the disease.

Therapeutic Approach

Excision or extraction of the parasites was uniformly performed, and no additional antiparasitic treatment was required. This finding suggests that only infections that have progressed to lesions identified by patients and clinicians are diagnosed. Therefore, this review cannot assume that the infection is mild in humans, given that subclinical or early stage infections are likely not detected. Collectively, this illustrates that the detection of dirofilariasis in humans is dependent on clinical consequences rather than early detection of infection. Consequently, infections that do not produce lesions requiring medical attention are likely to remain undetected by current surveillance mechanisms.

Synthesis

In conclusion, this review found two consistent patterns in the gathered literature. First, there appears to be a species location association with anatomic location: *D. repens* is associated with the subcutaneous tissue, *D. immitis* with lung tissue, and both species can involve the eyes. Although this association is strong, clinicians should not use location as confirmation of species because there are exceptions. However, this can be used as a guide to inform preoperative thinking and should be considered if patients are from or have traveled to endemic regions (Franzò et al., 2026; Gabrielli et al., 2021). Second, the current diagnostic strategy may limit recognition of the broader disease spectrum and may result in incomplete characterization of the human disease burden. Despite reports of canine *D. immitis* infection in Indonesia, no confirmed human cases have been identified in the published literature. This discrepancy raises the possibility of underrecognition, although the current evidence is insufficient to distinguish between true absence of human infection and limitations in detection capacity (Chocobar et al., 2024; Dayanti et al., 2021; Dimzas et al., 2024; Mendoza-Roldan et al., 2021). Instead, it strongly suggests limitations in the current detection capacity. This review suggests that there is a significant detection gap on the human side, and the true burden of disease in humans is unknown.

Limitations

This study has some limitations. As mentioned, the use of case reports only limits the ability to make population-wide generalizations. Case reports by nature describe patients with either more severe disease or unusual manifestations. Additionally, inconsistencies in diagnostic methodology, particularly the use of confirmatory PCR, limit confidence in species classification and may impact our understanding of tropism patterns. Finally, because diagnosis is based on the excision of most lesions, we are unable to understand the full clinical spectrum, as subclinical cases will go undetected. Future studies are limited by small sample sizes and reliance on case reports. The causality between variables cannot be determined, and publication bias is likely because case reports are biased toward atypical cases. Thus, these findings are intended to identify patterns and not serve as epidemiological estimates.

Clinical and Public Health Relevance

Given the potential for dirofilariasis to be overlooked in clinical practice, this review proposes several clinical and public health considerations. Clinicians should consider dirofilariasis as a possible differential diagnosis for nodules, particularly those occurring in subcutaneous tissues or the lungs, especially in patients from areas where transmission is plausible. Diagnostic evaluation for dirofilariasis should be considered before invasive procedures when clinical, epidemiological, or imaging findings raise suspicion, particularly in regions where canine heartworm infection is present. However, decisions regarding intervention should be individualized and guided by the overall clinical context, including the differential diagnosis, imaging findings, and patient condition. Referral hospitals may benefit from strengthening diagnostic capacity, including access to molecular confirmation methods and improving pathology expertise in the morphological identification of *Dirofilaria*. Given the limited availability of human dirofilariasis data in Indonesia, this review recommends strengthening surveillance through the integration of veterinary parasitology, entomology, and human clinical care. A one-health approach may facilitate the timely recognition of potential cases and support the development of evidence-based control strategies. Without systematic surveillance efforts, human cases may continue to be identified primarily through opportunistic clinical detection rather than structured case identification.

Areas of Future Study

Several recommendations for future research can be proposed in this area. First, population-based cross-sectional studies are required to estimate the prevalence and clinical spectrum of human dirofilariasis in potentially endemic areas. Prospective surveillance or longitudinal studies are required to estimate the incidence and temporal patterns of infection. Such studies could initially focus on regions with high canine *D. immitis* seroprevalence, as these areas may represent priority locations for evaluating potential zoonotic transmission. Second, research should be conducted to develop noninvasive diagnostic methods for identifying active infections, potentially through serological approaches or characteristic radiological findings. Third, entomological surveys are required to identify local vector species capable of transmitting *D. repens* and *D. immitis*. Fourth, integrated One Health surveillance approaches combining human, veterinary, and entomological data may improve the understanding of transmission patterns and potential zoonotic risks. Until such data become available, the magnitude of potential under-recognition or clinical detection gaps in human dirofilariasis cannot be reliably estimated.

CONCLUSION

Species-specific tropism has been observed in human dirofilariasis. Humans infected with *Dirofilaria repens* show a predilection for subcutaneous involvement, whereas *D. immitis* more commonly involves pulmonary and ocular tissues. However, overlap in clinical presentation exists between species, and anatomical predilection alone cannot establish species identification without etiological confirmation. Diagnosis remains primarily dependent on histopathology, with limited application of molecular diagnostic tools, and retrospective identification may contribute to uncertainty in species classification.

The absence of documented human cases in Indonesia should be interpreted cautiously, as the available evidence is insufficient to determine whether human infection is truly absent or remains undetected. Current findings indicate the presence of ecological conditions that may support transmission; however, further verification through active surveillance integrating human, veterinary, and entomological data is required. One Health approach may address these evidence gaps by integrating veterinary, entomological, clinical, and molecular surveillance. Veterinary surveillance of canine *Dirofilaria* infection can help identify areas with potential zoonotic exposure, whereas entomological surveillance can clarify vector distribution and transmission potential. Clinical surveillance may improve the recognition of suspected human cases, while molecular diagnostics can strengthen species confirmation and reduce uncertainty in reported species distribution. Together, these approaches can help distinguish the true absence of human infection from limitations in current detection systems.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

In preparing this manuscript, the author employed a generative AI writing assistant (DeepSeek) to help with organization, analysis, and editing. Upon utilizing this tool/service, the author reviewed and edited the content as necessary and took full responsibility for the content of this publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Methodology; Data curation; Investigation; Formal analysis; Writing - original draft; Writing - review and editing.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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