Parasitic Infections in Falcons (*Falco spp.*): Linking Parasite Ecology, Clinical Significance, Diagnosis, and Integrated Control

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ABSTRACT

Parasitic infections continue to represent a major health issue in falcons (*Falco* spp.) kept for falconry, breeding, rehabilitation, conservation and free-ranging populations. This targeted narrative review summarizes the current status of the major parasitic infections reported in falcons with particular emphasis on their distribution, transmission, clinical importance, diagnosis, management and prevention. Structured searches of four bibliographic databases, supplemented by Google Scholar and citation tracking (1980 to June 2025), identified 17 eligible publications: 12 falcon-specific primary studies, four broader raptor or avian sources and one contextual falcon-health study, each appraised for relevance and reliability. The main groups considered are gastrointestinal helminths, *Caryospora* spp., *Trichomonas gallinae*, *Serratospiculum* spp., haemoparasites and ectoparasites. Studies of falcons have shown considerable population variation: *Caryospora* spp. were detected in 7.5% of 3,975 falcons examined in the United Arab Emirates, *C. neofalconis* in 10.7% of 149 healthy falcons in central Saudi Arabia, *T. gallinae* in 26.58% of 158 Saudi falcons, and *Serratospiculum* spp. in 18% of wild falcons admitted to care in the greater Sydney region. The results suggest that location, host origin, prey contact, husbandry, vectors, intermediate hosts, and captive versus free-ranging status affect parasite presence. Clinical effects range from subclinical infection to gastrointestinal disease, upper digestive lesions, respiratory compromise, poor body condition, anemia, and reduced performance. A consistent finding in the literature is that detection of a parasite does not necessarily imply clinical disease; interpretation depends on parasite burden, anatomical location, lesions, host condition and concurrent disease. Control currently relies on parasite-specific therapy, combined with quarantine, environmental sanitation, safe prey management and reduction of exposure to vectors or intermediate hosts. The available evidence supports an integrated view of falcon parasitology in which the ecological and clinical relevance of parasites is considered in tandem to protect falcon health, welfare and performance.

Keywords: *Falco spp.*, avian parasitology, Caryospora, Serratospiculum, Trichomonas gallinae

INTRODUCTION

Falcons (*Falco* spp.) occupy a unique position at the intersection of wildlife conservation, veterinary medicine and human cultural activity. They are important avian predators ecologically and have a long history of falconry, particularly in the Middle East, as well as modern breeding, rehabilitation and conservation programs. Expectations of falcons in managed settings are unusually high, as many are expected not only to survive but also to perform athletically for extended periods. Respiratory efficiency, body condition, feather condition, eyesight and rapid recovery from exercise are all important in successful flight. Thus, diseases causing mild physiological impairment may have clinical significance even when there is no overt illness.

Falcons are exceptionally specialized for speed, agility and hunting, so health problems that reduce energy, respiratory efficiency or recovery can become evident as a decline in flight performance before severe clinical illness develops. This makes regular health monitoring particularly important in falconry birds (Panthakkan et al., 2024).

Parasites are a permanent part of this health landscape. The known parasite fauna of raptors comprises protozoa, nematodes, cestodes, trematodes, haemoparasites and ectoparasitic arthropods, but the distribution and importance of individual taxa differ between host species and regions (Atkinson et al., 2008; Kutzer et al., 1980). A considerable body of falcon-specific evidence has been generated in dedicated hospitals and breeding centers in the Arabian Peninsula. For example, Mateuta and Samour (2017) analyzed 3,975 individual falcons from seven hospitals in the United Arab Emirates (UAE) and identified *Caryospora* spp. in 7.5% of birds. More recently, studies from Saudi Arabia have characterized *Caryospora neofalconis*, *Trichomonas gallinae* and *Haemoproteus tinnunculi* in several *Falco* species using molecular tools (Alfaleh et al., 2020a, 2020b; Alrefaei, 2020).

However, falcon parasitology should not be viewed as a simple list of organisms. Parasite prevalence is a result of the interaction of host ecology, prey selection, environmental contamination, vectors, intermediate hosts, husbandry, age, immune status and bird movement. The same parasite may be incidental in one bird and of clinical significance in another bird. This is especially relevant in performance falcons where reduced endurance, poor weight gain or slow recovery may occur before clinical signs appear. For example, Al-Timimi et al. (2009) found that many falcons infected only with *Serratospiculum* were asymptomatic, while others developed dyspnea or more subtle performance-related abnormalities.

Another issue is the geographical concentration of evidence. Middle Eastern studies are important due to the scale of falconry medicine in the region but cannot be generalized automatically to all *Falco* populations. Clinically relevant parasites have been found beyond the Arabian Peninsula in wild and rehabilitation studies. Schader and Baron (2021) found evidence of *Serratospiculum* spp. in 18% of wild falcons presented for care in the greater Sydney region, and *Serratospiculum tendo* has been identified in an Austral peregrine falcon in Argentina (Ibarra et al., 2019). These findings support a global ecological perspective but also highlight regional differences in exposure.

This review thus synthesizes current evidence on common and clinically relevant parasitic infections of falcons using a host-parasite-management framework. Rather than describing each parasite in isolation, each major group is discussed in terms of transmission, pathology, diagnosis and control (Table 1). The review then considers issues of epidemiological risk, diagnostic interpretation, evidence for treatment, biosecurity and research priorities. The central argument is that the clinical significance of parasitism in falcons is best understood by integrating parasite biology with the physiological demands and management situation of the host. The search strategy, eligibility criteria and the appraisal of each included source are reported in Section 2, and the size and type of the evidence base for each parasite group are summarized in Tables 3 and 4.

METHOD OF REVIEW

2.1 Review design

This paper is a targeted narrative review. It was not designed as a systematic review or meta-analysis, and it does not attempt to estimate pooled prevalence. Its purpose is to synthesize evidence on the parasites of established clinical relevance in *Falco* spp. and to interpret that evidence through a host–parasite–management framework. To allow readers to judge the completeness of the evidence base, the search, selection and appraisal procedures are reported below. Their reporting follows the items of the Scale for the Assessment of Narrative Review Articles (SANRA), in particular the explicit description of the literature search and of the appraisal of evidence (Baethge et al., 2019).

2.2 Information sources and search strategy

Electronic searches were run in four bibliographic databases: PubMed/MEDLINE, Web of Science Core Collection, Scopus and CAB Abstracts (CABI). Google Scholar was used as a supplementary source. These searches were supplemented by backward citation searching of the reference lists of all included articles and of the standard reference text on parasitic diseases of wild birds (Atkinson et al., 2008), and by forward citation searching ("cited by") of the key falcon studies. Hand-searching covered recent issues of the journals that published most of the falcon-specific literature: *Journal of Avian Medicine and Surgery*, *Parasitology Research*, *Parasite* and *Journal of Wildlife Diseases*.

The search covered publications from January 1980 to June 2025. The lower limit was chosen so that the classical survey of the parasite fauna of diurnal birds of prey (Kutzer et al., 1980) was captured; earlier descriptive work is summarized in the reference literature. Publications in English were included, together with non-English publications that had an English abstract and extractable data.

Search strings combined a host block with a parasite block, and were adapted to the syntax and controlled vocabulary of each database (for example, MeSH terms in PubMed and title/abstract/keyword fields in Scopus). Representative strings were:

2.3 Eligibility criteria

Publications were included when they met all of the following criteria:

(i) Host: *Falco* spp. in any management context (falconry, hospital, breeding, rehabilitation or free-ranging), or mixed raptor or avian populations when they reported falcon data or provided the only available evidence for a parasite group relevant to falcons;

(ii) Parasite: one of the six groups covered by this review (gastrointestinal helminths, coccidia and other intestinal protozoa, *Trichomonas gallinae*, *Serratospiculum* spp., haemoparasites and ectoparasites);

(iii) Content: original data on occurrence or prevalence, taxonomy or life cycle, clinical presentation, pathology, diagnosis, treatment outcome or environmental transmission, or an authoritative reference text used for general principles;

(iv) Publication type: peer-reviewed journal articles, case reports, full peer-reviewed conference papers and scholarly books.

Publications were excluded when they (a) concerned only non-raptor birds, unless they were needed to resolve the taxonomy of a parasite that infects falcons; (b) reported only experimental infection of non-avian hosts; (c) were conference abstracts, theses, popular falconry magazines or non-peer-reviewed web content; (d) did not state the diagnostic method; (e) contained no extractable parasitological or clinical information; or (f) duplicated a population already reported, in which case the largest or most complete report was retained. One falcon-health source that is not parasitological (Panthakkan et al., 2024) was cited only for clinical context, to illustrate performance demands and non-parasitic differential diagnoses, and it was not used as parasitological evidence.

2.4 Study selection

Titles, abstracts and full texts were screened against the eligibility criteria by the authors, and uncertainties about inclusion were resolved by discussion within the author team, which includes a co-author in veterinary clinical practice in the UAE. When several publications addressed the same question, priority was given, in order, to (1) falcon-specific over broader raptor data; (2) larger and clearly defined sampling frames; (3) studies that confirmed parasite identity by molecular methods, endoscopy or necropsy; and (4) more recent publications. Because this is a targeted narrative review, the number of records screened at each stage was not recorded in a PRISMA flow diagram. Instead, every included source is listed individually with its design, setting and appraisal (Table 4), so that readers can assess the coverage of the evidence directly.

2.5 Classification of evidence

Each included source was assigned to one of three categories. **Category A** comprises falcon-specific primary research, in which all parasitological data were obtained from *Falco* spp. **Category B** comprises broader raptor or avian research and reference texts, in which falcons were absent or formed part of a mixed host sample. **Category C** comprises falcon-health sources that are not parasitological and were cited for clinical context only. Category B evidence is used in this review to explain general principles, such as parasite diversity, diagnostic artefacts, ectoparasite ecology and haemoproteid taxonomy. It is identified as such in the text and is not used to state the prevalence of infection in falcons. Each source was also classified by design: retrospective clinical or hospital series, cross-sectional prevalence survey, environmental or age-stratified study, taxonomic description, life-cycle study, case report or reference text.

2.6 Appraisal of relevance and reliability

Relevance was rated as high (falcon host, target parasite and a clinical or epidemiological outcome), moderate (falcon host with a taxonomic or life-cycle focus, or a mixed raptor sample) or contextual (non-falcon host or general reference text). **Reliability** was judged qualitatively against five questions: (1) Were the sampling frame and denominator clearly described? (2) Was the sample size adequate for the estimate reported? (3) Was the diagnostic method stated, and was parasite identity confirmed by a second method (molecular analysis, endoscopy or necropsy)? (4) Were clinical signs, lesions or concurrent disease recorded, so that infection could be separated from disease? (5) For treatment data, was there follow-up with an objective outcome, and was there a comparison group? On this basis each source was rated as higher, moderate or lower reliability (Table 4). This appraisal is not a formal risk-of-bias score. It was used to weight interpretation, so that large, well-described and diagnostically confirmed studies carry more weight in the discussion than single case reports or uncontrolled treatment series.

The review also distinguishes three levels of evidence: occurrence, association and causation. Occurrence means a parasite or its DNA has been detected. Association links infection with host factors, lesions or clinical abnormality. Causation requires stronger evidence that the parasite causes disease and that reducing the infection improves outcome. We make this distinction throughout the discussion so as not to conflate sensitive detection of parasites with clinically meaningful disease.

2.7 Synthesis and overview of the evidence base

The literature is heterogeneous in terms of host composition, study design, diagnostic method and sampling context. Thus, prevalence estimates are given as population-specific observations rather than pooled estimates. Where studies looked at different parasites or used very different methods, no direct comparison was made. This is important because a hospital population, a breeding center, a falcon market and a wildlife rehabilitation cohort are different epidemiological systems.

Seventeen publications were retained (Tables 3 and 4). Twelve are falcon-specific primary studies (Category A), four are broader raptor or avian sources (Category B) and one is a contextual falcon-health study (Category C). Of the 12 falcon-specific studies, ten come from the Arabian Peninsula and Gulf region (Saudi Arabia, the UAE and Kuwait), one from Australia and one from Argentina. By design, they comprise four retrospective clinical or hospital series, four cross-sectional prevalence surveys, one environmental age-stratified study, one taxonomic description, one life-cycle study and one case report. Three studies report treatment outcomes, all as uncontrolled case series, and no randomized or controlled treatment trials were identified. The evidence is therefore strongest for *Serratospiculum* spp. and *Caryospora* spp., limited for gastrointestinal helminths, *T. gallinae* and haemoparasites, and largely extrapolated from mixed raptor data for ectoparasites. Each subsection of Section 3 closes with a short statement of the evidence on which it rests.

Important Parasitic Diseases Of Falcons

3.1 Gastrointestinal helminths

Falcons have nematodes, cestodes and trematodes as gastrointestinal helminths. Capillariid and ascarid-type nematodes are clinically important in birds because they may involve the crop, esophagus, stomach or intestine. The carnivorous diet of falcons provides several transmission routes: some infections are acquired from contaminated environments, while others depend on intermediate or paratenic hosts consumed as prey. For instance, Schuster et al. (2014) described the life cycle of the heteroxenous stomach nematode of falcons, *Paraspiralatus sakeri*, highlighting the significance of intermediate-host ecology in understanding transmission.

Clinical presentation depends on the parasite load, location of infection and host status. Infection with capillarids may be associated with anorexia, weight loss, weakness, regurgitation, abnormal feces and gastrointestinal injury. Tarello (2008) reported capillariid infection in 52 of 3,988 captive falcons from the Middle East. Half of these birds had concurrent parasitoses. In falcons in which capillariosis was the only infection detected, clinical signs included anorexia, weight loss, weakness, dyspnea, regurgitation, diarrhea and dark tarry feces. The report also documented the clinical and parasitological response to ivermectin treatment, offering one of the relatively few therapeutic data sets for falcons.

Fecal microscopy remains the mainstay of diagnosis of gastrointestinal parasites, but a single negative sample does not exclude infection as shedding may be intermittent. Fresh specimens, proper flotation or sedimentation methods and multiple samples increase diagnostic value. Interpretation should also take into account pseudoparasitism and stages from prey, a problem recognized in classical raptor parasitology (Kutzer et al., 1980). Where wild prey is fed, the clinical history should include prey species and source.

Evidence base. This subsection rests on two falcon-specific primary studies, a Middle Eastern clinical case series with treatment data (Tarello, 2008) and a life-cycle study (Schuster et al., 2014), together with one broader raptor survey (Kutzer et al., 1980), which is cited for the general problem of pseudoparasitism. None of the included sources estimated the overall prevalence of gastrointestinal helminths in falcons, so the clinical picture described here depends mainly on a single case series.

3.2 Coccidia and other intestinal protozoa

Caryospora spp. are some of the most studied protozoa of falcons. In the UAE, Mateuta and Samour (2017) analyzed fecal samples from individual falcons (n = 3,975) and found 297 positive birds, giving an overall prevalence of 7.5%. Several *Caryospora* species were identified morphologically, including *C. kutzeri*, *C. neofalconis*, *C. megafalconis* and *C. falconis*. The study also revealed differences between falcon species and hybrids, providing further evidence of the diversity of host-parasite relationships within managed falcon populations.

Studies from Saudi Arabia have also contributed to the understanding of coccidian diversity. Alfaleh et al. (2012) detected *Eimeria biarmicus* in lanner falcons (*Falco biarmicus*), and Alfaleh et al. (2020a) examined 149 healthy falcons from central Saudi Arabia for *C. neofalconis* by microscopy and PCR. Microscopy was positive in 16 birds (10.7%), most of them peregrine falcons. Molecular validation based on the 18S rRNA gene confirmed the usefulness of the combined morphological and genetic approaches.

Environmental contamination is critical in coccidian transmission. Juárez et al. (2020) studied 356 fecal, fomite and environmental samples from a gyrfalcon breeding center in the UAE. No *Caryospora* oocysts were detected in chick-associated samples from 10 to 60 days of age, but there was a sharp increase in positivity at 67 and 70 days, with oocysts also detected in environmental samples. These results demonstrate that infection pressure can change rapidly with age, housing and contamination. They also show why treatment alone cannot substitute for sanitation and environmental management.

Clinical coccidiosis should be distinguished from oocyst shedding. Young, stressed or heavily infected falcons may develop anorexia, diarrhea, dehydration, weight loss or more severe enteric disease; however, detection in

a clinically normal bird does not establish disease. Quantitative or semi-quantitative assessment, repeat sampling, hydration status, body condition and concurrent disease should be considered before ascribing signs to *Caryospora*.

Evidence base. Four falcon-specific primary studies (a hospital series, a cross-sectional molecular survey, an environmental age-stratified study and a taxonomic description) support this subsection, all from the Arabian Peninsula. No broader raptor data were needed. The evidence is strong for occurrence and species diversity, but weaker for the link between oocyst shedding and clinical disease.

3.3 Trichomonosis

Trichomonas gallinae is a flagellated protozoan of particular importance to raptors as columbids are major hosts and can transmit infection to predators. In falcons, the infection is mainly in the oral cavity, pharynx, esophagus and crop. Caseous lesions can affect swallowing and food intake. Progressive weight loss and systemic deterioration can be seen in severe disease.

Alrefaei (2020) studied 158 falcons, including saker, peregrine and gyrfalcons, in Saudi Arabia and reported an overall *T. gallinae* prevalence of 26.58%. Sequencing of the internal transcribed spacer region revealed four genotypes, indicating genetic heterogeneity in falcon infections. The study is important not only for its prevalence data but also for showing how molecular characterization can reveal transmission complexity not apparent by routine microscopy or culture.

Diagnosis should include careful examination of the oral cavity and crop, with sampling of active lesions or crop contents. Molecular confirmation can be useful when morphology is not conclusive or when an epidemiological characterization is required. Management should target the infected bird and the prey pathway. Sourcing and inspection of prey are essential to prevention, because pigeons and doves are central to the ecology of trichomonosis.

Evidence base. One falcon-specific primary study, a cross-sectional molecular survey (Alrefaei, 2020), supports this subsection. The description of lesions and clinical course is consistent with the general wild-bird literature (Atkinson et al., 2008) but has not been quantified in falcons in the included sources, and should be read as broader avian evidence.

3.4 Respiratory nematodes: *Serratospiculum* spp.

Serratospiculum spp. are among the most clinically distinctive parasites of falcons due to the location of the adult nematodes in the air sacs. Their importance is increased by the respiratory demands of flight. Some infected falcons look normal at rest but parasites of the air sacs may cause irritation, inflammation (airsacculitis), reduced exercise tolerance, dyspnea and secondary complications.

This spectrum is reflected in large Middle Eastern clinical series. Al-Timimi et al. (2009) diagnosed *Serratospiculum* spp. in 1,360 of 7,200 falcons examined in Saudi Arabia. Of 467 birds with serratospiculosis alone, 286 were clinically normal and 181 had mild to moderate abnormalities including dyspnea; less obvious findings included poor appetite, unsatisfactory weight gain and rapid exhaustion. Tarello (2006) reported *Serratospiculum seurati* in 149 of 1,706 captive falcons in Kuwait, with both symptomatic and asymptomatic infections.

Wildlife evidence suggests that serratospiculosis is not restricted to captive Middle Eastern falcons. Schader and Baron (2021) found Serratospiculum eggs in 10 of 57 (18%) wild falcons admitted to care in the greater Sydney region and identified *S. tendo* by PCR in a brown falcon (*Falco berigora*). Ibarra et al. (2019) reported *S. tendo* in an Austral peregrine falcon (*Falco peregrinus cassini*) in Argentina. The studies support a broad geographic distribution but also highlight differences in host ecology and surveillance.

Endoscopy is particularly useful because it permits direct visualization of adult worms and associated air-sac pathology. Fecal examination can identify eggs or larvae but may not provide a full characterization of the burden

or tissue response. Treatment studies are available, but protocols vary and should be interpreted according to species, parasite burden, formulation and current veterinary guidance, rather than generalized from older case series.

Evidence base. Four falcon-specific primary studies from three regions support this subsection: two large clinical series with treatment data (Al-Timimi et al., 2009; Tarello, 2006), one wild-bird prevalence study with molecular identification (Schader & Baron, 2021) and one case report (Ibarra et al., 2019). This is the best-documented parasite group in the review, although the treatment evidence comes from uncontrolled case series.

3.5 Blood parasites

Falcons may carry blood parasites of the genera *Haemoproteus*, *Leucocytozoon* and *Plasmodium*, among others. Their epidemiology depends on blood-feeding vectors and, therefore, varies with geography, season and host movement. Interpretation of haemoparasite detection is especially difficult, as low-level parasitaemia may be seen in the absence of overt disease.

Alfaleh et al. (2020b) investigated the blood of 100 falcons from central Saudi Arabia for *Haemoproteus tinnunculi* by microscopy and nested PCR. Prevalence was 1% by microscopy and 3% by PCR, and infections were detected only in saker falcons. This difference between methods illustrates the increased sensitivity of molecular testing but also raises the question of clinical significance when identifying very low-level infections.

Molecular studies have improved the taxonomic resolution of avian haemoproteids. Valkiūnas et al. (2019) used microscopy and molecular markers to characterize widespread *Haemoproteus* species, including parasites of falcons. Such approaches are useful for surveillance and species identification, but molecular positivity should be interpreted alongside parasitaemia, hematology, pathology and host condition. A sensitive test can show that the parasite is present, but not that the parasite causes weakness or substandard performance.

Evidence base. This subsection rests on one falcon-specific cross-sectional study (Alfaleh et al., 2020b) and one broader avian molecular-taxonomy study (Valkiūnas et al., 2019). None of the included sources reported falcon-specific data on *Leucocytozoon* or *Plasmodium*, so statements about these genera draw on general avian parasitology.

3.6 Ectoparasites

Raptor ectoparasites include lice, feather mites, ticks, fleas and other arthropods. Clinical effects range from minimal infestation to irritation, dermatitis, feather damage, blood loss or possible pathogen transmission. The quality of feathers is especially important for falcons because damaged remiges or rectrices can affect aerodynamics.

In a captive raptor population in Mexico, de Oliveira et al. (2011) found an overall ectoparasite prevalence of 16.2% among 74 birds, with lice the most common ectoparasites; no clinical signs were observed in infested birds. Although the population included multiple raptor species and not just falcons, the study illustrates two principles relevant to falcon management: ectoparasites can exist without overt disease and detailed examination of incoming birds is an important part of captive biosecurity.

Inspection should include feathers, skin, periocular areas and protected body regions. If an infestation is found, the environment should be considered because treating the bird alone may allow rapid reinfestation. Veterinary judgment is necessary in the selection of a product for birds, as safety and efficacy cannot be extrapolated from products formulated for mammals.

Evidence base. None of the included sources reported ectoparasite data from falcons alone. This subsection relies on one mixed captive-raptor study (de Oliveira et al., 2011) and on general principles, and it should be read as broader raptor evidence. Falcon-specific ectoparasite surveys are a clear gap (Section 8).

Epidemiology And Risk Factors

Four interacting domains shape falcon parasite epidemiology: host origin and physiology, prey and environmental exposure, vector or intermediate-host ecology, and management-related movement. These domains help explain why prevalence differs between studies (Table 2) and why raw percentages should not be compared without context.

Captive management can both reduce and increase risk. Controlled diets and routine veterinary care can limit exposure to some parasites, but repeated use of the same enclosure can concentrate infective stages. Free-ranging or recently trapped birds are exposed to a wider community of prey and vectors, while rehabilitation centers may receive individuals of unknown history. The epidemiological contrast is therefore not simply captive versus wild, but one of pattern and intensity of exposure.

Prey is a particularly important interface between ecology and clinical medicine. Transmission of *T. gallinae* revolves around columbids. Insects and vertebrate prey can act as intermediate or paratenic hosts of helminths. Environmental contamination is more important for directly transmitted intestinal stages and coccidia. The pathways require different preventive responses: the risk related to prey is handled by sourcing and feeding practice while the environmental risk depends on sanitation and removal of organic material.

Age and husbandry can alter the infection pressure in the same facility. Juárez et al. (2020) observed a sharp rise in *Caryospora* positivity late in the chick-rearing period at a gyrfalcon breeding center, suggesting that risk is not static but dynamic. Therefore, longitudinal sampling is more informative than isolated screening to identify where and when transmission occurs.

Falcon movement adds another dimension. Birds can be born in one country, trained in another, shipped for hunting, and treated in specialist hospitals. Movement can expose birds to new vectors, prey communities and parasite populations. A modern clinical history should therefore encompass origin, recent travel, type of prey, previous findings of parasites and antiparasitic treatment. In future, molecular epidemiology may connect parasite lineages to movement networks.

Clinical Significance And Performance

The clinical impact of parasitism is not determined by the mere presence of parasites. Outcome is modified by burden, anatomical site, host age and immune status, nutrition, concurrent disease and physiological demand. This is particularly relevant in falcons as the threshold for clinically significant impairment may be lower in a bird expected to perform sustained high-intensity flight.

Clinical signs linked with parasitic disease should also be interpreted against other important falcon disorders. Liver disease can reduce energy and hunting ability, while aspergillosis may produce respiratory difficulty, lethargy and reduced flight performance; these overlapping presentations reinforce the need to distinguish parasitic disease from major non-parasitic conditions (Panthakkan et al., 2024).

The respiratory nematodes provide the best example. A falcon with a low air-sac burden may appear normal during a routine exam but may tire quickly during exercise. Similarly, haemoparasitaemia may be clinically silent in one bird but may contribute to reduced endurance where associated with anemia or systemic disease. Gastrointestinal parasites can have indirect effects on performance by affecting appetite, hydration, nutrient absorption and body-mass maintenance.

Reduced performance, however, is not specific. Aspergillosis, bacterial respiratory disease, musculoskeletal injury, nutritional imbalance, cardiovascular disease and training factors can all mimic parasite-associated decline. Therefore, diagnostic reasoning should not anchor on the first positive parasite test result. Attribution is strongest when the detection of the parasite is associated with compatible lesions, objective physiologic abnormalities, and improvement following appropriate therapy.

Current Diagnostic Status

Diagnosis of parasitic infections in falcons is currently based on the correlation of clinical findings with evidence of the specific parasite. Routine parasitological examination commonly detects gastrointestinal helminths and coccidia; trichomonosis is diagnosed by characteristic lesions in the upper-digestive tract and confirmatory testing; serratospiculosis is diagnosed by respiratory evaluation; and haemoparasites are detected by blood-based examination. The use of molecular methods to confirm species identity and to characterize parasite diversity is a growing trend in research and reference settings (Alfaleh et al., 2020a, 2020b; Alrefaei, 2020).

The present clinical emphasis is not on more complex testing, but on interpretation. Subclinical infection has frequently been described in falcons, especially for *Serratospiculum* spp. and some blood parasites. Therefore, a positive parasite finding should be interpreted in conjunction with body condition, lesion severity, presence of respiratory or gastrointestinal signs and changes in performance. The differentiation between infection and disease is still one of the most important issues in contemporary falcon parasitology.

Treatment And Integrated Management

Management of falcon parasitoses today is parasite-specific and increasingly guided by the clinical relevance of infection. Published falcon case series report treatment experience for capillariosis and serratospiculosis. Correction of husbandry factors that favor reinfection is also part of contemporary management (Al-Timimi et al., 2009; Tarello, 2006, 2008).

Where infection is of clinical significance, parasite-directed therapy may need to be supplemented with supportive care for dehydration, poor body condition, anemia or respiratory compromise. Restoration of normal condition and flight tolerance is an important part of clinical recovery in performance birds.

Routine observation of appetite, activity, body condition and flight tolerance remains useful during follow-up. Recent falcon-health literature similarly emphasizes vigilant monitoring and early intervention as practical elements of maintaining the health of birds used in hunting and other performance settings (Panthakkan et al., 2024).

At the population level, quarantine is key to prevention. Newly introduced falcons may be carriers of parasites without obvious signs and risk-based screening during quarantine can identify gastrointestinal, respiratory, blood or external parasites before birds are added to established collections. Quarantine is more effective when combined with travel history, prey history and repeated testing than when used as a stand-alone period of isolation.

Environmental hygiene is needed for parasites transmitted by fecal contamination. Frequent removal of feces and food debris, cleaning of perches and feeding surfaces and management of contaminated water all reduce the chance of reinfection. The environmental Caryospora study at a UAE gyrfalcon breeding center provides direct evidence that oocysts can be present in the breeding environment and that contamination patterns vary over time (Juárez et al., 2020).

Prey management is just as important. For trichomonosis, the food item itself can be the source of infection. Indirect life cycles of helminths may include prey or arthropods as intermediate or paratenic hosts. Therefore, vector and intermediate-host control must be parasite-specific and ecologically informed, not based on indiscriminate chemical treatment.

Preventive management remains the mainstay because environmental, prey-associated, vector or intermediate-host exposure may continue to cause reinfection. Therefore, quarantine, hygiene, prey management and control of pertinent vectors or intermediate hosts are complementary to treatment and are key components of current falcon health programs.

Current Knowledge Gaps

The present evidence is geographically uneven with a preponderance of studies from areas with established falconry medicine, notably the Arabian Peninsula. Prevalence varies between captive, hospital, breeding and wild populations, making generalization difficult. More comparable regional data are needed to elucidate which parasites are consistently important across *Falco* species.

Another limitation is the inconsistent evidence linking parasite presence to clinical disease. Some infections can be found in seemingly healthy birds, while heavier or anatomically important infections can influence body condition, respiration, feeding or performance. Recent literature therefore favors a clinical interpretation of falcon parasitism, not just a detection-only perspective.

The prevalence and case-report literature also provide limited falcon-specific evidence on treatment. There is published clinical experience for major infections like capillariosis and serratospiculosis. The strength of evidence varies by groups of parasites.

Evidence from Australia and South America confirms that important falcon parasites are not exclusive to Middle Eastern captive populations (Ibarra et al., 2019; Schader & Baron, 2021). The current global picture is therefore one of widespread diversity of parasites, with substantial regional differences in host exposure and available surveillance.

Overall, the literature to date is strongest in documenting parasite occurrence and selected clinical associations. It is less comprehensive in understanding the burden at which infection becomes clinically significant and in comparing treatment outcomes between falcon species and management systems.

The depth of evidence also differs sharply between parasite groups (Table 3). Four falcon-specific studies each support the sections on *Caryospora* spp. and *Serratospiculum* spp., whereas trichomonosis and haemoparasites each rest on a single falcon-specific survey, and no falcon-only ectoparasite study was included. Targeted surveys of *T. gallinae*, haemoparasites (including *Leucocytozoon* and *Plasmodium*) and ectoparasites in falcons, especially outside the Arabian Peninsula, would therefore add the most to current knowledge.

Limitations of this review. This is a targeted narrative review, not a systematic review. Screening counts were not recorded in PRISMA format, and the appraisal of reliability was qualitative rather than a formal risk-of-bias assessment. Restricting the search to English-language publications, apart from non-English papers with English abstracts, and excluding theses and grey literature may have missed regional reports, including clinical experience from falcon hospitals that is not published in peer-reviewed journals. Ten of the 12 falcon-specific studies come from the Arabian Peninsula and Gulf region, so the findings may not apply equally to wild or captive falcons elsewhere. Prevalence figures were not pooled because sampling frames and diagnostic methods differ between studies.

CONCLUSION

Parasitic infections remain relevant to captive, free-ranging, breeding, rehabilitation, and performance falcons. Gastrointestinal helminths, *Caryospora* spp., *T. gallinae*, *Serratospiculum* spp., haemoparasites, and ectoparasites differ markedly in transmission, pathology, and clinical significance. Their management therefore cannot be reduced to a universal deworming schedule.

The most important clinical principle is that parasite detection is not synonymous with parasitic disease. Reliable interpretation requires integration of parasite identity and burden with anatomical location, pathology, host condition, and performance. Conventional parasitology remains indispensable, while endoscopy and molecular diagnostics provide increasingly powerful complementary information.

Sustainable control depends on connecting treatment with ecology. Targeted therapy, quarantine, environmental hygiene, prey management, vector and intermediate-host control, and post-treatment assessment together provide a more defensible approach than repeated empirical medication. Future progress will depend on

standardized surveillance, molecular epidemiology, falcon-specific therapeutic studies, and clinically meaningful measures of treatment success. Such integration can strengthen parasite management while supporting the welfare, performance, and conservation of falcons. Because the falcon-specific evidence base is still small and geographically concentrated, these conclusions are firmest for *Caryospora* spp. and *Serratospiculum* spp. and should be treated as provisional for the less-studied parasite groups.

Table 1 Major parasite groups of falcons and their clinical relevance

Parasite/group	Main transmission	Principal site	Potential clinical significance	Useful diagnostic approach
Capillariids/ascarid-type nematodes	Environment; prey depending on species	Upper GI tract/intestine	Anorexia, enteritis, weight loss, poor condition	Fecal microscopy; repeated sampling
Caryospora spp.	Fecal-environmental	Intestine	Subclinical shedding to enteric disease	Fecal microscopy; molecular confirmation
Trichomonas gallinae	Columbids/prey	Oropharynx, crop	Caseous lesions, dysphagia, weight loss	Oral/crop examination, culture/PCR
Serratospiculum spp.	Arthropod intermediate hosts	Air sacs	Airsacculitis, dyspnea, reduced endurance	Endoscopy; fecal testing; molecular identification
Haemoproteus and related haemoparasites	Blood-feeding vectors	Blood/tissues	Often subclinical; possible anemia/systemic effects	Blood smear and PCR
Ectoparasites	Direct/environmental exposure	Skin/feathers	Irritation, feather damage, blood loss	Physical and microscopic examination

Table 2Selected falcon-specific epidemiological findings

Study	Population	Main finding	Interpretive value
Mateuta & Samour (2017)	3,975 falcons, UAE hospitals	*Caryospora* spp. detected in 7.5%	Large hospital-based estimate; species diversity
Alfaleh et al. (2020a)	149 healthy falcons, Saudi Arabia	*C. neofalconis* 10.7% by microscopy	Microscopy plus PCR/phylogeny
Alrefaei (2020)	158 falcons, Saudi Arabia	*T. gallinae* 26.58%; four genotypes	Demonstrates genetic diversity
Al-Timimi et al. (2009)	7,200 falcons, Saudi Arabia	*Serratospiculum* spp. in 1,360 birds	Large clinical series; many subclinical infections
Schader & Baron (2021)	Wild falcons in care, Australia	*Serratospiculum* evidence in 18%	Shows relevance in wild rehabilitation population
Alfaleh et al. (2020b)	100 falcons, Saudi Arabia	*H. tinnunculi* 1% microscopy; 3% PCR	Illustrates sensitivity difference between methods

Table 3 Number and types of studies considered for each major parasite group

Parasite group	Falcon-specific primary studies (Category A), n	Types of falcon-specific study (sources)	Broader raptor or avian sources (Category B), n	Strength of falcon evidence and main gap
Gastrointestinal helminths	2	Clinical case series with treatment (Tarello, 2008); life-cycle and morphology study (Schuster et al., 2014)	1 (Kutzer et al., 1980: raptor parasite survey)	Limited. No falcon prevalence survey of helminths overall; treatment data are uncontrolled.
Caryospora spp. and other coccidia	4	Retrospective hospital series (Mateuta & Samour, 2017); cross-sectional survey with PCR (Alfaleh et al., 2020a); environmental age-stratified study (Juárez et al., 2020); taxonomic description (Alfaleh et al., 2012)	0	Moderate for occurrence and diversity; weak for clinical association. All studies from the Arabian Peninsula.
Trichomonas gallinae	1	Cross-sectional survey with ITS genotyping (Alrefaei, 2020)	0	Limited. A single falcon study; no falcon clinical or treatment data in the included sources.
Serratospiculum spp.	4	Retrospective clinical series with treatment (Al-Timimi et al., 2009; Tarello, 2006); wild-bird cross-sectional survey with PCR (Schader & Baron, 2021); case report (Ibarra et al., 2019)	0	Strongest group. Large series, recorded clinical status and three regions; treatment evidence uncontrolled.
Haemoparasites	1	Cross-sectional survey with microscopy and nested PCR (Alfaleh et al., 2020b)	1 (Valkiūnas et al., 2019: molecular taxonomy)	Limited. Occurrence only; no falcon data on *Leucocytozoon* or *Plasmodium* in the included sources.
Ectoparasites	0	None	1 (de Oliveira et al., 2011: mixed captive raptors)	Very limited. Falcon-specific conclusions are extrapolated from mixed raptor data.
Cross-cutting and context	0	None	1 (Atkinson et al., 2008: reference text)	Background principles. One falcon-health study (Panthakkan et al., 2024; Category C) is cited for clinical context only.
Total	**12**		**4** (plus 1 Category C source)	**17 publications**

Category A, falcon-specific primary research; Category B, broader raptor or avian research and reference texts; Category C, falcon-health source cited for clinical context only. Each publication is counted once, under the parasite group for which it is mainly cited.

Table 4 Characteristics and appraisal of the 17 included publications

Source	Cat.	Design	Host, sample and setting	Parasite group; diagnostic approach	Highest evidence level	Relevance / reliability
Mateuta & Samour (2017)	A	Retrospective hospital series	3,975 falcons, seven hospitals, UAE	Coccidia; fecal microscopy, morphological speciation	Occurrence	High / higher (very large sample; morphology only)
Alfaleh et al. (2020a)	A	Cross-sectional survey	149 healthy falcons, central Saudi Arabia	Coccidia; microscopy and 18S rRNA PCR	Occurrence	High / moderate (healthy birds; one region)
Juárez et al. (2020)	A	Environmental, age-stratified study	356 fecal, fomite and environmental samples,	Coccidia; oocyst detection	Association (age, environment)	High / moderate (single facility)

Source	Cat.	Design	Host, sample and setting	Parasite group; diagnostic approach	Highest evidence level	Relevance / reliability
			gyrfalcon breeding center, UAE			
Alfaleh et al. (2012)	A	Taxonomic description	Lanner falcons, Saudi Arabia	Coccidia (*Eimeria biarmicus*); oocyst morphology	Occurrence	Moderate / moderate
Tarello (2008)	A	Retrospective clinical series with treatment	52 of 3,988 captive falcons, Middle East	Capillariids; fecal microscopy, follow-up after ivermectin	Association; uncontrolled treatment	High / moderate (no comparison group; half co-infected)
Schuster et al. (2014)	A	Life-cycle and morphology study	*Paraspiralatus sakeri* in falcons and intermediate hosts	Gastrointestinal helminths; morphology of developmental stages	Occurrence (biology)	Moderate / moderate
Alrefaei (2020)	A	Cross-sectional survey	158 saker, peregrine and gyrfalcons, Saudi Arabia	*T. gallinae*; ITS sequencing and genotyping	Occurrence	High / moderate (one region; molecular confirmation)
Al-Timimi et al. (2009)	A	Retrospective clinical series with treatment	7,200 falcons, Saudi Arabia (1,360 positive)	*Serratospiculum* spp.; clinical and parasitological examination	Association; uncontrolled treatment	High / moderate to higher (very large sample; clinical status recorded)
Tarello (2006)	A	Retrospective clinical series with treatment	149 of 1,706 captive falcons, Kuwait	*S. seurati*; parasitological diagnosis, melarsomine and ivermectin outcomes	Association; uncontrolled treatment	High / moderate (no comparison group)
Schader & Baron (2021)	A	Cross-sectional survey, wild birds in care	57 wild falcons, greater Sydney, Australia	*Serratospiculum* spp.; fecal egg detection, PCR (*S. tendo*)	Occurrence	High / moderate (small sample)
Ibarra et al. (2019)	A	Case report	One Austral peregrine falcon, Argentina	*S. tendo*; parasite identification	Occurrence	Moderate / lower (single case)
Alfaleh et al. (2020b)	A	Cross-sectional survey	100 falcons, central Saudi Arabia	*H. tinnunculi*; blood smear and nested PCR	Occurrence	High / moderate (few positives)
Valkiūnas et al. (2019)	B	Molecular taxonomy	Multiple avian hosts, including haemoproteids of falcons	Haemoparasites; microscopy and molecular markers	Occurrence (taxonomy)	Moderate / higher
de Oliveira et al. (2011)	B	Cross-sectional survey	74 captive raptors (Falconiformes and Strigiformes), Mexico	Ectoparasites; inspection and identification	Occurrence	Moderate (mixed hosts) / moderate
Kutzer et al. (1980)	B	Parasite fauna survey	Diurnal birds of prey, Austria	Multiple groups; parasitological examination	Occurrence	Moderate / moderate (older methods)
Atkinson et al. (2008)	B	Reference text	Wild birds	All groups; expert synthesis	Background	Contextual / higher

Source	Cat.	Design	Host, sample and setting	Parasite group; diagnostic approach	Highest evidence level	Relevance / reliability
Panthakkan et al. (2024)	C	AI image-classification study (conference paper)	Falcon disease classification	Not parasite-specific	Context only	Contextual / not appraised as parasitological evidence

Evidence level follows Section 2.6 (occurrence, association, causation); no included study reached the level of causation. Relevance and reliability are qualitative judgements based on the five appraisal questions in Section 2.6.

Ethics statement: Not applicable. This review is based solely on published literature and involved no experimental work on animals or human participants.

Conflict of interest: The authors declare no conflict of interest.

Data availability: No new data were generated or analyzed in this study.

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