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Review Article

Zoonotic diseases associated with pet birds

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Summary
Birds are the most popular pet animals kept by humans in many areas of the world. Budgerigars, Canaries, Lovebirds, and Cockatiels are the most common pet birds. Zoonotic diseases are one of the most critical concerns related to pet birds worldwide. The people at the most risk of zoonoses are immunocompromised patients, veterinarians, pet bird owners, pet bird shops, and workers in pet exhibitions. Zoonotic diseases are transmitted via the fecal-oral, inhalation, and vector-borne routes. Zoonotic pathogens infect humans through direct or indirect contact with infected birds, contaminated birds' cages, food dishes, or droppings. Several bacterial, viral, parasitic, and fungal zoonoses are known in pet birds. Some zoonoses, such as highly pathogenic avian influenza, salmonellosis, and chlamydiosis, have significant public health risks that lead to serious human diseases. Newcastle disease and giardiasis are minor zoonoses that cause self-limiting infections in humans. Salmonellosis and campylobacteriosis are food-borne zoonoses with global importance in human health. Biosecurity and hygiene, cleaning and disinfecting bird cages, and using human protective equipment can help to control zoonoses in birds and humans.
Keywords: Pet birds, Prevention, Public health, Zoonotic pathogens, Zoonoses.

Introduction

Keeping animals and birds as pets have been trending over the past several decades. Birds are the most popular pets for their colorful and attractive appearance (Chomel and Sun, 2011). According to the statics, birds are the third and fourth most popular companion animal to keep as a pet in the European Union (EU) and United States, respectively (Peng and Broom, 2021). A pet or companion bird is a bird kept and bred primarily for ornamental purposes (Boseret et al., 2013). The three most common orders of birds kept as pet birds include Psittaciforms (parakeets, parrots, love birds, cockatiel, and budgerigars), Passeriformes (finch, canary, mynah, starling, and sparrows), and Columbiformes (pigeons and doves). Budgerigars (*Melopsittacus undulatus*), canaries (*Serinus canaria*), lovebirds (*Agapornis sp.*), and cockatiels (*Nymphicus hollandicus*) are the most common pet birds in developed and developing countries (Boseret et al., 2013; Peng and Broom, 2021).

Zoonotic diseases are one of the most critical concerns related to pet birds (Rahman et al., 2020). Zoonoses are infectious diseases transmitted

between animals or birds and humans. Zoonotic diseases transmit directly or indirectly from birds to humans (Guo et al., 2022). Some zoonoses transmit via asymptomatic reservoirs such as wild birds (Rahman et al., 2020). Some zoonoses, such as highly pathogenic avian influenza, salmonellosis, and chlamydiosis, are significant public health concerns leading to serious human diseases (Boseret et al., 2013). Salmonellosis and campylobacteriosis are food-borne zoonoses with global importance on human health, which can be transmitted from pet birds to humans (Rahman et al., 2020).

The severity of zoonotic diseases depends on various factors, such as organism's virulence, route of transmission or infection, and human's immunity level. Children, older people, immunocompromised and cancer patients are more likely to get zoonotic diseases (Pfeffer and Dobler, 2010). The people at the most risk of zoonoses are veterinarians, breeders of ornamental birds, pet birds owners, pet bird shops, and workers in exhibitions that have close contact with pet birds (Boseret et al., 2013). This review briefly discusses the most important zoonotic diseases transmitted from pet birds, their transmission route, and guidelines to control and prevent transmission from birds to humans.

Zoonoses transmission route

The infectious pathogens of zoonoses disseminate through various routes. The pathogens are excreted from infected birds' feathers, feces, and various secretions (like saliva, ocular, tracheal, and other body fluids). Infected feathers, feces, and secretions infect food dishes, water bowls, and the environment in which birds live (including cages and soil). Infectious pathogens may persist in infected feces and soil for a long time (Hollingsworth et al., 2015). The zoonotic agents can be transmitted directly (through direct contact with sick birds) or indirectly (through touch with contaminated cages, food dishes, water bottles, and the environment around birds) to humans (Rahman et al., 2020). Zoonotic pathogens can enter the human body via various methods, including ingestion, inhalation, mucous membrane, and damaged skin (Heesterbeek et al., 2015).

Some birds, particularly wild birds, can be asymptomatic reservoirs for zoonotic organisms and transmit them to humans without having any clinical signs. Various pathogens may be transferred from wild birds to pet birds kept outdoors (via contaminated feces), and humans become infected following contact with these pet birds (Ebani et al., 2021). Mites, mosquitoes, and ticks are mechanical vectors for some zoonotic pathogens, and the infectious agents are transmitted to humans via biting (Socha et al., 2022). Bird fairs, live pet shops, and markets are potential sources for some important zoonotic diseases, such as chlamydiosis and avian influenza (Magouras et al., 2020). Some zoonoses are food-borne diseases and can be transmitted from food chains to humans. Salmonella spp. is shed from sick birds' excreta and can contaminate birds' eggs and meat, and contaminated eggs and meat infect humans (Ehuwa et al., 2021). In zoonotic diseases, mostly transmission happens from infected birds to humans, but transmission between humans (inter-human transfer) is usually rare (Heesterbeek et al., 2015).

Classification of zoonoses

Zoonoses are classified depending on the etiology of infection into various groups: bacterial, viral, parasitic, and fungal zoonoses (Chomel, 2009). Table 1 summarizes the most important zoonotic disease with their etiological agents, clinical signs, and clinical symptoms reported in humans.

Bacterial zoonoses

Various bacterial species cause bacterial zoonosis. The most common zoonotic bacteria transmitted from birds to humans include *Salmonella* spp., *Chlamydia* spp., *Mycobacterium* spp., *Listeria* spp., *Escherichia coli*, *Campylobacter* spp., and *Staphylococcus* spp. (Day et al., 2016; Boroomand and Faryabi, 2020). Some zoonotic bacterial diseases, such as chlamydiosis and salmonellosis, have a higher occurrence in pet birds, which may be transferred to their owners leading to infection in humans (Jacob and Lorber, 2015). The bacterial

zoonotic agents with low occurrence in pet birds are *Yersinia* spp., *Pasteurella* spp., *Mycoplasma* spp., and *Klebsiella* spp. (Dorrestein et al., 2009; Jorn et al., 2009). *Escherichia coli* O157:H7, *Salmonella* spp., and *Mycobacterium Avium* can transmit from passerine birds (such as starlings) to humans (Gaukler et al., 2009; Kauman and LeJeune, 2011). Chlamydiosis, salmonellosis, mycobacteriosis, campylobacteriosis, and Lyme disease are the most critical bacterial zoonoses in pet birds (Rahman et al., 2020).

Table 1. Summary of the most important zoonotic diseases in pet birds (Boseret et al., 2013; Contreras et al., 2016).

Disease	Etiology	Sensitive host	Transmission route to humans	Major clinical signs in birds	Major Clinical symptoms in human	Risk factors	OIE listed disease
Histoplasmosis	*Histoplasma capsulatum*	All	Airborne, Inhalation of the fungus	Often asymptomatic, chronic gastrointestinal infection and disseminated infections	Often asymptomatic, weight loss, respiratory symptoms chronic progressive lung disease, chronic cutaneous, systemic disease, hepatosplenomegaly, and hematologic disturbances	Immunocompromised individuals, Caves, guano	No
Dermatophytosis	*Microsporum* spp., *Trichophyton* spp.	All	Direct contact with infected birds or material	Classical ring lesion with central healing and crusts at the peripheral area, some degree of folliculitis	Skin lesions as red areas, along with skin itching and central pallor	Immunocompromised individuals	No
Giardiasis	*Giardia* spp.	All	Fecal-oral	Asymptomatic and diarrhea	Sometimes asymptomatic weight loss, diarrhea, and abdominal pain	Lack of hygiene in bird equipment, water and feeders	No
Cryptosporidiosis	*Cryptosporidium* spp.	All	Fecal-oral	Asymptomatic; diarrhea, respiratory symptoms	Sometimes asymptomatic, slight fever, diarrhea, abdominal pain, nausea and malaise; organ lesions (liver, pancreas, and respiratory tract)	Lack of hygiene in bird equipment, water and feeders	No
Cryptococcosis	*Cryptococcus neoformans*, *Cryptococcus gattii*	Parrots, little pet birds	Airborne, mainly by inhalation of fungus, occasionally through breaks in the skin	Asymptomatic, grows in the feces of pigeons and other bird species Focal or disseminated infection, affecting a single organ system or many, and central nervous system involvement	Mostly asymptomatic, fever, nausea, and vomiting respiratory and nervous symptoms, severe symptoms in immunocompromised individuals, Meningitis/meningoencephalitis Cutaneous, ocular, pulmonary and central nervous system involvements	Aerosolized droppings	No
Campylobacteriosis	*Campylobacter jejuni*, *Campylobacter coli*	Estrildidae mostly	Food-borne	Diarrhea in young birds, Inapparent in adults, and healthy carriers	Acute gastrointestinal symptoms and Self-limiting infection	High prevalence in poultry farms, Cross-contamination of chicken carcasses, and Lack of hygiene in food preparation	No
Tuberculosis	*Mycobacterium avium*, *M. tuberculosis*	Psittacine birds and canaries	Fecal-oral, inhalation, and airborne	Diarrhea, weight loss, granulomatous lesions in the gastrointestinal and respiratory tract	Fever, abdominal pain, fatigue, chronic diarrhea, and anemia	Respiratory secretions, Contaminated water, soil and dust, and Immunocompromised individuals	Yes

Salmonellosis	*Salmonella* spp.	All (open-air aviaries)	Foodborne, fecal-oral, contamination in the surroundings of companion birds	Diarrhea and mortality in young birds and inapparent in adult birds (Healthy carriers)	Fever, gastroenteritis, and abdominal pain	Contamination of eggs, poultry meat and their by-products, lack of hygiene in food preparation, and little risk with companion birds	No
Psittacosis/ chlamydiosis/ornithosis	*Chlamydia* spp.	Psittacine birds, canaries, and finches	Respiratory transmission (dried and aerosolized feces)	depression, anorexia, ruffled feathers, weight loss diarrhea, conjunctivitis, and serous ocular and nasal discharges	Cough, dyspnea, pleuritic chest pain, epistaxis, sore throat, hemoptysis, fever, malaise, anorexia, chills, nausea, vomiting, myalgias, arthralgias, headache, and abdominal pain	Companion birds (specially Psittacine birds) and Occupational zoonosis	Yes
West Nile fever	flavivirus	All	Percutaneous by mosquito bite (*Culex* spp., *Aedes* spp.)	Asymptomatic Occasionally, severe symptoms with high mortality	Several neurological disorders, weakness, swollen lymph nodes, convulsions, tremors, disorientation, and neck stiffness, convulsions, and paralysis	Mosquito breeding sites and Sick or carrier wild birds	Yes
Influenza disease	Orthomyxovirus	Passerines	Airborne, Secretions and feces of sick birds or healthy carriers	High mortality in birds and Asymptomatic in wild carriers	Respiratory symptoms High fatality rate	Wild reservoir (waterfowl), Intermingling of wild birds of different origins, and Live bird markets	Yes
Newcastle disease	Paramyxovirus	All	Direct or indirect contact, respiratory secretions or droppings	Usually respiratory symptoms, mild, moderate and very virulent forms	Mild and self-limited conjunctivitis	Direct contact with sick or carrier birds Live vaccines	Yes
Lyme disease (borreliosis)	*Borrelia burgdorferi* sensu lato	All	Percutaneous (tick bite)	Mainly asymptomatic	Fever, headache, skin rash, and erythema migrans, and cardiac symptoms	Migratory birds with *Ixodes*: geographical spread of *Borrelia burgdorferi*	No

Chlamydiosis

Chlamydiosis is one of the most important bacterial zoonoses caused by *Chlamydophila psittaci* (Sachse et al., 2015). This organism is a small intracellular bacterium excreted from infected birds' nasal discharges and feces (Smith et al., 2011). Chlamydiosis is also known as psittacosis, ornithosis, or parrot fever (Cheong et al., 2019). The disease is called psittacosis if humans become infected via contact with psittacine birds. The term ornithosis is applied if the infection in humans happens due to contact with non-psittacine birds (Malik et al., 2021). All avian species are susceptible to chlamydiosis, but turkeys, pigeons, and ducks are the most vulnerable hosts for the disease. Pigeons, doves, waterfowl, herons, cockatoos, and parrots are the most commonly represented sources of human infection (Circella et al., 2011; Sachse et al., 2015).

The infection is mainly transmitted by respiratory secretions and feces of sick birds. There is no report about the vertical transmission of *C. psittaci* through birds' eggs (Smith et al., 2011). The infected birds are a commonly asymptomatic carrier for *C. psittaci* but can shed the bacterium in feces and nasal discharges. Sometimes, non-specific clinical signs such as depression, anorexia, lethargy, ruffled feathers, and weight loss may be seen in some birds. Infected birds often develop diarrhea, conjunctivitis, and serous ocular and nasal discharge (Cheong et al., 2019). It is complicated to diagnose the disease, especially in asymptomatic birds. Tissue smears, feces, conjunctival, choanal, and cloacal swab samples, and liver biopsy can be used to diagnose infection

in birds. Various diagnostic tests, including antibody detection, antigen detection, bacteriologic culture, and polymerase chain reaction (PCR), are recommended for evidence of chlamydiosis in birds (Stokes et al., 2021).

Human infection with *C. psittaci* occurs by inhalation of infectious aerosols from dried feces, direct contact with a sick bird and their respiratory secretions, and the fecal-oral route (Malik et al., 2021). Usually, the incubation period in humans is 5 - 14 days. Flu-like symptoms such as fever, headache, dry cough, respiratory distress, muscle pain, and pneumonia are observed in infected people (Hogerwerf et al., 2017). Less common clinical manifestations in patients are hepatitis, arthritis, and meningoencephalitis. The infection severity in human varies from mild to sepsis with multiple organ failures (Smith et al., 2011). Disease in humans can be diagnosed using complement fixation test (CFT), enzyme-linked immunosorbent assay (ELISA), nucleic acid amplification tests (NAATs), and PCR (Bryan et al., 2019). Tetracycline, doxycycline, or azithromycin are drug choices. Treatment duration varies based on the drug type, but at least 14 days is recommended for tetracycline (Shi et al., 2021). Prevention of *C. psittaci* infection in humans is vital. Removing debris and fecal material from cages, and cleaning and disinfecting bird cages, water bowls, and food containers help avoid spreading infected material to humans. People should not work with large numbers of pet birds in closely and dusty areas. Also, people should use personal protective equipment that covers the head, eyes, and hands to prevent and control this disease (Malik et al., 2021).

Salmonellosis

Salmonellosis is one of the most dangerous bacterial zoonoses with a global distribution caused by salmonella spp. (Barbour et al., 2015). It is one of the most prevalent food-borne diseases worldwide (Pui et al., 2011). Salmonellosis has remarkable diversity in the host range and is seen in humans, animals, and domestic and wild birds (Anamaria et al., 2018). About 2,500 Salmonella serovars have been identified worldwide, and the best-known Salmonella serovars are *S. enterica*, which causes illness in birds, animals, and humans (El-Tayeb et al., 2017). *S. Pullorum* and *S. Gallinarum* are two of the most important serovars in poultry with considerable economic losses. *S. Pullorum* and *S. Gallinarum* are host-specific for birds and responsible for causing a wide range of infections (from subclinical to severe) in chickens (Andino and Hanning, 2015; Jajere, 2019). These serovars are non-pathogenic for humans and animals and have low zoonotic risk (Ren et al., 2017). *S. Typhimurium* and *S. Enteritis* serovars are not host-specific and have a wide range of hosts. They are transmitted through food to humans and cause food poisoning and mass infection (Lawson et al., 2014).

Salmonellosis occurs in passerines, psittacines, turkeys, waterfowls, quails, pigeons, pheasants, parrots, and sparrows. The most susceptible pet birds to salmonella infection are pigeons, finches, canaries, and parrots. *S. Typhimurium* is frequently isolated from passerines, pigeons, ducks, and geese (Rahmani et al., 2011; Lawson et al., 2014). Salmonellosis is mainly an asymptomatic infection in pet birds. Some pet birds remain potential carriers for a long time and shed the bacteria into the environment through their feces (Wibisono et al., 2020). However, infected birds sometimes exhibit mild clinical signs, including depression, dehydration, anorexia, diarrhea, septicemia, and crop stasis. Granulomatous lesions in the spleen, ceca, and liver, ocular infection, arthritis, and osteomyelitis have been seen in infected passerines by *S. Typhimurium* (Boseret et al., 2013). The infection can be transmitted between birds horizontally (via direct and indirect contact with sick birds) and vertically (through eggs; Gow et al., 2009; Jones et al., 2011).

Salmonella transmission from birds to humans occurs via direct or indirect exposure to infected birds. Also, consuming water or food contaminated with infected birds' feces plays a significant role in human infection by Salmonella (Saravanan et al., 2015; Nidaullah et al., 2017). It has been reported that some outbreaks of *S. Typhimurium* in humans were following contact with the pellet food of

infected birds (Boseret et al., 2013). Furthermore, wild songbirds and starlings have been documented as potential Salmonella bacteria carriers to humans and mammals (Wibisono et al., 2020).

The prevalence of salmonellosis in humans has been increased in the 20th century due to the high consumption of animal products and poultry meat and eggs (Kallapura et al., 2014; Nidaullah et al., 2017). In addition, keeping pet birds and their close contact with humans is another reason for increasing the incidence of salmonellosis in humans in recent years (Antunes et al., 2016; Antillón et al., 2017). Eight to 48 hours after the Salmonella bacterium enters the human body, the disease appears in the form of gastroenterocolitis with clinical symptoms of increased body temperature, chill, vomiting, diarrhea, and myalgia in the infected individual. Vomiting, foul-smelling watery diarrhea, greenish color diarrhea, headache, abdominal cramps, fever, and nausea are more common clinical symptoms in infected humans (Jarvis et al., 2016; Antillón et al., 2017). Occasionally, human salmonellosis may be complicated by endocarditis, myelitis, and cerebral meningitis, requiring hospitalization. Usually, the illness in humans last 4 to 7 days, and death may rarely occur (Wu et al., 2011). Various reports indicate that in 2010 and 2011, about 9,000 cases of food poisoning caused by Salmonella were recorded in Poland, of which about 70% required hospitalization. Also, in 2013, about 8300 patients were identified in Poland, of which 70% were hospitalized. According to the European Food Safety Authority (EFSA) report, 93648 incidences of food poisoning by Salmonella were recorded in 30 EU countries in 2012. The EFSA also recorded 82694 cases in the EU in 2013 (Wojtyniak et al., 2013; Osek and Wieczorek, 2014).

The successful growth of organisms on selective enriched culture media is essential for definitive diagnosis. Sensitive antibiotics and supportive care are used for the treatment of infected humans. Disinfecting the surface and cage, cleaning the bird's water and food dishes, and avoiding contact with infected bird help prevent Salmonella infection in humans (Hung et al., 2017; Kurtz and Goggins, 2017).

Mycobacteriosis

Mycobacteriosis or tuberculosis is a significant disease caused by the bacterium *Mycobacterium avium*, which occurs in captive exotic, pet, domestic, and wild birds worldwide (Tsiouris et al., 2021). *M. avium* has four pathogenic subtypes for birds, including *M. avium* Subsp. *avium*, *M. avium* Subsp. *silvaticum*, *M. avium* Subsp. *hominissuis* (Haridy et al., 2014). *M. avium* Subsp. *avium* (serotypes 1, 2, and 3) is primary agent for avian mycobacteriosis (Haridy et al., 2014; Fulton et al., 2018). *M. avium* and *M. genavense* are the most common isolated species from pet birds, especially parrots, parakeets, and budgerigars (Lennox, 2007). *M. avium* Subsp. *paratuberculosis* is a pathogen of mammals (Tsiouris et al., 2021).

Avian tuberculosis affects all species of birds. Chickens, turkeys, pheasants, ducks, geese, and pet birds are the more susceptible host for tuberculosis (Fulton et al., 2018). Usually, mycobacteriosis affects birds older than one year. Infected birds with *M. avium* usually show no clinical symptoms but may become emaciated and lethargic. Diarrhea, weight loss, and colorless wattle and comb are seen in infected birds. Some birds develop respiratory distress, dyspnea, and sudden death due to granulomatous lesions in the lung. Granulomatous ocular lesions and skin lesions have also been reported in affected birds. Mycobacteriosis develops granulomatous lesions in various organs (including intestinal tract, liver, spleen, and lung) in birds (Dhama et al., 2011; Fulton et al., 2018).

Infected, untreated, and carrier birds are potential reservoirs of bacteria for humans that have a significant impact on public health. *M. avium* is transmitted directly and indirectly to humans, which causes a progressive disease in humans, especially in immunosuppressive patients. Infected people show weight loss, fever, abdominal pain, fatigue, chronic diarrhea, and anemia. In some patients, localized diseases occur with central nervous system infection, endocarditis, and cervical lymphadenitis (Fulton et al., 2018).

M. tuberculosis is the main species responsible for tuberculosis in humans. Several reports documented that *M. tuberculosis* was isolated from canary and parrots in New York and Switzerland. These infected birds developed lethargy, osteomyelitis, and granulomatous hepatitis. It was reported that *M. tuberculosis* could circulate between humans and birds, which has public health importance. There is a concern that pet birds can be a potential reservoir of this organism for humans and other birds (Hoop, 2002; Steinmetz et al., 2006).

Identifying infected birds is one of the primary ways to prevent mycobacteriosis in humans. Mycobacterial culture, serological test, and PCR apply for the definitive diagnosis of mycobacterium in birds. The Tuberculin test is a more common serologic test for determining the prevalence of infection in birds. The tuberculin test is used for domestic fowl and is less useful in pet birds. In waterfowl birds, a whole blood stained-antigen agglutination test is used to diagnose mycobacteriosis (Tsiouris et al., 2021).

Antibiotics such as rifampin, ethambutol, azithromycin, or clarithromycin are used to treat mycobacteriosis in pet birds. Destroying bacteria with disinfectants and avoiding humans from contact with sick birds are the best ways to prevent mycobacterium infection in humans. Mycobacterium persists in the environment for several months. Therefore, disinfecting the environment and cage with bleach and the phenolic compound helps destroy and inactivate the bacteria (Fulton et al., 2018).

Campylobacteriosis

Campylobacteriosis is another dangerous zoonotic disease with significant veterinary and public health concerns caused by *Campylobacter* spp. (Kaakoush et al., 2015). Campylobacteriosis is one of the most important causes of global diarrheal illness (Hsieh and Sulaiman, 2018). *Campylobacter* spp. is a gram-negative bacterium with three strains: *Campylobacter jejuni*, *Campylobacter lari*, and *Campylobacter coli* (Maësaar et al., 2020). Poultry, turkey, chicken, geese, and duck are infected with *Campylobacter* spp., particularly *C. jejuni* and *C. coli* (Kürekci et al., 2021). It has been reported that *C. jejuni* is the most isolated strain from broiler flocks (Maësaar et al., 2020). Wild and pet birds (primary canaries and parrots) are other asymptomatic reservoirs for *C. jejuni* (Mughini-Gras et al., 2021). *C. jejuni* and *C. coli* are colonized in the intestinal tract of chicken and turkey without any clinical disease. Wild birds carry these bacteria asymptomatically, and their feces are a potential source for the organism (Antilles et al., 2015; Johansson et al., 2018). *C. jejuni* is the most common species (over 80%) isolated from human with campylobacteriosis (Taheri et al., 2019).

Campylobacteriosis is a food-borne disease, and consuming contaminated or undercooked meat is the primary transmission route from birds to humans (Mohan et al., 2013). Also, the infection is transmitted to humans through close exposure with infected birds or their feces and inhalation of the infected droplets and particles (Taff and Townsend, 2017). In addition, humans can be infected following a contact with surfaces and equipment contaminated with bird droppings (French et al., 2009; Mulder et al., 2020). After 2-5 days, the clinical symptoms develop in the form of fever, vomiting, watery or sticky diarrhea, abdominal pain, headache, and muscle pain in infected humans (Awofisayo-Okuyelu et al., 2017). The clinical infection mainly occurs in immunosuppressive people. Usually, the complication is rare; however, septicemia, endocarditis, and arthritis are sporadically seen. Meningitis, colitis, acute cholecystitis, and Guillain–Barré syndrome can rarely occur in patients (Fernandez-Cruz et al., 2010; Backert et al., 2017, Brooks et al., 2017). Three are some reports of mild diarrhea in children infected by *C. lari* (Kaakoush et al., 2015). According to EFSA statistics, campylobacteriosis was a more common zoonosis in humans in 2010, and contaminated poultry meat was the primary source of *campylobacter* spp. (Kirk et al., 2010; Scallan et al., 2011).

Another serious public health concern of *Campylobacter* is antibiotic resistance, particularly for tetracyclines and fluoroquinolones. Ciprofloxacin resistance has been reported in some areas, such as the U.S. (Iannino et al., 2019). Histopathological examination, serologic tests, and PCR are used to diagnose the infection. Fluid and electrolyte therapy apply to the treatment of patients. Antibiotic treatment decreases the shed of *Campylobacterium* (Scallan et al., 2011).

Lyme disease

Lyme disease (Lyme borreliosis) is a prevalent tick-borne infectious disease caused by the bacterium *Borrelia burgdorferi* (Hao et al., 2011). *Borrelia* spp. is transmitted to humans through the bite of an infected tick from the genus Ixodid (Ogden et al., 2015). The most common hosts for *Borrelia* spp. are wild birds, songbirds, sparrows, and canaries (Scott et al., 2012; Dumas et al., 2022). Birds can not directly transmit *Borrelia* spp. to humans but can carry ticks containing the organism to a new area. Therefore, migrating and wild birds have a significant role in the worldwide distribution of *Borrelia* spp. (Cohen et al., 2015; Dumas et al., 2022). The ticks are a vector for the organism transmitted from birds to humans by biting (Hamer et al., 2012).

Different species of *Borrelia*, including *B. burgdorferi*, *B. afzelii*, and *B. garinii*, were isolated from ticks collected on pet birds (Sürth et al., 2021). *B. garinii* is the most common isolated species of birds and the most common agent of Lyme disease in humans (Coipan et al., 2016; Barstad et al., 2018). Infected ticks attack the head and the skin around the ear and eyes of birds. Infected birds usually show no significant clinical signs but are a vector for infected ticks. Infected ticks may drop off the bird into a yard and garden, then they can later bite and infect a human. *Borrelia* spp. is entered into the body of humans through a bite from infected ticks. Fever, fatigue, headache, skin rash, and erythema migrans were seen in diseased humans (Stanek et al., 2012; Steere et al., 2016). However, the infection may spread to people's nervous systems, hearts, and joints. Diagnosis is based on clinical symptoms, skin rash, and exposure to infected ticks (Mygland et al., 2009). Treatment is done with a few weeks of antibiotic therapy. Applying pesticides, removing ticks promptly, using insect repellent, and reducing tick habitat help prevent Lyme borreliosis (Steere et al., 2016).

Viral zoonoses

Some viruses like avian influenza, avian paramyxovirus, and West Nile virus (WNV) are main viral zoonoses found in pet birds. Mostly, viral pathogens are transmitted between humans and birds through arthropod, mechanical and biological vector. Some zoonotic viruses are transmitted through wild birds as reservoirs (Venkatesan et al., 2010). Among zoonotic agents, avian influenza is the most dangerous pathogen. Infection with avian paramyxovirus in humans results in a self-limiting eye infection (Kozdruń et al., 2015).

Avian influenza

The influenza virus belongs to the family Orthomyxoviridea. It has three types: A, B, and C. Influenza A virus is a zoonotic agent and infects a wide variety of hosts, including humans, sea mammals, pigs, horses, dogs, wild and domestic birds. Influenza B and C viruses naturally infect humans, and the influenza C virus has also been isolated from swine (Wright et al., 2013). Influenza A viruses are classified into various subtypes based on two surface glycoproteins: hemagglutinin (H) and neuraminidase (N) (Hill et al., 2019; Modirihamedan et al., 2021). Some subtypes are adapted only for birds and are not pathogenic for humans, known as the avian influenza virus (AIV) (Giotis et al., 2019). However, some other subtypes are not host-specific and infect various host ranges like birds, animals, and humans (Wang et al., 2021). Notably, all influenza A viruses have been isolated from wild birds, and birds are vital hosts for the ecology of the viruses (Zanaty et al., 2019). Infection with avian Influenza viruses (AIVs) in domestic poultry (turkey and chicken) can lead to respiratory diseases with various clinical symptoms from mild to severe (Karimi Madab et

al., 2013). The severity of clinical signs depends on the strain type of virus and host sensitivity (Samy et al., 2018). Many wild birds (including aquatic birds, free-ranging ducks, shorebirds, and passerines) are infected with all strains of influenza A (Bi et al., 2016). However, they are asymptomatic reservoirs for influenza A viruses and only shed viruses to the environment for a long time through their feces (Lang et al., 2016). Wild aquatic birds, especially waterfowl, can naturally transmit the infection to humans, domestic and pet birds (Ramey et al., 2022). Several types of psittacine birds, including lovebirds, parakeets, budgerigars, cockatiels, and parrots, are susceptible to AIV infection (Jiao et al., 2012a,b). Sometimes, the infected pet birds with AIV show no or few clinical signs (Su et al., 2015). There is a report of a 3-month-old red-lored Amazon parrot (*Amazona autumnalis*) infected with AIV (subtype H5N2) with clinical signs such as severe lethargy, melena, and regurgitation (Hawkins et al., 2006).

The AIV transmits mainly between birds through fecal-oral and inhalation of infected droplets and aerosols route (Su et al., 2015). Some strains of influenza A (low pathogenic avian influenza virus) cause mild to moderate respiratory signs in broiler chickens. Other strains, termed highly pathogenic avian influenza, cause severe systemic infection with high mortality of about 100% in flock broilers (França and Brown, 2014.). Depression, anorexia, diarrhea, and neurologic signs are also seen in infected broilers with the Influenza virus. The principal diagnosis method is viral isolation from cloacal and tracheal swabs of sick birds (Spackman et al., 2014).

Human infection with some subtypes of AIV like H5N1, H7N9, and H9N2 has been reported (Lai et al., 2016). Transmission of AIV to humans occurs via direct or indirect contact with infected birds, oral-fecal, and inhalation of infected aerosols. It is noticeable that human-to-human transmission of avian influenza viruses is rare (Sergeev et al., 2013). Infected humans may show mild to severe clinical symptoms (Sun et al., 2010). Conjunctivitis, fever, cough, severe pneumonia, dyspnea, sepsis shock, and even death can develop in infected people. Encephalitis and gastrointestinal symptoms have been reported in some people (Chen et al., 2014; Belser et al., 2018). It is noticeable that waterfowl strains of AIV have a low ability to replicate well in the human body and mainly immunosuppressive people are at risk for infection (Gray et al., 2011). The genome of the influenza virus is segmented; therefore, exchange of RNA segments between various subtypes can lead to producing a new virus that overcomes this host restriction (Long et al., 2019). It has been documented that human and avian influenza viruses can be well replicated in the pig's body. Pig is a mixing vessel for the genetic re-assortment between human and avian influenza viruses and the source of new viruses (Mostafa et al., 2018). Countries with close contact between humans, pigs, and birds can be considered an epicenter for emerging strains of influenza A virus. Therefore, pigs may transmit new viruses to birds (Zhang et al., 2021). Pet birds can be infected with new strains of influenza viruses via exposure to the feces of wild birds (Ebani et al., 2021). Live-bird markets and pet stores are important epicenters for all subtypes of influenza A and have an essential role in the transmission of virus to humans (Li et al., 2022).

Controlling the disease in poultry and other birds is the primary method of decreasing the risk to humans. Vaccinating chickens, avoiding human exposure to infected birds or their feces, and cleaning and disinfecting the cage and environment can help to prevent influenza infection in humans (Pan et al., 2022).

West Nile Fever

West Nile fever [known as West Nile fever virus (WNV)] is a viral disease in birds caused by the flavivirus genus (Chancey et al., 2015). The flavivirus is transmitted by arthropod vectors (mainly mosquitoes) (Michel et al., 2018). Canaries, parrots, and house sparrows are the primary hosts for WNV (Perez-Ramirez et al., 2014). Mostly, birds are infected subclinical and show no significant clinical signs. Sometimes, infected birds show ocular disease, convulsions, ataxia, torticollis, and paralysis of the pelvic and

thoracic limbs (David and Abraham, 2016). The WNV infection in some pet birds, such as psittacine and passerine birds, is fatal. Some pet birds survive and become potential reservoirs for human infections (Marzal et al., 2022). Wild, free-living, and migratory birds are also potential reservoirs for the virus (Ziegler et al., 2019). When the mosquito feeds on the sick bird, it becomes infected and then spreads the flavivirus to humans through biting (Kampen et al., 2020). The infection in birds is diagnosed by virus isolation and PCR. Infected tissues (spleen, brain, and kidneys) and cloacal or oral swabs of birds are used for virus isolation (Reemtsma et al., 2022).

Humans can be infected by flavivirus via direct or indirect exposure to infected birds, organ transplants, and blood donation products (Reemtsma et al., 2022). The virus causes respiratory signs in humans (Bai et al., 2019). The clinical symptoms in infected humans develop 3-14 days after biting an infected mosquito. Clinical symptoms are seen only in 20% of the infected humans, including fever, nausea, headache, vomiting, and rash (David and Abraham, 2016). Clinical signs may persist for a few days to a week. Severe clinical symptoms such as weakness, convulsions, tremors, disorientation, and neck stiffness may develop rarely. In these cases, the duration of the disease may last for weeks, and the neurological signs may be permanent (Bai et al., 2019; Reemtsma et al., 2022).

West Nile Fever treatment is primarily supportive. No treatment is needed in mild cases. Severe cases of infection in humans may require hospitalization. The primary way of prevention is to limit exposure to mosquitoes. Spraying the area with insecticides and using body protection clothes against the mosquito can help control the infection (Bai et al., 2019).

Newcastle disease

Newcastle disease is a minor zoonosis caused by an avian paramyxovirus of the family paramyxoviridea (Behboudi and Hamidi Sofiani, 2021). There are different paramyxovirus serotypes, and each serotype is adapted to a specific host. Avian paramyxovirus serotype 1 (APMV-1) has significant economic and public health concerns, causing Newcastle disease in birds (Linde et al., 2011). Newcastle disease is a critical disease in poultry, leading to respiratory disease accompanied by a high mortality rate, intestinal tract, and neurological signs. Newcastle disease has high economic loss in the poultry industry worldwide due to weight loss, decreased weight gain, and increased mortality rate. Newcastle disease is notifiable and requires prompt steps for eradication (Narayanan et al., 2010).

Many species of birds, including poultry, pigeon, parrot, passerine, domestic and wild birds, are susceptible to APMV-1. Mostly, waterfowl birds are asymptomatic reservoirs and shed the APMV-1 via their feces (Munir et al., 2012). The virus is shed from respiratory secretions and feces of infected birds and can contaminate the environment. Direct or indirect contact with infected birds, environment, and equipment leads to transmitting the Newcastle disease between birds. The virus enters the bird's body due to inhalation and ingesting contaminated particles (Yune and Abdela, 2017). Serological tests, viral isolation, and molecular tests are used for Newcastle disease diagnosis in birds (Alazawy and Al Ajeeli, 2020).

APMV-1 is transmitted from birds to humans, causing mild flu-like symptoms, conjunctivitis, and laryngitis. Veterinarians, people working with live Newcastle virus vaccines, and people contacting sick birds are at risk of infection by APMV-1. In humans, clinical signs occur 1-2 days after infection. Infected humans show conjunctival redness, watery eyes, subconjunctival ecchymoses, and eyelid swelling. The illness is self-limiting, and symptoms usually persist for a few days (Ul-Rahman et al., 2022).

Pigeon paramyxovirus-1 (PPMV-1) is another zoonotic virus of the genus Avulavirus, family paramyxoviridea. Pigeons and doves are the primary hosts for PPMV-1. Infection with PPMV-1 leads to green diarrhea, lethargy, twisting of the neck, head flicking, and dyspnea in pigeons. Close contact with infected pigeons or their droppings

can transmit PPMV-1 to humans. The PPMV-1 infection causes respiratory disease in humans, especially in immunocompromised individuals (Kuiken et al., 2018)

Parasitic zoonoses

There is a wide variety of cestodes, protozoa, trematodes, and nematodes, with zoonoses concern between animals and humans (Schurer et al., 2016). A few parasites like *Giardia* spp. and *Cryptosporidium* spp. in pet birds can lead to disease in humans. Parasites transfer to humans via various routes, including vectors, contact with infected birds, and exposure to contaminated birds' equipment and environments around the birds. Wild and pet birds can be potential reservoirs for the various parasites (Ebani et al., 2021).

Giardiasis

Giardiasis is a zoonotic parasitic disease caused by *Giardia* spp. Different species of *Giardia* are known in birds: *G. psittaci*, *G. duodenalis*, and *G. ardeae* (Ryan and Cacciò, 2013). *G. psittaci* and *G. ardeae* are specific to birds and not transmissible to humans (Cano et al., 2016). *G. duodenalis* is a zoonotic parasite and usually causes a self-limiting infection in humans. It has been reported that parrots are the host for some species of *G. duodenalis*, which are colonized in the small intestine of birds and shed from their feces (da Cunha et al., 2017). Feces of various pet birds, mainly parrots, are a source of *Giardia* spp. infection in humans. Infection in humans is mainly asymptomatic, but sometimes has mild clinical signs like abdominal pain, diarrhea, and weight loss (Reboredo-Fernandez et al., 2015).

Cryptosporidiosis

Cryptosporidiosis is caused by *Cryptosporidium* spp., which is isolated from droppings of various birds like pigeons, parrots, and songbirds. *C. galli*, *C. meleagridis*, and *C. baylei* are not zoonotic agents and only infect birds leading to respiratory, intestinal, and nephrotic clinical signs in the bird (Cano et al., 2016; da Cunha et al., 2017). *C. hominis* and *C. parvum* are two important *Cryptosporidium* spp. with zoonotic ability. These species are isolated from various types of pet birds, which can lead to human infection (Braima et al., 2019). Contaminated areas, water, and food are sources of infection in humans. Very young children and HIV-positive patients are at the highest risk for cryptosporidiosis by *C. hominis* and *C. parvum*. Infected individuals develop respiratory signs and lesions in various organs such as gastrointestinal tract, liver, and pancreas (Sak et al., 2011; Braima et al., 2019).

Toxoplasmosis

Toxoplasmosis is a zoonosis caused by the protozoan parasite *Toxoplasma gondii* infecting animals, birds, and mammals worldwide. *T. gondii* causes infection in humans, especially in immunocompromised individuals and unborn fetuses (Ammar et al., 2021). The most important hosts for the organism are finches, budgerigars, and canaries (Boseret et al., 2013). Huang et al. (2019) reported that 34.29% of Java sparrows (*Lonchura oryzivora*) are infected with *T. gondii*. In the previous studies, it has been reported that the prevalence of *T. gondii* in pigeons and pet parrots were 11.86% and 8.36%, respectively (Cong et al., 2012; Zhang et al., 2014). Exposure to infected feces or eating raw or undercooked meat has a vital role in the transmission of pathogenic agent to humans. The infection with *T. gondii* causes abortion and congenital malformations in pregnant humans (El-Sherbini et al., 2019).

Fungal zoonoses

Various fungal infections are known in humans. Some fungi are air born and the environment has an important role in their distribution. A number of fungal pathogens have zoonotic potential and public health importance transmitting naturally between birds, animals, and humans (Gnat et al., 2021). Infectious fungi can affect humans as a primary pathogen or opportunists. In most cases, fungal zoonoses develop no or mild clinical signs. However, immunosuppressive patients show severe diseases that can lead to dead (Seyedmousavi, 2015). *Aspergillus* spp. and *Candida* spp. transmit from pet birds to humans

that cause severe diseases in immunocompromised patients (Cray, 2011; Boseret et al., 2013).

Among the zoonotic diseases, fungal zoonoses have not received enough attention at the international public health level, leading to insufficient attention to their preventive strategies (Seyedmousavi, 2015). Infected birds contaminate the soil and the environment, and fungal pathogens are mainly transmitted to human by direct or indirect contact with sick birds, exposure to contaminated environment, and inhalation of aerosols and respiratory particles (Richard et al., 2017). Some fungi like *Histoplasmosis* spp. and *Cryptococcus* spp. transfer from birds to soil and grow in soil, and consequently the contaminated soil can be a way for zoonoses transmission (Rahman et al., 2020). The most common fungal zoonoses from birds are dermatophytosis, histoplasmosis and cryptococcosis, which are explained below.

Cryptococcosis

Cryptococcosis is an infectious zoonotic disease by *Cryptococcus* spp. (Lugarini, 2008). *C. neoformans* is isolated from bird excreta, and can transmit to humans. Several birds, including chickens, pigeons, and pheasants, are hosts for *Cryptococcus* spp. (Gnat et al., 2021). Pigeons and parrots (mainly different cockatoo species) are the primary hosts of *C. neoformans* (Lugarini, 2008). Also, other pet birds, such as canaries, lovebirds, budgerigars, and cockatiels, are susceptible to *C. neoformans* as potential reservoirs for the fungus (Brilhante et al., 2010). Mostly, sick birds have no significant clinical signs except increasing body temperature and fever. The cutaneous lesions has been reported in cockatoos infected by *C. neoformans*. Birds shed the fungus through feces, and contaminated cages and soil with birds' feces are transmission routes for humans. Infection in people can occur through the inhalation of infected particles (Hashemi et al., 2014).

Infection by *C. neoformans* in humans is commonly an opportunistic infection. Meningoencephalitis often occurs in immunosuppressed persons (HIV/AIDS patients and organ transplant recipients). The infected patients may show clinical symptoms such as headaches, fever, malaise, stiff neck, nervous signs, and even death. Respiratory and cutaneous forms of cryptococcosis can also occur in infected humans (Pasa et al., 2012; Hayashida et al., 2017; Zhang et al., 2019). Cutaneous nodular lesions have been reported in immunosuppressed pet cockatoo owner by infection with *C. neoformans* (Nosanchuk et al., 2000).

Histoplasmosis

Hisplasmosis is a fungal disease caused by *Histoplasma capsulatumn*, which is isolated from feces of various animals and birds. Pigeons and doves are the most common hosts for *H. capsulatum*. The bat droppings, feces of infected birds, and birds' nests (especially starlings) are the sources of infection for humans (Haag-Wackernage et al., 2004; Adebiyi and Oluwayelu, 2018). This fungus can be persisted in soil and suitable environments for several years and transmitted to humans through contaminated soil (Rahman et al., 2020). Also, inhalation of fungal spores is another route of transmission to humans. Incubation period in human infections is about 3-17 days. Mostly, *H. Capsulatum* infection in human occurs as an asymptomatic disease. In a few cases, respiratory symptoms including malaise, headache, fever, dry cough, and chest pain can develop. Pneumonia occurs in rare cases, usually seen in untreated infected people that may even lead to death. In some patients, it develops skin ulcers and lymphadenopathy (Nagoda et al., 2012; Adebiyi and Oluwayelu, 2018).

Dermatophytosis

Dermatophytes, known as ringworm fungi, are the most common isolated fungi from birds and animals (Nweze, 2010). Dermatophytes have three different genera, including *Trichophyton*, *Epidermophyton*, and *Microsporum* spp. (Popoola et al., 2006; Nweze, 2010). *Trichophyton* and *Microsporum* spp. are zoophilic, causing skin lesions in animals and birds. Contact with infected birds, feathers, and skin debris represents a potential role of fungi transmission to humans. In people with dermatophytosis, skin lesions can be seen as red areas, along with skin itching and

central pallor, which appears as a "ring" (Fehr, 2015; Adebiyi and Oluwayelu, 2018).

Prevention and control of transmission from birds to human

The occurrence of zoonotic diseases depends on the interaction of birds, humans, and the environment. Therefore, managing and performing effective protocols are required for the control and prevention of these diseases (Chomel, 2009). Restricting human contact with sick birds and hand washing with disinfectant sprays and gels are the major crucial strategies to control zoonoses (Al-Tayib et al., 2019). Identifying, quarantining, and treating sick birds help to prevent zoonoses. Cleaning and disinfecting the birds' cage, food and water bowls with a bleach solution decreases the risk of infection and transmission of zoonotic pathogens to humans. Keeping pet birds away from high-risk individuals (such as very young and very old people or patients with weakened immune systems) will help reduce their risk of infection (Aenishaenslin et al., 2013; Dahal and Kahn, 2014). Detection and eradication of carriers, biological and mechanical vectors can avoid the transmission of zoonotic agents between birds and humans (Boseret et al., 2013; Rahman et al., 2020).

Conclusion

Zoonotic diseases associated with pet birds do not mainly lead to a severe infection in healthy humans, but immunocompromised individuals are at serious risk for infection by zoonotic pathogens. Exposure to infected pet birds or their secretions and droppings leads to transmitting zoonoses to humans. Identifying and treating sick birds and applying hygiene protocols significantly decrease zoonotic infection risk in people.

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Ethical approval

Not applicable.

Conflicts of interest

The author declares no conflict of interest.

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