Review

Zoonoses at the Human-Avian Interface: A Review

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Abstract

Birds, a significant member of our ecosystem are also a major reservoir for many zoonotic infections. They can transmit several emerging and reemerging infectious diseases to humans mostly through direct contact or consumption of contaminated meat, eggs, and water. With the ever-growing expansion of global trade, population explosion, human movement and changing demographic behavior, there has been tremendous eversion of pathogens. Such infections continue to pose risks to human health in most parts of the world and are economically important too. This review, focused on the most important infectious diseases of poultry which can cause human health hazard by describing general information, epidemiology, clinical signs, and strategies for prevention/control with the objective to create awareness among all the stakeholders to avoid associated fatal complications.

Keywords: Poultry; Zoonoses; Epidemiology; Human Health

Introduction

Livestock rearing is one of the most important economic activities in the rural areas of most of the developing regions of world. It not only acts as a source of income to most of the families dependent on agriculture but is also a source of protein supplement to the family members of the household in the form of milk, meat and eggs. Therefore, animal husbandry acts as an adjunct to agriculture and it is crucial for overall food security too. In the livestock sector, poultry industry is considered to be the fastest growing industry among the agriculture based industries. With the growing popularity of backyard and small production flocks, the concerns regarding human health risks associated with poultry diseases are also increasing. There are various diseases/infections that are naturally transmissible between vertebrate animals and man, commonly referred to as zoonoses [1]. In general, humans can get infection from poultry through contact with or being around live birds and secondly, through consumption of contaminated chicken and eggs from the infected birds. The occurrence of zoonoses depends on a number of factors such as: duration of exposure, effective contact, pathogenicity and virulence of the pathogen and its survival, route of infection and transmission, involvement of mechanical and biological vectors, etc. Zoonotic diseases in poultry exert dual impacts on human population. This could be either through direct risk of infection or through reduced production by the birds resulting in food insecurity and poverty [2]. Human health problems resulting from direct or indirect contact with live infected birds and their secretions, excretion or food products are associated with bacterial, viral, fungal and chlamydial agents (Table 1). The present review describes such infectious diseases/agents of avian species which can pose serious risks/threats to human health as well as recent information on their prevalence and epidemiological observations reported from various geographical regions of world including India (Table 2).

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### Table 1: The zoonotic agent associated with birds and their transmission dynamics

<table>
<thead>
<tr>
<th>Agents</th>
<th>Diseases/Infections</th>
<th>Major mode of transmission of infection from infected birds to humans</th>
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<tbody>
<tr>
<td>Viruses</td>
<td>Avian Influenza</td>
<td>Contact with live infected birds and their secretions and excretions</td>
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<td>West Nile Virus infection</td>
<td>Bites from infected mosquitoes</td>
</tr>
<tr>
<td></td>
<td>New Castle Disease</td>
<td>Contact with live infected birds and their secretions and excretions</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Campylobacteriosis</td>
<td>Contaminated meat and water</td>
</tr>
<tr>
<td></td>
<td>Colibacillosis</td>
<td>Contaminated poultry meat, eggs and water</td>
</tr>
<tr>
<td></td>
<td>Salmonellosis</td>
<td>Contaminated poultry meat, eggs and water</td>
</tr>
<tr>
<td></td>
<td>Avian Tuberculosis</td>
<td>Direct contact with infected birds, ingestion of contaminated feed and water, or contact with a contaminated fomites.</td>
</tr>
<tr>
<td>Protozoan</td>
<td>Toxoplasmosis</td>
<td>Contaminated poultry meat</td>
</tr>
<tr>
<td>Fungi</td>
<td>Aspergillosis</td>
<td>Inhalation of spores present in soil, water and feed</td>
</tr>
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<td></td>
<td>Cryptococcosis</td>
<td>Inhaling dust contaminated with bird droppings</td>
</tr>
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<td></td>
<td>Histoplasmosis</td>
<td>Contact with soil contaminated by bird or bat droppings</td>
</tr>
<tr>
<td>Chlamydia</td>
<td>Ornithosis</td>
<td>Inhalation of organism shed by infected birds, handling of dead infected birds, nasal discharge, bite and person to person contact</td>
</tr>
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### Table 2: Avian Zoonoses: Recent trends, epidemiological features and reports

<table>
<thead>
<tr>
<th>Disease</th>
<th>Spatial distribution (Host)</th>
<th>Major epidemiological observations</th>
<th>Year of report</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avian Influenza</td>
<td>India (Poultry)</td>
<td>H5N1 outbreak occurred resulting in mortality of 1760 birds and culling of 5,263 birds</td>
<td>2016</td>
<td>[109]</td>
</tr>
<tr>
<td></td>
<td>India (Poultry)</td>
<td>Highly pathogenic avian influenza (H5N8) viruses detected in waterfowls. Both viruses were different 7:1 reassortmants of H5N8 viruses isolated from wild birds in the Russian Federation and China, suggesting virus spread during southward winter migration of birds.</td>
<td>2017</td>
<td>[110]</td>
</tr>
<tr>
<td>Global occurrence</td>
<td>Global occurrence (Human)</td>
<td>A total of 860 human cases of avian influenza A(H5N1) have been reported from 16 countries globally with 454 deaths.</td>
<td>2017</td>
<td>[111]</td>
</tr>
<tr>
<td>Disease</td>
<td>Country (Species)</td>
<td>Description</td>
<td>Year</td>
<td>Reference</td>
</tr>
<tr>
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</tr>
<tr>
<td>West Nile Disease</td>
<td>India (Birds)</td>
<td>2.46% of birds showed evidence of flavivirus antibodies suggesting rare infection among wild migratory birds.</td>
<td>2012</td>
<td>[114]</td>
</tr>
<tr>
<td></td>
<td>India (Ducks)</td>
<td>WNV specific antibodies detected in 11.5% of duck in Kerala, India.</td>
<td>2016</td>
<td>[115]</td>
</tr>
<tr>
<td></td>
<td>India (Humans)</td>
<td>Neutralizing antibodies against WNV was found in 21.5% of tested human sera.</td>
<td>2017</td>
<td>[116]</td>
</tr>
<tr>
<td></td>
<td>India (Mosquitoes and Poultry)</td>
<td>WNV identified from field-collected <em>Culex pseudovishnui</em> and <em>Mansonina uniformis</em>. The study also highlighted the role of sentinel chickens for WNV surveillance.</td>
<td>2017</td>
<td>[117]</td>
</tr>
<tr>
<td>New Castle Disease</td>
<td>United Kingdom (Human)</td>
<td>New Castle Disease virus as a cause of human conjunctivitis due to exposure to large quantities of virus.</td>
<td>2000</td>
<td>[118]</td>
</tr>
<tr>
<td></td>
<td>United States of America (Human)</td>
<td>Mild, self-limiting influenza like disease with fever and headache reported in humans.</td>
<td>2003</td>
<td>[119]</td>
</tr>
<tr>
<td></td>
<td>United States of America (Human)</td>
<td>Isolation and identification of avian paramyxovirus 1 (APMV-1) from a lethal case of human pneumonia.</td>
<td>2007</td>
<td>[120]</td>
</tr>
<tr>
<td>Campylobacteriosis</td>
<td>US (Poultry)</td>
<td>Crop of poultry is an important niche for <em>Campylobacter</em> and may represent a major source of contamination during processing.</td>
<td>2015</td>
<td>[121]</td>
</tr>
<tr>
<td></td>
<td>India (Poultry and Human)</td>
<td><em>C. jejuni</em> were more frequent than <em>C. coli</em> in poultry and chicken acts as a potential source of infection to children</td>
<td>2013</td>
<td>[122]</td>
</tr>
<tr>
<td></td>
<td>Switzerland (Poultry and Human)</td>
<td>Prevalence of Campylobacter in broilers, with a 2-week lag, has a significant impact on disease incidence in humans.</td>
<td>2015</td>
<td>[123]</td>
</tr>
<tr>
<td></td>
<td>USA (Poultry and Human)</td>
<td>Multistate outbreak of campylobacteriosis associated with consumption of undercooked chicken liver</td>
<td>2015</td>
<td>[124]</td>
</tr>
<tr>
<td>Colibacillosis</td>
<td>Brazil (Poultry)</td>
<td>Avian pathogenic <em>E. coli</em> (APEC) is a reservoir/subpathotype of human Extraintestinal Pathogenic <em>E. coli</em> (ExPEC)</td>
<td>2017</td>
<td>[125]</td>
</tr>
<tr>
<td></td>
<td>USA (Poultry, rats and humans)</td>
<td><em>E. coli</em> isolates from healthy chicken feces contain ExPEC-associated genes, exhibit ExPEC-associated in vitro phenotypes, and can cause ExPEC-associated infections in animal models, and thus may pose a health threat to poultry and consumers.</td>
<td>2017</td>
<td>[126]</td>
</tr>
<tr>
<td></td>
<td>India (Poultry)</td>
<td>Colibacillosis in poultry with prevalence of 17.16% and highest prevalence at the age group of 3-6 weeks in Assam (India).</td>
<td>2018</td>
<td>[127]</td>
</tr>
<tr>
<td>Zoonosis</td>
<td>Country/Location (Category)</td>
<td>Description</td>
<td>Year</td>
<td>Reference</td>
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<tr>
<td>-------------------</td>
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</tr>
<tr>
<td>Salmonellosis</td>
<td>Republic of Srpska (Poultry)</td>
<td>Higher incidence of Multidrug-resistant <em>Salmonella</em> Infantis in poultry meat than <em>S. Enteritidis</em></td>
<td>2017</td>
<td>[128]</td>
</tr>
<tr>
<td></td>
<td>India (Poultry)</td>
<td>Isolation of <em>S. Enteritidis</em>, <em>S. Typhimurium</em> in addition to <em>S. Gallinarum</em> from Fowl typhoid affected birds in winters.</td>
<td>2015</td>
<td>[129]</td>
</tr>
<tr>
<td></td>
<td>India (Poultry)</td>
<td>Poultry litter, environmental and post evisceration stages at retail chicken processing, are critical sources of cross contamination of invasive <em>Salmonella</em> spp.</td>
<td>2017</td>
<td>[130]</td>
</tr>
<tr>
<td>Avium Tuberculosis</td>
<td>Japan (Human)</td>
<td>Dry pleurisy complicating solitary pulmonary nodules in humans caused by <em>Mycobacterium avium</em></td>
<td>2015</td>
<td>[131]</td>
</tr>
<tr>
<td></td>
<td>Republic of Korea (Humans)</td>
<td>Hydropneumothorax in lung diseases of humans caused by <em>M. avium</em> and <em>M. intracellulare</em></td>
<td>2016</td>
<td>[132]</td>
</tr>
<tr>
<td>Toxoplasmosis</td>
<td>India (Poultry)</td>
<td>The prevalence of <em>Toxoplasma</em> antibodies in chicken was found to be 18.7%</td>
<td>2005</td>
<td>[133]</td>
</tr>
<tr>
<td></td>
<td>China (Poultry)</td>
<td>The prevalence of <em>Toxoplasma</em> antibodies in chicken was found to be 67.14% from farms with <em>T. gondii</em> positive in soil and 41.0% from farms with <em>T. gondii</em> negative in soil.</td>
<td>2017</td>
<td>[134]</td>
</tr>
<tr>
<td></td>
<td>Kenya (Poultry)</td>
<td>Brain samples of chicken revealed overall <em>T. gondii</em> prevalence of 79.0%</td>
<td>2016</td>
<td>[135]</td>
</tr>
<tr>
<td></td>
<td>Italy (Poultry)</td>
<td>Chicken Meat juice serology revealed 36.4% prevalence of <em>T. gondii</em> antibodies</td>
<td>2016</td>
<td>[136]</td>
</tr>
<tr>
<td></td>
<td>Brazil (Poultry)</td>
<td>Four new genotypes of <em>T. gondii</em> were described with 16.6% seroprevalence.</td>
<td>2018</td>
<td>[137]</td>
</tr>
<tr>
<td>Aspergillosis</td>
<td>Kalyoubia Governorate, (Human)</td>
<td><em>A. fumigatus</em> isolated from sputum samples of poultry farm workers.</td>
<td>2014</td>
<td>[138]</td>
</tr>
<tr>
<td>Cryptococcosis</td>
<td>Thailand (Human)</td>
<td>Cryptococcal meningitis in HIV affected patients.</td>
<td>2004</td>
<td>[139]</td>
</tr>
<tr>
<td>Histoplasmosis</td>
<td>Bangladesh (Human)</td>
<td>Ulcers in nasopharynx and granulomatous lymphadenitis in patients affected with HIV who contracted the infection from soil infected with bird's droppings.</td>
<td>2010</td>
<td>[140]</td>
</tr>
<tr>
<td></td>
<td>West Africa (Human)</td>
<td>A total of 470 cases of Histoplasmosis have been reported since 1952-2017. The majority of cases were found to be caused by <em>H. capsulatum</em>.</td>
<td>2018</td>
<td>[141]</td>
</tr>
<tr>
<td>Chlamydiosis</td>
<td>Hong Kong (Human)</td>
<td>Human beings in close contact with birds acquired the respiratory infection indicated Chlamydial infection.</td>
<td>2015</td>
<td>[142]</td>
</tr>
<tr>
<td></td>
<td>New south Wales (Human)</td>
<td>Nine people developed the respiratory illness due to exposure to fetal membranes of a mare.</td>
<td>2017</td>
<td>[143]</td>
</tr>
</tbody>
</table>
Viral Infections are the most common cause of losses, not only in large commercial flocks, but also in backyard poultry. Most viral diseases in poultry do not respond to drug treatment. Therefore, treatment is either not recommended or relies on supportive therapy. The prevention and control strategies are cornerstone in limiting economic losses as well restricting the potential risks to human health. This relies on vaccination where this is effective, or by limiting exposure to infected birds. Some common viral zoonotic agents/disease of poultry are:

Avian Influenza

Among viral diseases of zoonotic significance, avian influenza is the most dangerous one. In recent past, India suffered multiple outbreaks of avian Influenza (H5N1 and H5N8) at various epicenters in Delhi, Gwalior (MP), Rajpura (Punjab), Hissar (Haryana), Bellary (Karnataka), Alappuzha and Kottayam (Kerala), Ahmedabad (Gujarat), Daman (Daman) and Khordha and Angul [3].

Avian influenza viruses are highly contagious; extremely variable that is widespread in domestic, wild, and ornamental birds. Wild birds in aquatic habitats are thought to be their natural reservoir hosts, but domesticated poultry are readily infected. Influenza viruses belong to the Orthomyxoviridae family. Three types - A, B, and C are distinguished, but the type A viruses are the most important. They can infect both animals and humans. The pathogenicity of influenza viruses results from their significant antigenic variation due to antigenic drift and antigenic shift. As a result, 256 progeny strains can potentially develop [4]. Most viruses cause only mild disease in poultry, and are called low pathogenic avian influenza (LPAI) viruses. Highly pathogenic avian influenza (HPAI) viruses can develop from certain LPAI viruses, usually while they are circulating in poultry flocks [5]. In birds, avian influenza viruses are shed in the feces and respiratory secretions. Fecal–oral transmission is the predominant means of spread in aquatic wild bird reservoirs. Once an avian influenza virus has entered a poultry flock, it can spread on the farm by both the fecal–oral route and aerosols, due to the close proximity of the birds. Fomites can be important in transmission, and flies may act as mechanical vectors [6,7]. Clinical signs in poultry induced by LPAI viruses are some reduction in weight gain in fattening poultry or a slight and temporary decline in egg production in layers [8]. In contrast, HPAI viruses can result in mortalities up to 90–100% in a flock within 48 hours, and cause epidemics that may spread rapidly, devastate the poultry industry and result in severe trade restrictions [9]. Infection of poultry with LPAI viruses capable of evolving into HPAI viruses also affects international trade [10].

Avian influenza is primarily a disease of birds but it may appear among the human population as a result of poor hygiene or prolonged contact with infected birds, their secretions or excretions. The two most commonly reported avian influenza viruses from human clinical cases have been the Asian lineage H5N1 HPAI viruses, and H7N9 LPAI viruses in China [11]. The people who are at highest risk of getting this infection include poultry farm workers, veterinarians, wildlife biologists, ornithologists etc. Symptoms of avian influenza infection in people are almost similar to common cold and may include fever, malaise, cough, sore throat, muscle aches, abdominal pain, chest pain, conjunctivitis, parenchymal pneumonitis and diarrhoea. However, it may result in much more severe course than classic influenza.

For diagnosis, avian influenza viruses can be detected in oropharyngeal, tracheal and/or cloacal swabs from live birds and samples from internal organs of dead birds. In humans, viruses may be found in samples from the upper and/or lower respiratory tract. Viruses can be isolated in embryonated eggs. Real – time polymerase chain reaction (RT-PCR) assays can detect influenza viruses directly in clinical samples, and real – time PCR is the diagnostic method of choice in many laboratories [12]. For screening the flocks, enzyme linked immunoassays including rapid tests are more reliable and quick. Serology may not prove not very useful in diagnosing HPAI infections but is of utmost importance in epidemiological surveillance and demonstrating freedom from infection [13]. There is no specific treatment for influenza virus infections in animals. Poultry flocks infected with HPAI viruses are depopulated (this is generally mandatory in HPAI-free countries). The disposition of infected LPAI flocks may vary with the virus and the country. In humans, treatment for may vary, depending on the severity of the case, and can include various drugs, including antibiotics to treat or prevent secondary bacterial pneumonia, and antivirals. Antiviral drugs are most effective if they are started within the first 48 hours after the onset of clinical signs.

Measures to prevent and control cases of zoonotic avian influenza infection include controlling the source of the virus (e.g., closing infected poultry markets); avoiding contact with sick birds, birds known to be infected, and their environments; employing good sanitation and hygiene (e.g., hand washing); and using personal protective equipment (PPE) like respiratory and eye protection such as respirators and goggles, as well as protective clothing including gloves, wherever appropriate. The hands should be washed with soap and water before eating, drinking, smoking, or rubbing the eyes [14]. Since, these viruses have been found in eggs and meat from several avian species, therefore, careful food handling practices are very important when working with poultry or wild game bird products in endemic areas. All poultry products including eggs and meat should be completely cooked before eating [15]. Constant monitoring of avian influenza infections in captive as well as free-living wild birds is part of control programme for avian influenza in India.

West Nile Virus (WNV)

West Nile virus (WNV) is an emerging zoonotic arthropod borne flavivirus maintained in mosquito-bird transmission cycle. West Nile virus is
related to the Japanese and St. Louis encephalitis viruses. It was first isolated from the blood of an ill woman in 1937 in Uganda region of West Nile Delta [16]. In subsequent years, the virus significantly extended its severity, frequency, host range as well as geographical distribution [17,18]. The emergence of WNV in America and its impact on the health of humans, horses and birds, have caused global concern about this virus. West Nile virus causes a potentially fatal encephalomyelitis (inflammation of the brain and spinal cord) in a variety of mammals such as birds, horses, and humans [19,20]. Birds are natural reservoir hosts and may be clinically or asymptptomatically infected. In India, this virus is known to be active in mosquitoes, birds and pigs and there are some reports of its association with human encephalitis cases [21].

Various species of Culex mosquitoes acts as vectors for WNV. The common species of Culex which have shown competence for both infection and transmission of West Nile virus are Cx. tarsalis and species belonging to Culex pipiens complex. Apart from mosquitoes, the role of other arthropods is also considered in the maintenance of this virus during inter-enzootic periods. The possible role of ardeid birds as vertebrate amplifying host of WNV in the Indian subcontinent was also described by [22]. Though very few clinically overt cases of human encephalitis due to WNV are observed, Japanese encephalitis virus (JEV) is found to dominate in southern India. Infection in humans and horses is most often the result of bites from infected mosquitoes that have fed on infected birds. They are considered as accidental and dead-end hosts. The clinical signs of disease typically present within three to 14 days of exposure. The virus may also be transmitted through contact with other infected birds, their blood, or other tissues. A very small proportion of human to human infections have occurred through organ transplant, blood transfusions and breast milk. Classic clinical signs of horses infected with the WNV include mild to severe ataxia. Signs can range from slight in coordination to recumbency. Some horses exhibit weakness, muscle fasciculation and cranial nerve deficits. Fever is not a consistently recognized feature of the disease in horses [23,24].

West Nile virus can cause a fatal neurological disease in humans. However, approximately 80% of people who are infected will not show any symptoms. In rest 20%, it appears as a mild, non-fatal, febrile, self-limiting illness rarely leading to encephalitis. However some rare non-neurological complication like myocarditis, and pancreatitis have also been reported [25,26]. No vaccine or specific antiviral treatments for West Nile virus infection are available. Over-the-counter pain relievers can be used to reduce fever and relieve some symptoms. In severe cases, patients often need to be hospitalized to receive supportive treatment, such as intravenous fluids, pain medication, and nursing care.

For diagnosis, enzyme linked immunosorbant assay, haemagglutination inhibition test, neutralization test and reverse transcriptase – PCR have been used [24,27]. Specific methods are not available for the treatment of WNV infection. However, in patients with encephalitis supportive therapy is recommended. Though a few candidate vaccines are under laboratory trial, no vaccine has been available commercially for the control of WNV infection in human and animals. The effective prevention and control of human WNV infections depends on the development of comprehensive, integrated mosquito surveillance and control programmes in endemic areas. The integrated mosquito control strategies includes the use of personal protective measures like protective clothing, bed nets, both chemical and plant based mosquito repellants, insecticides, insecticide impregnated curtains, and biological control methods by larvivorous fish, introducing natural parasites and predators and bacterial agents [28,29].

**Newcastle Disease (NCD)**

After Avian influenza, the other very serious disease that has tremendous impact on poultry health with profound economic consequences in global poultry industry is Newcastle disease. The disease causative agent is a highly variable single stranded RNA virus, avian paramyxovirus serotype 1 virus which, with viruses of the other eight serotypes (avian paramyxovirus 1-9) has been placed in the family Paramyxoviridae. Within the one serotype, pathotypes of Newcastle disease based on clinical signs and lesions vary in virulence and severity from mild subclinical infections (leptogenous) to very virulent (velogenic) strains where mortality approaches 100% [30]. Virulent strains are endemic in poultry in most of Asia, Africa, and some countries of North and South America. It is thought that nearly every species of bird is susceptible and more than 200 susceptible species have been documented [31]. The transmission of virus occurs through respiratory aerosols, exposure to fecal and other excretions from infected birds, through newly introduced birds, selling and giving away sick birds and contacts with contaminated feed, water, equipment and clothing [32]. In poultry, it may take the form of haemorrhagic enteritis and paralysis, or an acute respiratory disease.

Although, NCD too has a zoonotic potential, but is much less severe in humans than avian influenza. Newcastle disease virus was first documented as a human zoonosis many decades ago. While mild, self-limiting infections in poultry workers and researchers are occasionally documented, fortunately, the virus does not represent a significant or severe threat to human health and human-to-human spread has never been reported. But, the potential for human to bird transmission exists [33]. Clinical infections in humans usually result from accidental exposure to vaccines or fluids from infected birds or carcasses. Commonly, conjunctivitis develops within 24 hours and is sometimes accompanied by larcimation, palpebral edema, pain. Rarely, fever, chills, depressed appetite and photophobia has also been reported in humans [34].

Diagnosis relies primarily on history, clinical signs and lesions. All these together may establish a strong index of suspicion but the laboratory con-
Bacterial Agents Transmissible from Poultry to Humans

Many bacterial agents affect poultry of all ages and their successful control entails isolating and identifying disease-producing species, if present, and preventing multiplication and spread of the organism within the animal’s body or to other animals. Some common bacterial agents/diseases found in poultry, which can pose significant risks to human health are:

Campylobacteriosis

Campylobacteriosis is caused by member of genus *Campylobacter* (Greek Campylo means curverd; little rods) consisting of 25 species, 8 subspecies and 2 provisional species of which *Campylobacter jejuni*, *C. fetus* (sub-species *veneralis*) and *C. coli* are of veterinary and human importance [36]. These are thin, sea-gull winged shaped, Gram-negative, motile, non-spore forming, microaerophilic bacterium. Globally, *C. jejuni* subsp. *jejuni* is responsible for approx. 95% of all Campylobacter enteritis in humans followed by *C. coli* (5%). Poultry has been recognized as the primary reservoir of *Campylobacter* spp. It harbors three different species of this bacterium: *Campylobacter jejuni*, *C. coli*, and *C. lari* but thermophilic *C. jejuni* and to some extent *C. coli* are the leading cause of gastroenteritis in humans worldwide [37]. It is believed that 80% of broiler flocks are infected with *C. jejuni*. Once associated with vibrionic hepatitis in laying hens, today these bacteria are not important in avian microbiology and pathology; however, they are a source of serious food poisoning in humans [38].

The campylobacters are generally regarded as one of the most common bacterial cause of gastroenteritis worldwide. Its infection has been among the most commonly reported zoonoses in the European countries (1%) followed by Salmonellosis and Yersiniosis [39]. In US from 1997 to 2008, 262 outbreaks with 9135 illnesses, 159 hospitalizations and only 3 deaths were recorded. In India, *Campylobacter* infections are sporadic in nature but some outbreaks have also been reported at times e.g. in U.P., Haryana etc. [37]. Campylobacteriosis is estimated to affect over 2.4 million persons annually, or 0.8% of the population [40]. In both developed and developing countries, they cause more cases of confirmed foodborne bacterial diarrhea than *Salmonella* bacteria [41]. Campylobacteriosis occurs much more frequently (roughly twice) in the summers than in the winters [42]. Infections in humans occur mainly as a result of consumption of uncooked or partially cooked poultry meat which has not been subjected to proper heat treatment and due to handling of contaminated poultry. The non-chlorinated drinking water, unpasteurized milk, contaminated beef and pork products are also responsible for infection in humans. The disease in humans is generally self-limiting (after 3-6 days symptoms usually disappear) but may sometimes leave behind debilitating sequelae with complications like reactive arthritis, Guillain–Barre’ syndrome (GBS), nephritis, myocarditis, pancreatitis or septic abortion. Guillain-Barré Syndrome is a neuropathological disorder characterized by acute ascending bilateral paralysis and it is thought to occur in roughly 1 out of 1,000 reported *Campylobacter* spp. infections [43]. In a study conducted in New Zealand, it was found that there was Decline in Guillain-Barré Syndrome by 13% after decline in Campylobacteriosis cases by 52% [44]. After the eradication of polio in most parts of the world, GBS has become the most common cause of acute flaccid ascending paralysis [45].

The campylobacter infection is usually self-limiting and supportive therapy includes fluids and electrolytes. Nowadays, erythromycin is the drug of choice and can be used in children, and tetracycline in adults. In some human clinical trials, azithromycin has also been found effective [46]. In severe cases, ciprofloxacin was the drug of choice but there are reports of ciprofloxacin resistant *Campylobacter* spp., which may have developed due to its unrestricted use and the use of enrofloxacin in poultry [47]. The ubiquity of the bacteria in the environment makes eradication and prevention of infection at the farm level nearly impossible. However, pasteurization of milk, chlorination of drinking water and proper cooking of food especially poultry meat prove beneficial in preventing disease in humans. Infected health care workers should not provide direct patient care and make sure that persons with diarrhea, especially children, wash their hands carefully and frequently with soap to reduce the risk of spreading the infection.

Colibacillosis

This is the common name for a large variety of food-or water-borne diseases caused by the bacterium *Escherichia coli*, which is a part of physiological flora of gastrointestinal tract of all warm blooded animals. Under certain unfavourable conditions such as poor management, poor sanitation, immune deficiency, stress, and viral infection etc., a sudden proliferation of the bacteria takes place which lead to emergence of opportunistic infections [48]. There are a number of different strains, many species-specific. Not all strains are pathogenic. In poultry, *E. coli* infections are often confounding. These bacteria may be associated with septicemia, chronic
Salmonella

Salmonellas are highly infectious and can be transmitted by mice, rats, other domestic animals and are capable of causing diarrhoea in humans. Through contaminated feed, birds and/or through contaminated feed. Symptomless adult birds continuously shed bacteria, and the second category comprises serovars non-specific to birds. Serovars which are pathogenic for poultry are divided into two categories: the first is serovars specific for poultry (Salmonella pullorum and Salmonella gallinarum), which are usually not pathogenic for humans and other animals but in birds cause high morbidity, carriage, and shedding; and the second category comprises serovars non-specific to birds but pathogenic for humans. The most important serovar in this category is Salmonella enteritidis. Although, Salmonella infections may affect all domestic poultry, but birds usually appear healthy and continue to shed Salmonella serotypes that lead to human illness; additionally, shedding can be intermittent [53]. Salmonella may also contaminate hatching eggs, which results in diarrhoea, depression and death in young chicks. These bacteria are highly infectious and can be transmitted by mice, rats, other birds and/or through contaminated feed. Symptomless adult birds constitute a human health risk if meat and egg hygiene are not adequate. Prevention of Salmonella infection in poultry birds is often difficult, which could be attributed to its long and often asymptomatic carriage. It is believed that carrier state may last for several days or weeks and even a lifetime for some of the serovars [54].

Food, mainly poultry meat and eggs, plays the most important role in the epidemiology of human salmonellosis. After the incubation period of 8 to 48 h, the infection proceeds mainly in the form of gastroenterocolitis, accompanied by signs such as increased body temperature, chills, and myalgia. Depending on the virulence of the bacteria, they can also produce enterotoxins. Despite awareness of the risk of salmonellosis from handling raw poultry, people are generally not aware that Salmonella can also spread between live poultry and humans. In recent years, in both household and public settings, there are numerous reports of human Salmonella infection which has been linked to contact with live poultry [55,56,57,58]. Human salmonellosis from contact with live poultry is a challenging, yet largely preventable, public health problem. Prevention requires an integrated One Health approach including public and animal health officials collaborating with the other stakeholders.

Avian Tuberculosis

Mycobacterium avium infections are found worldwide in a variety of birds ranging from domesticated poultry and game birds to wild and zoological species. Avian tuberculosis is an infectious disease caused by the bacteria Mycobacterium avium subsp. avium serovars 1, 2, and 3. Due to modern management practice, it is rarely seen today in commercial flocks but is quite often reported in backyard poultry. In poultry, M. avium forms tubercular nodules in the small intestine which later spread to other organs, particularly spleen liver, and bone marrow. The resulting chronic debilitating disease leads to emaciation and eventual death of affected birds. The agents get transmitted via fecal-oral route to humans. In humans, M. avium infections can cause local wound infections with swelling of regional lymph nodes [31]. The severity of infection is very high in immune-compromised people such as HIV/AIDS patients [59]. Although, most Mycobacterium infections can be treated with antimicrobials but M. avium is highly resistant to some of commonly used antimicrobial agents. Therefore, complete depopulation of affected poultry flocks is generally recommended to prevent its further spread to other birds as well as to susceptible humans.

Protozoan Agents Transmissible from Poultry to Humans

Toxoplasmosis

Toxoplasmosis, as a zoonotic disease of poultry has not yet established its impact but the recent reports of its seroprevalence in avian species has drawn the attention of many researchers. Toxoplasmosis is a zoonotic disease caused by infection with the protozoan parasite Toxoplasma gondii. It
is an obligate intracellular parasite that infects humans and a broad range of vertebrate hosts. Felids are the definitive host and excrete the infective oocysts in their feces. The transmission of *T. gondii* occurs by ingestion of oocysts shed from feline feces, by ingestion of *T. gondii* cysts from chronically infected tissues, or by vertical transmission [60]. *T. gondii* infections are widely prevalent in human beings and animals worldwide. Foodborne transmission is one of the major sources of *T. gondii* infection. Humans can become infected by ingesting tissue cysts from undercooked meat, consuming food contaminated with oocysts, or by accidentally ingesting oocysts from the environment [61]. Additionally, ingestion of infected chicken meat can be a source of infection for *T. gondii* infection in humans and other animals. Between 15 and 85% of the world adult human population is chronically infected with *T. gondii* depending on the geographical location [62]. One third of the world population has antibody against *T. gondii* which is an indicator of parasite distribution all around the world. Recent findings indicated that latent toxoplasmosis is not only unsafe for human, but also may play various roles in the etiology of different mental disorders [63]. Estimates suggest that 23% of adolescents and adults are infected with *T. gondii*, and accounts for 24% of deaths due to foodborne illness in the USA [64]. Toxoplasmosis in human during pregnancy may lead to death of fetus or cause serious defects in fetus [65]. Infection in immunocompromised population may also cause serious problems and sometimes even death [66].

Rarely, toxoplasmosis can cause clinical disease in chickens [67]. Chickens, turkeys, ducks, sparrows and other birds can be infected with *T. gondii* intermediate host and acquire infection by digesting infective oocysts shed from the feces of definitive host i.e. felines. Domestic breeding birds and poultries are less infected than free-ranging or industrial breeding since they are not allowed to contact with infective oocysts or feline. Infected birds are considered one of the best indicators for soil contamination with *T. gondii* oocysts because they feed on the ground [68]. The new trend in the production of free-range organically raised meat could increase the risk of *T. gondii* contamination of meat, although there is no document about infection transmission by eggs [69,70]. The studies have indicated that prevalence rates in the free-ranging chicken varied from as low as 6.2% in Mexico, 16.9% in Ohio state of the USA, 17.9% in India, 40-65.15% in Brazil, 40.4-47.2% in Egypt, and as high as 65.5% in Argentina. In these studies, about 70% isolates from chicken were genotype I and 27% isolates from chicken were genotype III. [60, 65, 71, 72]. Several serological tests, including the Sabin-Feldman Dye Test (DT), Complement Fixation Test (CFT), complement inhibition test, Indirect Haemagglutination Test (IHAT), Indirect Fluorescent Antibody Test (IFAT), Latex Agglutination Test (LAT), Enzyme-Linked Immunosorbent Assay (ELISA) and the Modified Agglutination Test (MAT) are employed to detect antibodies to *T. gondii* in sera of chickens [73,74,75]. The presence of cysts in the tissues, bioassays and DNA based tests like polymerase chain reaction are the diagnostic tests employed for the detection of *T. gondii* in chicken [76,77,78]. *T. gondii* infection can be prevented by measures to reduce *T. gondii* in meat; adequate cooking, freezing, or physical/chemical treatment of meat. The organisms in meat can be killed by exposure to extreme cold or heat. Tissue cysts in meat are killed by heating the meat throughout to 67°C and by cooling to −13°C [79]. The cross contamination from raw meat should be prevented. The measures that prevent *T. gondii* infection of cats, and therefore, decrease spreading of oocysts into the environment (e.g. keeping cats indoors and not feeding raw meat to cats) should be followed. Due to the risk to the fetus, pregnant women should avoid contact with cats, soil, and raw meat. Pet cats should be fed only dry, canned, or cooked food. The cat litter box should be emptied every day [80].

**Fungal Agents Transmissible from Poultry to Humans**

**Aspergillosis**

All domestic poultry, wild birds, other animals and humans can be infected by fungi. The most common fungal disease in birds is aspergillosis. It is an important occupational problem in poultry industry leading to huge economic losses in terms of heavy mortality and morbidity especially in chicks [81]. A wide host range for of this filamentous ubiquitous and opportunistic pathogen has been reported throughout the world. *Aspergillus fumigatus* is one of the most pathogenic and prevalent species known followed by *Aspergillus flavus* and *Aspergillus niger* [82]. Inhalation of spores present in soil, water and feed is one of the most important modes of transmission to affected animals and human beings. This infection usually contracts the people which are immune-compromised or using extensive medications like corticosteroids and antibiotics [83,84]. The zoonotic implication of Aspergillosis is seen more pronounced in workers serving poultry farm, handling the infected birds and their contaminated litter or feed [85]. This fungus and the metabolites produced are quite efficient to produce respiratory form of diseases and can spread to kidneys, liver, intestine, brain and bones through hematogenous route. The diagnosis of this disease is often difficult due to non-specific symptoms depicted by the infected ones and can be best demonstrated by isolation, x-rays and serology [86]. In human beings, granulomatous pulmonary lesions produced by this fungus predispose them to Mycobacterial infections, cerebral lesions, hepatic carcinoma etc. Pulmonary form is most important and common form in human beings as well as animals including poultry and can lead to chronic productive cough, hemoptysis, labored and soundless breathing due to plugs of fungal hyphae or allergic reaction in bronchi [82,87].

The hazardous inter species spread of this fungus can be prevented by proper inspection of litter, feed and water in poultry industry. Use of chlorinated water, cleaned utensils, and timely use of better antifungal agents further can be better alternate to constrict the hazardous outcomes of this fungus.
**Cryptococcosis**

An opportunistic and zoonotic yeast *Cryptococcus neoformans* is documented as a long back to be transmitted through inhalation of droppings/guano of variety of bird species like chickens, pigeons, parrots, canaries etc. [88]. Decaying material of trees (Eucalyptus) along with droppings is also supposed to be the major carrier of *C. gattii*. A variety of animal species including dogs, horses, donkeys, felids, cattle, sheep, goats, pigs and wild animals are found to be affected by this fungus. But in birds the clinical outcome of the infection is rarely seen [89]. In spite of species variation *Cryptococcus neoformans* and *Cryptococcus gattii* are major fungal forms associated with casualties. The immune-compromised people with defective cell mediated immunity are the major victims affected with this infection i.e. AIDS patients, recipients of organ transplants etc. Although the infection has been reported to affect immune-competent individuals as well as reported by [90], where a patient exposed to a pet bird pica (magpie) acquired the infection. This organism undergoes colonization in the nasal cavity of affected beings and can lead to the formation of fungal granulomas in different organs. Occasionally the transmission through abraded skin, nosocomial route, direct contact, organ transplant, mammary gland has also been reported in animals. The infection usually led to the development of nervous signs in individuals as the agent causes encephalomyelitis in human beings [90]. The symptomatic diagnosis of infection is difficult, as non-specific clinical manifestations like dyspnoea, anorexia, diarrhoea, paralysis, blindness are evident in the patient. But necropsy examination often reveals presence of myxomatous deposits in brain, respiratory tract and abdominal cavity [90-92]. Prognosis of this infection is poor in affected individuals, so precautionary measures are suitable assets. Prevention can be implemented by adequate ventilation in farms, proper disposal or incarnation of droppings of birds, tree trunks, nests and perches [93].

**Histoplasmosis**

Histoplasmosis is an infectious, granulomatous and non-contagious disease of man, dog, horse, cattle, sheep and wild animals. Although dogs are most susceptible to this infection, *Histoplasma capsulatum* is an important pathogenic opportunistic fungal species which is transmitted to human beings through soil contaminated with the droppings of birds around their nests or caves. Inhalation of spores from infected soil serves as a most potent mode of transmission to human beings and other animals [94]. Although this infection is not of much economic significance to poultry industry but its zoonotic implication throws lime light on its transmission by poultry. This fungus usually proliferate within macrophages and leads to extensive proliferation of reticuloendothelial cells [95]. Classical granuloma in lungs composed of giant cells is characteristic feature of this infection. In histoplasmosis acute to chronic pneumonia, cutaneous ulcers and lymphadenopathy in human beings are often evident. Lymphadenopathy is again a feature associated with extensive reticuloendothelial cell proliferation. Like *Cryptococcus* the incidence of this infection is also more reported in old age groups or persons affected with immunosuppressive diseases like AIDS [96]. Acute and chronic pulmonary histoplasmosis, progressive disseminated histoplasmosis and mediastinal lymphadenitis are various forms of this infection [97]. The diagnosis of this organism is based upon Periodic Acid-Schiff (PAS), Gomori Methenamine-Silver Nitrate Stain (GMS) and Bauer staining methods. Other associated techniques involve complement fixation test, agar plate precipitation test, cultural isolation and skin test with histoplasmin [98]. Preventive measures include avoiding exposure to dropping of infected birds, use of protective coats while dealing with birds in poultry industries or farms. Amphotericin B is considered as a best treatment of choice for the patients infected with this deadly fungal infection and Fluconazole is less effective than Amphotericin B [99,100].

**Chlamydial Agents Transmissible from Poultry to Humans**

**Chlamydiosis**

Chlamydiosis (ornitosis or psittacosis or parrot fever) is a complex, occupational, emerging zoonotic infection caused by *Chlamydia psittaci* (non-motile, intracellular bacteria) which can affect birds (psittacine as well as non-psittacine through natural infection), mammalian species as well as human beings [101]. Pet birds are supposed to be an important reservoirs for *Chlamydia* induced infections to human beings and reported from India first time by [101] and globally first report was recorded in year 1893 [102]. The infection is usually sub-clinical in birds (wild as well as domestic) but spread the infection amongst workers in poultry processing plants, veterinarians and bird dealers [103,104]. Inhalation of organism shed by infected birds, handing of dead infected birds, nasal discharge, bite, person to person contact are the pivot modes of transmission of this infection to human beings. The zoonotic implication of this disease can often be assessed by many global outbreaks indicating flu like clinical manifestations in human beings and the magnitude of pathogenic potential has been found to be more pronounced in pregnant ladies [105,106]. In human Chlamydiosis leads to fever, respiratory symptoms (pharyngitis, dyspnoea, pneumonia, bradycardia), photophobia, diarrhoea, splenomegaly and other complications like conjunctivitis, arthritis, endocarditis, encephalitis and fetal death [107,108]. In animals, respiratory distress, conjunctivitis, fibrinous pericarditis, pleurisy, enteritis, polyarthritis are important recorded manifestations [101].

Diagnosis of this infection is based upon the cultural isolation, serology and molecular tools and isolation needs biosafety level 3. Detection of intra-cytoplasmic inclusions in tissues or exudates by Gimenez or Giemsa stains, serological tests like ELISA, CFT, Microimmunofluorescence (MIF) and DNA probe can be helpful [107]. But the samples for error free diagnosis must be collected before the start of antibiotic treatment. Tetra-
cyclines are the drug of choice for the treatment of affected individuals but patient must take the treatment up to 21 days to reduce the risk of further relapse or spread [107].

Non-availability of any potent vaccine and lack of awareness makes it difficult to eliminate this infection successfully. So the deadly outcomes of this infection can be prevented by notifying such disease like other countries (Hong Kong) [107]. Protective clothing to workers in poultry farm, poultry processing plants and pet bird handlers; proper disposal and collection of autopsy samples from dead and infected birds; distinction of area where the aborted animals or affected birds are kept; adoption and surveillance regarding hygiene to prevent the spread of infection are important preventive tools which can prevent the spread of infection.

Conclusion

With the escalating demand of organic and nutritious food, developments in food science and technology, liberalization of food trade and growing awareness towards public health, it becomes essential to produce and supply quality products. Therefore, to ensure the healthy status of poultry industry, it is important that birds should be kept in good health and all the measures to prevent the introduction and spread of harmful biological substances in the poultry population should be carefully designed. Hence, biosecurity measures act as a cornerstone for reaping the maximal benefits out of this profitable enterprise. Various infectious agents are continuously diagnosed in poultry species. Although, frequency of disease transmission from birds to humans is low, but the diseases crossing the species barrier always pose a significant public health risk to especially occupationaly exposed people like veterinarians and health care providers and YOPI (Young, Old and Ill people) along with their economic consequences. Control/prevention of zoonotic diseases and protection of public health are challenging tasks as the world population is increasing proportionately. The prevention of these infections depends on improved diagnosis and highly effective therapeutics/prophylactics. The collective effort of professionals from medical and veterinary and others is necessary to combat these zoonotic infections. Therefore, an integrated One Health approach involving the poultry industry, feed manufacturers, healthcare providers, backyard flock rears and veterinarians, and is needed to help prevent spread of avian zoonotic diseases.

Conflict of Interest

The authors declare no conflict of interest.

References:


111. WHO 2017.

112. OIE, WAHIS interface.


