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Review Article

A Review on Bacterial Infectious Diseases of Dogs

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Abstract

In recent years, the tendency of raising dogs as companion animals has increased in urban and semi-urban settings. Amongst other pathogens viz virus, protozoa, dogs are highly susceptible to diseases of bacterial origin. Bacterial infections in dog causes wide range of illness, ranging from self-limited skin conditions to life-threatening systemic diseases. Some diseases such as brucellosis, leptospirosis, tuberculosis, salmonellosis, and bordetellosis will have a significant influence on the economic status and livelihood of pet owner. These bacterial infections, albeit lethal, can be avoided if intervened earlier, and their impact on humans can be reduced to a greater extent. Here, we reviewed common bacterial diseases of dog and discussed disease etiology, clinical signs, diagnosis, treatment and zoonotic potential. Raising awareness and continuing to educate veterinarians and pet owners about companion animal diseases would not only limit transmission risk but also improve animal as well human health.

Keywords: Bacterial Diseases; Companion Animal; Dogs; One Health; Zoonosis

Introduction

Dogs (Canis familiaris) are believed to be the earliest domesticated animal on the globe, having evolved from wolves roughly 23 millennia ago [1]. Dogs were originally employed mostly for hunting in ancient times. Because of their intellect, cognitive behaviour, and ability to communicate with people, they have become one of the most sought companion animals. Dogs are one of the most popular pets for guarding, companionship, pet shows, and emotional support.

Bacteria are ubiquitous in nature. While majority of bacterial pathogens exist as commensal and protect the host immune system from other pathogens, a few may cause disease. Dogs in general are exposed to different pathogen from diverse sources like environment, fomites, humans and other animals. Bacterial infection can be exacerbated by a variety of factors, including poor diet, ageing, allergies, lack of exercise, stress, and other disorders. Host immune system plays a vital role in protecting the animal against pathogen. Predominantly, host immune system obviate the bacterial pathogen without causing significant damage to host. However, in young and immune-compromised dogs immune mechanism may not effectively avert the disease.

Dogs are susceptible to various bacterial diseases like leptospirosis, staphylococcus, ehrlichiosis, brucellosis that could cause

considerable mortality when not diagnosed or treated early. The emergence of antimicrobial resistance against bacteria has been a major worry in veterinary medicine in recent years, with significant implications for canine health. Some of these diseases may pose a significant challenge to veterinarians and public health workers as they are zoonotic [2,3].

These necessitate the importance of knowing about the common bacterial infections in dogs, which provides knowledge and awareness to control and prevent the diseases and also to mitigate zoonotic transmission to humans. Therefore, this review is mainly focused on the transmission, signs and symptoms, diagnosis, prevalence, treatment, control measures and zoonotic concern of important bacterial diseases.

Brucellosis

Brucella canis causing canine brucellosis is an emerging zoonotic disease. *B. abortus* and *B. suis* are also implicated in canine brucellosis. *B. canis* infection is the most common cause of reproductive failure in dogs and is endemic in many countries [4]. The infection in dogs is mainly due to ingestion, inhalation, or contact with aborted fetal contents. During the first eight weeks after infection, the infected dogs shed the organism through venereal transmission. Sporadic shedding of organism can be seen in dogs for years. Post-abortion fetal contents from the infected dogs contain a high amount of bacteria thereby remain as a source of infection to other dogs and humans. The disease in dogs is presented with following signs including, intraocular inflammation, generalized lymphadenopathy, late abortion (45-59 days), discospondylitis, stillbirth and failure to conceive in female dogs. However, epididymitis, prostatitis, orchitis, and infertility are noticed in male dogs. The transmission of the disease to humans is possible. The most commonly employed tests for diagnosis include rapid slide agglutination tests, β-mercaptoethanol test, indirect ELISA and agar gel immunodiffusion test. Only based on serological tests animals cannot be assumed free of brucellosis as serological tests suffer from certain limitations like lack of sensitivity and specificity and in chronic cases, which are intermittently bacteremic goes undetected. Isolation of organisms from blood and urine remains the gold standard. However, the requirement of BSL-3 makes it impracticable under field conditions. Vaginal swabs or semen are suitable clinical specimens for nucleic acid tests like PCR [5].

Infection with *B. canis* has been treated with a combination of tetracyclines and aminoglycosides [6]. Presently, the vaccine is not available for the disease. For prevention and control of disease transmission, the large roaming dog population should be removed, educating owners about the zoonotic potential of the disease, antimicrobial therapy, proper and frequent testing, or euthanasia in cases where the control measures cannot be implemented and proper hygiene [5].

Leptospirosis

Leptospirosis is a systemic disease caused by a gram-negative spirochaete, *Leptospira*. Earlier, two species were recognized namely *Leptospira interrogans* (pathogenic) and *Leptospira biflexa* (saprophyte), but now many pathogenic species are recognized. At present, there are 30 serogroups and more than 300 serovars are present [7]. The most common serogroup in dogs is Icterohaemorrhagiae and Canicola, recently other serogroups like Grippotyphosa, Pomona, Australis are reported in dogs. Transmission occurs via direct contact with urine or contact with contaminated soil, mud or water. Venereal and placental transmission, penetration through broken skin or intact mucosae also occurs sometimes. Rats and mice act as reservoirs of icterrohaemorrhagiae, while dogs are reservoirs of canicola serovar. The clinical signs vary from per-acute to chronic depending upon the virulence, immunity of the host, age of the animal, and environmental factors [8]. Sudden death is possible in peracute situations (less than 24 hours). Pyrexia, vomiting, diarrhoea, dehydration, and jaundice contribute to acute renal failure in acute cases (1 to 2 days). Fever, vomiting, diarrhoea, polyuria, polydipsia, pale mucous membrane, petechiae, abortion, and mortality might occur in subacute instances (2 to 7 days). Polyuria, polydipsia, jaundice, emaciation, anterior uveitis, abortion, and mortality are symptoms of the chronic type. *Leptospira* organisms are potential zoonotic pathogens [7].

Diagnosis is based on clinical signs, blood profile, and serum biochemistry profile, bacterial culture method (usually in a semi-solid medium like EMJH with tween 80, serum and incubated at 29°C for >12 weeks), silver staining, dark-field microscopy with a mid-stream urine sample, immunofluorescence, immunoperoxidase test and PCR based on 16S rRNA, *lipL21, lipL32, lipL41* can be done [8]. Antibody detection methods such as the microscopic agglutination test (gold standard test) with 1:100 are taken as the positive titer. The four-fold increase in the paired acute and convalescent serum sample indicates the presence of leptospira recent infection [7].

Acute and subacute cases are treated with amoxicillin at 20mg/kg body weight I/V every 6 hours for two weeks or doxycycline at 5mg/kg body weight bis in die (BID) orally every 12 hours for two weeks with supportive fluid and plasma therapy can be given. In chronic cases, doxycycline along with antihypertensive drugs, vitamin supplements are given [9]. Vaccines against leptospirosis are serovar specific and do not provide cross-immunity. The bivalent vaccine provides immunity against the canicola and icterohaemorrhagiae serovars, whereas the quadrivalent vaccine provide protection against canicola, icterohaemorrhagiae, grippotyphosa, and pomona serovars [10].

Tuberculosis

Mycobacterium spp. are non-motile, aerobic, non-spore forming, acid-fast bacteria. Tuberculosis is caused by the *M. tuberculosis* complex, of which *M. tuberculosis* in many cases and less frequently by *M. bovis*, *M. microti*, *M. africanum*, and *M. canetti* [11]. Dogs can get infected with *M. bovis* and *M. tuberculosis*. *M. bovis* infections in dogs are more often produced by infected cattle or unpasteurized milk or by-products, whereas *M. tuberculosis* infections are primarily caused by human respiratory illnesses. The clinical indicators of TB in dogs are non-specific and vary depending on the organs affected and the degree of the illness, such as weakness, weight loss, fever, and coughing. Polymorphic lesions exist. Clinical symptoms of *M. tuberculosis*-induced pulmonary TB in dogs progress slowly. They include inappetence, weight loss, and fatigue, as well as a persistent, productive, or non-productive cough. Neurologic symptoms, weight loss, vomiting, and diarrhoea are rare side effects of dissemination to non-pulmonary locations such as the central nervous system (CNS), liver, or kidney [12].

Microscopy, culture, or nucleic acid amplification are used to confirm tuberculosis, which is usually done after an autopsy. In dogs and cats, intradermal skin testing is inconclusive and inaccurate. Treating a mycobacterial disease is lengthy and challenging. Treatment is not suggested due to the unknown risk of TB transmission from an infected dog to humans. The majority of animals diagnosed with TB are put to sleep. Rifampin, isoniazid, and clarithromycin were used to treat a dog with *M. tuberculosis* infection, but the dog suffered convulsions and had to be euthanized. The seizures were thought to be a side effect of the isoniazid treatment [13].

Salmonellosis

Salmonella spp. is still a major food-borne zoonotic pathogen in all parts of the world, with *Salmonella* Typhimurium being one of the most prevalent serovars accountable for illness in both animals and humans. *Salmonellae* are facultative aerobic, gram-negative, flagellated bacteria that are non-sporulated. *Salmonella* spp. may cause a number of symptoms in people and animals, including gastroenteritis, abortions, pneumonia, and deadly septicemia. The illness in dogs is usually asymptomatic. Infected dogs may continue to be carriers and faecal shedders, functioning as sources of salmonella infection for people and other animals, even if the majority of cases are latent and non-clinical [14]. Severe infection is often seen in young or debilitated dogs. Signs of clinical salmonellosis in dogs include high fever, anorexia, diarrhea, bloody stools, vomiting, weight loss, cough, abdominal pain are most common. The main sources of infection for dogs are ingestion of contaminated raw food diets (raw meat) and contaminated environmental exposure. The people handling Salmonella-contaminated raw animal food have a more likely chance of getting infected [15].

For diagnosis, isolation of the organisms from affected tissue, blood, cerebral-spinal fluid or transtracheal washings is required. Selective indicator media (brilliant green agar, xylose lysine deoxycholate agar or Salmonella-Shigella media) or enrichment broth (selenite F broth, tetrathionate broth, Gram-negative broth) can be used to isolate organisms. Molecular techniques PCR, RT-PCR are used to detect *Salmonella* in dog feces or clinical samples. The treatment of healthy carriers is not recommended since it may raise the risk of antimicrobial resistance and antibiotic-associated diarrhoea. Antimicrobials are not usually used for simple gastroenteritis, although they may be necessary for animals with severe illness, including young and old animals, and immunocompromised animals [16].

Staphylococcal infection

Staphylococcus is a spherical, gram-positive bacteria, it is a commensal organism usually present on the upper respiratory tract, epithelial surface of the skin and anal region. *Staphylococcus pseudintermedius* is the major *Staphylococcal* species causing secondary bacterial infections in immuno-compromised dogs, followed by *S. aureus* and other species. Canine pyoderma is a common bacterial skin infection in dogs that may be superficial or deep pyoderma.

Canine pyoderma is predominantly caused by *Staphylococcus spp.* and also other minor species like *E. coli*, *Pseudomonas*, *Proteus* and *Streptococci.* A superficial pyoderma is a frequent form, characterized by erythema, papules, pustules, epidermal collarettes and alopecia. Deep pyoderma is less frequent and involves the dermis, also leading to hematogenous spread and bacteremia [17]. *S. pseudintermedius* is frequently isolated from canine pyoderma cases followed by *S. aureus* and *S. epidermidis* and *S. schleiferi* subsp. *coagulans.* One human case of pyoderma acquired from a pet dog has been reported. Otitis externa caused by *Staphylococcus* is also a sequel of secondary infection to hyperthyroidism, allergies, atopic dermatitis, foreign body. *S. pseudintermedius* spreads to neonates through dam's milk that has undergone cesarean section and causes neonatal septicemia resulting in mortality. Lesions are usually present on the omentum, footpad, and dermatitis called black spot disease [18].

Diagnosis can be made by direct microscopy with gram staining, culture identification (*S. aureus* produces yellow-pigmented colonies while *S. pseudintermedius* are colorless colonies), biochemical tests. Novobiocin and polymyxin B disc tests can be used to differentiate *S. aureus* and *S. pseudintermedius*. The other tests like PCR using mecA gene, nuc gene, MALDI-TOF can be done to identify methicillin resistant strains [19]. Treatment of canine pyoderma with random antibiotics should be avoided due to the rise of antibiotic resistance, therefore antibiotic sensitivity testing should be done for appropriate therapy. For mild cases, topical management alone is desirable with antiseptic shampoos containing chlorhexidine, benzyl peroxide. In case of treatment of otitis externa, antibiotics such as a combination of amoxicillin plus sulbactam at 5-7 mg/kg I/M along with ear cleanser such as salicylic acid is suggested and other antibiotics like gentamicin, ciprofloxacin, neomycin are also effective [20].

Kennel cough

Kennel Cough is a highly contagious disease of canines caused by *Bordetella bronchiseptica. B. bronchiseptica* is a gram-negative organism that mainly affects the upper respiratory tract, hence the disease is also known as Infectious tracheobronchitis. Canine distemper virus, canine parainfluenza, Canine adenovirus type 2, and canine herpesvirus can cause co-infections. Infection with *B. bronchiseptica* is uncommon in humans, however it has been observed in both healthy and immunocompromised people. The incubation period varies between 1-8 days with clinical signs for 1-2 weeks. The infected dogs may shed the organism for 2-3 months. In adult dogs, this condition is typically self-limiting. In puppies and young adult dogs, a more serious form of the disease may be seen. Affected dogs usually have a recent history of exposure to other dogs, as well as sudden and acute onset of a harsh, paroxysmal "goose honk" cough. Other clinical signs commonly noticed include depression, fever, oculonasal discharge, and conjunctivitis. The most common sign is spasms of harsh, dry coughing, which may be followed by retching and gagging. The cough normally gets better after the first five days, although the illness lasts for 10 to 20 days [21]. Development of more severe signs, including fever, pus-containing nasal discharge, depression, loss of appetite, and a productive cough, especially in puppies, usually indicates the presence of an additional infection such as distemper or bronchopneumonia. Stress, particularly from adverse environmental conditions and improper nutrition, may contribute to relapse during recovery [22]. Tracheobronchitis is usually suspected whenever a dog demonstrates the distinctive harsh cough and has a history of exposure to other susceptible or affected dogs [23].

Diagnosing kennel cough might still be a bit difficult since it is a multi-etiological disease. Laboratory tests are usually normal. Bordetellosis in animals has been detected by isolation of organism and molecular methods (PCR, RT-PCR). Chest x-rays are important to determine the severity of the disease and to rule out other causes of coughing. At a temperature of 37 °C, *Bordetella* species grow well on blood agar, Bordet-Gengou agar, Smith-Baskerville culture medium, and MacConkey agar. *Bordetella* spp. are catalase, oxidase, and citrate positive and negative for indole, H2S and sugar fermentation. Several serological tests like indirect haemagglutination, tube agglutination and ELISA have been developed to diagnose the disease. The *B. bronchiseptica* isolate was susceptible to azithromycin, tetracycline polymixin-B, gentamicin, nalidixic, piperacillin + tazobactum, imipenam, ciprofloxacin and etrapenem, whereas resistant to amoxicillin + clavulanic acid, vancomycin, amoxicillin, ceftriaxone, lincomycin, nitrofurantoin, penicillin, cefotaxime and ceftazidime [24].

Kennel cough can be prevented by using live avirulent intranasal vaccinations containing *B. bronchiseptica* alone or in combination with canine adenovirus-2 and canine parainfluenza virus. *B. bronchiseptica* vaccinations, both intranasal and injectable, may

provide significant protection against *B. bronchiseptica* infection [25].

Escherichia coli infection

Escherichia coli is a gram-negative, rod-shaped facultative anaerobic bacteria causing extra-intestinal and gastrointestinal disease in dogs. *E. coli* remains to be the major cause of diarrhoea in canines. The predilection site for *E.coli* is the lower intestine and is generally beneficial, but it can cause disease in puppies in few cases. Pathogenic strains or clones of *E. coli* found in dogs are capable of causing severe morbidity and mortality in pets as well in humans. Symptoms of *E. coli* infection in dogs can vary. Most commonly seen symptoms include diarrhea, vomiting, lack of appetite, depression, dehydration and weakness or lethargy [26]. There are 7 pathotypes include diarrheagenic *E. coli*: enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC), enteroinvasive *E. coli* (EIEC), enterohemorrhagic *E. coli* (EHEC), shiga-toxin producing *E. coli* (STEC), adherent-invasive *E. coli* (AIEC) and enteroaggregative *E. coli* (EAEC). It has been reported that EPEC and ETEC are common causes of enteric disease in young pups. Despite current data indicating that *Enterococcus* spp. and *Pseudomonas* spp. are becoming increasingly prominent causes of Urinary tract infection (UTI) in dogs, *E. coli* remains the most common cause of UTI in dogs [27]. The UTI in dogs is characterized by dribbling of urine, painful micturition, vaginal discharge, lethargy, hematuria. UTI caused by extraintestinal pathogenic *E. coli* (ExPEC) is common in both humans and dogs and therefore ExPEC transmission between pets and their humans has also been documented [28]. *E. coli* is regularly isolated from the faeces of both healthy and diarrheic dogs on bacteriological media. MacConkey agar, a differential media, is frequently used. Gram's staining and biochemical characterization (catalase, methyl red, indole and nitrate-positive) are usually performed [27].

Dogs with profound diarrhea due to pathogenic *E.coli* should be given intravenous therapy. Prior to treatment susceptibility testing should be performed to choose antimicrobials that penetrate intracellularly, such as chloramphenicol, rifampin, fluoroquinolones and trimethoprim-sulfonamides [16]. There is no vaccine available for dogs till date.

Campylobacteriosis

Campylobacter spp. are gram-negative slender rods (0.2-0.8µm wide × 0.5-5µm long) with a polar flagellum that can be found single, in pairs, or in chains as long spirals. Some *Campylobacter* species are non-motile (*C. gracilis*), while some have multiple flagella (*C. showae*). Various species of *Campylobacter* cause mild to severe disease in dogs. The most common species includes *C. upsaliensis, C. jejuni, C. helveticus,* and *C. coli.* The majority of infection remains subclinical, however, some cases develop mild to moderate enteritis. The risk factor for infection includes young age, intensive housing (e.g. kennel or shelter), presence of concomitant or intestinal disease, contaminated pet food, and other environmental factors [29].

The disease transmission occurs mainly through the faecal-oral route. The source of infection involved undercooked or raw food and unpasteurized milk, water. Dogs may get infections directly from fresh faeces from infected animals. Indirect routes of transmission include fomites, vectors and contaminated environments. Clinical signs of disease are non-specific and depend on the severity of the infection. In case of enteritis, clinical signs include mild to watery diarrhea (sometimes bloody or mucoid with tenesmus), lethargy, dehydration, anorexia, and less commonly vomiting, fever and abdominal pain. Extra-intestinal infections may result in the development of cholangiohepatitis/cholecystitis and bacteraemia, and hepatic involvement can result in icterus and other clinical signs of liver disease [27]. Sometimes, infection with *C. jejuni* may associate with abortion. Campylobacter infection is considered to be a major triggering agent of immune-mediated peripheral nerve disorder called acute polyradiculoneuritis (APN) in dogs. Recovered animals may remain long-term carriers [29]. Campylobacter infection in dogs is considered to be a public health concern due to its zoonotic potential. Dogs and puppies are the major reservoirs for campylobacter. Contact with infected dogs is a risk factor for *C. jejuni* and *C. coli* infection in humans, with children and immunocompromised individuals, are at the highest risk [30]. *Campylobacter* spp. causes acute bacterial enteritis in people worldwide.

Faecal samples are considered the best for cultural isolation and identification of *Campylobacter* organisms. The modified charcoal cefoperazone deoxycholate agar (mCCDA) medium was the first selective agar created specifically for the recovery of *C. jejuni* and *C. coli* and is still employed in human and veterinary diagnostic labs. Another basal agar having cefoperazone, amphotericin and teicoplanin (CAT) has been used for detection of *C. upsaliensis, C. lari*, *C. jejuni, C. helveticus* and *C. coli* from faecal samples of dogs. Mo-

lecular techniques, including PCR and real time PCR are considered the gold standard for genus and species identification and allow a more rapid diagnosis of organisms [29]. ELISA has been developed for faecal sample testing as a rapid, simple and low-cost diagnostic method. Multilocus sequence typing (MLST) was used for Subtyping of *Campylobacter* spp. The disease is generally self-limiting in most cases with mild to moderate signs of enteritis requiring supportive therapy. Animals with severe clinical signs can be treated with erythromycin or azithromycin for 5-21 days [29].

The prognosis of campylobacteriosis in dogs is generally very good when treated with appropriate antibiotics and where no systemic complications are present. Due to increasing antimicrobial resistance in dogs as well as in human, antimicrobial treatment of campylobacteriosis should be reserved for dogs with more severe disease and those where shedding organisms into the environment would result in significant risk to humans and other animals [31].

Borreliosis/Lyme's disease

Borreliosis also called Lyme's disease caused by *Borrelia burgdorferi*, is a multisystemic disease found globally. The disease is a tick-borne infection affecting humans, dogs and other mammals. The disease is zoonotic in nature. The nymphs and adults of Ixodes species act as a vector for Lyme's disease. The other mode of disease transmission includes transplacental, blood, or urine. Mice are the reservoir host for the disease. In dogs, the disease is characterized by acute arthritis and arthralgia. Since dogs and humans live together in the same environment, it has been said that dogs can be employed as sentinel animals in assessing the risk in humans through serological studies. Dogs and Humans are the dead-end hosts. The incubation period of the disease in dogs is between 2-5 months [27]. The infected dogs may show increased temperature along with lameness. However, 95% of the infected dogs remain asymptomatic, whereas anorexia, transient fever, and arthritis are seen in puppies. Another characteristic clinical sign associated with Lyme's disease is Lyme nephropathy. Nephropathy due to Lyme's disease is characterized by renal failure (acute/chronic), vomiting, polyuria, wasting, anorexia, dehydration and polydipsia. The other abnormalities include vasculitis with edema or effusion, blindness or murmur in the heart due to hypertension, pulmonary thrombosis with difficulty in breathing and saddle thrombus with weakness in the hindlimbs. Neurological signs like nystagmus, seizures leading to collapse are also observed. The diagnosis for Lyme's disease is either identification of organism or serological tests. The identification of organisms can be done by isolation of organisms by culture, cytology and PCR. Serological tests like ELISA, indirect flouroscent antibody tests (IFAT) and western blot, SNAP4D x Plus (IDEXX), SNAP-3Dx, Lyme Quant C6 have been employed for the diagnosis of Lyme's disease. The comparison of these tests revealed that ELISA was more sensitive than IFAT in the serodiagnosis of Lyme's disease [32].

B. burgdorferi infection in dogs can be treated by antibiotics, doxycycline and minocycline, at a dosage of 10 mg/kg PO once a day or twice a day for 30 days. Dogs with Lyme's nephropathy may require an extended dose of doxycycline along with fluid therapy, low-dose aspirin, omega-3 fatty acids, and dietary therapy. Several commercial vaccines are available worldwide for the prevention of disease in dogs [32]. These vaccines include killed whole borreliae bacteria or specific recombinant or chimeric outer surface proteins (OspA and/or OspC), with or without adjuvant [33]. Lyme's vaccine has been generally recommended in endemic areas. The initial vaccination can be done at 9/12 weeks of puppies, while the 2nd dose can be administered 2-4 weeks later. Annual booster is recommended in spring before tick exposure since the duration of immunity against *B. burgdorferi* is short [34].

Pasteurellosis

Pasteurella species are non-motile, gram-negative coccobacilli that normally inhabit the oral and gastrointestinal tract of healthy, diseased, domestic and wild animals. 70-90% of the cats and 20-50% of the dogs act as a carrier for *Pasteurella* species [35]. Various *Pasteurella* species like *P. multocida* subsp *multocida, P. multocida* subsp *septica, P. canis, P. dagmatis* and *P. stomatis* are often implicated in wounds from animal bites. Human infection is associated with scratches and bites from cats or dogs. The main agent responsible for superficial infections like pyoderma and cutaneous abscesses in animals and 26% of dog-inflected bites in humans is *P. canis* [36]. In addition to superficial infections, osteomyelitis, systemic bacteremia, septic arthritis, and lower respiratory infections are associated with *P. canis* in dogs [37]. *P. multocida* causes meningitis in dogs as well as humans and infection is characterized by nausea, nuchal rigidity, fever, headache and altered level

of consciousness [35]. The identification of *Pasteurella* bacteria in laboratories is by phenotypic assays, while for research purposes genetic identification of housekeeping genes has been used for diagnosis. On Gram staining, *P. canis* and other species of the genera show small, gram-negative coccobacilli. On sheep blood agar, non-hemolytic colonies are formed. *P. multocida* are oxidase-positive, catalase-positive, ornithine decarboxylase positive, indole positive, mannitol positive and urease negative, whereas *P. canis* ornithine, indole and mannitol negative. *Pasteurella* spp. are susceptible to a wide range of antibiotics, and the most effective therapy is a penicillin such as amoxicillin, penicillin G and ampicillin [38].

Listeriosis

Listeriosis caused by the gram-positive, facultative intracellular bacterium, *Listeria monocytogenes* is one of the leading causes of death due to foodborne illness in the developed world. *L. monocytogenes* infections are characterized by septicaemia, meningoencephalitis, and abortion in animals and humans and are distributed in the environment (soil, sewage, and silage). It can also be isolated from the faeces of healthy animals and humans. Transmission of *Listeria* from animals to humans with direct contact is possible but rare. *L. monocytogenes* can be transmitted by infected fleas [27]. Listeriosis being foodborne infection therefore contaminated foods are the main source of transmission of the disease. Clinical listeriosis is rare in monogastric animal like dog but usually manifests as septicemia [39].

The bacteria can survive in varying pH and temperature conditions. However, the growth of the organism is restricted at low temperatures and pH. The organism grows best at 30-37 °C, characteristic tumbling motility is observed at 25°C [40]. The bacteria may survive for several years outside of the body of their hosts in a humid environment. Thus presents a health risk for humans, where humans and dogs are in close contact. Listeria organism has been isolated from the canine in various conditions including tonsillitis, urinary tract infection and myocarditis [41]. The dog's condition improved favorably to antibiotic therapy with ampicillin/sulbactam, enrofloxacin, and minocycline [42].

Actinomycosis

Actinomycosis is an infectious disease caused by gram-positive, non-spore-forming, filamentous anaerobic, or microaerophilic bacteria of the genus *Actinomyces.* The majority of *Actinomyces spp.* are free-living saprophytes that comprise a major part of the soil microbiome. The bacterium is a normal inhabitant of a dog's mouth. Opportunistic infection occurs due to inhalation or ingestion of grass lawns or penetration of skin or mucosa by a foreign body. Actinomycosis occurs most commonly in hunting dogs and large breed dogs that have access to the outdoors. In the dog, actinomycosis commonly affects the skin and cutaneous/subcutaneous tissue and less commonly abdominal cavity, nervous system and bones. The disease is slowly progressive and characterized by suppurative or pyogranulomatous inflammation with pleural and peritoneal exudates, frank abscesses, and fistulous tracts with draining sinuses [43]. The affected dog may show symptoms like sores and abscesses in the mouth or facial regions, serosanguinous drainage from the site of infection, swelling in the jaw, coughing, difficult or rapid breathing, fever and weight loss. Central nervous system (CNS) infections usually develop from hematogenous dissemination from a primary site. Other risk factors related to the disease include periodontal infection and immunosuppressive disorders [43]. *Actinomyces viscosus*, *A. hordeovulneris*, *A. bovis*, *A. canis*, *A. bowdenii*, *A. odontolyticus*, *A. israelii*, and *A. naeslundii* have been reported in associated with canine Actinomycosis and dental plaque [27].

The disease can be tentatively diagnosed based on cytological identification of gram-positive branching coccobacilli obtained from affected tissues. The confirmatory diagnosis is carried by light microscopy and anaerobic culture isolation. Sulfur granules composed of branching, filamentous, gram-positive bacteria surrounded with bright eosinophilic material called splendore-hoeppli material may be seen in draining fistulas and tissue sections [44].

Prolonged administration of antibiotics is required to eliminate the infection. Penicillins such as Ampicillin (10-20 mg/kg IV/IM/SC every 6-8h) and Amoxicillin (10-30 mg/kg IM/SC/PO every 12h); Macrolides/Lincosamides viz., Clindamycin (5 mg/kg IV/IM/SC/PO every 12h), Erythromycin (10 mg/kg PO every 8h) and Chloramphenicol (50 mg/kg IV/IM/SC/PO every 8h) are employed in the treatment of actinomycosis [43].

Clostridium infection

Clostridium is a fastidious Gram-positive, rod-shaped, spore-forming, anaerobic bacillus that is an important enteropathogen

in many species including dogs and humans. *Clostridia* spp, particularly *C. difficile*, and *C. perfringens* are well-recognized enteric pathogens of dogs and can cause a mild to severe or self-limiting fatal acute hemorrhagic diarrhea and colitis. Both *C. difficile*, and *C. perfringens* are commonly regarded as a community-acquired enteropathogen that causes acute canine hemorrhagic diarrhoea, but also recognised as a cause of chronic canine diseases [45]. In humans, *C. difficile* is the most prevalent cause of hospital and antimicrobial-associated diarrhoea and it has also been linked to nosocomial diarrhoea in dogs and cats in veterinary clinics. The main route of transmission is either via direct/indirect faecal-oral route or through spores. Majority of *C. perfringens* infection in dogs and cats belong to biotype A, which also causes the food-borne disease in humans. *C. perfringens* infection in canine is characterized by haemorrhagic enteritis, nosocomial diarrhoea, large bowel diarrhea (acute/chronic) and rapid peracute death [46].

On microscopic examination of the faecal smear by Wright stain, spore-forming rods can be visualized. The rods containing endospores appear like "tennis racquets or safety pins". PCR and RT-PCR were used for confirmatory diagnosis [47].

Dogs and cats are resistant to tetanus toxemia, caused by a neurotoxin produced by *C. tetani*. Due to their great tolerance to tetanus toxin, they have a long incubation period and typically develop localized tetanus; nonetheless, generalized tetanus does arise in these species. Localized tetanus commonly manifests as stiffness and rigidity in a limb with a wound, stiffness in neck muscles, hyperesthesia and tonic spasms. Dogs are treated with an i/v administration of antitoxin or penicillin while a combination of diazepam or phenobarbital and chlorpromazine can regulate seizures and hyperesthetic reactions [48].

Yersiniosis

Yersinia spp. are gram-negative anaerobic bacteria, commonly found in the gastrointestinal tract of dogs. *Y. enterocolitica* and *Y. pseudotuberculosis* are pathogenic species in dogs. *Y. enterocolitica* is a commensal as the organism is recovered from the feces of healthy dogs. Yersiniosis in canine manifests as generalized, intestinal and secondary focal infection [49]. Adult dogs have been diagnosed with hepatic yersiniosis caused by *Yersinia enterocolitica* 4: O3. In Hepatic yersiniosis, on gross examination of the liver, white to yellow nodules containing degenerated inflammatory cells, bacterial clumps and cell debris, and histopathologically suppurative and necrotizing hepatitis was noticed. It was confirmed as *Y. enterocolitica* 4:O3 by immunohistochemistry [50]. Clinical signs viz., anorexia, cachexia, bloody stool and depression were observed in dogs infected with *Y. enterocolitica* infection [51]. Dogs are believed to be indicator animals for plague surveillance but their association with human infection is rare [52]. Isolation and identification, quantitative direct culture, immunohistochemistry, autoagglutination and calcium dependency, PCR have been previously employed in various studies for the confirmation of yersiniosis in dogs. The treatment involves the use of broad-spectrum antibiotics like gentamicin, clindamycin and trimethoprim sulphomethaxozole [53].

Nocardiosis

Nocardia spp. are gram-positive facultative intracellular bacteria belonging to phylum Actinobacteria. They are ubiquitous, aerobic and non-motile organisms. *Nocardia* is said to have around 111 species of which 11 species are of veterinary significance [43]. In dogs, Nocardia commonly causes pulmonary, cutaneous and disseminated infections. Pulmonary nocardiosis is characterized by hypothermia, dyspnoea and weight loss, whereas cutaneous form is characterized by pustules, ulcers and abscesses. In disseminated form, lesions are prominent within the body with abscesses in multiple organs. The disseminated form is often associated with pulmonary nocardiosis [27]. The pulmonary form of nocardiosis is more common in dogs. The zoonotic potential of canine nocardiosis is still unknown. However, Human comes in contact with infected dogs, may poses risk of getting infection [54].

The clinical signs and symptoms of nocardiosis are not pathognomonic, therefore laboratory testing is required for a definite diagnosis. Direct microscopy by Gram and modified Kinyonn acid-fast techniques or histopathological examination by Brown and Brenn method can demonstrate the presence of *Nocardia* organisms from sputum, pus, tissues samples. To identify Nocardia, at the species level, molecular methods such as PCR and RFLP can be used [55]. A recent study reported Cefotaxime (25-50 mg/kg IV/IM/SC every 6h), Amikacin (10-30 mg/kg IV/IM/SC every 24h) and Imipenem-cilastatin (3-10 mg/kg slow IV every 8h) as effective [43].

Ehrlichiosis

Canine ehrlichiosis, caused by the *Ehrlichia* species, is a tick-borne infection with public health significance. The various species

of *Ehrlichia* like *Ehrlichia canis* (canine monocytic ehrlichiosis), *E. ewingii* (canine granulocytic ehrlichiosis) and *E. chaffeensis* (human monocytic ehrlichiosis) have been implicated in canine ehrlichiosis. The majority of infection in canine is due to *E. canis*, which have an affinity for hematopoietic stem cells and is the principal cause of canine monocytic ehrlichiosis (CME) [56]. Canine monocytic ehrlichiosis in dogs is also called tropical canine pancytopenia. The main mode of disease transmission is through brown dog tick *Rhipicephalus sanguineus.* In the acute stage, the disease is characterized by depression, fever, dyspnea, anorexia and weight loss. The hematological findings in the acute stage include thrombocytopenia, leucopenia, mild anemia and hypergammaglobulinemia. The acute ehrlichiosis lasts for 2-4 weeks. The onset of the subclinical stage is 40 days and may last for years. Mild thrombocytopenia is noticed in the subclinical stage. The chronic stage is characterized by hemorrhage, epistasis and edema. The dogs, once infected, may remain infected for a lifetime even after antibiotic treatment [56].

The cytological examination of morulae in mononuclear cells and neutrophils in the Giemsa stained blood smear is the main mode of diagnosis. Cytological examination, although not sensitive, detects only 10% of cases. The indirect immunofluorescence (IFA) test is the gold standard test for the diagnosis of CME. However, IFA necessitates expensive equipments as well as skilled personnel, therefore cannot be employed in all places. Alternatively, enzyme-linked immune assays like dot ELISA Kit are being used for antibody detection against *Ehrlichia* [57].

For *Ehrlichia* infection the recommended treatment is doxycycline at 5mg/kg every 12 hours or 10mg/kg per os every 24 hours for 30 days. Minocycline 10mg/kg per os twice daily for 3-4 weeks or rifampicin 10mg/kg PO once daily for 21 days are considered an alternative medical option where there are poor tolerance and contraindication for doxycycline [58].

Conclusion

Bacterial diseases in dogs are often self-limiting, but in certain circumstances they could be life threatening. However, the disease can be effectively managed if diagnosed and treated at the earliest. Antimicrobial stewardship training and a better awareness of zoonotic diseases among veterinarians, dog owners, and the general public might help to reduce zoonoses. Since dogs can be a sentinel animal for many infectious diseases, the monitoring and screening of dogs for different bacterial pathogens may give us valuable information regarding disease status in a society thereby aiding in prevention and control. Following stringent immunization protocols, proper hygiene and husbandry practices can mitigate the transmission of bacterial diseases.

Conflict of Interest

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