Chapter 8
Fungal Diseases and Therapy in Dogs

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8.1 Aspergillosis

Aspergillosis is a fungal disease caused by *Aspergillus* species, usually settles in the respiratory tract, and sometimes causes systemic infections. Among the *Aspergillus* species, *A. fumigatus* is the leading species that causes disease in dogs (Connole 1990). However, there are different types of *Aspergillus* that cause disease in dogs such as *A. flavus*, *A. nidulans, A. terreus, A. niger*, and *A. deflectus* (Connole 1990).

Three main forms of aspergillosis in dogs are observed, namely, sinonasal aspergillosis (SNA), disseminated canine aspergillosis (DCA), and bronchopulmonary aspergillosis (Seyedmousavi et al. 2015). Cases of otitis have also been reported (Ghibaudo and Peano 2010; Goodale et al. 2016).

8.2 Canine Sinonasal Aspergillosis (SNA)

In veterinary medicine, infections of the upper respiratory tract with *Aspergillus* spp. are of great clinical importance in dogs (Day 2009). Sinonasal aspergillosis (SNA) is the most common form of aspergillosis seen in dogs (Connole 1990;

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Seyedmousavi et al. 2015). Canine SNA is a common disease worldwide (Day 2009). SNA is predominantly caused by *A. fumigatus* (predominantly). However, various species such as *A. niger*, *A. nidulans,* and *A. flavus* have also been reported (Connole 1990; Sharman and Mansfield 2012).

Aspergillus species may cause SNA as an opportunistic primary pathogen or may participate secondary to the formation of infection in the presence of other predisposing factors (Benitah 2006). Localized tissue damage of the nasal mucosa is probably the most common predisposing factor for infection (Mortellaro et al. 1989). Factors that can predispose dogs to infection include injury to mucous membranes, catheter use, facial trauma, nasal foreign bodies, neoplasia, dental diseases, antibiotic use, and immunosuppressive drugs or other diseases (Benitah 2006; Day 2009; Sharman and Mansfield 2012; Seyedmousavi et al. 2015). Any breed of dog, especially medium to large size, with a dolichocephalic or mesaticephalic head is at risk (Peeters and Clercx 2007). It is very rare in brachycephalic dogs. German Shepherds and Rottweilers are commonly affected breeds (Seyedmousavi et al. 2015). Also, although most are young to middle-aged female animals, there is no specific age or gender predisposition (Börkü et al. 2003; Ferreira et al. 2011; Sharman and Mansfield 2012; Ballber et al. 2018).

Clinical signs are chronic seropurulent, mucopurulent, or sanguinopurulent nasal discharge (usually unilateral at the beginning, but becomes bilateral after destruction of the nasal septum), episodic epistaxis, regional nasal pain, sneezing, and nasal itching (Börkü et al. 2003; Benitah 2006; Day 2009; Abd Alfatah 2019). It can be stertor, stridor, or open mouth breathing (Schuller and Clercx 2007). Depigmentation, ulceration, or hyperkeratosis can be seen in the nasal planum. In advanced stages of the disease, facial deformity, ocular involvement, and epiphora may occur due to obstruction of the nasolacrimal ducts (Day 2009; Sharman and Mansfield 2012; Belda et al. 2018).

Clinical diagnosis of SNA in dogs is not simple, although clinical findings and course of the disease are suspicious for SNA. Methods such as radiology, computed tomography, or magnetic resonance imaging are used to evaluate the degree of tissue (bone) damage (Saunders et al. 2004; Day 2009; Valdes et al. 2018). In most cases, rhinoscopic examination is performed to identify a characteristic fungal plaque adhered to the mucosal surface and to determine the degree of local tissue damage (Saunders et al. 2004; Schuller and Clercx 2007; Day 2009; Valdes et al. 2018). Nasal cytology (lavage) can be used to identify fungal elements. Biopsies can also be collected for histopathological examination, and the fungal culture of such specimens should also be made (Schuller and Clercx 2007; Day 2009; Ballber et al. 2018; Valdes et al. 2018). Since a single diagnostic procedure does not have 100% sensitivity and specificity, it is recommended to use a combination of a number of procedures, including diagnostic imaging (computed tomography (CT) or radiography), rhinoscopy/sinuscopy, histopathology, cytology, fungal culture, serology, and molecular techniques (Benitah 2006; Day 2009; Sharman and Mansfield 2012; Seyedmousavi et al. 2015). Also, other common causes of chronic nasal disease should be considered and distinguished, including neoplasia, nasal foreign bodies, secondary rhinitis due to dental disease, and idiopathic lymphoplasmacytic rhinitis (Day 2009; Sharman and Mansfield 2012; Seyedmousavi et al. 2015).

8.3 Disseminated Canine Aspergillosis (DCA)

DCA is a relatively rare fatal disease in dogs. It is usually caused by *A. terreus* and *A. deflectus*. However, less frequently *A. fumigatus, A. flavus, A. niger, A. flavipes, A. versicolor, A. carneus, A. alabamensis*, and *A. deflectus* have also been reported (Robinson et al. 2000; Schultz et al. 2008; Burrough et al. 2012; Zhang et al. 2012; Seyedmousavi et al. 2015; Bennett et al. 2018). A case of disseminated aspergillosis caused by *A. caninus* in a 2-year-old Rottweiler dog was also reported recently (Yang et al. 2020). DCA is mainly seen in German Shepherd Dogs (Robinson et al. 2000; Taylor et al. 2015). Therefore, it has been suggested that genetic factors play an important role in susceptibility and pathogenesis, and IgA deficiency is a possible predisposing factor for disseminated aspergillosis (Berry and Leisewitz 1996; Bruchim et al. 2006). However, it has been reported that immunosuppression in any dog breed may pave the way for infection, and the use of corticosteroids may also be effective (Bruchim et al. 2006; Kalokhe et al. 2010). This disease has also been described in other breeds such as Dalmatian, English Setter, Pug, Rhodesian Ridgeback, Springer Spaniel, and Whippet (Kabay et al. 1985). Transuterine transmission by *A. terreus* has also been reported (Elad et al. 2008).

The clinical signs of DCA may come on suddenly or develop slowly within a few months. Its clinical manifestations are lethargy, discospondylitis, osteomyelitis, spinal column pain, spinal hyperpathia, vestibular abnormalities, ataxia, paraparesis, weight loss, anorexia, pyrexia, inflammatory ocular disease, uveitis, hematuria, urinary incontinence, lameness, renal failure, respiratory distress, generalized lymphadenopathy, and neurologic deficits (Robinson et al. 2000; Berry and Leisewitz 1996; Bruchim et al. 2006). Granulomatous inflammation is common in multiple organs, including bone, kidney, and spleen (Kabay et al. 1985; Berry and Leisewitz 1996; Bruchim et al. 2006).

Common abnormalities in complete blood count include normocytic normochromic anemia, leukocytosis, left shift, and neutrophil toxicity (Schultz et al. 2008). Hyperglobulinemia, azotemia, hypercalcemia, and/or hypoalbuminemia can be seen in the serum biochemical profile (Schultz et al. 2008; Bennett et al. 2018; Yang et al. 2020). Isosthenuria, hematuria, and pyuria are commonly found in urinalysis. Fungal hyphae can sometimes be seen in urinary sediment and aspirates from other affected areas such as lymph nodes, kidneys, pleural effusion, lung, bone, joint fluid, and transtracheal irrigation. Pyogranulomatous inflammation is frequently seen in cytological samples. CSF often shows neutrophilic pleocytosis in dogs with neurological findings (Schultz et al. 2008).

DCA in dogs can often be diagnosed with a combined approach using clinical signs, imaging techniques (radiography and computed tomography), and laboratory findings such as serology, cytology, mycology, and histopathology (Schultz et al. 2008). The diagnosis can be made by identifying fungal hyphae in tissue samples or urine or by detecting the fungal cell wall antigen galactomannan in blood or urine (Garcia et al. 2012). Since disseminated mycosis caused by other fungal species, including *Penicillium* spp., may mimic disseminated aspergillosis, fungal culture is required to confirm the clinical diagnosis and identify the specific pathogen (Schultz et al. 2008).

8.4 Bronchopulmonary Aspergillosis

Bronchopulmonary aspergillosis, like DCA, is also a rare disease in dogs and has been sporadically reported (Southard 1987; Kim et al. 2003; Adamama-Moraitou et al. 2011; Pavelski et al. 2018). Cases caused by *A. flavus, A. niger*, and *A. fumigatus* have been reported (Kim et al. 2003; Adamama-Moraitou et al. 2011). Nonspecific clinical signs such as depression, fever, and cough are observed (Adamama-Moraitou et al. 2011). Its diagnosis is similar to that of DCA (Seyedmousavi et al. 2015). Diffuse nodular lesions in the lung can be seen on chest radiographs, and differential diagnosis can be made with fungal culture of bronchoalveolar lavage samples (Kim et al. 2003; Seyedmousavi et al. 2015; Pavelski et al. 2018). Histopathology contributes to the diagnosis of mycotic bronchopneumonia, and the identification and confirmation of *Aspergillus* spp. can be done by PCR (Adamama-Moraitou et al. 2011).

Humoral mucosal immunity and cell-mediated immunity are of great importance in preventing *Aspergillus* infection. Also, cleaning maintenance equipment is essential to prevent fungal infection.

8.5 Dermatophytosis

Dermatophytosis (ringworm) mainly affects domestic animals. It is caused by zoophilic, geophilic, or anthropophilic fungal agents, especially *Microsporum canis, M. gypseum*, and *Trichophyton mentagrophytes*. It is a superficial fungal infection limited to keratinized epithelial tissue such as nail, paw, hair, and stratum corneum (Mattei et al. 2014; Moriello et al. 2017). It is an important skin disease that is contagious, infectious, and can be transmitted to humans (Moriello et al. 2017).

Immunosuppressive diseases are thought to make dogs predisposed to dermatophytosis (Mignon and Losson 1997). It has been described that Yorkshire Terrier dogs are predisposed to superficial dermatophytosis and subcutaneous dermatophytic infections, and the pathogenic agent is *M. canis* (Bergman et al. 2002; Brilhante et al. 2003; Cerundolo 2004; Cafarchia et al. 2004; Moriello et al. 2017). It has been reported that hunting and training dogs (German Shorthaired Pointers, Fox Terrier, Labrador Retriever, Belgian Shepherd, Beagle, Pointer, Jack Russell Terrier, German Shepherd, and Jagdterrier) are particularly susceptible to dermatophytosis caused by *M. persicolor* and *M. gypseum* (Carlotti and Bensignor 1999; Muller et al. 2011).

The hot and humid climate is the best condition for infection (Brilhante et al. 2003). Infection is transmitted through direct contact with infected animals or equipment contaminated with fungi such as grooming equipment (Chermette et al. 2008; Bagcigil et al. 2010). The incubation period of the infection is 1–3 weeks (Ganguly et al. 2017).

Although there are no clinical findings in many infected dogs, these dogs can be subclinically infected (Abd Alfatah 2019). When the infection progresses, hair loss, papules, scaling, crusting erythema, follicular obstruction, hyperpigmentation,

alopecia foci, changes in nail growth, and appearance can be seen. Lesions can be single or multiple and are localized anywhere in the dog, and multiple lesions may coalesce (Cerundolo 2004; Cafarchia et al. 2004; Chermette et al. 2008; Bagcigil et al. 2010; Abd Alfatah 2019). Pruritus is variable, generally minimal or absent. Dogs can develop nodular dermatophyte infections, mainly diagnosed by biopsy or cytological examination of aspirates (Moriello et al. 2017).

Infected hairs fluoresce bright green under lamp of Wood. With the exception of *Trichophyton schoenleinii*, fluorescence-producing dermatophytes are members of the *Microsporum* genus. The most important primary dermatophyte-producing fluorescence is *M. canis*. *M. gypseum*, one of the pathogenic agents causing dermatophytosis in dogs, has no fluorescence or is very light green in color. The characteristic green fluorescence observed in hair shafts infected with *M. canis* is caused by a water-soluble chemical metabolite (pteridine) found in the cortex or medulla of the hair (Moriello et al. 2017).

There is no gold-standard method for the diagnosis of dermatophytosis in dogs. Dermatophytosis infection is diagnosed using a range of complementary diagnostic tests, including Wood's lamp, direct microscopy, fungal culture, and biopsy. For examination with Wood's lamp, fluorescence is sought in hair shafts infected with *M. canis*, but false positive and negative results can be obtained. Therefore, failure to detect fluorescence does not mean that there is no infection (Moriello et al. 2017; Abd Alfatah 2019). The presence of fungal hyphae and/or ectothrix spores can be monitored by staining the fur and skin scrapings of infected dogs with dye (lactophenol cotton blue, India Ink) or by direct microscopic examination with unpainted potassium hydroxide. This examination is thought to be very important in the diagnosis of dermatophytosis (Mattei et al. 2014; Moriello et al. 2017; Abd Alfatah 2019). Definitive diagnosis of dermatophytosis is made by fungal culture. Skin scraping or biopsy specimens are inoculated into fungal culture medium such as Sabouraud's dextrose agar and dermatophyte test medium (Mattei et al. 2014; Abd Alfatah 2019). It may also be useful to detect dermatophyte DNA by polymerase chain reaction (PCR). However, a positive PCR test result does not necessarily indicate active infection. Because it has been reported that dead fungal organisms can also be detected by PCR in a successfully treated infection (Cafarchia et al. 2004; Mattei et al. 2014; Ganguly et al. 2017).

Hygienic measures should be implemented as well as good care should be taken of animals. The possibility of infection arises when it comes into contact with infected animals or contaminated environments. The best way to prevent infection is to avoid this contact.

8.6 Blastomycosis

Blastomycosis is a chronic, cutaneous, and systemic mycotic infection with purulent and granulomatous character caused by a dimorphic fungus *Blastomyces dermatitidis*. Blastomycosis is a systemic fungal infection that can be fatal if not diagnosed early (McMillan and Taylor 2008; Choptiany et al. 2009).

Blastomycosis is common in Canada, the south of the United States, and particularly in North America (Legendre et al. 1981; Choptiany et al. 2009; Benedict et al. 2012). Cases are most common in autumn, but can occur at any time of the year (Rudmann et al. 1992; Benedict et al. 2012). Blastomycosis occurs mainly in juveniles and large breed dogs (Selby et al. 1981; Rudmann et al. 1992; Arceneaux et al. 1998). It is most prevalent in Coonhounds, Pointers, and Weimaraner (Selby et al. 1981; Rudmann et al. 1992). In addition, Doberman Pinschers and Retrievers can be at risk for blastomycosis. It can occur to any breed of dog if they are exposed to microorganisms (Brömel and Sykes 2005). In some reports, the prevalence has been reported to be higher in males than in females (Legendre et al. 1981; Selby et al. 1981; Rudmann et al. 1992). In addition, while most cases are seen in stray dogs, they can also be found in pets (Brömel and Sykes 2005; Benedict et al. 2012). Dogs that live near waterways or hunt and excavate are more exposed to *B. dermatitidis* spores (Rudmann et al. 1992; Baumgardner et al. 1995; Arceneaux et al. 1998).

B. dermatitidis occurs in nature as saprophytic mycelial forms that form infective spores. Infected spores enter the body of susceptible hosts through respiration and turn into yeast form in tissues (Brömel and Sykes 2005). *B. dermatitidis* causes respiratory and/or disseminated infection. If the inhaled fungal spores are small and the animal is not immunocompromised, the infection may be confined to the respiratory tract and may have a few or no clinical signs. They form a primary infection in the lung and then spread to the body (lymph nodes, eyes, bones, central nervous system, kidneys, liver, spleen, skin, genitourinary system, heart, and adrenal glands) by hematogenous and lymphogenous ways. They cause granulomatous or pyogranulomatous inflammation in many organs (De Groote et al. 2000; Brömel and Sykes 2005; Yildiz et al. 2016). It has been reported that the most affected tissues are the respiratory system, lymphatic tissues, eyes, skin, and bones (Legendre et al. 1981; Bloom et al. 1996; Arceneaux et al. 1998). The most common clinical signs are nonspecific anorexia, weight loss, and fever (Legendre et al. 1981; Brömel and Sykes 2005). Respiratory abnormalities such as exercise intolerance, tachypnea, and cough are also common clinical findings (Legendre et al. 1981; Baumgardner et al. 1995; Brömel and Sykes 2005). Nodular or interstitial infiltrates, often referred to as "snowstorm pattern," are seen on radiography (Schwartz 2017). Less commonly, thoracic radiographs show tracheal bronchial lymphadenopathy, masses, or cavitary lesions (Arceneaux et al. 1998). Draining skin tracts and lymphadenopathy are commonly found. Ulcerative and granulomatous type skin lesions are common (Legendre et al. 1981). Less commonly, bones, lymph nodes, central nervous system, genitourinary system, testis, and prostate may also be affected. Testicular enlargement and prostate enlargement are uncommon findings (Legendre et al. 1981; Totten et al. 2011). Cardiovascular blastomycosis has also been reported in dogs (Schmiedt et al. 2006).

In dogs with ocular lesions, findings such as endophthalmitis, uveitis, posterior segment disease and anterior segment disease, retinal detachment, panophthalmitis, glaucoma, photophobia, conjunctival hyperemia, miosis, blepharospasm, aqueous flare, and blindness have been reported (Legendre et al. 1981; Buyukmihci 1982; Bloom et al. 1996; Arceneaux et al. 1998). It has been reported that rupture of the

lens is a possible complication of the disease (Legendre et al. 1981; Hendrix et al. 2004; Brömel and Sykes 2005). Nonregenerative anemia, neutrophil leukocytosis (mostly left shift), monocytosis, lymphopenia, hyperglobulinemia, hypoalbuminemia, hypercalcemia, and hypoglycemia can be detected in blood parameters (Legendre et al. 1981).

Cytology and/or histopathology is accepted as the gold-standard method for the diagnosis of blastomycosis. Blastomycosis can be diagnosed by cytological examination of cerebrospinal fluid and samples taken from cutaneous lesions, peripheral lymph nodes, lungs, and bones by fine-needle aspiration biopsy and by histopathological examination of tissue and bone biopsy samples (Legendre et al. 1981; De Lorimier and Fan 2010). The diagnosis can also be made by culture method, but the diagnostic performance of both cytology and or histopathology methods is better than culture (Patel et al. 2010). In addition, the mycelium form of the fungus is not used because it increases the risk of infection of laboratory personnel (Denton et al. 1967). Surface antigens of *Blastomyces* can be detected by an enzyme immunoassay (EIA) from body fluids such as urine, serum, bronchoalveolar lavage fluid, and cerebrospinal fluid (Durkin et al. 2004; Spector et al. 2008). It is reported that EIA methods with antibody detection have higher sensitivity than antigen detection (Klein et al. 2006; Mourning et al. 2015). It has also been reported that the specificity of antibody EIA is high, but cross-reactions can be observed in dogs with histoplasmosis (Mourning et al. 2015). It has been reported that imaging techniques such as magnetic resonance imaging and tomography can be used in dogs with central nervous system blastomycosis (Legendre et al. 1981).

Since the clinical signs and symptoms of blastomycosis are similar to other respiratory tract infections, they are overlooked. A commercially available vaccine against blastomycosis is currently not available. A better understanding of the pathogenesis of blastomycosis and the host immune response against blastomycosis is required to facilitate early diagnosis and treatment of blastomycosis and to develop effective prevention and control strategies.

8.7 Histoplasmosis

Histoplasmosis is a noncommunicable systemic infection caused by a dimorphic, saprophytic soil fungus *Histoplasma capsulatum* (Mitchell and Stark 1980; Brömel and Sykes 2005; Sumithra et al. 2013). *H. capsulatum* has a worldwide distribution in temperate and subtropical climates. It is an endemic disease in the midwest and south of the United States (Colombo et al. 2011). In addition, it is the most frequently diagnosed systemic mycosis in dogs (Sumithra et al. 2013). It affects dogs of all age groups, but is especially seen in young person (Brömel and Sykes 2005). Several dog breeds, including Terriers, Pointers, Weimaraners, and Brittany Spaniels, have been reported to have an increased risk of histoplasmosis (Sumithra et al. 2013). Immunocompromised animals or dogs receiving immunosuppressive therapy are susceptible to histoplasmosis (Clinkenbeard et al. 1988; Mackie et al. 1997).

H. capsulatum easily grows on the surface of moist soils containing high nitrogen where the feces of poultry (avian) and bats are abundant, and the infection begins when the spores spilled into the environment are inhaled by sensitive living species (Lyon et al. 2004). Mycelial fragments transform into yeast form in host tissues, are phagocyted by macrophages, and continue to multiply. The pathogenic agent spreads to other organs and tissues by hematogenous and lymphogenous ways (Sumithra et al. 2013).

Infection may be subclinical or cause clinical pulmonary granulomatous disease or disseminated infection (Tyre et al. 2007). Acute pulmonary histoplasmosis is rarely seen in dogs. In dogs, this form is characterized by dyspnea and cyanosis. Animals with chronic pulmonary histoplasmosis usually have mild symptoms of chronic cough, weight loss, and loss of appetite (Sumithra et al. 2013). Disseminated disease mainly affects the liver, spleen, lymph nodes, gastrointestinal tract, bone, bone marrow, and eyes (Tyre et al. 2007; Schumacher et al. 2013). In gastrointestinal infection, macrophages loaded with pathogens accumulate in the mucosa and submucosa, and edema and necrosis occur in the submucosa and associated lymph nodes. Ulcerative lesions can be seen. Granular to nodular appearance on the surface of the abdominal organs, granulomatous nodules, or pinpoint lesions within the viscera, focal, or diffuse granulomatous pneumonia, granulomatous dermatitis, mycotic osteomyelitis, and peritoneal effusion can be detected. It leads to hepatomegaly, splenomegaly, lymphadenopathy, and anemia (Sanford and Straube 1991; Schumacher et al. 2013). Endocarditis was reported in 41% of cases in which necropsies were performed in dogs (Mitchell and Stark 1980). Chronic diarrhea (usually with hematochezia or melena), weight loss, lethargy, malaise, pale mucous membranes, fever, anorexia, respiratory abnormalities, and lameness are common clinical signs. Ascites, optic neuritis, granulomatous chorioretinitis, oropharyngeal erosions, and central nervous system symptoms can also be seen (Reginato et al. 2014).

Histoplasmosis is suspected based on clinical and radiographic findings. The most common thoracic abnormalities in dogs with pulmonary histoplasmosis on radiographic examination are bronchointerstitial or interstitial lung pattern and hilar lymphadenopathy (Schulman et al. 1999; Sumithra et al. 2013). The terms “snow storm effect” and “cotton tuft” are used to describe pulmonary radiographic patterns. In dogs, tracheobronchial lymph nodes can rarely be found to be enlarged or mineralized (Sumithra et al. 2013).

Currently, the definitive diagnosis of *H. capsulatum* is made by identification with cytology or fungal culture. The scope of molecular diagnostic techniques and antigen detection tests in animals is being investigated (Wheat 2003). Although various techniques such as serum immunodiffusion tests and complement fixation tests are used to detect antibodies against *H. capsulatum*, more studies are needed (Cordeiro et al. 2011; Sumithra et al. 2013). Prevention of exposure to histoplasma-laden areas such as chicken coops, bird and bat roosts, and construction and excavation areas, and the prevention of bat manure or bird droppings’ accumulation by keeping bats and birds away from buildings with chemical repellants are recommended protection methods (Sumithra et al. 2013). In addition, it has been declared that formalin solution (3–4%) is the most effective chemical (Bartlett et al. 1982).

8.8 Rhinosporidiosis

Rhinosporidiosis is a rare, noninfectious, and chronic granulomatous mycotic disease that is characterized by the polypoid growth of mucocutaneous tissues caused by *Rhinosporidium seeberi* (Hoff and Hall 1986; Caniatti et al. 1998). The disease is thought to be associated with contact with flowing and stagnant groundwater in both humans and animals (Arseculeratne 2002). In addition, local trauma in the nasal mucosa is a predisposing factor for rhinosporidiosis (Hoff and Hall 1986).

The infection is generally not fatal, and polypoid granulomatous masses in the nose are characteristic lesions of rhinosporidiosis (Rao and Jain 1971; Kennedy et al. 1995; Wallin et al. 2001). The disease in dogs is clinically characterized by wheezing, sneezing, unilateral seropurulent nasal exudate, and nosebleeds (Mosier and Creed 1984; Easley et al. 1986; Miller and Baylis 2009; Borteiro et al. 2018). Polyps can be seen in the nostrils and are pink and soft. They have a friable or fragile structure (Easley et al. 1986). It can also bleed easily and has small white spots (Caniatti et al. 1998).

Definitive diagnosis is made by histopathology. Endospores and sporangia are detected in native preparations (slides) made from nasal exudate and both in native preparations made from polyps and in stained sections (Sinha et al. 2012). It has also been reported that rhinosporidial disease can be confirmed from nasal swab samples with the specific polymerase chain reaction (PCR) test (Borteiro et al. 2018).

Its biology and risk factors have not been fully established. General hygienic conditions are recommended for protection.

8.9 Sporotrichosis

Sporotrichosis is a chronic, granulomatous, and often lymphocutaneous infection caused by the dimorphic fungus *Sporothrix schenckii* (Miranda et al. 2011). *S. schenckii* is commonly found in soil, water, and rotting plants. Sporotrichosis is common worldwide, especially in regions with high humidity and temperate climates (De Araujo et al. 2001; Ramírez-Soto et al. 2018). Although sporotrichosis is common in cats, it is rarely seen in dogs, and most of the cases published in the literature have been reported from the United States, France, Canada, Ontario, Italy, and especially Brazil (Koehne et al. 1971; Dion and Speckmann 1978; Moriello et al. 1988; Sykes et al. 2001; Schubach et al. 2006; Cafarchia et al. 2007; Whittemore and Webb 2007; Crothers et al. 2009; Rossi et al. 2013). It is more common in hunting dogs and dogs exposed to piercing objects in nature (Cafarchia et al. 2007). On the other hand, there are reported cases of dogs contacting cats (Viana et al. 2018).

The fungus is the main entry route to the body through traumatic wounds on the skin and often causes lymphangitis (Cafarchia et al. 2007). It has been explained that infection may occur with the sporadic inhalation of conidia (Schubach et al. 2006).

The most common clinical manifestation of sporotrichosis is chronic granulomatous lymphocutaneous infection (Cafarchia et al. 2007). Multiple, circular, alopetic lesions and ulcers in the extremities, brown-colored nodules, nonulcerative nodules on the auricle, and erosive lesions on the nose have been reported (Cafarchia et al. 2007; Mascarenhas et al. 2018; Viana et al. 2018). Respiratory symptoms such as sneezing, shortness of breath, and runny nose (Mascarenhas et al. 2018; Viana et al. 2018), and rarely osteoarticular and disseminated forms (Farias et al. 2015) have been reported.

The definitive diagnosis of infection is based on cytological examination of exudates, histological examination of the biopsy specimen, or isolation of *S. schenckii* with fungal culture (Miranda et al. 2011). It has been explained that serological methods (i.e., immunofluorescence test) can be used, but a positive result does not indicate an active infection, although it indicates exposure to the fungus (Cafarchia et al. 2007).

There are no known practical measures for preservation other than removing known contaminated materials. Infected animals, especially cats, should be detected and separated to prevent the spread of the microorganism. Skin wounds, which are the main entry route of the microorganism to the body, should be treated immediately, and animals should not be kept in areas where hard and sharp objects are in excess. In addition, general hygienic measures should be taken.

8.10 Geotrichosis

Geotrichosis is a fungal disease caused by *Geotrichum candidum* (Reppas and Snoeck 1999; Pal et al. 2002). *G. candidum* is found as a saprophyte or as a parasite in many natural sources, including soil, dairy, and plants (Lincoln and Adcock 1968). It has been described in animals that it is isolated either as part of the resident microflora or as a pathogen and is an opportunistic pathogen that can cause disease under appropriate conditions (Rhyan et al. 1990). *G. candidum* can cause disease in immunocompromised hosts (Reppas and Snoeck 1999; Pal et al. 2002). It has been rarely reported from dogs, and cases of pulmonary, cutaneous, oral, and disseminated geotrichosis have been reported (Rhyan et al. 1990; Pal 2005; Lee et al. 2010). The disease can progress rapidly and is fatal (Lincoln and Adcock 1968).

The symptoms of the infection vary according to the organ in which the disease occurs. Nodular erythematous skin lesions and signs of alopecia have been reported in cutaneous cases (Pal et al. 2002). Cough, fever, polydipsia, anorexia, difficulty in breathing, wheezing, vomiting, diarrhea, and icterus have been reported in pulmonary and disseminated cases (Lee et al. 2010). It has been reported that nodules in the lung and an increase in pleural fluid were detected on radiographic examination (Lincoln and Adcock 1968).

In pulmonary and disseminated cases, granulomas are detected in the organs (Lee et al. 2010). In addition, a significant increase in blood urea nitrogen and a high

icteric index have been reported hematologically. Clinical and histopathological findings are not sufficient to make a diagnosis (Lincoln and Adcock 1968). Fungus isolation and identification are essential for diagnosis (Lee et al. 2010). Characteristic rectangular arthrospores and septate hyphae are observed in direct microscopic examination of the stool (feces) with 15% KOH or in direct microscopic examination performed by staining with lactophenol cotton blue (Lee et al. 2010).

There is no known protection measure. As it is an opportunistic pathogen, animals should be kept away from stress and their immune system should be supported. In addition, general hygienic measures should be taken.

8.11 Phaeohyphomycosis

Phaeohyphomycosis is a mycotic infection caused by opportunistic, saprophytic, dematiaceous (pigmented) fungi (Dillehay et al. 1987). Several fungal species have been reported from canine infections such as *Ochroconis gallopavum* (Singh et al. 2006), *Bipolaris spicifera* (Waurzyniak et al. 1992; Giri et al. 2011; Rothenburg et al. 2017), *Phialemonium obovatum* (Lomax et al. 1986), *Alternaria infectoria* (Dedola et al. 2010), and *Cladosporium bantianum* (Schroeder et al. 1994; Lobetti 1996; Guillot et al. 2004). *C. bantianum* has been reported to be the most common fungus isolated among phaeohyphomycosis cases in dogs (Schroeder et al. 1994; Lobetti 1996; Guillot et al. 2004).

Predisposing factors for dogs have been reported to be immunosuppressive therapy or immunodeficient diseases. Cases of chronic skin, subcutaneous, mucosal, cerebral, or systemic infections, osteomyelitis, and nephritis in dogs have been reported (Dedola et al. 2010).

Clinical findings such as ulcerated cutaneous nodules, progressive weight loss, loss of appetite, polyuria, polydipsia, vomiting, hepatomegaly, nystagmus, loss of sensation in the right side of the face, seizure, neck stiffness, convulsions, circling, weakness of the extremities, postural deficits, falling to both sides, and altered mentation have been reported (Dedola et al. 2010).

Diagnosis can be made by direct microscopy, culture, histopathology, and molecular analysis (Ferrer et al. 2001). Numerous yellowish-green to black necrogranulomatous foci can be detected in the necropsy, liver parenchyma, spleen, renal cortex, and adrenal glands. Lesions in cerebral infections range from multifocal encapsulated abscesses to pyogranulomatous inflammation (Schroeder et al. 1994). Histopathological examination demonstrated pigmented fungal hyphae in the liver, spleen, kidneys, portal lymph node, and adrenals, as well as in the brain. Since Phaeohyphomycosis has various etiological agents and has similar morphology in tissue sections, specific identification can only be made by fungal culture method (Schroeder et al. 1994).

Stress conditions for prevention should be eliminated, and general hygienic measures should be taken.

8.12 Treatment Methods

8.12.1 Aspergillosis

Chemotherapy is generally used for the treatment of fungal diseases. The most widely used antifungal agents for treating canine SNA belong to the azole group comprising imidazoles (ketoconazole, clotrimazole, and enilconazole) and triazoles (fluconazole and itraconazole) (Sharman and Mansfield 2012). They all inhibit fungal wall synthesis by blocking 14α-sterol demethylase which is a fungal cytochrome P450 enzyme (Maertens 2004). Also, topical azole drugs including clotrimazole and miconazole cause direct lytic effect on fungi (Mazu et al. 2016). Treatment of canine SNA is often challenging and consists of surgical debridement of involved tissues, administration of systemic antifungal, and application of topical antifungal agents. In cases where only the sinuses are involved, trephination is recommended to confirm the presence of the fungal infection and facilitate debridement and topical treatment (Day 2009). Topical antifungal treatment is regarded as the treatment of choice provided that the cribriform plate is intact. Topical antifungal solution is infused through a catheter. Topical application of enilconazole or clotrimazole is more effective than orally administrated antifungal drugs for nasal aspergillosis in dogs (Mathews et al. 1998). A short, five-minute flushing of 1% topical clotrimazole solution followed by a 1% clotrimazole cream instilled as a depot agent after frontal sinus trephination has been used for SNA therapy (Sissener et al. 2006). The therapy compares favorably with topical clotrimazole (Mathews et al. 1998) and enilconazole (Sharp et al. 1993). Infusion of clotrimazole cream into the frontal sinus by trephination provides a fast and effective treatment technique for SNA.

Effective treatment of DCA in dogs has always been difficult due to low effectiveness of the available drugs such as Amphotericin B, itraconazole, high cost of drugs such as voriconazole, and the limited number of effective drugs against DCA (Kelly et al. 1995; Graybill et al. 2004; Corrigan et al. 2016). Recently, novel antifungal agents, including voriconazole, posaconazole, and echinocandin, have been used for treatment of DCA. These drugs are highly expensive for veterinary use and have to be used for dog's whole life. Posaconazole belonging to triazoles is most effective of the azoles on *Aspergillus* spp. Posaconazole administered at a dose of 5 mg/kg PO q12h seems to be safe and well tolerated for long-term DCA in dogs. Unfortunately, even if seemingly successful, relapses are quite common, and most of the dogs die. This drug should be considered as an option for treating DCA in dogs (Corrigan et al. 2016).

Similar to DCA, the treatment of bronchopulmonary aspergillosis with antifungal drugs is also difficult. The efficacy of itraconazole appears to be greater than that of fluconazole and ketoconazole for bronchopulmonary aspergillosis. Even if long-term antifungal medication relapses often occur following cessation of the antifungal therapy (Whitley et al. 2010).

8.12.2 Dermatophytosis

Dermatophytosis is treatable and curable disease. Treatment of dermatophytosis involves oral and/or topical formulations of azoles or allylamines (Gupta and Cooper 2008). As transmission of dermatophytosis happens through direct contact with an infected dog, topical therapy is critical to prevent or minimize the risk of spreading infection to humans and other animals (Moriello 2004). Topical antifungal agents used for treating generalized dermatophytosis in dog include lime sulfur, enilconazole, ketoconazole, terbinafine, or a miconazole/chlorhexidine shampoo. Although treatment with miconazole or chlorhexidine alone is poorly effective, their combination is more effective for topical therapy (Perrins et al. 2005). Oral treatment with antifungal agents is necessary for severe or disseminated cases. Oral medications used for dermatophytosis in dogs include griseofulvin, fluconazole, itraconazole, ketoconazole, and terbinafine. Among these drugs, itraconazole and terbinafine are the most effective and safe therapy. Ketoconazole and fluconazole are less effective compared to itraconazole and terbinafine. However, griseofulvin, ketoconazole, and fluconazole have more adverse effects (Legendre et al. 1996).

8.12.3 Blastomycosis

Animals with blastomycosis may be treated medically. Rarely, primary cutaneous or ocular blastomycosis may be treated by surgical excision (Bateman 2002). Treatment of choice for canine blastomycosis is limited to Amphotericin B, ketoconazole, terbinafine, and itraconazole. Amphotericin B and itraconazole continue to be the main medications used for treating dogs with blastomycosis. Itraconazole is the preferred agent due to its effectiveness similar to Amphotericin B, ease of use, low toxicity, and low cost (Needles 2017). Ketoconazole is rarely used due to its low effectiveness compared to itraconazole or Amphotericin B. The therapeutic potential of Amphotericin B is limited due to causing nephropathy in dogs (Rubin et al. 1989). Combination of Amphotericin B with an azole antifungal such as itraconazole, which allows for a decreased total dose of Amphotericin B to be administered, and the uses of liposomal or lipid-complexed form of Amphotericin B may lessen renal impairment in the dogs. Also, terbinafine has been used for treating blastomycosis in dogs occasionally in combination with azoles such as itraconazole (Wiebe and Karriker 2005; Sakai et al. 2011).

8.12.4 Histoplasmosis

Unfortunately, histoplasmosis is often fatal to dogs, and therefore, prolonged treatment (at least 6 months in most cases) with antifungal agents is required to successfully treat the disease. Newer azole antifungal agents including itraconazole and

fluconazole are used for treating canine histoplasmosis due to being less toxic and more effective than the old ones. Amphotericin B and ketoconazole cause more adverse effects in dogs, and relapse is common following withdrawal after therapy with these drugs. In dogs with severe disseminated histoplasmosis, combination therapy with Amphotericin B and itraconazole or Amphotericin B and ketoconazole may provide a more effective control of the infection (Lavely and Lipsitz 2005). Corticosteroids can be used successfully in the treatment of dogs with airway obstruction secondary to hilar lymphadenopathy caused by chronic histoplasmosis (without dissemination) as well as an antifungal medication (Schulman et al. 1999).

8.12.5 Rhinosporidiosis

The single or multiple polyps with associated inflammation occur within the nasal cavity of dogs with rhinosporidiosis. Antifungal and antibacterial medications are not effective in the treatment of rhinosporidiosis in animals (Hill et al. 2010). Surgical excision, preferably with electrocautery, is the treatment of choice for this disease and may be curative when a single polyp is excised (Miller and Baylis 2009). However, relapse is most likely to occur after the surgery. Medical treatment can be performed if the lesion is inoperable or recurs in spite of repeated surgeries (Allison et al. 1986). Ketoconazole eliminated nasal discharge in a dog with rhinosporidiosis within 4 days, although the disease recurred 6 months later (Miller and Baylis 2009). Also, dapsone has been demonstrated to be useful in such patients (Vieson et al. 2012).

8.12.6 Sporotrichosis

Sporotrichosis in dogs is usually characterized by multiple cutaneous lesions, although osteoarticular and disseminated form may also develop (Sykes et al. 2001). Treatment of sporotrichosis in dogs has involved oral administration of itraconazole, terbinafine, ketoconazole, and potassium iodine. The iodine therapy causing severe adverse effects has been replaced by new drugs such as itraconazole for treating sporotrichosis in human and veterinary medicine. Although ketoconazole is effective in the treatment of canine sporotrichosis, relapses and drug toxicity may limit therapy (Goad and Goad 1986; Mayer et al. 2008). Itraconazole therapy (about 6 months) has been used successfully to treat canine sporotrichosis (Sykes et al. 2001; Whittemore and Webb 2007). Terbinafine can be also used as alternative to itraconazole in treatment of canine sporotrichosis since it is an effective and well-tolerated alternative to drug therapy of cutaneous sporotrichosis (Viana et al. 2018).

8.12.7 Geotrichosis

The cutaneous, oral, intestinal, pulmonary, and systemic geotrichosis have been reported in dogs (Rhyan et al. 1990; Sidhu et al. 1993; Pal 2005; Lee et al. 2010). Optimal therapeutic strategy for geotrichosis is unknown. In human, Amphotericin B, itraconazole, and voriconazole have been successfully used for treating geotrichosis (Sfakianakis et al. 2007; Durán Graeff et al. 2017). Information about antifungal agent used in geotrichosis treatment in dogs is limited. In a case report, ketoconazole (20 mg/kg) and metronidazole (25 mg/kg) were orally administered for a period of 3 weeks to a dog with intestinal geotrichosis. Also, oral prednisolone (2 mg/kg for the first 3 days and 1 mg/kg for the following 4 days) was tapered after 1 week of therapy. Canine intestinal geotrichosis got successfully cured using ketoconazole (Lee et al. 2010).

8.12.8 Phaeohyphomycosis

Phaeohyphomycosis is often poorly responsive to medical therapy. Systemic antifungal agents including Amphotericin B, lipophilic Amphotericin B, flucytosine, itraconazole, ketoconazole, voriconazole, posaconazole, and fluconazole are used for treating phaeohyphomycosis in small animals. Multiple drugs given in combination are more effective than a single-drug therapy (Rothenburg et al. 2017; Dedeaux et al. 2018). The most severe form of phaeohyphomycosis is disseminated disease, which commonly involves central nervous system (CNS) infection in dogs, and the disease in the patients has been mostly fatal (Anor et al. 2001). In a case of intracranial phaeohyphomycosis, after the granuloma was debulked, the dog was cured successfully by using fluconazole for 4 months, followed by voriconazole for further 10 months. Voriconazole belonging to triazole penetrates well into the CNS, making it the first choice for treatment of the infection in dogs (Bentley et al. 2011). A dog with disseminated cutaneous phaeohyphomycosis has been cured successfully by combination of systemic antifungals including Amphotericin B and itraconazole (Swift et al. 2006). In cases where lesions are suitable for focal or extensive surgical excision, a combined medical and surgical approach may be effective (Dedeaux et al. 2018).

8.13 Conclusion

Fungal infections of dogs are common all over the world. The infection may produce local infections involving the skin surface or systematic disease that can lead to fatal damage. As the symptoms of these infections can be similar to those of other

diseases that mimic a disseminated fungal infection, diagnosis and treatment are often delayed. The knowledge about clinical manifestations of each fungal infection and diagnostic methods, and early diagnosis of these infections are critical to effective treatment, prevention, and control. Diagnosis of these infections is difficult because of the lack of specific signs and symptoms, and rapid and accurate diagnostic tests. In addition, therapy for these infections, especially systemic diseases, is expensive due to drug costs, toxic due to high side effects of the drugs, and requires several weeks for treatment. Many fungal infections are zoonotic, and the infections can occur in both humans and animals and can be transmitted either by domestic pets or by wildlife animals. Among pet animals, dogs are responsible for transmission of these infections to owner and vice versa. The owners should be informed about the route of transmission to avoid these infections.

References

Abd Alfatah ME (2019) A review on bacterial and fungal diseases in dogs. JSM Vet Med Res 2:1–7

Adamama-Moraitou KK, Pardali D, Day MJ, Denning DW, Papazoglou L, Papastefanou A, Rallis TS (2011) *Aspergillus fumigatus* bronchopneumonia in a hellenic shepherd dog. J Am Anim Hosp Assoc 47(2):13–18

Allison N, Willard MD, Bentinck-Smith J, Davis K (1986) Nasal rhinosporidiosis in two dogs. J Am Anim Hosp Assoc 188(8):869–871

Anor S, Sturges BK, Lafranco L, Jang SS, Higgins RJ, Koblik PD, Lecouteur RA (2001) Systemic Phaeohyphomycosis (*Cladophialophora bantiana*) in a dog—clinical diagnosis with stereotactic computed tomographic-guided brain biopsy. J Vet Intern Med 15(3):257–261

Arceneaux KA, Taboada J, Hosgood G (1998) Blastomycosis in dogs: 115 cases (1980–1995). J Am Vet Med Assoc 213(5):658–664

Arseculeratne SN (2002) Recent advances in rhinosporidiosis and *Rhinosporidium seeberi*. Indian J Med Microbiol 20(3):119–131

Bagcigil AF, Ikiz S, Ozgür NY, Ilgaz A (2010) Recovery of dermatophytes in pet grooming tools from veterinary clinics and pet grooming salons. J Small Anim Pract 51(1):39–42

Ballber C, Hill TL, Bommer NX (2018) Minimally invasive treatment of sino-nasal aspergillosis in dogs. J Vet Intern Med 32(6):2069–2073

Bartlett PC, Vonbehren LA, Tewari RP, Martin RJ, Eagleton L, Isaac MJ, Kulkarni PS (1982) Bats in the belfry: an outbreak of histoplasmosis. Am J Public Health 72:1369–1372

Bateman BS (2002) Disseminated blastomycosis in a German shepherd dog. Can Vet J 43(7):550

Baumgardner DJ, Paretsky DP, Yopp AC (1995) The epidemiology of blastomycosis in dogs: north central Wisconsin, USA. J Med Vet Mycol 33:171–176

Belda B, Petrovitch N, Mathews KG (2018) Sinonasal aspergillosis: outcome after topical treatment in dogs with cribriform plate lysis. J Vet Intern Med 32(4):1353–1358

Benedict K, Roy M, Chiller T, Davis JP (2012) Epidemiologic and ecologic features of blastomycosis: a review. Curr Fungal Infect Rep 6:327–335

Benitah N (2006) Canine nasal aspergillosis. Clin Tech Small Anim Pract 21(2):82–88

Bennett PF, Talbot JJ, Martin P, Kidd SE, Makara M, Barrs VR (2018) Long term survival of a dog with disseminated *Aspergillus deflectus* infection without definitive treatment. Med Mycol Case Rep 22:1–3

Bentley RT, Faissler D, Sutherland-Smith J (2011) Successful management of an intracranial phaeohyphomycotic fungal granuloma in a dog. J Am Vet Med Assoc 239(4):480–485

Bergman RL, Medleau L, Hnilica K, Howerth E (2002) Dermatophyte granulomas caused by *Trichophyton mentagrophytes* in a dog. Vet Dermatol 13(1):49–52

Berry WL, Leisewitz AL (1996) Multifocal Aspergillus terreus discospondylitis in two German shepherd dogs. J S Afr Vet Assoc 67(4):222–228
Bloom JD, Hamor RE, Gerding PA (1996) Ocular blastomycosis in dogs: 73 cases, 108 eyes (1985–1993). J Am Vet Med Assoc 209:1271–1274
Börkü MK, Güzel M, Kocasarı Ş, Özkanlar Y (2003) Bir Köpekte Nazal Aspergillozis ve Sağaltımda Flukonazol Kullanımı. YYÜ Vet Fak Derg 14(2):91–93
Borteiro C, Etcheverze J, de León N, Nieto C, Arleo M, Debat CM, Kolenc F, Ubilla M, Freire J, Dutra F (2018) Rhinosporidiosis in a dog from Uruguay and review of the literature. Braz J Vet Pathol 11(3):92–96
Brilhante RS, Cavalcante CS, Soares-Junior FA, Cordeiro RA, Sidrim JJ, Rocha MF (2003) High rate of *Microsporum canis* feline and canine dermatophytoses in Northeast Brazil: epidemiological and diagnostic features. Mycopathologia 156(4):303–308
Brömel C, Sykes JE (2005) Histoplasmosis in dogs and cats. Clin Tech Small An P 20:227–232
Bruchim Y, Elad D, Klainbart S (2006) Disseminated aspergillosis in two dogs in Israel. Mycoses 49(2):130–133
Burrough E, Deitz K, Kinyon J, Andreasen C, Frana T, Sutton D, Thompson E, Fu J, Wickes B, Hostetter J (2012) Disseminated aspergillosis in a dog due to *Aspergillus alabamensis*. Med Mycol Case Rep 1(1):1–4
Buyukmihci N (1982) Ocular lesions of blastomycosis in the dog. J Am Vet Med Assoc 180(4):426–431
Cafarchia C, Romito D, Sasanelli M, Lia R, Capelli G, Otranto D (2004) The epidemiology of canine and feline dermatophytoses in southern Italy. Mycoses 47(11–12):508–513
Cafarchia C, Sasanelli M, Lia RP, de Caprariis D, Guillot J, Otranto D (2007) Lymphocutaneous and nasal sporotrichosis in a dog from southern Italy: case report. Mycopathologia 163(2):75–79
Caniatti M, Roccabianca P, Scanziani E, Finazzi M, Mortellaro CM, Romussi S, Mandelli G (1998) Nasal rhinosporidiosis in dogs: four cases from Europe and a review of the literature. Vet Rec 142(13):334–338
Carlotti DN, Bensignor E (1999) Dermatophytosis due to Microsporum persicolor (13 cases) or *Microsporum gypseum* (20 cases) in dogs. Vet Dermatol 10:17–27
Cerundolo R (2004) Generalized *Microsporum canis* dermatophytosis in six Yorkshire terrier dogs. Vet Dermatol 15(3):181–187
Chermette R, Ferreiro L, Guillot J (2008) Dermatophytoses in animals. Mycopathologia 166:385–405
Choptiany M, Wiebe L, Limerick B, Sarsfield P, Cheang M, Light B, Hammond G, Macdonald K, Trepman E, Pappas P, Embil JM (2009) Risk factors for acquisition of endemic blastomycosis. Can J Infect Dis Med Microbiol 20(4):117–121
Clinkenbeard KD, Cowell RL, Tyler RD (1988) Identification of Histoplasma organisms in circulating eosinophils of a dog. J Am Vet Med Assoc 192:217–218
Colombo AL, Tobón A, Restrepo A, Queiroz-Telles F, Nucci M (2011) Epidemiology of endemic systemic fungal infections in Latin America. Med Mycol 49:785–798
Connole MD (1990) Review of animal mycoses in Australia. Mycopathologia 111(3):133–164
Cordeiro RA, Coelho CG, Brilhante RS, Sidrim JJ, Castelo-Branco DS, Moura FB et al (2011) Serological evidence of Histoplasma capsulatum infection among dogs with leishmaniasis in Brazil. Acta Trop 119:203–205
Corrigan VK, Legendre AM, Wheat LJ, Mullis R, Johnson B, Bemis DA, Cepero L (2016) Treatment of disseminated aspergillosis with posaconazole in 10 dogs. J Vet Intern Med 30(1):167–173
Crothers SL, White SD, Ihrke PJ, Affolter VK (2009) Sporotrichosis: a retrospective evaluation of 23 cases seen in northern California (1987–2007). Vet Dermatol 20(4):249–259
Day MJ (2009) Canine sino-nasal aspergillosis: parallels with human disease. Med Mycol 47(Supplement_1):S315–S323
De Araujo T, Marques AC, Kerdel F (2001) Sporotrichosis. Int J Dermatol 40(12):737–742
De Groote MA, Bjerke R, Smith H, Rhodes IIILV (2000) Expanding epidemiology of blastomycosis: clinical features and investigation of 2 cases in Colorado. Clin Infect Dis 30(3):582–584

De Lorimier LP, Fan TM (2010) Delayed diagnosis of fungal osteomyelitis with early scintigraphic lesions in a dog. Can Vet J 51:1394–1396

Dedeaux A, Grooters A, Wakamatsu-Utsuki N, Taboada J (2018) Opportunistic fungal infections in small animals. J Am Anim Hosp Assoc 54(6):327–337

Dedola C, Stuart AP, Ridyard AE, Else RW, van den Broek AH, Choi JS, de Hoog GS, Thoday KL (2010) Cutaneous *Alternaria infectoria* infection in a dog in association with therapeutic immunosuppression for the management of immune-mediated haemolytic anaemia. Vet Dermatol 21:626–634

Denton JF, Di Salvo AF, Hirsch ML (1967) Laboratory-acquired North American blastomycosis. JAMA 199(12):935–936

Dillehay DL, Ribas JL, Newton JC Jr, Kwapien RP (1987) Cerebral phaeohyphomycosis in two dogs and a cat. Vet Pathol 24(2):192–194

Dion WM, Speckmann G (1978) Canine otitis externa caused by the fungus *Sporothrix schenkii*. Can Vet J 19(2):44–45

Durán Graeff L, Seidel D, Vehreschild MJ, Hamprecht A, Kindo A, Racil Z, Wisplinghoff H (2017) Invasive infections due to Saprochaete and Geotrichum species: report of 23 cases from the FungiScope Registry. Mycoses 60(4):273–279

Durkin M, Witt J, Lemonte A, Wheat B, Connolly P (2004) Antigen assay with the potential to aid in diagnosis of blastomycosis. J Clin Microbiol 42(10):4873–4875

Easley JR, Meuten DJ, Levy MG, Dykstra MJ, Breitschwerdt EB, Holzinger EA, Cattley RC (1986) Nasal rhinosporidiosis in the dog. Vet Pathol 23(1):50–56

Elad D, Lahav D, Blum S (2008) Transuterine transmission of *Aspergillus terreus* in a case of disseminated canine aspergillosis. Med Mycol 46(2):175–178

Farias MR, Assunção DL, Duarte G, Vandresen G, Werner J, Tarqeti U (2015) Canine bone sporotrichosis: a case report. Sem Cienc Agrar 36(3):1445–1450

Ferreira RR, Ferreiro L, Spanamberg A, Driemeier D, Machado ML, Bianchi SP, Schmidt D, Guillot J (2011) Canine sinonasal aspergillosis. Acta Sci Vet 39(4):1009

Ferrer C, Colom F, Frases S, Mulet E, Abad JL, Alio JL (2001) Detection and identification of fungal pathogens by PCR and by ITS2 and 5.8S ribosomal DNA typing in ocular infections. J Clin Microbiol 39:2873–2879

Ganguly S, Ahmad Para P, Showkat S (2017) Mycological investigation of dermatophytosis in dog: a case study. J Entomol Zool Stud 5(1):970–971

Garcia RS, Wheat LJ, Cook AK, Kirsch EJ, Sykes JE (2012) Sensitivity and specificity of a blood and urine galactoman- nan antigen assay for diagnosis of systemic aspergillosis in dogs. J Vet Intern Med 26:911–919

Ghibaudo G, Peano A (2010) Chronic monolateral otomycosis in a dog caused by *Aspergillus ochraceus*. Vet Dermatol 21(5):522–526

Giri DK, Sims WP, Sura R, Cooper JJ, Gavrilov BK, Mansell J (2011) Cerebral and renal phaeohyphomycosis in a dog infected with Bipolaris species. Vet Pathol 48(3):754–757

Goad DL, Goad ME (1986) Osteoarticular sporotrichosis in a dog. J Am Vet Med Assoc 189(10):1326–1328

Goodale EC, Outerbridge CA, White SD (2016) Aspergillus otitis in small animals--a retrospective study of 17 cases. Vet Dermatol 27(1):3–e2

Graybill JR, Hernandez S, Bocanegra R, Najvar L (2004) Antifungal therapy of murine *Aspergillus terreus* infection. Antimicrob Agents Chemother 48:3715–3719

Guillot J, Garcia-Hermoso D, Degorce F, Deville M, Calvie C, Dickele G, Delisle F, Chermette R (2004) Eumycetoma caused by Cladophialophora bantiana in a dog. J Clin Microbiol 42:4901–4903

Gupta AK, Cooper EA (2008) Update in antifungal therapy of dermatophytosis. Mycopathologia 166(5–6):353–367

Hendrix DV, Rohrbach BW, Bochsler PN, English RV (2004) Comparison of histologic lesions of endophthalmitis induced by Blastomyces dermatitidis in untreated and treated dogs: 36 cases (1986–2001). J Am Vet Med Assoc 224(8):1317–1322

Hill SA, Sharkey LC, Hardy RM, Wilke VL, Smith MA, Anderson GM (2010) Nasal rhinosporidiosis in two dogs native to the upper Mississippi river valley region. J Am Anim Hosp Assoc 46(2):127–131

Hoff B, Hall DA (1986) Rhinosporidiosis in a dog. Can Vet J 27(6):231–232

Kabay MJ, Robinson WF, Huxtable CR, McAleer R (1985) The pathology of disseminated *Aspergillus terreus* infection in dogs. Vet Pathol 22(6):540–547

Kalokhe AS, Rouphael N, El Chami MF, Workowski KA, Ganesh G, Jacob JT (2010) *Aspergillus endocarditis*: a review of the literature. Int J Infect Dis 14(12):1040–1047

Kelly SE, Shaw SE, Clark WT (1995) Long-term survival of four dogs with disseminated *Aspergillus terreus* infection treated with itraconazole. Aust Vet J 72:311–313

Kennedy FA, Buggage RR, Ajello L (1995) Rhinosporidiosis: a description of an unprecedented outbreak in captive swans (*Cygnus* spp.) and a proposal for revision of the ontogenic nomenclature of Rhinosporidium seeberi. J Med Vet Mycol 33(3):157–165

Kim SH, Yong HC, Yoon JH, Youn HY, Yoshioka N, Kano R, Hasegawa A (2003) *Aspergillus niger* pulmonary infection in a dog. J Vet Med Sci 65(10):1139–1140

Klein BS, Squires RA, Lloyd JK, Ruge DR, Legendre AM (2006) Canine antibody response to *Blastomyces dermatitidis* WI-1 antigen. Am J Vet Res 61(5):554–558

Koehne G, Powell HS, Hail RI (1971) Sporotrichosis in a dog. J Am Vet Med Assoc 159(7):892–894

Lavely J, Lipsitz D (2005) Fungal infections of the central nervous system in the dog and cat. Clin Tech Small Anim Pract 20(4):212–219

Lee YJ, Hsu WL, Lin CF, Lee SW, Cheng FP (2010) Intestinal geotrichosis in a German shepherd. Turk J Vet Anim Sci 34(5):481–484

Legendre AM, Walker M, Buyukmihci N, Stevens R (1981) Canine blastomycosis: a review of 47 clinical cases. J Am Vet Med Assoc 178(11):1163–1168

Legendre AM, Rohrbach BW, Toal RL, Rinaldi MG, Grace LL, Jones JB (1996) Treatment of blastomycosis with itraconazole in 112 dogs. J Vet Intern Med 10(6):365–371

Lincoln SD, Adcock JL (1968) Disseminated geotrichosis in a dog. Pathol Vet 5(3):282–289

Lobetti RG (1996) Leukogram and serum globulin values in two dogs with systemic *Xylohypha bantiana* infection. J S Afr Vet Assoc 67(2):91–92

Lomax LG, Cole JR, Padhye AA, Ajello L, Chandler FW, Smith BR (1986) Osteolytic phaeohyphomycosis in a German shepherd dog caused by *Phialemonium obovatum*. J Clin Microbiol 23(5):987–991

Lyon GM, Bravo AV, Espino A, Lindsley MD, Gutierrez RE, Rodriguez I, Corella A, Carrillo F, Mcneil MM, Warnock DW, Hajjeh RA (2004) Histoplasmosis associated with exploring a bat-inhabited cave in Costa Rica, 1998–1999. Am J Trop Med Hyg 70:438–442

Mackie JT, Kaufman L, Ellis D (1997) Confirmed histoplasmosis in an Australian dog. Aust Vet J 75:362–363

Maertens JA (2004) History of the development of azole derivatives. Clin Microbiol Infect 10:1–10

Mascarenhas MB, Lopes NL, Pinto TG, Costa TS, Peixoto AP, Ramadinha RR, Fernandes JI (2018) Canine sporotrichosis: report of 15 advanced cases. Pesqui Vet Bras 38(3):477–481

Mathews KG, Davidson AP, Koblik PD, Richardson EF, Komtebedde J, Pappagianis D, Kass PH (1998) Comparison of topical administration of clotrimazole through surgically placed versus nonsurgically placed catheters for treatment of nasal aspergillosis in dogs: 60 cases (1990–1996). J Am Vet Med Assoc 213(4):501–506

Mattei AS, Beber MA, Madrid IM (2014) Dermatophytosis in small animals. SOJ Microbiol Infect Dis 2(3):1–6

Mayer UK, Glos K, Schmid M, Power HT, Bettenay SV, Mueller RS (2008) Adverse effects of ketoconazole in dogs–a retrospective study. Vet Dermatol 19(4):199–208

Mazu TK, Bricker BA, Flores-Rozas H, Ablordeppey SY (2016) The mechanistic targets of antifungal agents: an overview. Mini Rev Med Chem 16(7):555–578

McMillan CJ, Taylor SM (2008) Transtracheal aspiration in the diagnosis of pulmonary blastomycosis (17 cases: 2000–2005). Can Vet J 49:53–55

Mignon BR, Losson BJ (1997) Prevalence and characterization of Microsporum canis carriage in cats. J Med Vet Mycol 35(4):249–256
Miller RI, Baylis R (2009) Rhinosporidiosis in a dog native to the UK. Vet Rec 164:210
Miranda LH, Quintella LP, Menezes RC, dos Santos IB, Oliveira RV, Figueiredo FB, Lopes-Bezerra LM, Schubach TM (2011) Evaluation of immunohistochemistry for the diagnosis of sporotrichosis in dogs. Vet J 190(3):408–411
Mitchell M, Stark DR (1980) Disseminated canine histoplasmosis: a clinical survey of 24 cases in Texas. Can Vet J 21:95–100
Moriello KA (2004) Treatment of dermatophytosis in dogs and cats: review of published studies. Vet Dermatol 15(2):99–107
Moriello KA, Franks P, Lewis DD, King R (1988) Cutaneouslymphatic and nasal sporotrichosis in a dog. J Am Anim Hosp Assoc 24:621–626
Moriello KA, Coyner K, Paterson S, Mignon B (2017) Diagnosis and treatment of dermatophytosis in dogs and cats. Clinical consensus guidelines of the World Association for Vet Dermatol. Vet Dermatol 28(3):266–268
Mortellaro CM, Franca PD, Caretta G (1989) Aspergillus fumigatus, the causative agent of infection of the frontal sinuses and nasal chambers of the dog. Mycoses 32(7):327–335
Mosier DA, Creed JE (1984) Rhinosporidiosis in a dog. J Am Vet Med Assoc 185(9):1009–1010
Mourning AC, Patterson EE, Kirsch EJ, Renschler JS, Wolf LA, Paris JK, Durkin MM, Wheat LJ (2015) Evaluation of an enzyme immunoassay for antibodies to a recombinant Blastomyces adhesin-1 repeat antigen as an aid in the diagnosis of blastomycosis in dogs. J Am Vet Med Assoc 247(10):1133–1138
Muller A, Guaguère E, Degorce-Rubiales F, Bourdoiseau G (2011) Dermatophytosis due to *Microsporum persicolor*: a retrospective study of 16 cases. Can Vet J 52(4):385–388
Needles RK (2017) Successful treatment of blastomycosis in a 7-year-old, female golden retriever dog on Manitoulin Island, Ontario. Can Vet J 58(6):617
Pal M (2005) Role of *Geotrichum candidum* in canine oral ulcers. Rev Iberoam Micol 22(3):183
Pal M, Lee CW, Matsusaka N (2002) Occurrence of Geotrichum candidum in two cases of canine dermatitis. J Vet Clin 19:433–435
Patel AJ, Gattuso P, Reddy VB (2010) Diagnosis of blastomycosis in surgical pathology and cytopathology: correlation with microbiologic culture. Am J Surg Pathol 34:256–261
Pavelski M, Seixas SV, Warth JFG, Souza CD, Dittrich RL, Froes TR (2018) Fungal pneumonia in dogs and cats with pulmonary clinical signs in southern Brazil. Pesqui Vet Bras 38(4):696–702
Peeters D, Clercx C (2007) Update on canine sinonasal aspergillosis. Vet Clin North Am Small Anim Pract 37(5):901
Perrins N, Howell S, Moore M, Bond R (2005) Inhibition of the growth in vitro of *Trichophyton mentagrophytes*, *Trichophyton erinacei* and *Microsporum persicolor* by miconazole and chlorhexidine. Vet Dermatol 16:330–333
Ramírez-Soto MC, Aguilar-Ancori EG, Tirado-Sánchez A, Bonifaz A (2018) Ecological determinants of sporotrichosis etiological agents. J Fungi 4(3):95
Rao PVR, Jain SN (1971) Rhinosporidiosis in animals. Ind J Otol 23:106–109
Reginato A, Giannuzzi P, Ricciardi M, De Simone A, Sanguinetti M, Porcellato I, Mandara MT (2014) Extradural spinal cord lesion in a dog: first case study of canine neurological histoplasmosis in Italy. Vet Microbiol 170:451–455
Reppas GP, Snoeck TD (1999) Cutaneous geotrichosis in a dog. Aust Vet J 77(9):567–569
Rhyan JC, Stackhouse LL, Davis EG (1990) Disseminated geotrichosis in two dogs. J Am Vet Med Assoc 197(3):358–360
Robinson WF, Connole MD, King TJ, Pitt JI, Moss SM (2000) Systemic mycosis due to *Aspergillus deflectus* in a dog. Aust Vet J 78(9):600–602
Rossi CN, Odaguiri J, Larsson CE (2013) Retrospective assessment of the treatment of sporotrichosis in cats and dogs using itraconazole. Acta Sci Vet 41(1):1–5
Rothenburg LS, Snider TA, Wilson A, Confer AW, Ramachandran A, Mani R, Rizzi T, Nafe L (2017) Disseminated phaeohyphomycosis in a dog. Med Mycol Case Rep 15:28–32

Rubin SI, Krawiec DR, Gelberg H, Shanks RD (1989) Nephrotoxicity of amphotericin B in dogs: a comparison of two methods of administration. Can J Vet Res 53(1):23

Rudmann DG, Coolman BR, Perez CM, Glickman LT (1992) Evaluation of risk factors for blastomycosis in dogs: 857 cases (1980–1990). J Am Vet Med Assoc 201(11):1754–1759

Sakai MR, May ER, Imerman PM, Felz C, Day TA, Carlson SA, Noxon JO (2011) Terbinafine pharmacokinetics after single dose oral administration in the dog. Vet Dermatol 22(6):528–534

Sanford SE, Straube U (1991) Disseminated histoplasmosis in a young dog. Can Vet J 32:692

Saunders JH, Clercx C, Snaps FR, Sullivan M, Duchateau L, van Bree HJ, Dondelinger RE (2004) Radiographic, magnetic resonance imaging, computed tomographic, and rhinoscopic features of nasal aspergillosis in dogs. J Am Vet Med Assoc 225(11):1703–1712

Schmiedt C, Kellum H, Legendre AM, Gompf RE, Bright JM, Houle CD, Schutten M, Stepien R (2006) Cardiovascular involvement in 8 dogs with blastomyces dermatitidis infection. J Vet Intern Med 20(6):1351–1354

Schroeder H, Jardine JE, Davis V (1994) Systemic phaeohyphomycosis caused by *Xylohypha bantiana* in a dog. J S Afr Vet Assoc 65(4):175–178

Schubach TM, Schubach A, Okamoto T, Barros MB, Figueiredo FB, Cuzzi T, Pereira SA, Dos Santos IB, Almeida Paes RD, Paes Leme LR, Wanke B (2006) *Canine sporotrichosis* in Rio de Janeiro, Brazil: clinical presentation, laboratory diagnosis and therapeutic response in 44 cases (1998–2003). Med Mycol J 44(1):87–92

Schuller S, Clercx C (2007) Long-term outcomes in dogs with sinonasal aspergillosis treated with intranasal infusions of enilconazole. J Am Anim Hosp Assoc 43:33–38

Schulman RL, McKiernan BC, Schaeffer DJ (1999) Use of corticosteroids for treating dogs with airway obstruction secondary to hilar lymphadenopathy caused by chronic histoplasmosis16 cases (1979–1997). J Am Vet Med Assoc 214:1345–1348

Schultz RM, Johnson EG, Wisner ER, Brown NA, Byrne BA, Sykes JE (2008) Clinicopathologic and diagnostic imaging characteristics of systemic aspergillosis in 30 dogs. J Vet Intern Med 22:851–589

Schumacher LL, Love BC, Ferrell M, DeSilva U, Fernando R, Ritchey JW (2013) Canine intestinal histoplasmosis containing hyphal forms. J Vet Diagnostic Investig 25:304–307

Schwartz IS (2017) Blastomycosis in mammals. In: Emerging and epizootic fungal infections in animals, Medical microbiology, pp 159–176

Selby LA, Becker SV, Hayes HW (1981) Epidemiologic risk factors associated with canine systemic mycoses. Am J Epidemiol 113:133–139

Seyedmousavi S, Guillot J, Arné P, de Hoog GS, Mouton JW, Melchers WJ, Verweij PE (2015) *Aspergillus* and aspergilloses in wild and domestic animals: a global health concern with parallels to human disease. Med Mycol J 53(8):765–797

Sfakianakis A, Krasagakis K, Stefanidou M, Maraki S, Koutsopoulos A, Kofteridis D, Tosca A (2007) Invasive cutaneous infection with Geotrichum candidum–sequential treatment with amphotericin B and voriconazole. Med Mycol J 45(1):81–84

Sharman MJ, Mansfield CS (2012) Sinonasal aspergillosis in dogs: a review. J Small Anim Pract 53(8):434–444

Sharp NJH, Sullivan M, Harvey CE (1993) Treatment of canine nasal aspergillosis with enilconazole. J Vet Intern Med 7:40–43

Sidhu RK, Singh KB, Jand SK, Joshi DV (1993) Cutaneous geotrichosis in a dog and its handler a case report. Indian J Anim Res 32(1):75

Singh K, Flood J, Welsh RD, Wyckoff JH, Snider TA, Sutton DA (2006) Fatal systemic phaeohyphomycosis caused by *Ochroconis gallopavum* in a dog (*Canis familaris*). Vet Pathol 43(6):988–992

Sinha A, Phukan JP, Bandyopadhyay G, Sengupta S, Bose K, Mondal RK, Choudhuri MK (2012) Clinicopathological study of rhinosporidiosis with special reference to cytodiagnosis. J Cytol 29(4):246–249

Sissener TR, Bacon NJ, Friend E, Anderson DM, White RAS (2006) Combined clotrimazole irrigation and depot therapy for canine nasal aspergillosis. J Small Anim Prac 47(6):312–315

Southard C (1987) Bronchopulmonary aspergillosis in a dog. J Am Vet Med Assoc 190:875–877
Spector D, Legendre AM, Wheat J, Bemis D, Rohrbach B, Taboada J, Durkin M (2008) Antigen and antibody testing for the diagnosis of blastomycosis in dogs. J Vet Intern Med 22:839–843
Sumithra TG, Chaturvedi VK, Rai AK, Sunita SC, Siju SJ, Remya V, Susan C (2013) A review and update on canine and feline histoplasmosis. Asian J Anim Sci 1:14–26
Swift IM, Griffin A, Shipstone MA (2006) Successful treatment of disseminated cutaneous phaeohyphomycosis in a dog. Aust Vet J 84(12):431–435
Sykes JE, Torres SM, Armstrong PJ, Lindeman CJ (2001) Itraconazole for treatment of sporotrichosis in a dog residing on a Christmas tree farm. J Am Vet Med Assoc 218(9):1440–1421
Taylor AR, Young BD, Levine GJ, Eden K, Corapi W, Rossmeisl JH Jr, Levine JM (2015) Clinical features and magnetic resonance imaging findings in 7 dogs with central nervous system aspergillosis. J Vet Intern Med 29(6):1556–1563
Totten AK, Ridgway MD, Sauberli DS (2011) Blastomyces dermatitidis prostatic and testicular infection in eight dogs (1992–2005). J Am Anim Hosp Assoc 47(6):413–418
Tyre E, Eisenbart D, Foley P, Burton S (2007) Histoplasmosis in a dog from New Brunswick. Can Vet J 48:734–736
Valdes ID, van den Berg J, Haagsman A, Escobar N, Meis JF, Hagen F, Haas PJ, Houbraken J, Wösten H, de Cock H (2018) Comparative genotyping and phenotyping of *Aspergillus fumigatus* isolates from humans, dogs and the environment. BMC Microbiol 18(1):118
Viana PG, Figueiredo A, Gremião I, de Miranda L, da Silva Antonio IM, Boechat JS, de Sá Machado AC, de Oliveira M, Pereira SA (2018) Successful treatment of canine sporotrichosis with terbinafine: case reports and literature review. Mycopathologia 183(2):471–478
Vieson MD, Piñeyro P, LeRoith T (2012) A review of the pathology and treatment of canine respiratory infections. Vet Med 3:25–39
Wallin LL, Coleman GD, Froeling J, Parker GA (2001) Rhinosporidiosis in a domestic cat. Med Mycol J 39(1):139–141
Waurzyniak BJ, Hoover JP, Clinkenbeard KD, Welsh RD (1992) Dual systemic mycosis caused by *Bipolaris spicifera* and *Torulopsis glabrata* in a dog. Vet Pathol 29(6):566–569
Wheat LJ (2003) Current diagnosis of histoplasmosis. Trends Microbiol 11:488–494
Whitley NT, Cauvin A, Burton C, Bray J, Van Dongen P, Littlewood J (2010) Long term survival in two German shepherd dogs with Aspergillus-associated cavitary pulmonary lesions. J Small Anim Pract 51(10):561–561
Whittemore JC, Webb CB (2007) Successful treatment of nasal sporotrichosis in a dog. Can Vet J 48(4):411–414
Wiebe V, Karriker M (2005) Therapy of systemic fungal infections: a pharmacologic perspective. Clin Tech Small Anim Pract 20(4):250–257
Yang W, Jones BR, Rossi G, Stephens N, Arthur I, Merritt A, Reese S, Langner K (2020) First case of a dog infected with *Aspergillus* (Phialosimplex) *caninus* in Australasia. N Z Vet J 68(4):231–237
Yildiz K, Dokuzeylul B, Ulgen S, Or ME (2016) Blastomycosis: a systematical review. Res Rev J Vet Sci 2(1):84–88
Zhang S, Corapi W, Quist E, Griffin S, Zhang M (2012) Aspergillus versicolor, a new causative agent of canine disseminated aspergillosis. J Clin Microbiol 50(1):187–191