Journal of Infection 78 (2019) 48–53

Contents lists available at ScienceDirect

Journal of Infection

journal homepage: www.elsevier.com/locate/jinf

Infections with the agent of 'kennel cough' in patients with cancer

Ariel D. Szvalb[a,*], Kenneth V. Rolston[a], Nobuyoshi Mori[a], Jeffrey J. Tarrand[b], Victor E. Mulanovich[a]

[a] Department of Infectious Diseases, Infection Control and Employee Health, The University of Texas MD Anderson Cancer Center, 1515 Holcombe Boulevard, Unit 1460, Houston, TX, 77030, USA
[b] Department of Laboratory Medicine, The University of Texas MD Anderson Cancer Center, 1515 Holcombe Boulevard, Unit 0084, Houston, TX, 77030, USA

ARTICLE INFO

Article history:
Accepted 16 July 2018
Available online 23 July 2018

Keywords:
Bordetella bronchiseptica
Respiratory tract infection
Zoonosis
Kennel cough in humans

SUMMARY

Objective: To investigate the clinical manifestations, microbiological data, and outcomes of *Bordetella bronchiseptica* (Bb) infections in patients with cancer.
Methods: Review of electronic medical records of 24 patients with Bb infection, from 2000 to 2013. An infection was considered to be associated with Bb if both clinical manifestations plus microbial growth from infected sites were present.
Results: Ten patients (42%) had a monomicrobial infection, whereas multiple pathogens in addition to Bb were isolated from the rest (14 patients, 58%). The most frequent sites of infection were the respiratory tract (18 patients, 75 %) and bloodstream (17%). The most frequently associated conditions were lymphopenia (71%), tobacco use (42%), and chemotherapeutic or immunosuppressive agents (33% each). Animal exposure was established in four patients. Overall, the response rate to treatment was 100% for monomicrobial and 79% for polymicrobial infections, respectively.
Conclusions: Bb is an uncommon pathogen even in immunosuppressed patients. Predominant sites of infection are the respiratory tract and bloodstream. Bb should be considered pathogenic in immunocompromised hosts, particularly with history of zoonotic exposure, even if accompanied by co-pathogens. Therefore, contact with potential animal sources should be minimized. The infection ranges from mild to severe and has no specific clinical or radiographic manifestations.

Introduction

The *Bordetella* complex consists of three species, *Bordetella pertussis, Bordetella parapertussis* and *Bordetella bronchiseptica*. While the features of infections caused by *B. pertussis* and *B. parapertussis* are well described, *B. bronchiseptica* remains a lesser known pathogen. It is a Gram-negative coccobacillus, and is primarily a zoonotic pathogen. Unlike *B. pertussis* which is a host-specific and human adapted organism that causes 'whooping cough', *B. bronchiseptica* can cause disease in various mammalian species including 'kennel cough' in dogs, snuffles in rabbits, and atrophic rhinitis in swine. The organism is considered an airborne pathogen that spreads easily among animals living in close quarters. It may occasionally be found as a commensal or colonizer of the human respiratory tract, but causes true infection infrequently. *Bordetella bronchiseptica* human infections occur mostly in immunocompromised individuals exposed to infected pets or farm animals.[1,2] The infection has occasionally been reported in patients with no known animal exposure. Nosocomial transmission of infection was considered possible when two cases were identified in a pulmonary ward and were suspected to be due to patient-to-patient or third-party transmission.[3,4] It has been hypothesized that *B. bronchiseptica* gave origin to *B. pertussis* and *B. parapertussis*, which are exclusive human pathogens.[5,6] The latter two became more virulent and human specific after the loss of regulatory and control genes in the former.[7,8] Literature on human infections caused by *B. bronchiseptica* is scarce and consists of single case reports or small case series extending over several decades.[9]

Our institution (The University of Texas, MD Anderson Cancer Center in Houston, Texas) has been designated a Comprehensive Cancer Center by the National Cancer Institute and provides care exclusively for patients with cancer. Our center has approximately 650 beds, with around 25,000 hospital admissions annually. This unique setting enabled us to review and report on the characteristics of *B. bronchiseptica* infections in patients with cancer, including hematopoietic stem cell transplantation (HSCT) recipients.

* Corresponding author.
E-mail address: adszvalb@mdanderson.org (A.D. Szvalb).

https://doi.org/10.1016/j.jinf.2018.07.010
0163-4453/

Methods

Hospital setting and study population

This study was conducted at The University of Texas MD Anderson Cancer Center, Houston, Texas, after approval by the institutional review board (IRB). Our institutional microbiology laboratory receives and processes all clinical cultures. We conducted a retrospective review of the records of this laboratory in order to identify patients from whom *B. bronchiseptica* was recovered between January 1, 2000 and December 20, 2013. The organisms were identified in the laboratory using the Vitek-2 system. The medical records of these patients were reviewed in detail. Data from patients from whom *B. bronchiseptica* was the only pathogen isolated were analyzed separately from those with multiple pathogens isolated.

Definitions

Infection with *B. bronchiseptica* was defined as the presence of clinical manifestations (including systemic and/or localized signs or symptoms) along with recovery of the organism from clinically infected sites such as blood, respiratory specimens such as sputum or bronchoalveolar lavage (BAL), urine, or other normally sterile body sites. Patients who did not satisfy both requirements were excluded from this analysis. Pneumonia was defined by the presence of cough (with or without sputum production) and a new infiltrate on radiographic imaging of the chest such as X-ray or computed tomography (CT).[10] Patients with fever and clinical symptoms of respiratory tract infection without positive chest imaging were considered to have an upper respiratory tract infection (URI) or tracheobronchitis. Neutropenia was defined as an absolute neutrophil count of ≤500 cells/μL and lymphopenia was defined as an absolute lymphocyte count of ≤1000 cells/μL.

Data collection

We collected information on patient demographics (age, gender, and ethnicity), comorbid conditions, animal exposure, type of cancer and HSCT, as well as clinical features at the time of presentation. Additionally, laboratory, microbiological, and imaging data were also collected. Antibiotic susceptibilities, antibiotic regimen, and clinical outcomes including the need for intensive care unit (ICU), were also reviewed.

Statistical analysis

Descriptive statistics were utilized for analyzing demographic, clinical, and laboratory data. Continuous variables were summarized using mean with standard deviation or median with 25th and 75th percentile (Q1–Q3) depending on whether data were normally distributed. Categorical variables were summarized using frequencies and percentages.

Results

Demographic data

A review of the microbiological records of our institution during the study period identified twenty-four adult patients with positive cultures for *B. bronchiseptica*, Fig. 1. Ten patients (42%) had a monomicrobial infection (*B. bronchiseptica* as the only pathogen isolated), whereas multiple pathogens in addition to *B. bronchiseptica* were isolated from the rest (14 patients, 58%). Demographic details of these patients are shown in Table 1. The median age of these patients was 54.5 years (Q1–Q3 = 43–66). Most of the infections (92%) occurred in white men. The underlying cancers were almost equally distributed between hematological malignancies and solid tumors. None of the patients had human immunodeficiency virus (HIV) infection or acquired immunodeficiency syndrome (AIDS). Six patients (25%) underwent HSCT (4 autologous and 2 allogeneic). Both allogeneic HSCT recipients were receiving corticosteroids and tacrolimus at the time of infection. Two of the HSCT patients had contact with animals at home (dog in one case and cattle and horses in the other). Five of these six patients presented with a respiratory infection, 2 of them with pneumonia.

Table 1
Characteristics of patients with *Bordetella bronchiseptica* infection.

Variable	Episodes no. (%) ($n = 24$)
Age in years, median (Q1–Q3)	54.5 (43–66)
Male	18 (75)
Ethnicity	
White	22 (92)
Hispanic	1 (4)
Black	1 (4)
Underlying malignancy	24 (100)
Hematologic	13 (54)
Acute myeloid leukemia	6
Multiple myeloma	2
Follicular lymphoma	2
Chronic leukemia[a]	2
Non-Hodgkin's lymphoma	1
Solid	11 (46)
Non-small cell lung cancer	2
Melanoma	2
Others[b]	7
Stem cell transplantation status	6 (25)
Autologous	4
Matched unrelated donor	1
Matched related donor	1
Known animal exposure	4 (17)
Comorbidities	
Smoker	10 (42)
Immunosuppressive agents[c]	8 (33)
Chemotherapy[d]	8 (33)
COPD	3 (12)
Lymphopenia (<1000 cells/μL)	17 (71)
Neutropenia (<500 cells/μL)	4 (17)

Notes: Data are *N* (%), unless otherwise indicated.
COPD, Chronic Obstructive Pulmonary Disease.
[a] Chronic myeloid leukemia (1); and chronic lymphocytic leukemia (1).
[b] Urethral squamous cell carcinoma (1); esophageal carcinoma (1); prostate adenocarcinoma (1); carcinoid (1); anaplastic astrocytoma (1); and unknown primary (2).
[c] Administered within 3 months from clinical presentation: tacrolimus (3); temozolomide (2); rituximab (1); and corticosteroids (2).
[d] Administered within 3 months from clinical presentation.

The most frequently associated conditions were lymphopenia (71%), tobacco use (42%), and antineoplastic chemotherapy or use of immunosuppressive agents (including corticosteroids) within the previous 3 months (33% each). Neutropenia was documented in only 4 (17%) of patients suggesting that it is not a significant risk factor. Animal exposure was also documented only in 4 patients. Unfortunately, this information was either not obtained or not documented in the remaining patients probably underestimating the overall frequency of animal exposure.

Infection sites

Among the 10 patients with a monomicrobial infection, 5 met the definition for pneumonia, 3 had tracheobronchitis, and there was one instance each of bloodstream infection (BSI) and urinary

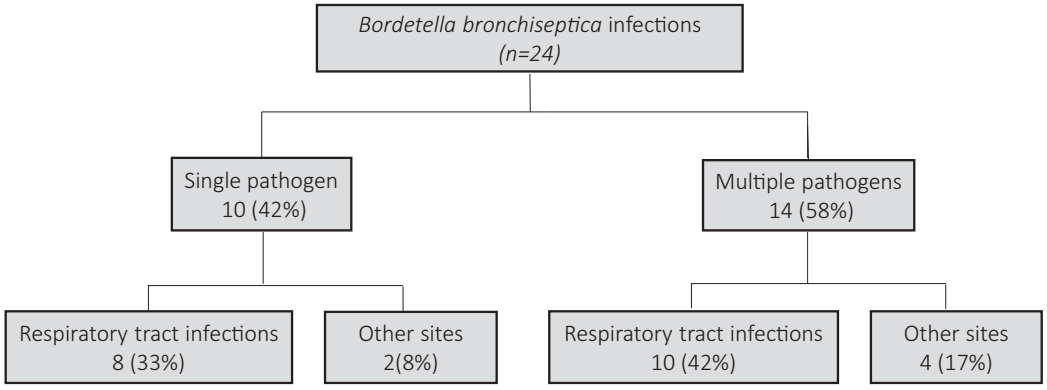

Fig. 1. *Bordetella bronchiseptica* infections. Single and multiple pathogen cases.

Table 2
Bordetella bronchiseptica as a single pathogen.

Patient	Cancer/HSCT	Syndrome	Source
1	AML	Bacteremia	Blood
2	AML/AUTO	Pneumonia	Sputum
3	Lung	Pneumonia	Sputum
4	Lung	Pneumonia	BAL
5	Melanoma	Pneumonia	BAL
6	Lymphoma	Pneumonia	Sputum
7	Lymphoma	Tracheobronchitis	Sputum
8	Lymphoma/MUD	Tracheobronchitis	Sputum
9	MM/AUTO	Tracheobronchitis	Sputum
10	Urethral	UTI	Urine

Note: HSCT: hematopoietic stem cell transplantation; AML: acute myeloid leukemia; AUTO: autologous stem cell transplantation; BAL: bronchoalveolar lavage; MUD: matched unrelated donor stem cell transplantation; MM: multiple myeloma; and UTI: urinary tract infection.

tract infection (UTI), Table 2. Among the 14 patients with polymicrobial infections there were 5 instances of pneumonia, 4 instances of tracheobronchitis, 3 instances of BSI, and 1 instance each of acute sinusitis and intra-abdominal infection (Table 3). Combining these data, the most frequent site of infection for the entire cohort was the respiratory tract (18 patients, 75%). BSI was the next most frequent infection (17%) with 3 of the 4 BSIs being polymicrobial.

Clinical and radiographic manifestations

The most common clinical manifestations were fever and cough (46% each), followed by dyspnea (33%), Table 4. Among the patients with a respiratory infection, the most common clinical manifestations were cough (46%) and dyspnea (33%), followed by fever (25%). In contrast, all 4 patients with BSI were febrile but none had cough or dyspnea. The cough was productive in 9 of 11 patients (82%) whereas the 2 other patients had a non-productive cough. Imaging studies of the chest showed lobar consolidation in 6 cases of pneumonia and diffuse infiltrates in the remaining four.

Laboratory analyses

The median absolute neutrophil count was 3590 cells/μL (Q1–Q3 = 840–7987), and 4 (17%) patients had neutropenia at the time of infection. The median lymphocyte count was 480 (Q1–Q3 = 260–1445), and 17 (71%) patients had lymphopenia.

Microbiology and antimicrobial susceptibility

In patients with single pathogen infection, *B. bronchiseptica* was isolated from respiratory specimens in 8 (6 sputum and 2 BAL), and from the blood and urine in one patient each. Five patients with pneumonia had multiple pathogens isolated, the most common co-pathogens being other bacteria (*Pseudomonas aeruginosa, Stenotrophomonas maltophilia, Escherichia coli, and Klebsiella pneumoniae*) and *Fusarium spp*. In the four patients with tracheobronchitis the co-pathogens were *Staphylococcus aureus, Pseudomonas aeruginosa, Mycobacterium fortuitum*, and respiratory syncytial virus (RSV). Co-pathogens from the 3 polymicrobial BSIs included *Staphylococcus aureus, Agrobacterium radiobacter*, and *Mycobacterium mucogenicum*. Finally, 2 other cases involved cultures obtained from a percutaneously drained intra-abdominal fluid collection and a sinus fluid drainage culture that exhibited growth of multiple organisms (Tables 2 and 3).

Antibiotic susceptibilities were determined for all 24 *B. bronchiseptica* isolates. As there are no established susceptibility and resistance breakpoints for *Bordetella bronchiseptica*, we were not able to classify the organisms as susceptible or resistant. Therefore, we considered the agents with relatively lower MICs as having good in-vitro activity, and those with higher MICs as being less active. Overall, the aminoglycosides (amikacin, tobramycin), beta-lactam/beta-lactamase combinations (amoxicillin/clavulanate, ticarcillin/clavulanate, and piperacillin/tazobactam), imipenem, the quinolones (ciprofloxacin, moxifloxacin) and tigecycline, had good in-vitro activity against most of the isolates tested, whereas trimethoprim-sulfamethoxazole and cefepime were less active.

Treatment modality and outcome

All patients received broad spectrum empiric antimicrobial therapy, with some modifications being made after the availability of susceptibility data. The agents used most often were the carbapenems, although a wide variety of agents were utilized overall. The response to therapy in the patients with monomicrobial infections was 100%. However, two patients in this group had respiratory failure with one requiring mechanical ventilation. Additionally, there was one event of circulatory shock. No relapses or recurrent cases of *B. bronchiseptica* infection were observed in this group at 30 and 90 days of follow up.

The overall response in patients with polymicrobial infections was 79%. Three patients within this group (2 with *Fusarium spp.* and 1 with methicillin-resistant *Staphylococcus aureus* as co-pathogens, respectively) developed acute hypoxic respiratory failure, with two requiring mechanical ventilation. Four patients with polymicrobial pneumonia died, but only three deaths could be directly attributed to the infection. Two of these 4 cases had *Fusarium spp*. as co-pathogen, and one had *Stenotrophomonas maltophilia* and *Escherichia coli* in the same culture as *B. bronchiseptica*. The fourth patient developed a fatal pulmonary saddle embolus. Patients with BSI or other infections had a benign course with no ICU

Table 3
Bordetella bronchiseptica and co-pathogens.

Patient	Cancer/HSCT	Syndrome	Source	Co-pathogen
1	Unknown primary	Abdominal abscess	Abscess fluid	*Staphylococcus aureus* *Pseudomonas putida*
2	Melanoma	Bacteremia	Blood	*Mycobacterium mucogenicum*
3	Esophageal	Bacteremia	Blood	*Staphylococcus aureus*
4	MM/AUTO	Bacteremia	Blood	*Agrobacterium radiobacter*
5	CML	Pneumonia	Sputum	*Stenotrophomonas maltophilia*
6	Prostate	Pneumonia	Sputum	*Pseudomonas aeruginosa* *Klebsiella pneumoniae*
7	CLL	Pneumonia	BAL	*Escherichia coli* *Stenotrophomonas maltophilia*
8	AML/CBT	Pneumonia	BAL	*Fusarium spp.*
9	AML	Pneumonia	Sputum	*Fusarium spp.*
10	AML	Sinusitis	Sinus fluid	RSV
11	Lymphoma/AUTO	Tracheobronchitis	Sputum	RSV
12	Unknown primary	Tracheobronchitis	BAL	*Mycobacterium fortuitum*
13	Carcinoid	Tracheobronchitis	Sputum	*Pseudomonas aeruginosa*
14	Astrocytoma	Tracheobronchitis	BAL	*Staphylococcus aureus*

Note: HSCT: hematopoietic stem cell transplantation; MM: multiple myeloma; AUTO: autologous stem cell transplantation; CML: chronic myeloid leukemia; CLL: chronic lymphocytic leukemia; BAL: bronchoalveolar lavage; AML: acute myeloid leukemia; CBT: cord blood transplantation; RSV: respiratory syncytial virus.

Table 4
Clinical manifestations and infectious syndrome.

Variable	Respiratory no. (%) 18 (75)	Bacteremia no. (%) 4 (17)	Others[a] no. (%) 2 (8)	Total no. (%) 24 (100)
Fever	6 (25)	4 (17)	1 (4)	11 (46)
Cough	11 (46)	0	0	11 (46)
Non-productive	2 (8)	0	0	2 (8)
Productive	9 (37)	0	0	9 (37)
Dyspnea	8 (33)	0	0	8 (33)
Wheezing	2 (8)	0	0	2 (8)
Crackles	6 (25)	0	0	6 (25)
Respiratory failure	5 (21)	0	0	5 (21)
Headaches	2 (8)	1 (4)	0	3 (12)
Mechanical ventilation	3 (12)	0	0	3 (12)
Hypoxemia	5 (21)	0	0	5 (21)
Shock	1 (4)	0	0	1 (4)
Sinus drainage	1 (4)	0	0	1 (4)

Note: Data are *N* (%), unless otherwise indicated. Percentages were rounded up.
[a] Intra-abdominal collection (1) and urinary tract infection (1).

admission or associated mortality. Overall, no recurrent cases of *B. bronchiseptica* infection were observed in these groups of patients at 30 and 90 days.

Discussion

B. bronchiseptica causes infection mainly in immunocompromised patients such as those with acute or chronic lymphocytic leukemia, Hodgkin's and non-Hodgkin's lymphoma, and HSCT.[11–13] Other predisposing factors include AIDS, solid organ transplant, use of immunosuppresive agents (temozolomide, corticosteroids), alcoholic liver disease, asplenia, and hypogammaglobulinemia.[14–19] Most of these conditions have lymphopenia and/or impaired cell mediated immunity. Our data confirm these findings.

A review of the literature suggests that *B. bronchiseptica* is an uncommon pathogen even in immunosuppressed individuals. It has been hypothesized that immunity due to *B. pertussis* vaccination or past infection with this phylogenetically related organism, confers cross-protection against *B. bronchiseptica* and probably accounts for the low frequency of infection.[20]

In the largest previously published series, Woolfrey and Moody summarized 25 cases of *B. bronchiseptica* infection between 1911 and 1991.[9] However, only 8 cases (32%) fulfilled stringent microbiological criterion for *B. bronchiseptica* identification. A definite animal contact was documented in 13 of these 25 patients (52%). Fourteen of these patients (56%) did not have known comorbidity prior to the infection.

The majority of our patients presented with respiratory tract infection, primarily pneumonia or tracheobronchitis. *B. bronchiseptica* has a well described tropism for the respiratory mucosa, probably because it produces an adenylate cyclase that can interfere with the bactericidal and secretory processes of neutrophils and macrophages in the respiratory epithelium. *B. bronchiseptica* produces nearly all the same virulence factors as *B. pertussis* except for the pertussis toxin. In addition, it also carries a Bordetella virulence gene (BvgAS) that facilitates mucosal colonization and ciliary stasis. By triggering the expression of filamentous hemaglutinin (FHA), *B. bronchiseptica* is able to develop strong biofilms that adhere to respiratory epithelial cells. Biofilm formation and the interference with mucous clearance may explain why *B. bronchiseptica* colonizes the human respiratory epithelium and its repeated recovery from respiratory cultures.[21,22]

Monomicrobial infections with *B. bronchiseptica* accounted for 42% of our cases. The remaining 58% had polymicrobial infections. It is difficult to elucidate the pathogenic role of individual organisms in polymicrobial infections. However, in our heavily immuno-

suppressed patient population, we believe *B. bronchiseptica* should be considered a probable pathogen when recovered from a clinically significant site, especially when definite animal contact is documented. Such patients should receive broad spectrum coverage against all pathogens isolated, including *B. bronchiseptica*.

Similar to other case series, we did not identify a specific pattern of disease or clinical manifestations among our patients. A broad range of imaging findings including lobar or interstitial pneumonia, bronchiectasis, mosaic attenuation, and pleural effusions has been previously reported.[23] Cases of single and multifocal cavitary pneumonia have been described in patients with underlying lymphoma, cardiac transplantation, and AIDS.

Six of our patients (24%) were HSCT recipients. Of these, 5 had a respiratory infection with one being polymicrobial. The first case of *B. bronchiseptica* pneumonia in HSCT was described in 1992 in a patient with acute myeloid leukemia, 11 days after transplantation. The source of infection was a sick dog. As of 2009, 5 other cases had been reported, all of them with respiratory manifestations. Nosocomial transmission was suspected in 2 of these cases who had visited the same clinic space, and were found to have the same strain growing in cultures.[4] We found no evidence of nosocomial transmission in our cases.

We had 4 cases of BSI, 3 of them being catheter-related and polymicrobial. Treatment involved antimicrobial therapy and line removal in all three. The remaining case had *B. bronchiseptica* as the only pathogen isolated. Cases of bacteremia have been described secondary to pneumonia, otitis media, and peritonitis.[24] An additional case related to a hemodialysis catheter was reported in a patient with HIV/AIDS.[25] Due to the ability of *B. bronchiseptica* to form robust biofilms, we favor line removal in addition to antimicrobial therapy when a catheter-related bacteremia is suspected or documented.

Since *B. bronchiseptica* infections are uncommon, there are no evidence-based treatment guidelines. A wide variety of antibiotic regimens were used in our patients, and for variable lengths of time. Consequently, we are unable to make specific antimicrobial recommendations based on our data. However, based on published in-vitro data and clinical reports, we believe that an appropriate antimicrobial regimen should include either a carbapenem (meropenem, imipenem), or an agent such as piperacillin/tazobactam. Also, in order to overcome the organism ability to avoid phagocytosis and to remain active in the phagolysosome, it may be prudent to add an agent with good intracellular penetration (minocycline, doxycycline, ciprofloxacin). As recommended by some authors, a prolonged antibiotic course of 3–6 weeks might result in complete eradication of the pathogen.[12]

In summary, *B. bronchiseptica* remains an uncommon pathogen even in immunosuppressed patients. The predominant sites of infection are the respiratory tract and bloodstream. The role of *B. bronchiseptica* in polymicrobial infections is unclear. Nevertheless, we believe that if isolated from the respiratory tract or bloodstream, *B. bronchiseptica* should be considered to be pathogenic in immunocompromised hosts particularly in individuals with zoonotic exposure. The infection ranges from mild to severe and there are no specific clinical or radiographic manifestations. Immunocompromised patients should minimize contact with dogs and cats especially those with recent administration of live-attenuated intranasal “kennel cough” vaccine.[26–29] Infection control measures in hospital units, including respiratory isolation, should be implemented in cases of *B. bronchiseptica* respiratory infections because of the possibility of nosocomial transmission. The optimal treatment has not yet been defined. However, prolonged therapy with combination regimens may be necessary in some patients.[30]

Potential conflicts of interests

None declared.

Financial support

This study was supported in part by funds from The University of Texas MD Anderson Cancer Center, Houston, Texas, and by the National Institutes of Health/National Cancer Institute, under award number P30CA016672.

References

1. Mani I, Maguire JH. Small animal zoonoses and immuncompromised pet owners. *Top Companion Anim Med* 2009;**24**:164–74.
2. Wernli D, Emonet S, Schrenzel J, Harbarth S. Evaluation of eight cases of confirmed Bordetella bronchiseptica infection and colonization over a 15-year period. *Clin Microbiol Infect* 2011;**17**:201–3.
3. Stevens-Krebbers AH, Schouten MA, Janssen J, Horrevorts AM. Nosocomial transmission of Bordetella bronchiseptica. *J Hosp Infect* 1999;**43**:323–4.
4. Huebner ES, Christman B, Dummer S, Tang YW, Goodman S. Hospital-acquired Bordetella bronchiseptica infection following hematopoietic stem cell transplantation. *J Clin Microbiol* 2006;**44**:2581–3.
5. Bjornstad ON, Harvill ET. Evolution and emergence of Bordetella in humans. *Trends Microbiol* 2005;**13**:355–9.
6. Ahuja U, Liu M, Tomida S, Park J, Souda P, Whitelegge J, et al. Phenotypic and genomic analysis of hypervirulent human-associated Bordetella bronchiseptica. *BMC Microbiol* 2012;**12**:167.
7. von Wintzingerode F, Gerlach G, Schneider B, Gross R. Phylogenetic relationships and virulence evolution in the genus Bordetella. *Curr Top Microbiol Immunol* 2002;**264**:177–99.
8. Gerlach G, von Wintzingerode F, Middendorf B, Gross R. Evolutionary trends in the genus Bordetella. *Microbes Infect* 2001;**3**:61–72.
9. Woolfrey BF, Moody JA. Human infections associated with Bordetella bronchiseptica. *Clin Microbiol Rev* 1991;**4**:243–55.
10. Sullivan RJ Jr., Dowdle WR, Marine WM, Hierholzer JC. Adult pneumonia in a general hospital. Etiology and host risk factors. *Arch Intern Med* 1972;**129**:935–42.
11. Stoll DB, Murphey SA, Ballas SK. Bordetella bronchiseptica infection in stage IV Hodgkin's disease. *Postgrad Med J* 1981;**57**:723–4.
12. Gomez L, Grazziutti M, Sumoza D, Beran M, Rolston K. Bacterial pneumonia due to Bordetella bronchiseptica in a patient with acute leukemia. *Clin Infect Dis* 1998;**26**:1002–3.
13. Goldberg JD, Kamboj M, Ford R, Kiehn TE, Gilhuley K, Perales MA. 'Kennel cough' in a patient following allogeneic hematopoietic stem cell transplant. *Bone Marrow Transpl* 2009;**44**:381–2.
14. Amador C, Chiner E, Calpe JL, Ortiz de la Table V, Martinez C, Pasquau F. Pneumonia due to Bordetella bronchiseptica in a patient with AIDS. *Rev Infect Dis* 1991;**13**:771–2.
15. Dworkin MS, Sullivan PS, Buskin SE, Harrington RD, Olliffe J, MacArthur RD, et al. Bordetella bronchiseptica infection in human immunodeficiency virus-infected patients. *Clin Infect Dis* 1999;**28**:1095–9.
16. Redelman-Sidi G, Grommes C, Papanicolaou G. Kitten-transmitted Bordetella bronchiseptica infection in a patient receiving temozolomide for glioblastoma. *J Neurooncol* 2011;**102**:335–9.
17. Chauncey JB, Schaberg DR. Interstitial pneumonia caused by Bordetella bronchiseptica in a heart transplant patient. *Transplantation* 1990;**49**:817–19.
18. Gisel JJ, Brumble LM, Johnson MM. Bordetella bronchiseptica pneumonia in a kidney-pancreas transplant patient after exposure to recently vaccinated dogs. *Transpl Infect Dis* 2010;**12**:73–6.
19. Mesnard R, Guiso N, Michelet C, Sire JM, Pouedras P, Donnio PY, et al. Isolation of Bordetella bronchiseptica from a patient with AIDS. *Eur J Clin Microbiol Infect Dis* 1993;**12**:304–6.
20. Gross R, Keidel K, Schmitt K. Resemblance and divergence: the "new" members of the genus Bordetella. *Med Microbiol Immunol* 2010;**199**:155–63.
21. Gueirard P, Weber C, Le Coustumier A, Guiso N. Human Bordetella bronchiseptica infection related to contact with infected animals: persistence of bacteria in host. *J Clin Microbiol* 1995;**33**:2002–6.
22. Bemis DA, Wilson SA. Influence of potential virulence determinants on Bordetella bronchiseptica-induced ciliostasis. *Infect Immun* 1985;**50**:35–42.
23. Patel AK, Prescott-Focht JA, Kunin JR, Essmyer CE, Rosado-de-Christenson ML. Imaging findings in human Bordetella bronchiseptica pneumonia. *J Thorac Imaging* 2011;**26**:W146–9.
24. Won KB, Ha GY, Kim JS, Kang HJ, Tak WT, Lee JH. Relapsing peritonitis caused by Bordetella bronchiseptica in continuous ambulatory peritoneal dialysis patient: a case report. *J Korean Med Sci* 2009;**24**(Suppl):S215–18.
25. Mazumder SA, Cleveland KO. Bordetella bronchiseptica bacteremia in a patient with AIDS. *South Med J* 2010;**103**:934–5.
26. Kotton CN. Zoonoses in solid-organ and hematopoietic stem cell transplant recipients. *Clin Infect Dis* 2007;**44**:857–66.

27. Hemsworth S, Pizer B. Pet ownership in immunocompromised children – a review of the literature and survey of existing guidelines. *Eur J Oncol Nurs* 2006;**10**:117–27.
28. Berkelman RL. Human illness associated with use of veterinary vaccines. *Clin Infect Dis* 2003;**37**:407–14.
29. Stull JW, Stevenson KB. Zoonotic disease risks for immunocompromised and other high-risk clients and staff: promoting safe pet ownership and contact. *Vet Clin North Am Small Anim Pract* 2015;**45**:377–92 vii.
30. Yacoub AT, Katayama M, Tran J, Zadikany R, Kandula M, Greene J. Bordetella bronchiseptica in the immunosuppressed population – a case series and review. *Mediterr J Hematol Infect Dis* 2014;**6**:e2014031.