Characteristics of different pathogenic bacterial infections and their effects on prognosis in adult patients with bronchiectasis

YUEYING NIU[1*], XUE LIAN[1,2*], XIAOSI LI[3], XIANG GE[1] and HAIQIN WANG[1]

[1]Department of Respiratory Medicine, The Second Affiliated Hospital of Jiaxing University, Jiaxing, Zhejiang 314000, P.R. China;
[2]Department of Respiratory Medicine, Bengbu Medical College, Bengbu, Anhui 233000, P.R. China;
[3]Clinical Laboratory, The Second Affiliated Hospital of Jiaxing University, Jiaxing, Zhejiang 314000, P.R. China

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Abstract. The present study aimed to analyse the types of pathogens infecting adults with bronchiectasis and the effects of different pathogens on the number of acute exacerbations and the length of hospitalization for 1 year in patients with severe bronchiectasis. A total of 522 patients with bronchiectasis admitted to the Department of Respiratory and Critical Care Medicine at the Second Hospital of Jiaxing (Zhejiang, China) between January 2019 and December 2022 were retrospectively analysed. The patients were divided into a mild to moderate group and a severe group according to the bronchiectasis severity index criteria. The basic and clinical information of all the patients was collected. The patients were followed up for 1 year after the day when the sputum or alveolar lavage fluid samples tested positive for pathogens. The follow-up information included the exacerbation of cough symptoms, the number of hospitalizations and the number of days of antibiotic use in patients with bronchiectasis. A total of 522 patients with bronchiectasis were positive for pathogens, including 192 patients with *Pseudomonas aeruginosa* (*P. aeruginosa*; 36.8%), 60 patients with *Klebsiella pneumoniae* (*K. pneumoniae*; 11.5%), 48 patients with mixed pathogens (≥2 pathogens at the same time; 9.2%), 36 patients with *Staphylococcus aureus* (6.9%), 33 patients with *Aspergillus fumigatus* (6.3%), 30 patients with *Haemophilus influenzae* (5.7%), 15 patients with *Acinetobacter baumannii* (*A. baumannii*; 2.9%) and 108 patients with other pathogens (20.7%). Compared with patients with mild to moderate bronchiectasis, patients with severe bronchiectasis were more likely to have *P. aeruginosa* but less likely to have *K. pneumoniae* and other pathogens. The length of hospitalization and duration of antibiotic use in the severe group of patients with bronchiectasis caused by *P. aeruginosa*, *A. fumigatus*, or *A. baumannii* were significantly longer than those in the mild to moderate group. During the 1-year follow-up, the number of acute exacerbations and hospitalizations of patients with severe bronchiectasis caused by *A. baumannii* and *P. aeruginosa* were significantly greater than those of patients with severe bronchiectasis caused by other pathogens. According to logistic regression analysis, *A. baumannii* and *P. aeruginosa* were independent risk factors for acute exacerbation of severe bronchiectasis in the following year. In patients with severe bronchiectasis, the pathogens *A. baumannii*, *P. aeruginosa* and *A. fumigatus* were independent risk factors for future acute exacerbations and increased risk of hospitalization.

Introduction

Bronchiectasis is considered a chronic respiratory disease that is characterized by anatomical changes (abnormal and permanent dilatation of bronchi) associated with specific clinical features, such as chronic cough, expectoration of large amounts of purulent sputum and/or recurrent haemoptysis and represents the final common pathway of different disease processes (1,2). In recent years, the prevalence of bronchiectasis has increased worldwide. There are significant differences in the prevalence of bronchiectasis between countries and regions, which are related to factors such as ethnicity and sociohygienic conditions. For example, in the United States, the prevalence of bronchiectasis in individuals aged ≥70 years and over is 272 per 100,000, whereas the prevalence in individuals aged 18-34 years is 4.2 per 100,000. Bronchiectasis is a common disease in Asian populations and its incidence and prevalence have increased in recent years. In China, for example, survey data from 2013 revealed that 1.2% (135/10,811) of residents >40 years of age in the urban areas of seven provinces and cities had been diagnosed with bronchiectasis and the prevalence increased with age. Data on the specific current status of bronchiectasis in South Asia (e.g., India, Pakistan, Bangladesh) may be relatively scarce, but the prevalence and disease burden of bronchiectasis may

Correspondence to: Dr Haiqin Wang or Dr Xiang Ge, Department of Respiratory Medicine, The Second Affiliated Hospital of Jiaxing University, 1518 Huanchen North Road, Jiaxing, Zhejiang 314000, P.R. China
E-mail: w_haiqin@163.com
E-mail: 13605735257@163.com

*Contributed equally

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not be negligible considering the socioeconomic conditions, healthcare level and demographic structure of the region.

A high frequency of acute exacerbations of bronchiectasis can lead to airway and systemic inflammation and is associated with progressive lung injury, decreased quality of life, accelerated decline in lung function and increased mortality (3-5). Therefore, reducing the frequency of exacerbations and/or shortening the time to the first exacerbation is highly important for reducing medical costs and improving patient prognosis.

Little is known about the pathobiology of acute exacerbations of bronchiectasis and even the clinical manifestations of this disease vary widely. Acute exacerbation of bronchiectasis is usually considered caused by colonization and infection by bacterial pathogens. Current treatment guidelines recommend antibiotics to control acute exacerbations (6). In 2017, the European Respiratory Society defined three or more acute exacerbations as the threshold for starting long-term antibiotic treatment to prevent future exacerbations (7). Infection and colonization by *Pseudomonas aeruginosa* are the main causes of bronchiectasis. There are also reports on the role of nontuberculous mycobacteria, *Staphylococcus aureus* and fungi in the prognosis of bronchiectasis. Studies on *Haemophilus influenzae* and *Klebsiella pneumoniae* are limited (8,9). With respect to the detection of pathogens in patients with bronchiectasis, a number of patients test negative for pathogens and in a few patients with a positive pathogen test, the distribution of pathogens is different; thus, in addition to *P. aeruginosa*, few pathogens have been well studied (10,11). One study revealed that *P. aeruginosa* infection led to poorer outcomes in patients with bronchiectasis with long-term chronic infection, as indicated by an increased risk of hospitalization and an increased frequency of acute exacerbations (12). It is still not clear whether there is a definite correlation between infection by different pathogens and the number of acute exacerbations, hospitalization rates, or mortality due to bronchiectasis.

In the present study, the characteristics of patients infected with pathogenic bacteria, the risk of acute exacerbation and the risk of hospitalization within 1 year following infection with different pathogenic microorganisms were retrospectively observed to improve understanding and treat bronchiectasis and to improve its prognosis.

Materials and methods

Research objects. The present study was a retrospective analysis of 522 patients with bronchiectasis admitted to the Department of Respiratory and Critical Care Medicine at The Second Affiliated Hospital of Jiaxing University (Zhejiang, China) between January 2019 and December 2022. The inclusion criteria were sputum or alveolar lavage fluid samples positive for pathogenic bacteria and imaging changes indicative of bronchiectasis on chest computed tomography (CT). The diagnostic criteria for bronchiectasis were based on the 2021 Chinese Expert Consensus on the Diagnosis and Treatment of Bronchiectasis in Adults (13). The exclusion criteria were: i) <18 years of age, ii) bronchiectasis caused by cystic fibrosis, iii) chronic bacterial colonization, iv) loss to follow-up and v) bronchiectasis caused by Mycobacterium tuberculosis infection.

The present study was approved by the Ethics Committee of The Second Affiliated Hospital of Jiaxing University (Zhejiang, China; approval no. 2024SW110-01). The clinical data from the patients were collected anonymously. The personally identifiable information and privacy of the patients were protected. The patients were verbally informed and agreed to participate during the telephone follow-up; therefore, signing informed consent was exempt.

Data acquisition. The present study analysed the clinical characteristics of 522 patients with bronchiectasis, including age, sex, clinical symptoms and signs, smoking history, alcohol consumption history, comorbidities, medical history and pathogen detection results in sputum or alveolar lavage fluid. Some haematology indicators and biochemical parameters of the laboratory examination for acute exacerbation of patients with bronchiectasis at the time of treatment included C-reactive protein (CRP), procalcitonin (PCT), white blood cell count, neutrophil count, haemoglobin, platelet count, erythrocyte sedimentation rate, duration of antibiotic use and number of hospitalization days during acute exacerbation of bronchiectasis.

The start point of the studies was the date of detection of positive pathogenic bacteria in the sputum or alveolar lavage fluid of the patient. The patient was followed up by telephone or in the clinic after 1 year. The number of hospitalizations, the number of outpatient visits, the presence of acute exacerbations of symptoms within 1 year and the need for antibiotic treatment were recorded.

Acute exacerbation of bronchiectasis was defined as a change in three or more of the following symptoms in patients with bronchiectasis: Cough, a change in sputum volume, purulent sputum, difficulty breathing, force or discomfort, or coughing up blood; this change had to last at least 48 h, after which clinical physicians needed to change the treatment plan for bronchiectasis (usually referring to the prescription of antibiotics) (14).

Pathogenic bacteria detection methods

Sputum culture. The patient coughs out respiratory secretions after waking up in the morning on the first day after admission to the hospital, puts the sample in a sterilized container and sends it to the hospital for immediate examination. In accordance with the traditional microbial standard culture method (inoculation-culture-identification-drug sensitivity), for the specific process, the samples were inoculated into a blood plate (AnTuBio), chocolate plate (Komatsu Biologicals), or Shabao weak plate (Komatsu Biologicals), incubated at 37˚C for 24 h and colonies of bacteria were suspected to be subjected to Gram-stained microscopic examination and then analysed by a fully automatic microbiological analyser (MALDI-TOF MS; Biomerieux, France). The suspected colonies were microscopically examined via Gram staining and the pathogenic species were identified via a fully automated microbiological analyser (matrix-assisted laser desorption/ionization time-of-flight mass spectrometry; bioMérieux SA).

Metagenomic next-generation sequencing (mNGS) technology. The bronchoalveolar lavage fluid (BALF) of each patient was

Table I. Baseline characteristics and clinical manifestations of patients with bronchiectasis.

Characteristic	Total (n=522)	Mild to moderate group (n=282)	Severe group (n=240)	χ^2	P-value[a]
Age, years				62.93	<0.001
<50	48	42	6		
50-69	288	174	114		
70-79	120	54	66		
≥80	66	12	54		
Sex				0.30	0.59
Male	222	123	99		
Female	300	159	141		
Clinical characteristics					
Cough and expectoration	444	220	224	0.07	0.79
Fever	78	36	42	0.92	0.34
Chest distress	105	27	78	49.54	<0.001
Pectoralgia	18	9	9	0	1
Hemoptysis	174	102	72	10.34	0.01
Pulmonary rale (unilateral)	78	45	33	3.69	0.08
Pulmonary rale (bilateral)	183	72	111	16.62	<0.001
Personal history					
Smoking	108	63	45	6	0.02
Alcohol drinking	78	48	30	8.31	0.01
Complications					
None	129	105	24	101.70	<0.001
Chronic obstructive pulmonary disease	84	12	72	85.71	<0.001
Respiratory failure	45	9	36	32.40	<0.001
Bronchial asthma	6	3	3	0	1
Interstitial pulmonary disease	6	1	5	5.33	0.08
Ischemic heart disease	15	1	14	22.53	<0.001
Hypertension	153	81	72	1.06	0.36
Diabetes	60	21	39	10.8	0.01
Rheumatoid arthritis	21	6	15	7.71	0.01
Malignant tumour	27	9	18	6.00	0.03
Miscellaneous[b]	198	102	96	0.36	0.62

[a]vs. mild to moderate group. [b]Miscellaneous: Thyroid nodules, pulmonary nodules, hepatitis B, abnormal liver function, fatty liver, anemia, femoral atherosclerosis with plaque and carotid atherosclerosis.

retained via bronchial lavage and sent to Fangliu Biological Company (http://www.idtbio.com/) for the detection of pathogenic bacteria via mNGS, which was performed in accordance with the standard specifications of Fangliu Biological Company. The mNGS samples were removed, preserved and transported according to the standard specifications of the detection institution.

Sample pretreatment. i) The samples of sputum and BALF were removed from the refrigerator at -80˚C and placed at room temperature (25˚C) until they were dissolved. ii) The sample was placed in a 50˚C water bath for 30 min after dissolution and then equilibrated at room temperature (25˚C). iii) The sample (0.5 ml) was pipetted into a clean 1.5 ml centrifuge tube.

Nucleic acid extraction and determination of nucleic acid concentration. A bacterial genomic DNA extraction kit (Tiangen Biotech Co., Ltd.; cat. no. DP302) was used for nucleic acid extraction according to the manufacturer's protocols. The nucleic acid concentration was determined via a micro UV spectrophotometer (NanoDrop 2000; NanoDrop Technologies; Thermo Fisher Scientific, Inc.), which was used to assess the purity of the samples. Sequencing of all the nucleic acids of the microorganisms extracted from the samples was performed via high-throughput sequencing. The quality control for sequencing reads was conducted by removing low-quality reads, adapter sequences, and duplicated or short (<36 bp) reads. The remaining qualified reads were first mapped to the human reference genome (hs37d5) using bowtie2 software and then the non-human reads were

Table II. Laboratory indicators in patients with bronchiectasis.

Index	Mild to moderate group (n=282)	Severe group (n=240)	P-value[a]
White blood cell count, 10^9/l	6.03±1.22	7.32±2.88	<0.001
Neutrophil count, 10^9/l	4.35±1.86	5.24±2.74	<0.001
Hemoglobin, g/l	4.04±0.32	3.98±0.48	0.09
reactive protein, mg/l)	23.0 (9.0-36.0)[b]	29.0 [10.0-58.0][a]	<0.001
Procalcitonin, ng/ml	0.05±0.01	0.09±0.02	<0.001
Erythrocyte sedimentation rate, mm/h	21.35±4.46	28.02±5.22	<0.001

[a]vs. mild to moderate group. [b]Values are median (interquartile range). Data are presented as mean ± standard deviation.

aligned to the microorganism genome database for pathogens identification.

Core respiratory pathogen nucleic acid test. When the patient was admitted to The Second Affiliated Hospital of Jiaxing University (Zhejiang, China), a professional nurse instructed the patient to obtain sputum from the deep respiratory tract and this was sent to the microbiology room of the Laboratory Department and tested with the Crystalline Core Respiratory Pathogenic Bacteria Nucleic Acid Detection Kit (Beijing CapitalBio MedLab), which conducts real-time fluorescence detection via the fluorescent dye doping method and amplifies the target nucleic acid with an S-shaped curve under the action of the polymerase with the function of chain replacement (which can react at a constant temperature of 65˚C). Under the action of polymerase with a chain-switching function (65˚C constant temperature reaction is available), the amplified target nucleic acid will show an S-shaped curve and then the target gene will be detected and amplified.

Study group. A total of 522 patients with bronchiectasis were included in the present study. They were scored on the bronchiectasis severity index (BSI) (14), which gives 1 point for each of the following: i) age ≥70 years; ii) forced expiratory volume in the first second to be ≤50% of the predicted value; iii) previous hospitalization for aggravation; iv) each acute exacerbation in the past year; v) colonization by *P. aeruginosa*; vi) dyspnoea-modified Medical Research Council score; and vii) chest CT showing that more than three lung lobes were infiltrated. In the present study, a score <4 indicated mild to moderate bronchiectasis and a score ≥4 was considered severe. There were 282 patients in the mild to moderate group and 240 patients in the severe group.

Statistical analysis. SPSS 27.0 software (IBM Corp.) was used for processing and analysis. Continuous variables are described through means, standard deviations and medians, whereas categorical variables are presented as frequencies and percentages. The χ^2 test or Fisher's exact test (when the number of expected cases was <5) was used to analyse categorical variables. Student's t-test was performed to analyse standard deviations and medians. Wilcoxon rank sum test was used to compare nonnormally distributed continuous variables, which are presented as medians (IQRs) and ranges. Univariate logistic regression analysis was performed to identify risk factors for hospitalization in the next year in adult patients diagnosed with bronchiectasis. P<0.05 was considered to indicate a statistically significant difference.

Results

Basic clinical characteristics of the patients. Among 522 patients with bronchiectasis whose sputum or alveolar lavage fluid test was positive for pathogens, 325 patients had positive sputum cultures and 197 patients had positive alveolar lavage fluid cultures. The patients were mainly middle-aged and elderly, with 91.8% being ≥50 years. The patients in the severe group were significantly older than the patients in the mild to moderate group (P<0.05). There was no significant difference in sex between the groups (P>0.05). Among the common clinical symptoms, chest tightness and bilateral pulmonary rales were significantly more common in patients in the severe group than in those in the mild to moderate group and the incidence of cough was lower than that in the mild to moderate group (P<0.05). There were no significant differences in cough, sputum, fever, chest pain, or unilateral pulmonary rales between the two groups (P>0.05). The proportion of smokers and drinkers in the severe group was significantly lower than that in the mild to moderate group (P<0.05). The severe group was more likely to have comorbidities; less likely to have chronic obstructive pulmonary disease, respiratory failure, ischaemic heart disease, diabetes and rheumatoid arthritis; and more likely to have malignant tumours (P<0.05). There was no significant difference in bronchial asthma, interstitial lung disease, or hypertension between the two groups (P>0.05). Table I lists the specific data.

Laboratory values of patients with different degrees of bronchiectasis. By comparing the complete blood count results and serum albumin levels between the two groups, it was found that the number of white blood cells, the number of neutrophils, the CRP level, the PCT level and the erythrocyte sedimentation rate were significantly greater in the severe group than in the mild to moderate group (P<0.05). There was no significant difference in haemoglobin (P>0.05). These specific data are shown in Table II.

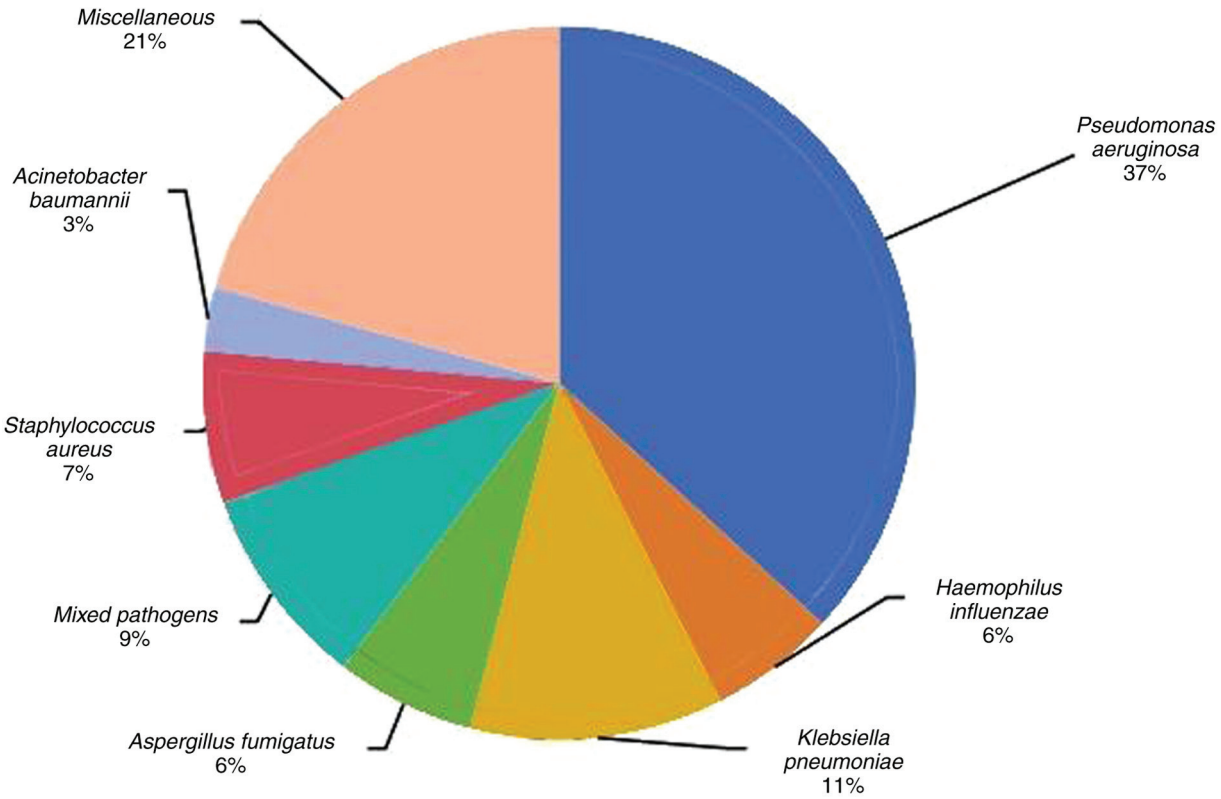

Figure 1. Distribution of positive pathogens in 522 patients with bronchiectasis. Mixed pathogens *Pseudomonas aeruginosa* and *Klebsiella pneumoniae*, other pathogens, *Staphylococcus aureus*, *Aspergillus fumigatus*, *Haemophilus influenzae* and *Acinetobacter baumannii*.

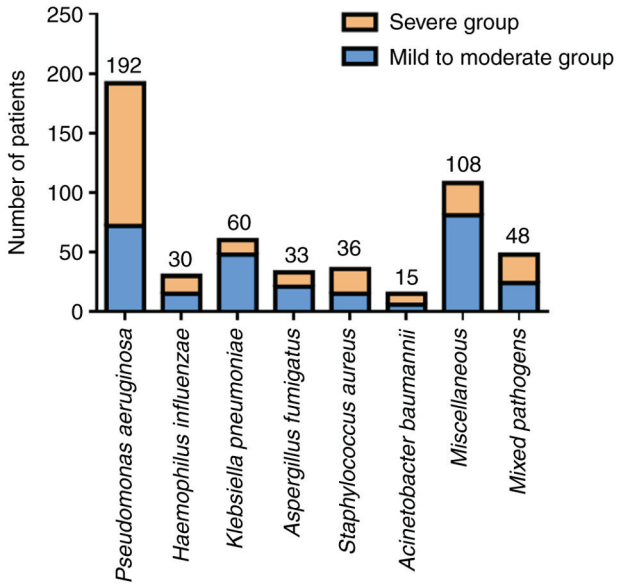

Figure 2. Distribution of positive pathogens in patients with bronchiectasis. The data were expressed as the number of patients.

Distribution characteristics of pathogens in patients with bronchiectasis with positive pathogen infections. Through the analysis of 522 patients with bronchiectasis whose sputum or alveolar lavage fluid was positive for pathogenic bacteria, *P. aeruginosa* was detected in 192 patients (36.8%) and *K. pneumoniae* was detected in 60 patients (11.5%). There were 48 patients infected with a mixture of pathogens (≥2 pathogens) (9.2%), 36 patients infected with *Staphylococcus aureus* (6.9%), 33 patients infected with *Aspergillus fumigatus* (6.3%), 30 patients infected with *Haemophilus influenzae* (5.7%), 15 patients infected with *Acinetobacter baumannii* (2.9%) and 108 patients infected with other pathogens (20.7%). Other pathogens include Enterobacter cloacae, *Proteus mirabilis*, *Acinetobacter junii*, *Pseudomonas putida*, *Corynebacterium striatum*, *Streptococcus mitis*, *Schizophyllum*, *Nocardia otitidiscaviarum* and *Stenotrophomonas maltophilia* (Fig. 1).

Compared with patients with mild to moderate bronchiectasis, patients with severe bronchiectasis were more likely to have *P. aeruginosa* infection but less likely to have *K. pneumoniae* and other pathogens ($P<0.05$). There was no significant difference between the two groups of patients in terms of the detection of *H. influenzae*, *A. fumigatus*, *S. aureus*, *A. baumannii*, or mixed bacteria ($P>0.05$; Fig. 2).

Effects of different pathogenic bacterial infections on the length of hospitalization and duration of antibiotic use in patients with bronchiectasis. To study whether infection with different pathogens affects the length of hospitalization, the number of hospitalization days for patients infected with different pathogens in the two groups was analysed. Compared with those in the mild to moderate group, the length of hospitalization of patients in the severe group infected with *P. aeruginosa*, *A. fumigatus*, *A. baumannii*, or mixed bacteria significantly increased ($P<0.05$). There was no significant difference in the hospitalization time of patients infected with

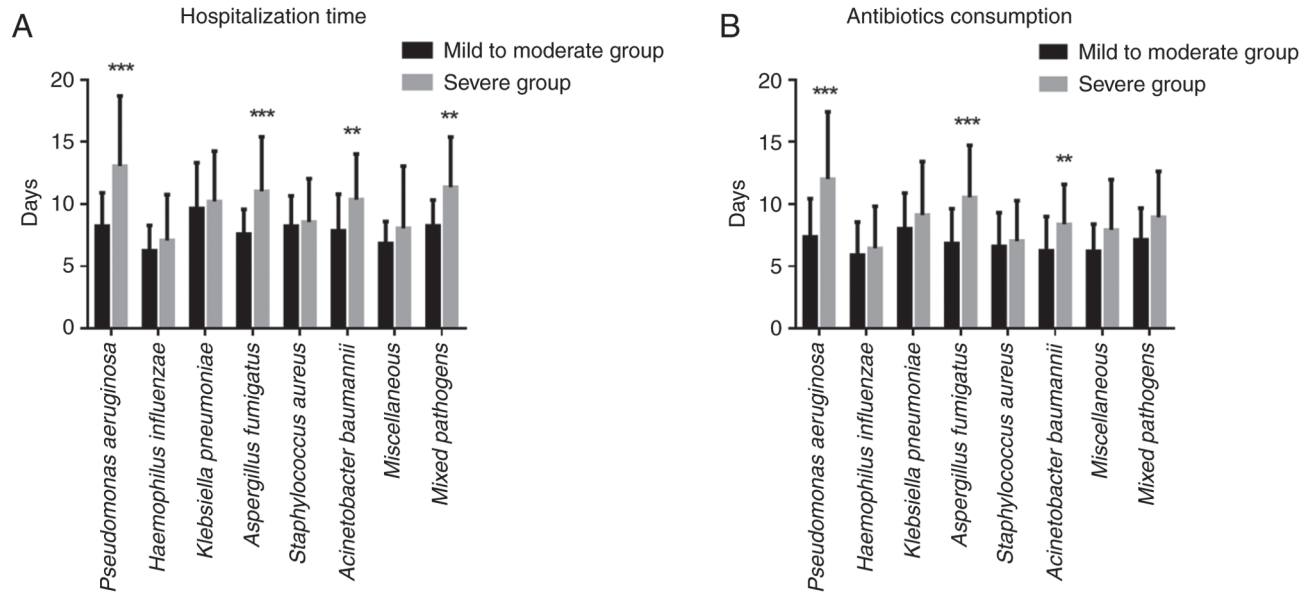

Figure 3. Hospitalization time and antibiotics consumption of different pathogens in patients with bronchiectasis. Data are presented as mean ± standard deviation. (A) Hospitalization time of different pathogens in patients with bronchiectasis. (B) Antibiotics consumption of different pathogens in patients with bronchiectasis. **P<0.01, ***P<0.001 vs. values in mild to moderate group.

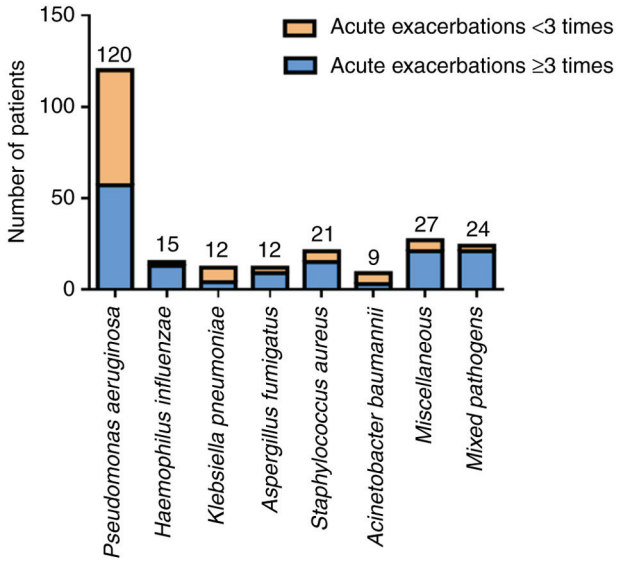

Figure 4. The frequency of acute exacerbations in patients with bronchiectasis infected by different pathogens within 1 year. The data were expressed as the number of patients.

H. influenzae, *K. pneumoniae, S. aureus*, or other pathogens between the two groups (P>0.05; Fig. 3A).

To study whether infection with different pathogens affects the time at which patients take antibiotics, the difference in antibiotic use between the two groups of patients infected with different pathogens were analysed. Compared with those in the mild-to-moderate group, the duration of antibiotic use in patients with severe infections, including *P. aeruginosa*, *A. fumigatus* and *A. baumannii* infections, was significantly longer (P<0.05). There was no significant difference in the duration of antibiotic use between the two groups of patients infected with *H. influenzae*, *K. pneumoniae*, *S. aureus*, mixed bacteria, or other pathogens (P>0.05; Fig. 3B).

Effects of different bacterial infections on the number of acute exacerbations and hospitalizations in patients with severe bronchiectasis. All the patients with severe bronchiectasis were followed for 1 year to observe the effects of different pathogen infections on the number of acute exacerbations and the number of hospitalizations. The pathogens that caused ≥3 acute exacerbations during the follow-up period were *A. baumannii* (66.7%), *P. aeruginosa* (50%), *K. pneumoniae* (50%), *S. aureus* (28.6%) and *A. fumigatus* (25%). By contrast, patients with severe bronchiectasis caused by *H. influenzae* (13.33%), other bacteria (22.22%), or mixed pathogens (22.50%) had fewer acute exacerbations during the 1-year follow-up. The data are shown in Fig. 4.

The pathogens most associated with hospitalization within 1 year were *A. baumannii* (100%), *K. pneumoniae* (83.33%), *P. aeruginosa* (58.33%) and *A. fumigatus* (50%). Patients with severe bronchiectasis caused by *H. influenzae* (13.33%), *S. aureus* (28.57%), mixed pathogens (33.33%), or other bacteria (33.33%) had a low probability of being hospitalized within 1 year of follow-up. The data are shown in Table III.

Analysis of independent risk factors for the development of acute exacerbations in patients with severe bronchiectasis in the following year. In the severe group of patients with bronchiectasis, the patients were followed up for 1 year to analyse the univariate analysis of the associations with different pathogens in patients with bronchiectasis with acute exacerbation. Compared with other pathogens, A. baumannii and P. aeruginosa had significant adverse effects on acute exacerbations in patients with bronchiectasis in the severe group, as these two pathogens were positively associated with the risk of acute exacerbations. Compared with infections caused by other pathogens, infections caused by mixed pathogens, *S. aureus*, or *H. influenzae* had fewer adverse effects on patients in the severe group. The data are shown in Table IV.

Table III. The frequency of hospitalization in patients with severe bronchiectasis infected by different pathogens within 1 year.

Pathogen	Total	Number hospitalized (%)	Hospitalized (%)
Pseudomonas aeruginosa	120	50 (41.67)	70 (58.33)
Haemophilus influenzae	15	13 (86.67)	2 (13.33)
Klebsiella pneumoniae	12	2 (16.67)	10 (83.33)
Aspergillus fumigatus	12	6 (50.00)	6 (50.00)
Staphylococcus aureus	21	15 (71.43)	6 (28.57)
Acinetobacter baumannii	9	0 (0.00)	9 (100.00)
Miscellaneous	27	18 (66.67)	9 (33.33)
Mixed pathogens	24	16 (66.67)	8 (33.33)

Table IV. Univariate Cox risk regression analysis of acute exacerbation in patients with severe bronchiectasis.

Pathogen	Regression coefficient	Standard error	Wald χ^2	Odds ratio	95% Confidence interval	P-value
Acinetobacter baumannii	2.335	1.072	4.744	10.333	1.263-84.510	0.029
Pseudomonas aeruginosa	1.022	0.292	12.262	2.779	1.568-4.925	<0.001
Klebsiella pneumoniae	0.021	0.595	0.001	1.021	0.318-3.278	0.972
Aspergillus fumigatus	-0.316	0.603	0.274	0.729	0.224-2.378	0.601
Mixed pathogens	-1.284	0.533	5.792	0.277	0.097-0.788	0.016
Staphylococcus aureus	-1.015	0.505	4.034	0.363	0.135-0.976	0.045
Haemophilus influenzae	-2.777	1.045	7.057	0.062	0.008-0.483	0.008

Discussion

P. aeruginosa is a longstanding cause of adult bronchiectasis infections. However, infections caused by pathogens other than *P. aeruginosa* account for more than half of all bronchiectasis cases and there is a lack of in-depth studies on the prognostic impact of these pathogens. The present study described the distribution of pathogens in adults with bronchiectasis. The most common pathogen was *P. aeruginosa*, followed by *K. pneumoniae*. In the exacerbation stage of adult bronchiectasis, among patients with severe bronchiectasis, the pathogens *A. baumannii*, *P. aeruginosa* and *A. fumigatus* are independent risk factors for future acute exacerbation and hospitalization.

Among the patients with bronchiectasis who tested positive for pathogens, those with severe bronchiectasis were generally older than those with mild to moderate bronchiectasis, indicating that the older the patients were, the more severe the symptoms of pathogenic bacterial infection. Sex had no effect on the severity of infection with pathogens in patients with bronchiectasis, which is consistent with the literature (15,16). In terms of common clinical symptoms, chest tightness and bilateral pulmonary rales were more obvious in patients with severe bronchiectasis caused by infection, indicating that chest tightness and bilateral pulmonary rales have greater effects on the severity of patients with bronchiectasis than other clinical symptoms. More patients with mild to moderate bronchiectasis smoked and drank more alcohol than patients with severe bronchiectasis. It is possible that too little attention has been given to mild to moderate bronchiectasis. Patients with mild to moderate bronchiectasis had relatively few comorbidities and an increase in comorbidities aggravated the disease progression of patients with bronchiectasis caused by the pathogen. According to the laboratory data, the changes in blood parameters were more obvious in patients with severe bronchiectasis compared with patients with mild to moderate bronchiectasis. This was also expected, as the clinical symptoms and laboratory test indices were consistent with each other (17). Therefore, it was hypothesized that more publicity and education should be provided to patients with bronchiectasis and that measures to prevent pathogenic infection should be implemented for older patients with more underlying diseases.

With respect to the distribution of pathogens in adult patients with bronchiectasis, most researchers consider that the most common pathogens are gram-negative bacteria, with *P. aeruginosa* being the most common (18). In a cross-sectional study of 184 hospitalized patients with bronchiectasis in Hainan, China, Shi *et al* (19) reported that 57.07% of patients had positive sputum microorganism results according to culture; gram-negative bacteria were the most common among the culture-positive pathogenic bacteria; and *P. aeruginosa* (38.10%), *K. pneumoniae* (14.29%) and *A. baumannii* (11.56%) were the most common gram-negative bacteria in the culture. There are other similar reports on the aetiology of patients with bronchiectasis. Wang *et al* (20) reported that gram-negative bacteria were the most common bacteria and accounted for 76.8%, followed by gram-positive

bacteria (19.4%), whereas fungi were the least common (accounting for 3.8%). Among the gram-negative bacteria, the top three were *P. aeruginosa* (25.6%), *A. baumannii* (17.5%) and *K. pneumoniae* (11.8%). However, several researchers have put forwards a different point of view, concluding that *H. influenzae* is the most common pathogen, followed by *P. aeruginosa* (21). The results of the present study revealed that among the 522 patients with bronchiectasis who had positive pathogenic bacteria tests, gram-negative bacteria were more common, with *P. aeruginosa* being the most common, followed by *K. pneumoniae*, *H. influenzae* and *A. baumannii*, accounting for 73% of all pathogens, which was consistent with previous reports (22). In addition, concerning the distribution of other pathogens, gram-positive bacteria accounted for 9.8% of all the strains, mixed pathogens accounted for 9.2% of all the strains and fungi accounted for 8% of all the strains; these findings are also consistent with the most common pathogens reported at home and abroad, but the distribution proportions were slightly different. The possible reasons are that the prevalence of pathogens in the population differs by region and climatic environment. This may also be due to the different severities of the conditions of the treated patients with bronchiectasis, especially because the proportions of patients with severe bronchiectasis were different (23).

P. aeruginosa was the main infection in patients with severe bronchiectasis, whereas *K. pneumoniae* was the main infection in patients with mild to moderate bronchiectasis. It was hypothesized that *P. aeruginosa* exacerbates the acute symptoms of bronchiectasis. In addition, the present study revealed that patients with bronchiectasis caused by the same pathogen had different durations of hospitalization and durations of antibiotic use. Patients with the same degree of bronchiectasis had different lengths of hospitalization and antibiotic use, depending on the pathogen. The duration of hospitalization and antibiotic use were greatest for patients infected with *P. aeruginosa*, which may be related to the mechanism of action of *P. aeruginosa* on bronchiectasis (24).

The present study involved a prognostic analysis of the pathogens found in clinical work and revealed that *P. aeruginosa* infection increased the risk of acute exacerbation and hospitalization in future patients with bronchiectasis. Additionally, *A. baumannii*, *K. pneumoniae* and *A. fumigatus* adversely affect the prognosis of patients with bronchiectasis (acute exacerbation, hospitalization). Long-term macrolide antibiotics currently have the highest level of evidence for reducing exacerbations (25). Long-term oral antibiotics can also be considered for patients with recurrent exacerbations who are otherwise optimally managed but should not be prescribed routinely. The results of the present study showed that patients with bronchiectasis caused by infection with *P. aeruginosa*, *H. influenzae*, *K. pneumoniae*, *A. fumigatus*, mixed pathogens, *S. aureus*, or *A. baumannii* could develop acute exacerbations in the future. Compared with patients infected with other pathogens, patients infected with *P. aeruginosa*, *K. pneumoniae*, *A. fumigatus*, or *A. baumannii* were more likely to experience acute exacerbations, hospitalization, or worsening of their conditions over 1 year. Depending on the clinical situation, antibiotics are usually prescribed for 7-14 days. Intravenous antibiotics for severe exacerbations are usually continued for at least 5 days and are often followed by oral antibiotics for a total duration of 10-14 days (26). If the culture is positive for *P. aeruginosa*, the common practice is to prescribe two weeks of oral ciprofloxacin and then repeat the sputum culture (27). Furthermore, Foumani *et al* (28) showed that the probiotics were not effective in the improvement of clinically bronchiectasis, consumption of antibiotics, the rate of pulmonary exacerbations with or without the need for hospitalization, forced expiratory volume in the first second (FEV1) and FEV1/forced vital capacity (FVC) and microbiological pattern. Up to now, there has been no sufficient evidence about the effects of probiotics on other respiratory infections such as bronchiectasis (29).

A. baumannii is found mainly in critically ill patients and infection most commonly manifests as ventilator-associated pneumonia, followed by blood, skin and soft tissue infections (30). The incidence of multidrug-resistant *A. baumannii* is high. A global drug resistance assessment revealed that ~45% of *A. baumannii* isolates were multidrug-resistant strains, which is a much greater percentage than that reported for other pathogens (31). However, in the present study, compared with patients infected with *P. aeruginosa*, *A. baumannii*, *K. pneumoniae*, or *A. fumigatus*, patients infected with *H. influenzae*, *S. aureus*, or mixed pathogens had fewer adverse effects on the prognosis of bronchiectasis (acute exacerbation, hospitalization), fewer acute exacerbations and a lower risk of hospitalization.

The present study analysed the effects of different pathogens on the prognosis of patients with bronchiectasis (acute exacerbation, hospitalization). Compared with patients infected with other pathogens, patients infected with *P. aeruginosa*, *A. baumannii*, *K. pneumoniae*, or *A. fumigatus* had a greater risk of acute exacerbation and/or hospitalization within 1 year. More attention should be paid to their anti-infective treatment, follow-up after discharge and health education.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

HQW and YYN conceived and designed the study. YYN and XL designed the methodology and contributed to data acquisition. YYN and XG confirm the authenticity of all the raw data. XSL and XG performed the statistical analyses. YYN and HQW drafted the manuscript. XG and HQW confirm

the authenticity of all the raw data. All authors have read and approved the final version of the manuscript.

Ethics approval and consent to participate

The present study was conducted in accordance with the Declaration of Helsinki (revised in 2013) and was approved by The Second Affiliated Hospital of Jiaxing University (Zhejiang, China; approval no. 2024SW110-01). Samples were obtained from all patients with written informed consent.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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