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ORIGINAL RESEARCH

Risk Factors for Pulmonary Infection and Nursing Interventions Post-Tracheostomy in Patients with Spinal Cord Injury

Qin Lv[1],*, Xinliang Zhang[1],*, Kucun Guo[1], Dezheng Hu[1], Zhuojun Deng[2]

[1]Department of Emergency, The Third Hospital of Hebei Medical University, Shijiazhuang City, Hebei Province, 050051, People's Republic of China;
[2]Department of General Medicine, The Third Hospital of Hebei Medical University, Shijiazhuang City, Hebei Province, 050000, People's Republic of China

*These authors contributed equally to this work

Correspondence: Xinliang Zhang, Department of Emergency, The Third Hospital of Hebei Medical University, No. 139 Ziqiang Road, Qiaoxi District, Shijiazhuang City, Hebei Province, People's Republic of China, 050051, Tel +86 18533112509; +86 311-88602030, Email zhangxinliangzhxl@126.com

Objective: We analyzed the characteristics and risk factors for pulmonary infection in patients with spinal cord injury who underwent tracheostomy and propose measures to help in early detection and intervention to reduce mortality and improve prognosis.

Methods: We collected data retrospectively from January 1, 2018, to December 31, 2022. The inclusion criteria were: Patients aged 18 years or more with a spinal cord injury who underwent tracheostomy, were treated with mechanical ventilation for over 48 hours, and were diagnosed as having a pulmonary infection. Sputum samples were cultured and analyzed.

Results: 101 cases of pulmonary infection were analyzed, and the incidence was 32.17%. Diabetes (OR 2.302, 95% CI 1.285–3.972), hypoproteinemia (OR 1.992, 95% CI 1.125–3.101), administration of glucocorticoids (OR 2.934, 95% CI 1.412–4.661), ASIA grade A (OR 3.672, 95% CI 1.988–5.046), mechanical ventilation for $\geq$ 6 days (OR 2.108, 95% CI 1.385–4.751), and length of hospital stay for $\geq$ 20 days (OR 2.137, 95% CI 1.092–3.842) were risk factors for pulmonary infection in patients with spinal cord injury post-tracheostomy. Among 213 pathogenic bacteria, 52 (51.48%) were Gram-negative and 24 (23.76%) were Gram-positive. Klebsiella pneumoniae (15.84%) and Staphylococcus aureus (8.91%) were the most common pathogenic bacteria. The mortality rate of patients with gram-positive infection was higher than that of patients with gram-negative infection. K. pneumoniae and S. aureus were sensitive to cefoperazone, meropenem, and levofloxacin.

Conclusion: Pulmonary infection is a complication post-tracheostomy in patients with spinal cord injury. Diabetes, hypoproteinemia, administration of glucocorticoids, mechanical ventilation for $\geq$ 6 days, length of hospital stay for $\geq$ 20 days were risk factors for pulmonary infection. Pulmonary infection was mainly caused by gram-negative bacteria. Timely and effective measures for managing risk factors are essential for improving the prognosis of pulmonary infection post-tracheostomy in patients with spinal cord injuries.

Keywords: risk factors of pulmonary infection, spinal cord injury, tracheostomy

Introduction

The main causes of acute traumatic spinal cord injury (ATSCI) include falls from heights, traffic accidents, industrial and construction accidents, and sports injuries.[1] It is estimated that most deaths usually occur within three days of a spinal cord injury.[2] The greater the extent of the injury, the higher is the mortality rate.[3] Spinal cord injury not only severely impairs sensory, motor, and sympathetic activity, but also causes respiratory muscle weakness or paralysis and respiratory impairment.[4] Pulmonary complications include atelectasis, pulmonary infection, respiratory failure, aspiration of gastric contents, pulmonary embolism, and bronchospasm,[5] which are the most common causes of morbidity in spinal cord injury and death.[5–8] Jackson et al[9,10] estimated that approximately 67% patients with spinal cord injury had pulmonary complications, and longer duration of mechanical ventilation were required once pulmonary complications set in.

Tracheostomy is often performed on critically ill patients in the emergency department, accounting for 6% of this population, and is one of the most commonly performed procedures for mechanically ventilated patients in the intensive care unit (ICU).[11–13] It is estimated that approximately 21% to 77% patients with complete cervical spinal cord injury require tracheostomy for respiratory support.[14,15] Tracheostomy is conducive for patients with prolonged and complicated mechanical ventilation to wean them off the ventilator, and reduces the complications of long-term endotracheal intubation,[16] shortens the length of stay in the ICU, increases comfort, improves vocalization and swallowing functions, reduces the dose of sedative drugs, shortens the duration of sedation,[17] improves lung drainage, and reduces pulmonary complications.

However, tracheostomy is an invasive procedure in which the tracheostomy acts as a bypass, eliminating the protective impact of the nasal passage that provides air filtration, humidification, and warming, thereby disrupting the body's barrier and inhibiting the airway's own defenses. Tracheostomy tubes also create a direct entry point for viruses and bacteria into the lower respiratory tract, and the presence of the cannula can also cause local inflammatory reactions, thereby increasing the risk of respiratory tract infections, delaying patient recovery and causing worsening of the disease.[18] In addition, pathogenic bacteria that cause infection in the hospital are more complex and may be multidrug resistant.

Pulmonary infection is a common and serious complication after tracheostomy in patients with a spinal cord injury. The objective of our study was to investigate the prognostic factors for pulmonary infection in such patients and propose measures for clinical nursing practices. Therefore, we aimed to analyze the characteristics of pulmonary infection in patients with spinal cord injury post-tracheostomy, identify the risk factors for pulmonary infection, and carry out early detection and intervention for secondary pulmonary infection in patients with spinal cord injury, which could help reduce mortality, improve prognosis, and provide a reliable basis for the treatment of clinical spinal cord injury. Additionally, we aimed to explore nursing interventions to prevent pulmonary infection in patients with spinal cord injury.

Data and Methods
Ethical Considerations
We carried out all research procedures in this study in accordance with relevant guidelines and regulations, and with the approval of the Ethics Committee of the Third Hospital of Hebei Medical University (approval number: Section 2022-005-1). This study was conducted in accordance with the declaration of Helsinki. The Ethics Committee of the Third Hospital of Hebei Medical University exempted the requirement of written informed consent: This clinical study is a retrospective study. It only collects the patient's clinical data, does not interfere with the patient's treatment plan, and will not bring risks to the patient's physiology. The researchers confirm that patients' information will not be disclosed unless it is de-identified, in order to maintain confidentiality and personal privacy.

Research Participants
In this study, we selected patients who underwent tracheostomy for acute traumatic cervical spinal cord injury and were admitted to our hospital from January 1, 2018 to December 31, 2022, as participants.

Inclusion Criteria
1. Based on imaging and the clinical data, patients who received a definite diagnosis of traumatic cervical spinal cord injury (including patients with cervical fracture dislocation and cervical spinal cord injury without fracture).
2. Patients with spinal cord injury who underwent tracheostomy during hospitalization.
3. Patients on mechanical ventilation for over 48 h.
4. Age ≥ 18 years.
5. The clinical data of patients were complete.

Exclusion Criteria

1. Patients with chronic cervical spinal cord injury due to other diseases.
2. Patients with chronic diseases of the respiratory system or obvious chest trauma.
3. Patients with locally open wounds who underwent debridement and suturing in the emergency department.
4. Patients who received other surgical treatment in the emergency department due to other organ injuries before surgery.
5. Patients with poor physical condition due to diagnosed tumors or other well-defined consumptive diseases.
6. Patients who received anti-infective therapy before admission.
7. Patients with a definite diagnosis or complications associated with other types of infections (such as urinary tract infections, incision infections, and so on) post-surgery.

Research Methods

Data Collection

We collected the following clinical data retrospectively: gender, age, body mass index, alcohol consumption, smoking, hypertension, diabetes, hyperlipidemia, hypoproteinemia (total plasma protein < 60 g/L), administration of glucocorticoids, indwelling gastric tube, type of spinal cord injury (grading based on the American Spinal Injury Association (ASIA) impairment scale),[19] duration of mechanical ventilation, length of hospital stay, and mortality. We divided patients into the pulmonary infection group and the non-pulmonary infection group based on whether there was pulmonary infection or not, respectively, and analyzed the characteristics of the two groups.

Diagnostic Criteria for Pulmonary Infection

In our study, we focused on pulmonary infections in patients with spinal cord injury post-tracheostomy, which is part of hospital-acquired pneumonia. The diagnosis of pneumonia was based on the following diagnostic criteria for hospital-acquired pneumonia formulated by the Respiratory Disease Branch of the Chinese Medical Association:[20] (1) Newly developed cough, expectoration, or worsening of the symptoms of the original respiratory disease, with purulent sputum. With or without chest pain; (2) Fever; (3) Signs of pulmonary consolidation and/or crackles; (4) Blood leukocytes > 10×10^9/L or <4×10^9/L, with or without left shift; (5) Chest X-ray showed patchy infiltrates or interstitial changes, with or without pleural effusion; (6) The time and place of disease onset were consistent with nosocomial infection. Definite diagnosis could be made with any of the above items from 1–4 plus items 5 and 6, excluding atelectasis, heart failure and pulmonary edema, pulmonary embolism, respiratory distress syndrome and other diseases. Reinfection was defined as redevelopment of pulmonary infection one week after discontinuation of antibiotics in patients with pulmonary infection who were stable after treatment.

Specimen Collection and Sputum Culture

Sputum was collected from patients diagnosed with pulmonary infection, and procedures were stringently followed to avoid contamination.[21]

All specimens were sent to the laboratory immediately for routine isolation and culture. We used the automatic bacterial culture detector Bact/ALERT@3D (bioMérieux, Marcy l'Étoile, France) to identify pathogenic bacteria, and the pathogenic bacteria were confirmed if more than two consecutive cultures gave the same results.

Gram-positive infection was defined as only gram-positive bacterium detected in the sputum culture, while gram-negative infection was defined as only gram-negative bacterium detected in the sputum culture. A diagnosis of mixed infection was made when two or more pathogenic bacteria were detected. We described each type of infection using the number and percentage of patients and analyzed the relationship between injury type and pathogenic bacteria distribution.

We used a sputum culture device to suck the deep secretions of the lower respiratory tract through the tracheal cannula, and the samples were immediately sent to our laboratory for bacteria culture and a drug sensitivity test. Sterile procedures were strictly adhered to during the process of sputum specimen collection.

Spinal Cord Injury Assessment

We referred to the Acute Cervical Spine and Spinal Cord Injury Management Guidelines formulated by the American Association of Neurological Surgeons (AANS)[22] for the diagnostic criteria for spinal cord injury In this study, we assessed the type of spinal cord injury as per the 5th edition of the American Spinal Injury Association's (ASIA) injury grading scale (Table 1),[19] and the categories were complete spinal cord injury (ASIA grade A) and incomplete spinal cord injury (ASIA grade B, C, and D). The assessment of the degree of nerve damage is usually based on neuroimaging findings. In this case, we used magnetic resonance imaging (MRI) to assess the degree of nerve injury and classified it as a high cervical cord injury (C1–C3) or a low cervical cord injury (C4–T1) based on the anatomical structure of the cervical spine and the location of the injury on the spinal cord.

The cervical spine consists of vertebrae C1 through C7, where C1 is the first bone of the cervical spine and C7 is the seventh bone of the cervical spine. The high cervical spinal cord refers to the part of the cervical spine from C1 to C3. This area is the connection between the neck and the head and mainly controls the movement and sensation of the head and neck. The lower cervical cord refers to the part of the cervical spine from C4 to T1, which is the connection between the neck and the upper body and mainly controls the movement and sensation of the upper body.

Therefore, we used MRI to assess and classify the nerve injury, to accurately understand the location and extent of the injury and facilitate more effective treatment and rehabilitation programs.

Statistical Analysis

We used the SPSS 24.0 software for statistical analysis. We used mean ± standard deviation analysis for normally distributed continuous variables and t-test for between-group comparisons. For continuous variables that did not fall into normal distribution, we expressed the results as the median and inter-quartile range (IQR) and used the Mann–Whitney U-test for between-group comparisons. We expressed counting data as number or percentage (%), and the chi-squared test was used for between-group comparisons. In univariate regression analysis, we used the chi-squared test or Fisher's exact probability method for categorical variables. In multivariate analysis, we used logistic regression to analyze risk factors associated with the development of pulmonary infection. In this study, we considered $P < 0.05$ as statistically significant. Diabetes mellitus, hypoproteinemia, coma ≥ 22 h, mechanical ventilation ≥ 6 d, hospital stay ≥ 20 d were risk factors for pulmonary infection. Sample size was calculated to be around 100.

Results

There were 531 patients with traumatic cervical spinal cord injury in our hospital from January 1, 2018 to December 31, 2022, and as per the inclusion and exclusion criteria, we included a total of 314 patients with spinal cord injury who underwent tracheostomy. The main causes of injuries included motor vehicle accidents, bruise injuries on the neck caused by heavy objects, injuries by falls from height, and falling over. All patients underwent tracheostomy to improve artificial respiration and correct respiratory impairment. Among them, there were 101 cases of pulmonary infection, with an incidence rate of 32.17%.

Table 1 Classification of the ASIA Impairment Grade

Grading of Neurological Function	Diagnostic Criteria	Degree
Grade A	No movement or sensation below the level of nerve damage	Complete injury
Grade B	Partial sensation below the level of nerve damage, but no movement	Incomplete injury
Grade C	More than half of the key muscles below the level of nerve damage are less than grade 3	
Grade D	More than half of the key muscles below the level of nerve damage are equal or more than grade 3	
Grade E	Normal movement or sensation function	Normal

Abbreviation: ASIA, American Spinal Injury Association.

Population Characteristics of Patients with Spinal Cord Injury Who Underwent Tracheostomy and Univariate Analysis of Pulmonary Infection

There were significant differences between the pulmonary infection group and the non-pulmonary infection group in terms of diabetes, hypoproteinemia, administration of glucocorticoids, ASIA grade, duration of mechanical ventilation, length of hospital stay, and fatality rate (all $P < 0.05$) (Table 2). There were no significant differences in gender, age, body mass index, alcohol consumption, smoking, hypertension, hyperlipidemia, indwelling gastric tube, and nerve injury level ($P > 0.05$).

Table 2 Summary of Influencing Factors in the Pulmonary Infection Group and Non-Pulmonary Infection Group in Patients with Spinal Cord Injury Post-Tracheostomy

Variables	Pulmonary Infection Group (n=101)	Non-Pulmonary Infection Group (n=213)	t/x^2	P
Sex (n)				
Male	59 (58.42%)	117 (54.93%)	0.338	0.56
Female	42 (41.58%)	96 (45.07%)		
Age (year)	41.26 ± 9.94	44.63 ± 8.07	−1.783	0.06
BMI (kg/m^2)	22.71±2.18	23.43±2.76	−1.423	0.26
Cause			1.008	0.80
Motor vehicle accidents	42 (38.18%)	76 (35.68%)		
Bruise injuries on the neck caused by heavy objects	9(0.08%)	20 (9.39%)		
Neck abrasions and falls	54 (49.09%)	111 (52.11%)		
Falls from height	5(0.04%)	6(2.82%)		
Alcohol use (n)				
Yes	61 (60.39%)	123 (57.75%)	0.198	0.66
No	40 (39.61%)	90 (42.25%)		
Smoking (n)				
Yes	38 (37.62%)	78 (36.62%)	0.030	0.86
No	63 (62.38%)	135 (63.38%)		
Hypertension (n)				
Yes	58 (57.43%)	125 (58.69%)	0.045	0.83
No	43 (42.57%)	88 (41.31%)		
Diabetes (n)				
Yes	48 (47.52%)	44 (20.66%)	23.875	0.000
No	53 (52.48%)	169 (79.34%)		
Hyperlipidemia (n)				
Yes	23 (22.77%)	46 (21.59%)	0.055	0.81
No	78 (77.23%)	167 (78.41%)		
Hypoproteinemia (n)				
Yes	48 (47.52%)	36 (16.91%)	32.789	0.000
No	53 (52.48%)	177 (83.09%)		
Administration of glucocorticoids (n)				
Yes	44 (43.56%)	38 (17.84%)	23.497	0.000
No	57 (56.44%)	175 (82.16%)		
Indwelling gastric tube (n)				
Yes	30 (29.71%)	70 (32.86%)	0.315	0.57
No	71 (70.29%)	143 (67.14%)		
Level of nerve damage			0.322	0.57
High level cervical cord injury C1-C3	36 (35.64%)	83 (38.97%)		
Low level cervical cord injury C4-T1	65 (64.35%)	130 (61.03%)		

(*Continued*)

Table 2 (Continued).

Variables	Pulmonary Infection Group (n=101)	Non-Pulmonary Infection Group (n=213)	t/x^2	P
ASIA impairment scale			116.162	0.000
Grade A injury	66 (65.35%)	19 (8.92%)		
Grade B injury	11 (10.89%)	36 (16.91%)		
Grade C injury	16 (15.84%)	59 (27.70%)		
Grade D injury	8(7.92%)	99 (46.47%)		
ASIA classification of injury			110.494	0.000
Complete injury	66 (65.35%)	19 (8.92%)		
Incomplete injury	35 (34.65%)	194 (91.08%)		
Duration of mechanical ventilation (days)	6.17±3.27	3.92±1.52	4.608	0.000
Length of hospital stay (days)	23.75±4.62	15.87±3.93	6.496	0.000
Death toll	24 (23.76%)	15 (7.02%)	4.012	0.000

Abbreviation: ASIA, American Spinal Injury Association.

Multivariate Analysis of Pulmonary Infection in Patients with Spinal Cord Injury Who Underwent Tracheostomy

We included the significant indicators in univariate analysis (diabetes, hypoproteinemia, administration of glucocorticoids, ASIA grade, duration of mechanical ventilation, length of hospital stay) in the logistic regression analysis. We found that diabetes (OR 2.302, 95% CI 1.285–3.972), hypoproteinemia (OR 1.992, 95% CI 1.125–3.101), administration of glucocorticoids (OR 2.934, 95% CI 1.412–4.661), ASIA grade A (OR 3.672, 95% CI 1.988–5.046), mechanical ventilation for $\geq$ 6 days (OR 2.108, 95% CI 1.385–4.751), and length of hospital stay for $\geq$ 20 days (OR 2.137, 95% CI 1.092–3.842) were risk factors for pulmonary infection in patients with spinal cord injury post-tracheostomy ($P < 0.05$) (Table 3 and Table 4).

Table 3 Risk Factors and Assignment of Pulmonary Infection

Factors	Variable	Assignment Description
Pulmonary infection	Y	Yes=1, No=2
Diabetes	X1	Yes=1, No=2
Hypoproteinemia	X2	Yes=1, No=2
Administration of glucocorticoids	X3	Yes=1, No=2
ASIA grade	X4	ASIA grade A injury=1, ASIA grade B-D injury=2
Duration of mechanical ventilation (days)	X5	$\geq$6=1, <6=2
Length of hospital stay (days)	X6	$\geq$20=1, <20=2

Abbreviation: ASIA, American Spinal Injury Association.

Table 4 Logistic Regression Analysis of Multifactorial Risk Factors for Pulmonary Infection in Patients with Spinal Cord Injury Post-Tracheostomy

Variable	β	sx	r^2	OR	95% CI	p
Diabetes	0.342	0.112	0.779	2.302	1.285–3.972	0.02
Hypoproteinemia	0.231	0.103	0.811	1.992	1.125–3.101	0.04
Administration of glucocorticoids	0.158	0.074	0.668	2.934	1.412–4.661	0.01
ASIA grade A injury	0.475	0.098	0.671	3.672	1.988–5.046	0.02
Mechanical ventilation $\geq$ 6 days	0.287	0.102	0.712	2.108	1.385–4.751	0.01
Length of hospital stay $\geq$ 20 days	0.201	0.116	0.651	2.137	1.092–3.842	0.02

Abbreviation: ASIA, American Spinal Injury Association.

Bacteriological Analysis of Pulmonary Infection in Patients with Spinal Cord Injury Who Underwent Tracheostomy

Bacteriological Distribution of Pulmonary Infection

We isolated a total of 213 pathogenic bacteria from the lower respiratory tract secretions of 101 patients with pulmonary infection—these included 52 cases (51.48%) of gram-negative bacteria infection and 24 cases (23.76%) of gram-positive bacterial infection. Among the pathogenic bacteria of pulmonary infection, *Klebsiella pneumoniae* (15.84%) and *Staphylococcus aureus* (8.91%) were the most common pathogens. The mortality rate of patients with gram-positive bacterial infection was significantly higher than that of patients with gram-negative bacteria infection ($P < 0.05$).

Among the 101 patients with pulmonary infection, a total of 21 (20.79%) had mixed bacterial infections, mainly *Candida tropicalis, S. aureus, Pseudomonas aeruginosa*, and *Acinetobacter baumannii* (Table 5).

Drug Resistance Rate and Susceptibility Test of *K. pneumoniae* and *S. aureus* in Patients with Pulmonary Infection

The antibiotic resistance rates and drug susceptibility tests of *K. pneumoniae* and *S. aureus* are shown in Table 6. *K. pneumoniae* and *S. aureus* were highly sensitive to cefoperazone, meropenem, and levofloxacin.

Table 5 Bacterial Distribution of Pulmonary Infection in Patients with Spinal Cord Injury Post-Tracheostomy (n = 101)

Pathogen	Number (n=101)	Percentage (%)	Death Toll (n=24)	Mortality Rate (%)
Gram-negative bacteria	52	51.48	5	4.95*
Klebsiella pneumoniae	16	15.84	3	2.97
Pseudomonas aeruginosa	14	13.86	2	1.98
Acinetobacter baumannii	12	11.88	0	0
Escherichia coli	10	9.90	0	0
Gram-positive bacteria	24	23.76	14	13.86
Staphylococcus aureus	12	11.88	7	6.93
Streptococcus pneumoniae	7	6.93	0	0
Staphylococcus epidermidis	3	2.97	0	0
Enterococcus faecalis	2	1.98	0	0
Fungi	4	3.96	2	1.98
Candida albicans	4	3.96	2	1.98
Mixed infection	21	20.79	3	2.97

Notes: *P<0.05, compared with mortality rate of patients with gram-negative bacterial infection.

Table 6 Antibiotic Resistance Rates and Susceptibility Test Results of *Klebsiella pneumoniae* and *Staphylococcus aureus*

Antibiotics	Antibiotic Resistance of *Klebsiella pneumoniae* (n=16)			Antibiotic Resistance of *Staphylococcus aureus* (n=12)		
	n	Resistance Rate (%)	Antibiotic Susceptibility (%)	n	Resistance Rate (%)	Antibiotic Susceptibility (%)
Levofloxacin	4	8.31	89.83	3	3.04	91.91
Gentamicin	20	75.32	15.53	10	41.12	56.13
Cefepime	5	21.22	77.81	5	11.52	77.44
Cefoperazone	2	9.98	94.14	4	3.21	92.18
Ampicillin	13	77.42	31.22	11	55.56	30.33
Meropenem	2	9.21	95.32	3	8.42	91.22
Sulfamethoxazole	12	73.77	21.13	14	68.93	25.32
Cefoxitin	3	7.81	80.03	3	5.04	84.392
Amoxicillin	14	67.98	35.64	13	76.21	12.52
Ceftriaxone	18	67.72	24.13	11	59.13	42.52
Norfloxacin	5	8.89	77.63	3	5.52	83.41

Discussion

The treatment of ATSCI remains a challenge in the field of spinal trauma. The concurrent incomplete or complete paralysis often leads to respiratory dysfunction due to phrenic nerve paralysis and respiratory muscle weakness, weakened ability to actively remove secretions, and poor coughing up of sputum caused by body position. This easily facilitates pathogenic bacteria to enter the lower respiratory tract and cause pulmonary complications. Among them, the most important focus of treatment is pulmonary infection, which is also one of the main causes of early death in patients with ATSCI. Therefore, in such patients, the prevention and control of pulmonary infection is the core challenge in the comprehensive treatment of spinal cord injury. To achieve favorable and effective recovery, it is essential to comprehensively understand the relevant factors toward preventing and treating pulmonary infection.

In this study, we found that the incidence of pulmonary infection in patients with spinal cord injury who underwent tracheostomy was 32.17%. The results of logistic regression analysis revealed that the most important factor affecting lung infection was ASIA grade A cervical spinal cord injury, and other risk factors were administration of glucocorticoids, diabetes, length of hospital stay for ≥ 20 days, mechanical ventilation for ≥ 6 days, and hypoproteinemia, in that order. It is essential to carry out early prevention and intervention for these risk factors in clinical nursing.

Post-tracheostomy, the air is not humidified and filtered by the upper respiratory tract, but directly enters the lungs, and this can damage the ciliated epithelium of the respiratory mucosa, making it difficult to remove secretions and foreign bodies.[23] Inhalation of dry air, blockage of sputum, pathogenic bacteria and particles containing pathogenic bacteria are likely to cause pulmonary infection.[24] Neurological function is impaired in patients with ASIA grade A spinal cord injury, and they have dysphagia, which can easily cause reflux and inhalation of gastric contents into the lungs. The bronchial mucosa and cilia can be damaged by digestive juices, resulting in pneumonia.[25,26]

Patients with diabetes have poorer immunity and an increased risk of infection when compared to non-diabetic patients.[27,28] It was found in one study[29] that the high-glucose environment of patients with diabetes provides a good breeding environment for pathogenic microorganisms, which can increase the risk of infection. Therefore, it is important to intensify interventions for improving the immune status and stabilizing blood glucose in patients with diabetes.

In addition, decreased pulmonary function caused by dysfunction of the spinal cord nerve is also an important cause of infection. Therefore, respiratory interventions should be improved. The general physical condition, resistance against pathogenic bacteria, and repairing ability are relatively poor in individuals with chronic underlying diseases, so they are more likely to develop pulmonary infections.[30] Thus, in addition to making necessary improvements in the immune status of these patients, close monitoring of blood glucose fluctuations and enhanced respiratory management are necessary treatments.[31]

In this study, we found that hypoproteinemia and administration of glucocorticoids were independent risk factors for pulmonary infection in patients post-tracheostomy. Albumin is an important protein synthesized by the liver, and changes in albumin level can reflect the nutritional status of patients to a certain extent,[32] suggesting that pulmonary infection in patients with tracheostomy is related to their nutritional status, resistance, and pulmonary function.

Glucocorticoids are important hormones that regulate the body's stress response and are frequently used in the emergency care of patients in intensive care units (ICU).[33] However, several studies[34,35] have shown that glucocorticoids can reduce immune function and lead to decreased anti-infection ability, which is an independent risk factor of infection, and hence suggest that administration of glucocorticoids for patients in the ICU should be restricted before and after tracheostomy. Additionally, patients need to be provided nutritional support based on their specific health conditions to improve their resistance and continuously prevent the occurrence of infection.

The ventilator is often used for patients with ASIA grade A/B spinal cord injury to assist breathing due to respiratory paralysis or shock, and the accompanying ventilator-related pneumonia is always the focus in the prevention and treatment of nosocomial infections. The main causes are contamination of colonizing bacteria in the oropharynx and upper respiratory tract and exogenous bacterial invasion, among others.[36] Studies have shown that in patients with spinal cord injury, the incidence of ventilator-associated pneumonia is higher due to respiratory muscle weakness, prolonged supine position, and ineffective cough.[37] In this study, we found that mechanical ventilation for ≥ 6 days and length of

hospital stay for ≥ 20 days were independent risk factors for pulmonary infection. Therefore, optimizing ventilator parameters and weaning patients early from the ventilator can reduce the incidence of pneumonia in patients.

In this study, we cultured sputum samples from patients for identification and analyzed the pathogenic bacteria species and distribution. We found that the pathogenic bacteria of pulmonary infection were still mainly gram-negative bacteria, followed by gram-positive bacteria and fungi. *K. pneumoniae* (15.84%) and *S. aureus* (8.91%) were the most common pathogenic bacteria in the distribution of pathogenic bacteria. The mortality rate of patients with gram-positive infection was significantly higher than that of patients with gram-negative infection.

We also found that the proportion of mixed infection in pulmonary infection was as high as 20.79%. Patients with ASIA grade A spinal cord injury have severely deteriorated respiratory muscle strength, significantly reduced cough and expectoration ability, sputum retention in alveoli and bronchi, and mass-production of different pathogens in the sputum, and these can easily cause mixed infections. Hence, we suggest that monitoring of pathogenic organisms should be enhanced and targeted therapy should be administered during treatment.

We found that *K. pneumoniae* and *S. aureus* were highly sensitive to cefoperazone, meropenem, and levofloxacin. Therefore, in clinical practice, the use of antibiotics must be based on resistance and susceptibility tests in order to improve their efficacy and safety.[38,39]

Clinical management and nursing procedures, including tracheostomy, dressing changes, and endotracheal intubation care, should strictly adhere to aseptic procedures. Additionally, bacterial culture of sputum and drug susceptibility test should be carried out in time, and antibiotics should be adjusted in time as per the test results. Contamination must be avoided during collection of the sputum specimen as this may affect the test results and delay treatment. It is important to perform timely suction of sputum to avoid infection of the tissue surrounding the tracheostomy incision and damage to the respiratory mucosa, thus reducing bacterial migration.[40,41] In addition, the patient must be placed in a reasonable position and periodic turning over and back-patting must be done to avoid sputum accumulation, which is conducive to prevent pneumonia.[42–44] In addition, early nutritional support is necessary and, if necessary, plasma or albumin should be administered to improve the body's resistance so as to prevent and reduce the chances of nosocomial infections.

There are several limitations of this study. First, this study is a retrospectively designed study, with all clinical data obtained from patient statements at the time of their clinical consultations and records of the attending physician. The data collected are limited. Second, there are many factors influencing the laboratory data collected. Despite our strict requirements for patient inclusion, there were still unavoidable confounding factors, and there may have been other factors affecting pulmonary infections that we could not include in the analysis. Third, follow-up research requires more large-sample, multi-center epidemiological investigations to clarify the distribution of pathogenic bacteria in patients who develop pulmonary infection with spinal cord injury post-tracheostomy, to more scientifically guide the early administration of antibiotics.

Conclusion

Pulmonary infection is a common and serious complication in patients with spinal cord injury post-tracheostomy. We found that diabetes, hypoproteinemia, administration of glucocorticoids, mechanical ventilation for ≥ 6 days, length of hospital stay for ≥ 20 days were risk factors for pulmonary infection. As per our study results, pulmonary infections were mainly caused by gram-negative bacteria. Timely and effective measures for risk factors are essential to improve the prognosis of pulmonary infection in patients with spinal cord injury following tracheostomy.

Data Sharing Statement

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Ethical Statement

This study was conducted with approval from the Ethics Committee of the Third Hospital of Hebei Medical University (approval number: Section 2022-005-1). This study was conducted in accordance with the declaration of Helsinki. The Ethics Committee of the Third Hospital of Hebei Medical University exempted the requirement of written informed

consent: This clinical study is a retrospective study. It only collects the patient's clinical data, does not interfere with the patient's treatment plan, and will not bring risks to the patient's physiology. The researchers confirm that patients' information will not be disclosed unless it is de-identified, in order to maintain confidentiality and personal privacy.

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Disclosure

The authors declare that they have no competing interests.

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