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Original Article

Comprehensive airway management of ventilator-associated pneumonia in ICU populations

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Abstract: Objective: To evaluate the validity of comprehensive airway management intervention on ventilator-associated pneumonia (VAP) in ICU patients requiring mechanical ventilation. Methods: In this retrospective observational study, the clinical data from 120 patients undergoing mechanical ventilation in the ICU of Hebei Chest Hospital from May 2020 to July 2022 were surveyed. Finally, 50 cases of VAP were identified and placed into an observation (n=25) and a control group (n=25) according to the nursing model they received. The control group was treated with routine nursing intervention, and the observation group was given comprehensive airway management intervention based on the control group. After 3 weeks of intervention, the clinical symptom recovery time, treatment-related indexes, nursing quality and nursing satisfaction score, and blood gas indexes and vital signs of the patients in the two groups were examined. The multivariate Logistic regression analysis was performed to identify the risk factors related to the death of critically ill patients. Results: The observation group showed a significant reduction in the recovery time of heart failure, wheezing cough, and lung rales compared with that in the control group. The duration of mechanical ventilation, hospitalization, and antibiotic use in the observation group were appreciably shorter compared with those in the control group (all $P<0.05$). Additionally, nursing satisfaction and nursing quality scores were higher in the observation group compared to the control group ($P<0.05$). The contrast of blood gas indexes and vital signs between the two groups before ventilation and 1 hour after evacuation ventilation showed that a statistical significance existed in the interaction between groups ($P<0.05$). The risk factors related to the death of critically ill patients included D-dimer (OR=1.051, 95% CI: 1.006-1.08, $P<0.05$) and lactic acid (OR=0.894, 95% CI: 0.923-1.031, $P<0.05$). Conclusion: Comprehensive airway management mode can reduce the occurrence of VAP in ICU patients requiring mechanical ventilation.

Keywords: Comprehensive airway management, ICU, mechanical ventilation, ventilator-associated pneumonia

Introduction

Ventilator-associated pneumonia (VAP) is a pulmonary infection that occurs more than 48-72 hours after endotracheal intubation [1]. It is a common and serious infection seen in the intensive care unit (ICU) [2], often prolonging the hospitalization time and increasing the morbidity and mortality among patients [3]. The incidence of VAP in mechanically ventilated patients ranged from 6-52 cases per 1000 mechanical ventilations, with a fatality rate of 14-50% [4]. A surveillance study of VAP incidence in 46 hospitals in China showed a thousand-day incidence rate of 8.89% (with 17,358 patients observed, 91,448 total intubation days, and 813 cases of VAP) [5]. VAP can lead to difficulties in being weaned from the mechanical ventilation, extending mechanical ventilation time by 5.4 to 21.8 days, ICU stays by 6.1 to 20.5 days, and overall hospital stays by 11 to 32.6 days [6]. Previous studies in the United States have shown that VAP increases the average hospitalization cost per patient by $40,000, with the annual cost of care for VAP patients reaching $2 billion [7]. The occurrence of VAP presents a serious challenge for hospital infection control, making the goal of VAP "zero tolerance" a critical part of hospital infection management [8].

Numerous studies have suggested that effective nursing intervention can more quickly alleviate clinical symptoms, shorten the length of stay, and improve the prognosis of patients [9]. Airway nursing in the ICU can be complex

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[10], as patients often have limited physiological reserves, increasing their risk of hemodynamic deterioration, severe hypoxemia, and cardiac arrest [11]. Since the lungs are the primary site of ventilator-associated pneumonia in ICU patients, there is a risk of respiratory tract infection [12]. Therefore, meticulous airway nursing is crucial, not only to prevent respiratory tract infection but also to ensure smooth breathing of patients.

The aim of this study is to assess the application of comprehensive airway nursing in the clinical treatment of VAP in ICU patient populations.

Materials and methods

Setting and population

The clinical data from 120 patients who underwent mechanical ventilation in the ICU of the Hebei Chest Hospital were retrospectively surveyed in this study. The age of the patients ranged from 30 to 81 years, with a mean age of 62.13±10.06, and the duration of mechanical ventilation ranged from 3.5 to 29 days (mean 14.67±4.81 days). Mechanical ventilation was individually tailored to each patient, with ventilator settings optimized to meet their specific clinical needs. For patients ready to be weaned from mechanical ventilation but had not yet completed the three-week intervention period, a gradual tapering protocol was initiated. This involved decreasing the level of support provided by the ventilator, such as reducing the assist level in a proportional assist mode or decreasing the inspiratory pressure in a pressure-controlled mode. The tapering process was halted or reversed if the patient exhibited signs of respiratory distress or if their clinical condition worsened. Mechanical ventilation was fully discontinued when the patient consistently met predefined weaning criteria and demonstrated stable respiratory function. In our study, the diagnosis of VAP was established based on the criteria defined by the Centers for Disease Control and Prevention (CDC) and the National Healthcare Safety Network (NHSN). A patient was considered to have VAP if they met the following conditions: 1) They had received mechanical ventilation for a minimum of 48 hours; 2) They presented with a body temperature of at least 38°C (100.4°F); 3) They showed new or gradually enlarging lung infiltrates on chest X-rays; 4) They exhibited signs of lung consolidation and/or wet rales during physical examination; 5) They produced purulent secretions in the respiratory passage; 6) In cases where sputum cultures were conducted, the detection of new pathogens indicated VAP.

Finally, Ventilator-Associated Pneumonia (VAP) was diagnosed in 50 cases, resulting in an incidence of 41.67%. The 50 patients with VAP were further assigned to either an observation group (n=25) or a control group (n=25) according to their nursing methods. The study was approved by the Ethical Committee of Hebei Chest Hospital and conducted in accordance with ethical standards.

Selection criterion

Inclusion criteria: Mechanically ventilated ICU subjects in whom the indications of pneumonia appeared more than 48 h from the intubation. Exclusion criteria: (1) Patients with autoimmune system diseases, liver, or kidney failure; (2) Patients with a complete loss of spontaneous respiratory function; (3) Patients who had a respiratory tract infection before mechanical ventilation; (4) Patients who were unable to cooperate with the researchers.

Nursing approaches

Patients in both groups were administrated ventilator support and nursing interventions. The control group was given routine nursing for mechanical ventilation, such as keeping the respiratory tract unobstructed, timely sucking of sputum, and monitoring of various vital signs. Comprehensive airway management intervention was given to the observation group on the basis of the control group, including: (1) Airway humidification management. Appropriate humidification methods and solutions were chosen according to the condition of patients; the disinfection and isolation system was strictly implement, avoiding pressure and folding of the drip pipe; an automatic water filling device was applied while ensuring the patency of straws and minting proper water level. (2) Respiratory circuit management. The contaminated respiratory line was replaced in a timely manner, and the condensed water was drained regularly. (3) Artificial airway balloon management. The pressure in the artificial airway balloon was monitored using continuous airbag pressure detector. (4) Oral management. Appropriate solution for oral care, such as 0.9% sodium chloride injection, boric acid solution, or 0.1% acetic acid solution were chosen for oral infection. Chlorhexidine solutions at recommended concentrations (2%, 0.2%, and 0.12%) as per guidelines for the Diagnosis, Prevention, and Management of Ventilator-Associated Pneumonia (2013) and the Chinese Adult Hospital Acquired Pneumonia and Ventilator-Associated Pneumonia (2018 Edition) can also be used. If necessary, 1%-4% sodium bicarbonate solution can be used to clean the mouth to prevent fungal infection. (5) Infection control. Hand hygiene of medical staff was strengthened, strictly following the principle of asepsis. Education and training for healthcare personnel in airway care were provided to ensure consistent application of the intervention across the study population. (6) Regular monitoring and proactive management. High-frequency oscillatory ventilation and other advanced techniques could be adopted when indicated. (7) Posture management. The bed head was raised by 35°-50° to prevent the occurrence of aspiration and reflux.

Evaluation indicators

After 3 weeks of intervention, the clinical symptom recovery time, treatment-related indexes, nursing quality and nursing satisfaction score, and blood gas indexes and vital signs of the patients in the two groups were examined.

Statistical analysis

Data processing was carried out with SPSS 22.00. Descriptive statistics were stated as mean ± SD, and categorical variables were denoted by percentages. Continuous variables were assessed by the student's t-test and categorical data by the χ^2 test. A *p*-value of less than 0.05 was considered statistically significant. To evaluate the influence of sample size on our findings, sensitivity analyses were conducted by adjusting the sample size and re-running our regression models. Results were compared to the base case to assess the stability of our conclusions. The robustness of the analysis was verified by checking for assumptions such as multicollinearity, heteroscedasticity, and normal distribution of errors. Adjustments were applied when necessary to ensure the validity of the results.

Results

Flow chart of patient inclusion

Our study initially involved a total of 139 patients who required mechanical ventilation in the ICU. Among them, 54 developed ventilator-associated pneumonia (VAP), and four patients were further excluded based on the exclusion criteria, including two patients with conditions that could potentially affect study outcomes, such as significant medical comorbidities or incorrect diagnoses; and another two patients due to their failure to attend scheduled follow-up appointments or their incompliance to medication regimens. Finally, 50 patients with VAP were considered eligible for inclusion in this study and further assigned into a control group (n=25) and an observation group (n=25) according to the nursing methods received (**Figure 1**).

Baseline characteristics of participants

The baseline characteristics of the 50 VAP patients are presented in **Table 1**. The patients' mean age was 62.13 years (range 30-81). In the observation group, 8 were under the age of 65, while in the control group, 6 were under the age of 65. The baseline characteristics of the two groups of VAP patients showed no significant differences in terms of gender, age, duration of mechanical ventilation, mode of ventilation, and progression of VAP (all P>0.05).

Comparison of the improvement time of clinical symptoms between the two groups

As shown in **Table 2**, the observation group exhibited significantly shorter recovery periods for heart failure (1.64±0.57 days vs. 3.26±0.98 days), wheezing cough (1.93±0.92 days vs. 5.28±1.95 days), and lung rale (5.41±1.02 days vs. 11.02±3.98 days), indicating that the intervention in the observation group was more effective in promoting symptom recovery (all P<0.05).

Comparison of treatment-related indicators between the two groups

The time of mechanical ventilation, hospitalization, and antibiotic use in the observation group were drastically reduced compared with those in the control group (all P<0.05, **Table 3**). Specifically, the observation group demonstrat-

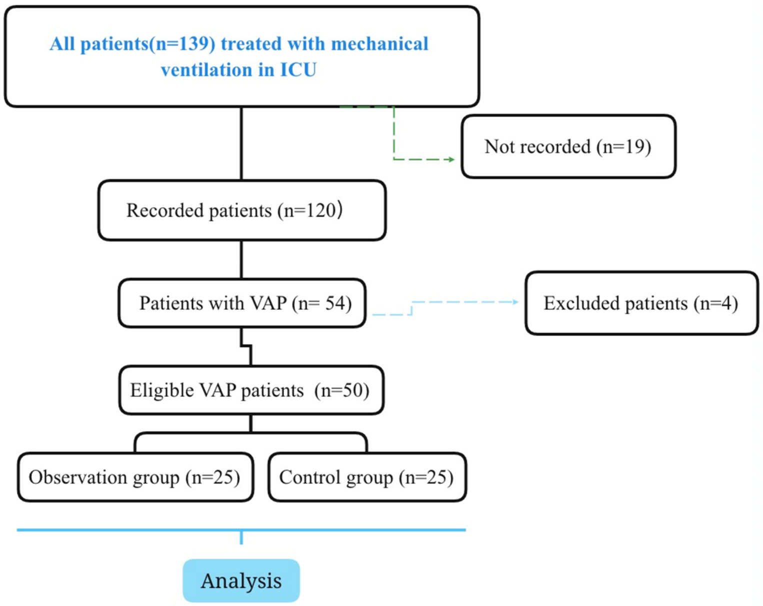

Figure 1. Flow chart exhibiting the inclusion of patients with VAP. VAP: ventilator-associated pneumonia.

Table 1. The baseline characteristics of the two groups of VAP patients

	Observation group (n=25)	Control group (n=25)	P
Gender			0.423
Male	19	14	
Female	6	11	
Age (years)			0.067
≥65	17	19	
<65	8	6	
Mechanical ventilation time (d)			0.669
≥15	13	15	
<15	12	10	
Ventilation approach			0.091
Endotracheal tube	14	16	
Tracheostomy tube	11	9	
Progression of VAP (%)			0.772
Early	12	14	
Late	13	11	

VAP: ventilator-associated pneumonia; IQR: interquartile range.

ed a mean duration of mechanical ventilation of 6.11±1.11 days, which was significantly shorter than the 9.35±1.46 days observed in the control group (P=0.018). Similarly, the duration of hospitalization was substantially reduced in the observation group, with a mean of 6.24±0.76 days, compared to 10.03±1.26 days in the control group (P=0.004). Besides, the observation group exhibited a significant decrease in antibiotic use duration, with a mean of 8.21±1.02 days, compared to the 12.05±3.58 days in control group (P=0.005). These data suggest that the treatment approach employed in the observation group led to more rapid patient recovery and a reduced duration of medical intervention.

Comparison of nursing quality and nursing satisfaction score between the two groups

After intervention, the score of nursing satisfaction and nursing quality in the observation group was significantly higher compared with those in the control group (all P<0.05, **Table 4**). Specifically, the nursing quality score in the observation group was 89.41±6.54, which was significantly higher than 70.35±5.38 in the control group (P=0.001). Similarly, the nursing satisfaction score was significantly better in the observation group, with a mean score of 90.66±7.03, compared to 70.88±5.97 in the control group (P=0.029).

Comparison of blood gas indicators and vital signs between the two groups before ventilation and 24 hours after withdrawal

Based on the data presented in **Table 5**, a comparative analysis of blood gas indices and vital signs was conducted between the observation group and the control group before ventilation and 1 hour after ventilation. The results showed significant improvements in the observation group in terms of $PaCO_2$, PaO_2, HR, and RR compared to the control group at 24 hours after withdrawal (all P<0.05).

Table 2. Assessment of clinical symptom recovery time between the two groups (Mean ± SD)

	Observation group (n=25)	Control group (n=25)	P
Heart failure	1.64±0.57	3.26±0.98	0.023
Cough	3.45±1.02	7.74±2.33	0.009
Wheezing	1.93±0.92	5.28±1.95	0.001
Lung rale	5.41±1.02	11.02±3.98	0.031

Table 3. Comparison of treatment-related indexes between the two groups (Mean ± SD)

	Observation group (n=25)	Control group (n=25)	P
Mechanical ventilation time	6.11±1.11	9.35±1.46	0.018
Hospitalization time	6.24±0.76	10.03±1.26	0.004
Antibiotic use time	8.21±1.02	12.05±3.58	0.005

Table 4. Comparison of nursing quality and nursing satisfaction scores between the two groups (Mean ± SD)

	Observation group (n=25)	Control group (n=25)	P
Nursing quality	89.41±6.54	70.35±5.38	0.001
Nursing satisfaction score	90.66±7.03	70.88±5.97	0.029

Table 5. Comparison of blood gas indexes and vital signs before ventilation and 1 hour after ventilation (Mean ± SD)

	Observation group (n=25)	Control group (n=25)	P
$PaCO_2$ (mmHg)			
Before ventilation	65.58±7.18	40.35±4.05	0.579
24 hours after withdrawal	44.39±5.26	45.61±4.90	0.006*
PaO_2 (mmHg)			
Before ventilation	55.25±6.24	88.04±9.45	0.285
24 hours after withdrawal	46.01±7.28	48.36±8.06	0.001*
HR (beats/min)			
Before ventilation	111.23±12.35	91.34±10.02	0.097
24 hours after withdrawal	86.30±9.73	87.22±9.41	0.023*
RR (beats/min)			
Before ventilation	30.04±4.35	20.67±2.36	0.728
24 hours after withdrawal	23.07±2.55	24.60±3.07	0.002*

*: P<0.05, observation group vs. control group. $PaCO_2$: arterial carbon dioxide tension; PaO_2: partial pressure of oxygen in artery; HR: heart rate; RR: respiration rate.

Multivariate logistic regression analysis of risk factors for death in critically ill patients

A logistic stepwise regression analysis was performed to identify prognostic risk factors for the ICU patients. The discharge outcome was taken as the dependent variable, while age, ALT, PCT, blood glucose, lactic acid, albumin, D-dimer, PT, and FIB were included as covariables (**Table 6**). The results showed that the risk factors for the death in critically ill patients included D-dimer (OR=1.051, 95% CI: 1.006-1.08, P<0.05) and lactic acid (OR=0.894, 95% CI: 0.923-1.031, P<0.05).

Discussion

Ventilator-associated pneumonia (VAP) is a common complication during mechanical ventilation, imposing significant economic burdens on patients' families and causing substantial psychological stress for patients [13]. The main causes of VAP include the destruction of preventive ability of respiratory tract and iatrogenic inhalation of oropharyngeal colonized bacteria [14]. Due to the difficulty in diagnosing this condition, patients exhibiting suspected symptoms should be treated with antibiotics immediately [15]. Evidence has indicated that the pathogens of VAP usually originate from the patients themselves [16]. Sputum accumulation in the oral cavity leads to high bacterial concentration in secretions, increasing the risk of infection complications [17]. Regular cleaning of secretions and sputum is crucial for maintaining a clear airway, eliminating numerous pathogenic bacteria, preventing their accumulation in the oropharynx, and reducing the incidence of VAP [18]. When patients were placed in a supine position, the concentration of endocrine substances in the pharynx, stomach and trachea were significantly higher than those in semi-recumbent position, increasing the likelihood of reflux and aspiration. Therefore, unless contraindicated, maintaining patients in a semi-recumbent position is recommended to reduce the risk of VAP [19].

Table 6. Results of multivariate Logistic regression analysis for predicting death in critically ill patients

	B	S.E.	Wald	P	OR	95% CI
Age	0.016	0.008	2.704	0.103	1.016	0.994-1.036
ALT	-0.002	0.003	0.337	0.564	0.993	0.997-1.004
PCT	0.017	0.012	1.386	0.251	1.069	0.988-1.032
Blood glucose	0.035	0.047	2.039	0.166	1.048	0.985-1.095
Albumin	-0.033	0.024	1.168	0.264	0.907	0.918-1.038
Lactic acid	-0.004	0.003	2.074	0.041*	0.894	0.923-1.031
PT	-0.050	0.049	0.051	0.863	0.965	0.937-1.077
FIB	0.019	0.066	0.053	0.827	1.019	0.886-1.185
D-dimer	0.025	0.012	4.575	0.021*	1.051	1.006-1.08

*: P<0.05. ALT: alanine aminotransferase; PCT: procalcitonin; FIB: fibrinogen; PT: prothrombin time.

Traditional nursing is gradually replaced by the concept of patient-centered nursing. For VAP patients, the implementation of targeted and individualized nursing measures according to the specific conditions of patients is helpful to improve the therapeutic effect [20]. In this study, patients in the observation group received comprehensive airway nursing based on routine nursing. Through the implementation of comprehensive airway management, the contaminated catheters were proactively replaced, and oral cavity hygiene were ensured [21]. In addition, the removal of sputum and other secretions from the airway might keep the respiratory tract unobstructed, while the artificial airway management effectively isolated the infection of foreign bacteria [22, 23]. As a preventive nursing model, comprehensive airway management is patient centered. Through the evaluation of the condition changes in patients and the implementation of a series of feasible and systematic intervention measures, this approach decreases the incidence of adverse events and promotes a healthy recovery [24, 25]. The present study underscores the pivotal role of comprehensive airway management in VAP patients. By implementing targeted and personalized nursing interventions based on an individual's needs, we observed a significant reduction in various clinical indicators, including recovery time for heart failure, duration of wheezing cough, and resolution of lung rales. Moreover, the time spent on mechanical ventilation, hospitalization, and antibiotic use were notably lower in the observation group, suggesting a more efficient and cost-effective approach to patient care.

The comprehensive respiratory and oral care regimen implemented in this study is a cornerstone of the observed improvements in VAP patient outcomes. The meticulous attention to bacterial removal from catheters and the maintenance of oral cavity cleanliness are essential components of this strategy. Bacteria readily colonize catheter surfaces, leading to biofilm formation and increased infection risk [26]. Timely removal of these bacteria is crucial to prevent their migration into the bloodstream, a process that can initiate sepsis and other systemic complications [27]. Furthermore, the oral cavity is a reservoir for diverse microbiota, which can be aspirated during mechanical ventilation. Regular oral care practices, such as toothbrushing, mouth rinsing, and the use of antiseptics, help to reduce the bacterial load and prevent the aspiration of pathogens into the lower respiratory tract. By doing so, these practices not only protect patients from VAP but also contribute to the overall reduction in healthcare-associated infections [28]. The process of secretion and sputum clearance is another critical component of the comprehensive airway management strategy. The accumulation of secretions in the airways can lead to atelectasis, hypoxemia, and increased work of breathing [29]. Effective suctioning and mobilization of secretions ensure a patent airway and prevent the pooling of secretions in the lung parenchyma, where they can serve as a nutrient source for bacteria and contribute to the development of VAP [30]. Moreover, the semi-recumbent position, a key feature of the intervention, offers several advantages in the management of VAP. This position decreases the likelihood of aspiration by gravity, as secretions and gastric contents are less likely to reflux into the upper airway.

Additionally, integrating innovative technologies, such as high-frequency oscillation therapy or aerosolized antibiotics, could further enhance the effectiveness of the comprehensive airway management strategy. Within the framework of patient-centered nursing, the comprehensive airway management model resonates with the principles of holistic care, emphasizing the comfort and well-being of patients. An individualized care approach was linked to increased nursing satisfaction and enhanced patient recovery, thereby creating a positive and respectful environment during hospitalization. These results highlight the significance of a patient-centric approach in the nursing care of critically ill patients, which not only improves clinical outcomes but also instills patient confidence and promotes overall recovery. Plasma D-dimer is a specific degradation product resulting from the hydrolysis of activated fibrin by fibrin monomers, which interact with the activation of the coagulation system [31]. Traditionally, D-dimer is often used in the diagnosis and prognosis of venous thrombosis and pulmonary embolism of the lower extremities. Recent studies have shown that D-dimer is closely related to the prognosis of cardiovascular disease, sepsis, aortic dissection, community-acquired pneumonia, and tumors [32]. Additionally, this study contributes to the growing body of research on the diagnostic and prognostic value of plasma D-dimer levels in critically ill patients. Our multivariate logistic regression analysis demonstrates that D-dimer is an independent predictor of mortality, suggesting its potential as a biomarker for assessing the severity and outcomes of critical illnesses. The strong correlation between D-dimer levels and mortality risks highlighting the importance of prompt diagnostic assessment and targeted therapeutic interventions in patients with elevated D-dimer levels. Moreover, the comprehensive airway management approach outlined in this study can be incorporated into existing clinical practice guidelines to enhance patient outcomes. With the rising incidence of VAP and the considerable economic and psychological burden it imposes, the adoption of such an approach could lead to substantial healthcare cost reductions and improved quality of life for patients and their families.

One limitation of this study is the retrospective nature of the data collection. While this provided valuable insights into real-world clinical practices, a prospective study design would have allowed for the collection of more detailed data, including potential confounders and intermediate outcomes. Additionally, the study was conducted in a single hospital setting, which may limit the generalizability of the findings to other healthcare environments. Future research will aim to replicate these findings in larger, more diverse patient cohorts and across various healthcare systems.

In conclusion, the comprehensive airway management model represents a promising approach to manage VAP in ICU patients. By integrating various nursing interventions and prioritizing patient-centered care, this strategy enhances clinical outcomes, reduces healthcare costs, and fosters a more positive patient experience. Future research will explore the broader applicability of this model across different patient populations and healthcare settings. Additionally, large-scale randomized controlled trials are warranted to further validate the efficacy and cost-effectiveness of the comprehensive airway management strategy in managing VAP and improving patient outcomes.

Disclosure of conflict of interest

None.

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