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The Application Effect of Nursing Interventions Based on Failure Mode and Effect Analysis in Non-invasive Positive Pressure Ventilation Therapy for Patients with Chronic Obstructive Pulmonary Disease Complicated by Type II Respiratory Failure

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Abstract: *Objective*: To investigate the application effect of nursing intervention based on Failure Mode and Effects Analysis (FMEA) in Non-Invasive Positive Pressure Ventilation (NPPV) treatment for patients with Chronic Obstructive Pulmonary Disease (COPD) complicated by Type II respiratory failure. *Methods*: Eighty patients with COPD complicated by Type II respiratory failure admitted from January 2024 to December 2025 were selected and randomly divided into a control group receiving conventional nursing and a study group receiving FMEA-based nursing intervention, with 40 cases in each group. Blood gas indicators, the incidence of adverse events, and quality of life scores were compared between the two groups after intervention. *Results*: After intervention, the blood gas indicators in the study group [PaO_2 (69.58 ± 5.21) mmHg, $PaCO_2$ (46.83 ± 4.56) mmHg, SaO_2 (93.87 ± 2.75) %] were significantly better than those in the control group [PaO_2 (63.12 ± 5.07) mmHg, $PaCO_2$ (52.15 ± 4.89) mmHg, SaO_2 (90.36 ± 2.89) %] ($p < 0.05$). The incidence of adverse events in the study group was significantly lower than that in the control group ($p < 0.05$). After intervention, the scores of all dimensions of the St. George's Respiratory Questionnaire (SGRQ) in the study group were significantly lower than those in the control group ($p < 0.05$), indicating a more significant improvement in quality of life. *Conclusion*: The FMEA-based nursing intervention constructed in this study can effectively improve blood gas indicators during NPPV treatment for patients with COPD complicated by Type II respiratory failure, reduce the incidence of adverse events, and significantly improve patients' quality of life, providing a widely applicable prospective risk prevention and control plan for specialized nursing management in clinical NPPV treatment.

Keywords: Chronic obstructive pulmonary disease; Type II respiratory failure; Non-invasive positive pressure ventilation; Failure mode and effects analysis; Nursing intervention; Quality of life

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1. Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a progressive respiratory disease characterized by persistent airflow limitation, with a long course and high recurrence rate. In advanced stages, it often complicates with Type II respiratory failure, seriously threatening patients' lives and health [1]. Non-Invasive Positive Pressure Ventilation (NPPV) treatment, as a first-line treatment for COPD complicated by Type II respiratory failure, can improve pulmonary ventilation function and correct blood gas disorders through positive pressure ventilation, avoiding complications such as airway injury and infection caused by invasive ventilation, and significantly reducing patient mortality [2]. However, clinical practice has found that the clinical efficacy of NPPV treatment highly depends on the quality of nursing. Conventional nursing mainly focuses on symptomatic intervention and passive monitoring, lacking prospective prediction and systematic prevention and control of potential risks throughout the treatment process, which can easily lead to adverse events, treatment interruption, and decreased ventilation efficiency, affecting patient prognosis [3]. Failure Mode and Effects Analysis (FMEA) is a prospective risk assessment and quality improvement tool that systematically identifies potential failure modes in processes, quantifies risk levels, and formulates targeted improvement measures to achieve the nursing goal of "prevention first, whole-process control". It has been widely applied in fields such as critical care nursing, surgical nursing, and medical device operation, showing significant effects in reducing adverse events such as nursing catheter slippage and medical device-related pressure injuries [4]. Based on this, this study explores the effect of FMEA-based nursing intervention in patients with COPD complicated by Type II respiratory failure, compensating for the lack of prospective risk prevention and control in conventional nursing, and providing evidence-based support for optimizing nursing plans and improving the safety and effectiveness of NPPV treatment in clinical practice.

2. Materials and methods

2.1. General information

Eighty patients with COPD complicated by Type II respiratory failure admitted from January 2024 to December 2025 were selected and randomly divided into a control group and a study group, with 40 cases in each group. The sample size in this study was calculated using a clinical research sample size estimation formula, determining that at least 38 cases were required in each group. With 40 cases in each group in this study, the statistical requirements were met. There was no statistically significant difference in general information between the two groups ($p > 0.05$), indicating comparability, as shown in **Table 1**.

Table 1. Comparison of general information between the two groups [n, (%) / ($\overline{x} \pm s$)]

Group	Number of cases	Gender (n, %)		Age (years, $\overline{x} \pm s$)	Disease duration (years, ± s)	COPD classification (n, %)	
		Male	Female			Grade III	Grade IV
Control group	40	23 (57.50)	17 (42.50)	62.35 ± 7.12	8.62 ± 3.25	18 (45.00)	22 (55.00)
Study group	40	25 (62.50)	15 (37.50)	63.18 ± 6.89	9.05 ± 3.11	20 (50.00)	20 (50.00)
Statistical value (χ^2/t)		0.208		0.530	0.605	0.202	
p-value		0.648		0.598	0.547	0.654	

Note: Comparison between the two groups showed $p > 0.05$, indicating comparability.

2.2. Inclusion and exclusion criteria

2.2.1. Inclusion criteria

(1) Meeting the diagnostic criteria for COPD and confirmed with type II respiratory failure through arterial blood gas analysis [5];
(2) No restriction on gender, aged between 45 and 75 years;
(3) Having clear consciousness and able to cooperate with NPPV treatment and nursing procedures;
(4) Patients and their families providing informed consent and signing the informed consent form.

2.2.2. Exclusion criteria

(1) Having severe organ failure in vital organs such as the heart, liver, or kidneys;
(2) Having absolute contraindications to non-invasive positive pressure ventilation (e.g., facial deformities, severe upper airway obstruction, massive gastrointestinal bleeding);
(3) Having mental disorders or cognitive dysfunction that prevent cooperation with nursing care;
(4) Transferring to another hospital during the study period, voluntarily withdrawing from the study, or being lost to follow-up.

2.3. Methods

The control group received routine NPPV nursing care: dynamic monitoring of patients' vital signs, regular blood gas analysis, daily inspection and maintenance of non-invasive ventilators, guidance on proper mask fitting and adjustment, assistance in assuming semi-recumbent or sitting positions for comfortable ventilation, enhanced respiratory tract humidification management, guidance on effective coughing and sputum expulsion, symptomatic supportive care for underlying comorbidities, and concurrent health education on related diseases along with routine psychological intervention.

The study group received FMEA-based nursing intervention in addition to the routine care. Specific measures were as follows:

(1) Establishment of an FMEA nursing team

The team was led by the head nurse of the respiratory department and included 2 supervisor nurses, 5 registered nurses, and 1 respiratory therapist. Each member had at least five years of clinical nursing experience in the respiratory department and was proficient in non-invasive ventilator operation and the FMEA method. The team received specialized training in FMEA theory and practice, achieving a 100% pass rate. The team was responsible for reviewing the entire NPPV treatment nursing process, comprehensively identifying potential failure modes at each step, conducting risk grading and quantification, and developing and implementing targeted prevention and control measures. The team dynamically tracked intervention effects and continuously improved quality.

(2) Identification of potential failure modes

Through brainstorming, review of clinical adverse event cases, and consultation of relevant domestic and international literature, combined with the entire NPPV nursing process, the team identified potential failure modes. Five high-risk potential failure modes were ultimately identified: mask leakage/displacement, improper ventilator parameter settings, patient intolerance, retention of respiratory secretions, and pressure injuries on the nasal and facial skin.

(3) Risk assessment and prioritization

Using a 1–10 scale, each failure mode was scored across three dimensions: severity (S), occurrence

frequency (O), and detection difficulty (D). The risk priority number (RPN = S × O × D) was calculated for each failure mode, and they were ranked from highest to lowest RPN to identify high-risk failure modes as priorities for nursing intervention.

(4) Development and implementation of improvement measures

① Mask leakage/displacement: Select masks precisely based on the patient's facial contour, ensuring appropriate size. When wearing, allow one finger's width of slack. Apply hydrocolloid or foam dressings on the nasal bridge to reduce friction. Assist in protecting the mask when the patient turns over or moves. ② Improper parameter settings: Conduct special training on adjusting non-invasive ventilator parameters. Adjust parameters dynamically based on the patient's body weight, blood gas analysis, respiratory rate, and clinical symptoms to ensure ventilation effectiveness. ③ Patient intolerance (including physiological and psychological aspects): Comprehensively assess psychological status and provide targeted psychological intervention. Use videos, images, and written materials to explain the principles, necessity, and key cooperation points of NPPV treatment, and invite recovered patients to share experiences to enhance treatment confidence. Address discomfort during ventilation promptly. ④ Retention of respiratory secretions: Develop individualized sputum evacuation plans based on the patient's condition, including regular turning and back tapping. Turn patients to semi-recumbent or lateral positions with the head of the bed elevated 30–45°, and use the hollow palm tapping method to assist sputum expulsion, with intensity tolerable to the patient. Use a mechanical vibration sputum evacuation device as prescribed when necessary. Instruct patients in respiratory function training, such as pursed-lip breathing and abdominal breathing exercises. ⑤ Nasal and facial pressure injuries: Prioritize soft, well-ventilated silicone masks. Apply prophylactic dressings to pressure points for pressure relief. Loosen the mask every 2–3 hours for 10–15 minutes, during which low-flow oxygen (2–3 L/min) is administered via nasal cannula. Regularly inspect nasal and facial skin, focusing on pressure points, and address any signs of pressure injury promptly.

(5) Effect monitoring and continuous improvement

Convene weekly FMEA team quality control meetings to inspect and evaluate the implementation of intervention measures, recalculate the RPN values for each potential failure mode, analyze causes for unresolved or newly emerging issues, and adjust and optimize intervention measures accordingly. Both groups were intervened for 7 days, starting from the day the patient began NPPV treatment.

2.4. Observation indicators

2.4.1. Blood gas indicators

Radial artery blood was collected, and a blood gas analyzer was used to measure the levels of arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), and oxygen saturation (SaO_2).

2.4.2. Adverse events

The occurrence and severity of adverse events during the intervention period were recorded. The severity was classified into levels I to IV according to the Nursing Adverse Event Grading Standards.

2.4.3. Quality of life

Assess using the Chinese version of the St. George's Respiratory Questionnaire (SGRQ) (Chinese version with good reliability and validity), which includes three dimensions: symptom dimension, activity limitation dimension, and disease impact dimension, with a total of 50 items. Each dimension is scored from 0 to 100, with higher scores indicating worse quality of life for the patient.

2.5. Statistical methods

Data analysis was performed using SPSS 26.0 statistical software. Measurement data were expressed as mean ± standard deviation ($\overline{x} \pm s$), and independent sample *t*-tests were used for comparisons between groups, while paired t-tests were used for comparisons within groups before and after intervention. Count data were expressed as frequency and percentage [n (%)], and χ^2 tests were used for comparisons between groups. A *p*-value < 0.05 was considered statistically significant.

3. Results

3.1. Comparison of blood gas indicators between the two groups before and after intervention

Before the intervention, there were no statistically significant differences in PaO_2, $PaCO_2$, and SaO_2 between the two groups of patients ($p > 0.05$). After the intervention, PaO_2 and SaO_2 in both groups increased significantly compared to those before the intervention, while $PaCO_2$ decreased significantly compared to that before the intervention ($p < 0.05$). Moreover, the extent of improvement in each blood gas indicator in the study group was significantly better than that in the control group ($p < 0.001$). See **Table 2**.

Table 2. Comparison of blood gas indicators between the two groups before and after intervention ($\overline{x} \pm s$)

Group	Number of cases	PaO_2 (mmHg)		$PaCO_2$ (mmHg)		SaO_2 (%)	
		Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Control group	40	52.36 ± 4.18	63.12 ± 5.07	58.63 ± 5.24	52.15 ± 4.89	84.25 ± 3.16	90.36 ± 2.89
Study group	40	52.89 ± 4.32	69.58 ± 5.21	59.07 ± 5.31	46.83 ± 4.56	84.68 ± 3.21	93.87 ± 2.75
t value		0.568	5.620	0.373	5.032	0.604	5.565
p value		0.572	< 0.001	0.710	< 0.001	0.548	< 0.001

Note: Compared with the same group before intervention, $p < 0.05$; compared with the control group after intervention, $p < 0.001$.

3.2. Comparison of the incidence of adverse events between the two groups

The total incidence of adverse events in the study group was 5.00% (2/40), which was significantly lower than that in the control group at 22.50% (9/40), with a statistically significant difference ($\chi^2 = 5.165$, $p = 0.023$). The two adverse events in the study group were both nasal-facial pressure injuries, and no serious adverse events occurred. See **Table 3**.

Table 3. Comparison of the incidence of adverse events between the two groups [n, (%)]

Group	Number of cases	Mask leakage/ displacement	Nasofacial pressure injury	Respiratory tract infection	Ventilator-associated pneumonia	Unplanned extubation	Total occurrence
Control group	40	3 (7.50)	2 (5.00)	2 (5.00)	1 (2.50)	1 (2.50)	9 (22.50)
Study group	40	0 (0)	1 (2.50)	0 (0)	0 (0)	0 (0)	2 (5.00)
χ^2 value							5.165
p value							0.023

3.3. Comparison of quality of life scores between the two groups before and after intervention

Before the intervention, there were no statistically significant differences in the scores of each dimension of the St. George's Respiratory Questionnaire (SGRQ) between the two groups ($p > 0.05$). After the intervention, the scores of each dimension of the SGRQ in both groups decreased significantly compared to those before the intervention ($p < 0.05$). Moreover, the scores of each dimension in the study group were significantly lower than those in the control group ($p < 0.001$), with the largest decrease observed in the symptom dimension score, indicating a more significant improvement in quality of life. See **Table 4**.

Table 4. Comparison of quality of life scores between the two groups before and after intervention (± s, points)

Group	Number of cases	Symptom dimension		Activity limitation dimension		Disease impact dimension	
		Before intervention	After intervention	Before intervention	After intervention	Before intervention	After intervention
Control group	40	58.76 ± 4.23	45.89 ± 3.54	62.34 ± 4.56	48.76 ± 3.67	56.89 ± 4.31	43.25 ± 3.48
Study group	40	59.12 ± 4.35	32.14 ± 3.26	62.56 ± 4.68	35.65 ± 3.42	57.12 ± 4.42	30.23 ± 3.15
t value		0.375	18.071	0.213	16.528	0.236	17.543
p value		0.709	< 0.001	0.832	< 0.001	0.814	< 0.001

Note: Compared with the same group before intervention, $P<0.05$; compared with the control group after intervention, $p < 0.001$.

4. Discussion

COPD complicated with type II respiratory failure is a common critical illness in respiratory medicine. As a first-line intervention, NPPV treatment can effectively improve patients' ventilation function, correct hypoxia and carbon dioxide retention, but its therapeutic effect is significantly influenced by the quality of nursing care [6]. Conventional nursing care mainly focuses on symptomatic interventions, lacking forward-looking risk prevention and control awareness, making it difficult to effectively avoid potential safety hazards during NPPV treatment, such as mask leakage, nasal and facial pressure injuries, and patient intolerance, thereby affecting treatment outcomes [7]. As a forward-looking risk assessment tool, FMEA achieves closed-loop optimization of nursing processes by systematically identifying failure modes in the process, quantifying risk levels, and formulating targeted improvement measures, and has been widely applied in the field of critical care nursing [8]. Through the closed-loop management of "identification-evaluation-intervention-monitoring", FMEA transforms nursing risk prevention and control from "post-event handling" to "pre-event prevention and in-event control", meeting the needs of refined nursing care for NPPV treatment and is the core reason for the significant intervention effect in this study.

The results of this study show that after intervention, the blood gas indicators of patients in the study group were significantly better than those in the control group. The reason is that the FMEA team identified "inappropriate ventilator parameter settings" as a high-risk failure mode by combing through the entire NPPV nursing process, formulated personalized parameter adjustment plans, and dynamically optimized ventilation parameters based on patients' weight, blood gas results, and clinical symptoms, avoiding ventilation insufficiency or excess caused by standardized parameter settings in conventional nursing care, effectively improving ventilation efficiency, and correcting patients' hypoxia and carbon dioxide retention. At the same time, by optimizing the nursing process, empirical nursing was transformed into standardized and standardized nursing, reducing human operational errors, further improving the effectiveness of

nursing operations and intervention effects, and ultimately achieving significant improvements in blood gas indicators. Adverse events during NPPV treatment are mostly related to deficiencies in the nursing process and insufficient risk anticipation, such as mask leakage often caused by inappropriate model selection and improper fixation, and nasal and facial pressure injuries related to prolonged local pressure and insufficient protective measures [9]. Liu Litian and others showed that nursing interventions using FMEA can significantly reduce nasal and facial medical device-related pressure injuries through forward-looking risk prevention and control, and the results of this study are consistent with that research, further verifying the clinical value of FMEA in preventing medical device-related pressure injuries [10]. The results of this study show that the incidence of adverse events in the study group was significantly lower than that in the control group, and no serious adverse events occurred, because FMEA comprehensively and systematically identified potential failure modes in the entire NPPV treatment process through team brainstorming, quantified risks through S, O, and D scores, and identified high-priority intervention targets, avoiding the drawback of "emphasizing treatment over prevention" in conventional nursing care. Targeted intervention measures formulated for each high-risk failure mode prevented adverse events from occurring at the source, effectively improving the safety of NPPV treatment. After intervention, the SGRQ scores in all dimensions of patients in the study group were significantly lower than those in the control group, with a more significant improvement in quality of life and the largest decrease in symptom dimension scores. Nursing interventions based on FMEA reduce patients' physiological pain by accurately avoiding adverse events, significantly improve patients' respiratory function through personalized parameter settings and airway management, enhance respiratory function reserve, and increase patients' daily activity capabilities. In addition, personalized psychological counseling and health education conducted for patients' intolerance effectively alleviate negative emotions such as anxiety and fear towards NPPV treatment, reducing the impact of psychological factors on patients' living conditions. FMEA interventions improve patients' living conditions comprehensively from both physiological and psychological dimensions, thus achieving a significant improvement in quality of life.

5. Conclusion

In summary, nursing interventions based on FMEA can effectively improve blood gas indicators and pulmonary ventilation function during NPPV treatment in patients with COPD complicated with type II respiratory failure, reduce the incidence of adverse events, and improve patients' quality of life from both physiological and psychological dimensions, with high clinical application value. This study has certain limitations. Firstly, it is a single-center study with a small sample size, which may lead to biased results. Subsequent studies can conduct multi-center, large-sample, prospective cohort studies to further verify the long-term effects of FMEA nursing interventions. Secondly, the observation period of this study was relatively short, only focusing on the effects within 7 days of intervention, and the impact on patients' long-term prognosis needs further follow-up observation. Subsequent studies will extend the follow-up period to 3 months or 6 months to explore the impact of FMEA interventions on patients' long-term pulmonary function, readmission rates, and mortality rates. At the same time, this study did not conduct an economic analysis of nurses' workload or nursing costs, and subsequent studies can conduct health economics research to evaluate the cost-effectiveness ratio of FMEA interventions and provide economic evidence for clinical promotion. In addition, this study did not conduct subgroup analysis on the intervention effects of patients with different COPD severity levels (Grade III/Grade IV), and subsequent studies can further explore the application differences of FMEA interventions in patients with different severity levels to provide more precise evidence-based support for the formulation of individualized nursing plans.

Disclosure statement

The authors declare no conflict of interest.

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