

Feedforward Control-Based Bundle Management for Hemoptysis in Pulmonary Tuberculosis Patients

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Objective: To explore the construction and application of a bundle management system based on feedforward control in the nursing intervention process for hemoptysis in pulmonary tuberculosis (TB) patients.

Methods: This retrospective study included 112 hospitalized pulmonary TB patients combined with hemoptysis were collected from the Department of Infectious Diseases at Changde First People's Hospital between September, 2023 to April, 2024. Patients were divided into two groups based on the nursing intervention they received: the control group (n=53) received standard nursing interventions, while the intervention group (n=59) received bundle management based on feedforward control. Clinical outcomes included time to stop hemoptysis, hospital stay duration, hemoptysis recurrence rate, incidence of massive hemoptysis, bronchial artery embolization surgery rate, and complication rates. Patient assessment measures included compliance scores, Hamilton Anxiety Rating Scale (HAMA) scores, and Patient Satisfaction Questionnaire-18 (PSQ-18) scores.

Results: The intervention group had a significantly shorter time to stop hemoptysis compared to the control group ($P < 0.001$). Additionally, the intervention group had lower recurrence rates of hemoptysis, incidence of massive hemoptysis, and bronchial artery embolization surgery rate compared to the control group ($P < 0.05$). HAMA scores were significantly lower in the intervention group compared to the control group ($P < 0.001$). Patient compliance and satisfaction were significantly higher in the intervention group compared to the control group ($P < 0.001$). The incidence of asphyxia and mortality in the intervention group were both significantly lower than those in the control group ($P < 0.05$).

Conclusion: The bundle management based on feedforward control can effectively prevent recurrence of hemoptysis and massive hemoptysis in patients with pulmonary TB. This approach can shorten the time of hemoptysis, reduce the incidence and mortality associated with asphyxia, improve patient compliance and satisfaction, and relieve patients' anxiety.

Keywords: tuberculosis, hemoptysis, bundle management, asphyxia, nursing, feedforward control

Introduction

Tuberculosis (TB) is a common chronic infectious disease in clinical practice, primarily caused by *Mycobacterium Tuberculosis* infection, and mainly affecting the lungs.^{1,2} TB remains a major global health threat, with an estimated 10.8 million new cases and 1.25 million deaths worldwide in 2023.³ Hemoptysis is one of the most severe complications of pulmonary TB.⁴ Massive hemoptysis has been found responsible for roughly 5% of TB deaths prior to effective treatment.⁴ The pathophysiology of TB-related hemoptysis involves erosion of vessels in pulmonary circulation and intercostal arteries, with tuberculous vascular lesions that can include pulmonary or bronchial arteritis, thrombosis, arterial dilation, and Rasmussen aneurysms.^{5,6} Nursing interventions are particularly important in hemoptysis management because nurses provide continuous patient monitoring, early recognition of warning signs, timely implementation of preventive measures, and patient education, which is essential for preventing the progression to massive hemoptysis and life-threatening complications such as asphyxiation.⁷

Recent nursing researches have shown that a feedforward control nursing model can effectively prevent potential risks and reduce the incidence of adverse events and complications through proactive and predictive interventions.^{8,9} Feedforward control, also known as advance control or preventive control, refers to a quality control method that predicts the consequences of management activities and takes preventive measures before management so that possible deviations can be avoided in advance.^{8,10} This approach is characterized by an attitude of “prevention first” and has shown significant advantages when applied in clinical nursing work, including reduced nursing errors, improved nursing attitudes, and increased patient satisfaction.⁹ Bundle management, defined as a set of three to five evidence-based interventions that, when performed collectively and reliably, improve patient outcomes more effectively than when implemented individually.¹¹ Despite these advances, existing nursing interventions for TB-related hemoptysis often lack standardization and integration of proactive prevention strategies. There is still a relative lack of research on bundled care interventions based on feedforward control in TB-related hemoptysis patients.

Therefore, this study applies bundle management based on feedforward control to patients with hemoptysis due to pulmonary TB, exploring its effectiveness in reducing the risk of massive hemoptysis and asphyxiation, improving patient compliance, and enhancing nursing satisfaction. The aim is to provide a more scientific and systematic intervention strategy for clinical nursing practice in caring for patients with hemoptysis due to pulmonary TB.

Materials and Methods

Study Subjects

A total of 112 pulmonary TB patients with hemoptysis who were hospitalized in the Department of Infectious Diseases at Changde First People's Hospital from September, 2023 to April 30, 2024 were enrolled in this retrospective study. Patients were allocated into two groups based on the nursing protocols implemented during their hospitalization. The control group consisted of 53 patients who received standard nursing care, while the intervention group included 59 patients who received bundle management based on feedforward control.

Inclusion and Exclusion Criteria

Inclusion Criteria: Age ≥ 14 years; Confirmed diagnosis of pulmonary TB according to WS288-2017; Presented with hemoptysis.

Exclusion Criteria: Patients with severe organ damage or dysfunction; Patients with communication disorders, cognitive impairments, or mental health issues.

Intervention Methods

Control Group

The control group received routine nursing interventions for pulmonary TB patients with hemoptysis. Upon admission, nurses immediately established intravenous access and administered prescribed medications. Supportive care included bedside suction devices, electrocardiographic monitoring, and oxygen therapy as needed. Nurses provided regular patient education about hemoptysis management, including dietary restrictions and rest guidelines. Hemostatic medications such as phentolamine or posterior pituitary extract were administered via intravenous pump, while phenylsulfate and tranexamic acid were given through intravenous infusion according to physician orders.

Intervention Group

The intervention group received bundle management based on feedforward control. A specialized pulmonary TB hemoptysis management team was established to systematically analyze risk factors that could lead to massive hemoptysis and asphyxiation. The team developed a standardized management protocol specifically designed for pulmonary TB patients with hemoptysis (Figure 1). The bundle management based on feedforward control included the following key steps: (1) Staff Training and Protocol Implementation: All department staffs underwent comprehensive training on the standardized management process. Upon patient admission, physicians assessed each patient and provided specific positioning instructions for hemoptysis episodes. Bedside nurses placed position guidance signs at patients' bedsides and delivered targeted health education. An integrated suction unit containing negative pressure suction device, 500 mL physiological saline, and disposable suction packs was maintained at

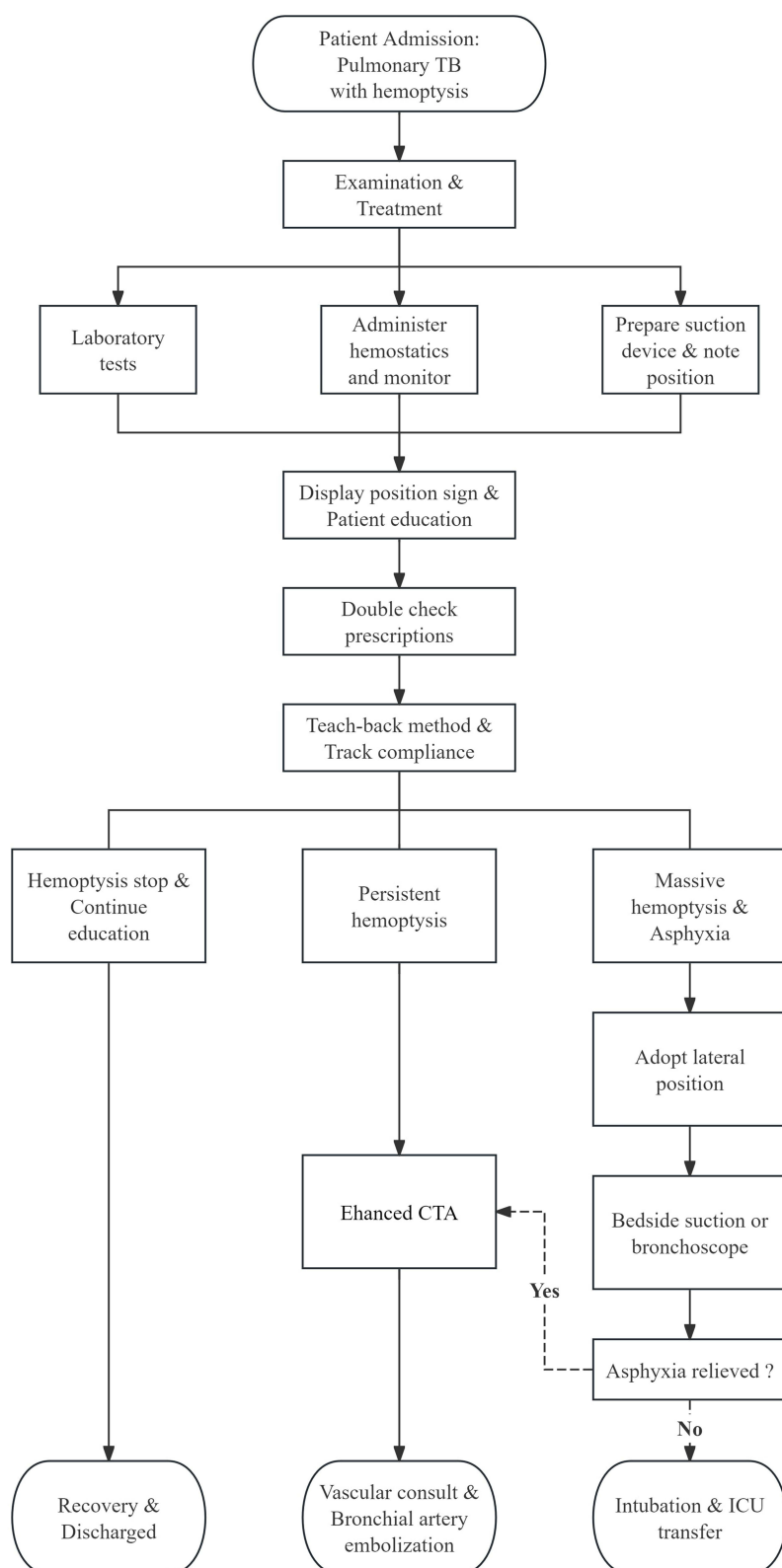


Figure 1 Management flow chart of hemoptysis in pulmonary TB.

each bedside, with equipment functionality verified during each shift change. (2) Patient Education and Risk Prevention: Patients received comprehensive education on hemoptysis management, including strict bed rest with slow positional changes, consumption of light and easily digestible cool foods, maintenance of regular bowel

movements while avoiding straining, and temporary avoidance of hot foot soaks and bathing. Patients were taught to recognize early warning signs of hemoptysis such as chest discomfort, restlessness, foreign body sensation, and breathing difficulties, with instructions to immediately notify healthcare providers when these symptoms occurred. Emergency response education included proper positioning during hemoptysis episodes, immediate activation of bedside call systems, and appropriate blood expectoration techniques while avoiding breath-holding or sitting positions. (3) Quality Monitoring and Continuous Improvement: The department implemented regular emergency response drills and training sessions for massive hemoptysis scenarios. Compliance with the standardized protocol served as a key performance indicator, with nurses conducting daily self-assessments and supervisors performing bi-weekly evaluations. Monthly data compilation and analysis were conducted using PDCA cycle methodology to identify non-compliance causes and implement targeted improvements for continuous quality enhancement.

Data Collection

All clinical data were retrospectively collected from the hospital's electronic medical record system.

- (1) Clinical Outcome: The following clinical outcomes were evaluated: 1) Time to hemoptysis stop, defined as the duration from admission to complete stop of blood expectoration for at least 24 hours; 2) Length of hospital stay, calculated from admission to discharge date; 3) Hemoptysis recurrence rate, defined as the reoccurrence of blood expectoration after an initial cessation period of at least 24 hours during hospitalization; 4) Incidence of massive hemoptysis, defined as hemoptysis volume exceeding 300 mL within 24 hours or hemoptysis causing hemodynamic instability; 5) Bronchial artery embolization surgery rate, documented as the proportion of patients requiring interventional bronchial artery embolization during hospitalization; 6) Complication rates, including incidence of asphyxia (defined as respiratory distress requiring immediate intervention due to airway obstruction by blood) and in-hospital mortality.
- (2) Patient Assessment: 1) Patient compliance was assessed using a standardized 10-point compliance scale evaluating adherence to medication regimens, dietary restrictions, activity limitations, and follow-up appointments, with scores categorized as poor (≤ 4 points), moderate (5–7 points), or good (8–10 points); (2) Anxiety levels were measured using the Hamilton Anxiety Rating Scale (HAMA), a validated 14-item questionnaire with total scores ranging from 0–56, where higher scores indicate greater anxiety severity.¹²
- (3) Patient satisfaction was evaluated using the Patient Satisfaction Questionnaire-18 (PSQ-18), which consisting of 18 items across seven dimensions: general satisfaction, technical quality, interpersonal manner, communication, financial aspects, time spent with doctor, and accessibility and convenience.¹³ Each item is rated on a 5-point Likert scale, with scores transformed to a 0–100 scale where higher scores indicate greater satisfaction. The PSQ-18 has demonstrated good reliability and validity in hospital settings and is widely used for healthcare quality assessment.

Statistical Analysis

The data were cleaned and analyzed using R 4.5.0 software. Categorical data were presented as the number of cases (percentage), and inter-group comparisons were conducted using the chi-square test or Fisher's exact probability test. For continuous variables, normality was assessed using the Shapiro–Wilk test. Normally distributed continuous data were expressed as mean \pm standard deviation ($\bar{x} \pm s$), and inter-group comparisons were performed using the independent samples *t*-test. For non-normally distributed data or when homogeneity of variance was not met, the Wilcoxon rank-sum test was used. A *P*-value < 0.05 was considered to indicate a statistically significant difference.

Results

Baseline Characteristics

Baseline demographic and clinical characteristics were well-balanced between the two groups (Table 1). No statistically significant differences were observed between the two groups in terms of age, sex, educational level, smoking history, comorbidities (hypertension and diabetes), presence of lung cavities, blood pressure measurements (systolic and diastolic), PLT, or HB levels ($P > 0.05$).

Table 1 Comparison of Baseline Characteristics Between the Two Groups

Variables	Control Group (n=53)	Intervention Group (n=59)	Statistics	P-Value
Age (years)	58.09 ± 15.75	62.42 ± 13.33	1.575	0.118
Sex, n (%)			1.509	0.219
Male	43 (81.1%)	42 (71.2%)		
Female	10 (18.9%)	17 (28.8%)		
Educational level, n (%)			2.024	0.363
Primary school or below	22 (41.5%)	30 (50.8%)		
Middle school	23 (43.4%)	23 (43.4%)		
High school or above	8 (15.1%)	4 (6.8%)		
Smoking history, n (%)	28 (52.8%)	31 (52.5%)	0.001	0.976
Hypertension, n (%)	8 (15.1%)	15 (25.4%)	1.825	0.177
Diabetes, n (%)	11 (20.8%)	12 (20.3%)	0.003	0.957
Lung cavity, n (%)	24 (45.3%)	34 (57.6%)	1.704	0.192
SBP (mmHg)	126.89 ± 19.93	128.75 ± 20.86	0.482	0.631
DBP (mmHg)	79.92 ± 11.52	79.05 ± 11.34	0.402	0.688
PLT (10⁹/L)	185.00 (149.00, 252.00)	217.00 (152.00, 306.00)	1.274	0.092
HB (g/L)	112.55 ± 24.18	111.25 ± 20.96	0.301	0.764

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; PLT, platelet count; HB, hemoglobin.

Primary Clinical Outcomes and Anxiety Assessment

As shown in Table 2, the intervention group had significantly shorter time to stop hemoptysis ($P < 0.001$) and lower HAMA scores ($P < 0.001$) compared to the control group. However, no significant difference was observed in length of hospital stay between the two groups ($P > 0.05$).

Hemoptysis Events and Clinical Interventions

As shown in Table 3, the intervention group demonstrated significantly lower rates of recurrent hemoptysis ($P = 0.023$) and massive hemoptysis ($P = 0.045$) compared to the control group. Additionally, fewer patients in the intervention group required bronchial artery embolization ($P = 0.019$). Although the incidence of asphyxia and mortality were lower in the intervention group, these differences did not reach statistical significance ($P = 0.103$ for both). No cases of asphyxia or mortality were observed in the intervention group.

Patient Compliance with Nursing Interventions

As shown in Table 4, the intervention group demonstrated significantly higher compliance scores ($P < 0.001$) and better compliance levels ($P < 0.001$) compared to the control group. No patients in the intervention group showed poor compliance, while nearly half achieved good compliance. The intervention group showed improved adherence to nursing interventions across all compliance categories.

Table 2 Comparison of Clinical Outcomes and Anxiety Level Between Groups

Group	Time to Stop Hemoptysis (Days)	Length of Hospital Stays (Days)	HAMA Score
Control group (n=53)	4.00 (2.00, 6.00)	8.00 (7.00, 11.00)	13.13 ± 2.35
Intervention group (n=59)	1.00 (1.00, 3.00)	8.00 (7.00, 12.00)	6.56 ± 1.57
t/ F/χ²	2.551	1.645	17.20
P	<0.001	0.634	<0.001

Abbreviation: HAMA, Hamilton Anxiety Rating Scale.

Table 3 Comparison of Hemoptysis Events and Clinical Interventions Between Groups

Variables	Control Group (n=53)	Intervention Group (n=59)	χ^2	P-Value
Hemoptysis events				
Recurrent hemoptysis, n (%)	19 (35.85%)	10 (16.95%)	5.197	0.023
Massive hemoptysis, n (%)	8 (15.09%)	2 (3.34%)	-	0.045*
Clinical interventions				
Bronchial artery embolization, n (%)	17 (32.08%)	8 (13.56%)	5.521	0.019
Complications				
Asphyxia, n (%)	3 (5.66%)	0 (0.00%)	-	0.103*
Mortality, n (%)	2 (3.78%)	0 (0.00%)	-	0.103*

Notes: *Fisher's exact test was used when expected cell counts were less than 5; all other comparisons used chi-square test.

Table 4 Comparison of Patient Compliance Between Groups

Variables	Control Group (n=53)	Intervention Group (n=59)	Statistics	P-Value
Compliance score	6.43 ± 1.37	8.22 ± 0.85	8.399	<0.001
Compliance level, n (%)			-	<0.001*
Poor	9 (16.98%)	0 (0.00%)		
Moderate	32 (60.38%)	30 (50.85%)		
Good	12 (22.64%)	29 (49.15%)		

Notes: *Fisher's exact test was used for compliance level comparison.

Patient Satisfaction Assessment

As shown in Table 5, patient satisfaction was assessed by PSQ-18 demonstrated significant differences between the two groups across multiple dimensions. The intervention group showed significantly higher satisfaction scores compared to the control group in general satisfaction, technical quality, interpersonal manner, communication, and accessibility and convenience ($P < 0.001$). However, no statistically significant differences were observed between the two groups in financial aspects and time spent with doctor ($P > 0.05$). The total PSQ-18 score was significantly higher in the intervention group compared to the control group ($P < 0.001$).

Table 5 Comparison of Patient Satisfaction Between Groups

PSQ-18 Dimensions	Control Group (n=53)	Intervention Group (n=59)	t	P-Value
General satisfaction	72.45 ± 8.23	82.67 ± 6.45	7.352	<0.001
Technical quality	75.32 ± 7.89	86.23 ± 5.98	8.296	<0.001
Interpersonal manner	71.58 ± 9.12	84.91 ± 6.72	8.865	<0.001
Communication	68.97 ± 8.76	76.34 ± 7.21	4.880	<0.001
Financial aspects	65.43 ± 10.25	66.78 ± 9.87	0.710	0.479
Time spent with doctor	69.81 ± 8.54	71.25 ± 8.19	0.910	0.365
Accessibility and convenience	70.29 ± 7.93	75.47 ± 6.85	3.709	<0.001
Total PSQ-18 score	70.55 ± 6.78	79.81 ± 5.43	8.014	<0.001

Discussion

Feedforward Control based bundle management is grounded in evidence, integrating a series of scientifically supported measures to guide nursing decisions, provide the best interventions for patients, and improve their clinical outcomes while promoting recovery.^{14,15} The nursing model based on proactive identification and analysis of potential problems and risks faced by patients, implementing proactive intervention measures to effectively prevent issues from arising, which has shown promising application prospects in the medical field.^{16,17} This study represents the first systematic application of this feedforward control-based bundle management approach targeted pulmonary TB patients with hemoptysis, demonstrating its effectiveness in reducing complications and improving patient outcomes.

Surveys have shown that among patients with hemoptysis caused by pulmonary TB, the incidence of anxiety and depression is typically higher than the general population.^{18,19} This high prevalence may be attributed to several factors, including the severity of the disease, its negative impact on social interactions, and a lack of sufficient understanding of the condition.²⁰ Hemoptysis, as a severe complication of pulmonary TB, may further exacerbate these psychological problems by inducing additional fear, panic, and anxiety about potential life-threatening consequences, thereby significantly elevating the overall psychological burden on patients. Bundle management based on feedforward control adopts a patient-centered approach that is both comprehensive and individualized, considering all aspects of the patient's physical and mental health.^{17,21} It not only facilitates in the gradual recovery of the condition and progressive reduction of hemoptysis symptoms but also truly demonstrates respect for individual patient needs, fostering enhanced patient satisfaction and compliance with care, which is crucial for the smooth implementation of various nursing and treatment measures.^{22,23}

The implementation of bundle management based on feedforward control requires the establishment of a dedicated TB hemoptysis management team.^{24,25} Utilizing the concept of feedforward control, the team identified and analyzed high-risk factors that could lead to massive hemoptysis and asphyxiation in advance.²⁶ Subsequently, targeted emergency plans and standardized operating procedures were developed, with the execution of these procedures serving as a key performance indicator for the department.²⁶ Regular training, drills, and quality supervision were conducted by the department staff to ensure that all aspects of nursing interventions were more scientific, systematic, and standardized.²⁵ Following discussions by multidisciplinary experts, the intervention group formulated a proceduralized emergency nursing protocol. This method prepares for serious complications such as asphyxiation or shock that may occur during massive hemoptysis in TB patients. Through mastering the emergency procedures, nurses could quickly and accurately assess patients and prepare all necessary items, medications, and equipment in advance, thereby reducing the time needed for emergency response. This approach has shown significant advantages in treating patients with TB combined with massive hemoptysis.²⁵ It not only enhances the professional skills and emergency response capabilities of nursing staff but also ensures that patients receive more rapid and effective treatment and nursing support in high-risk situations such as sudden massive hemoptysis, thereby reducing the incidence of asphyxiation and death. The potential mechanism by which feedforward control may reduce hemoptysis events could involve earlier identification of vascular complications associated with TB, such as bronchial artery erosion and Rasmussen aneurysm formation.⁷ Proactive risk assessment and timely interventions might help stabilize fragile vascular structures before progression to massive hemoptysis, though further prospective studies are needed to confirm these mechanisms.²⁷

Patient education represented another crucial component of the intervention. TB with hemoptysis is associated with a considerable mortality rate.²⁸ Most patients experience distress and anxiety during hemoptysis. The inability to assume the correct posture can lead to blood blocking the airway, causing asphyxiation and shock. If not promptly treated, it can result in death.²⁸ This study provided comprehensive education to patients about the proper body position during hemoptysis, regularly assessed their understanding, and placed warning signs at the bedside as visual reminders. When patients experience hemoptysis, they are instructed to maintain the correct body position, which provides valuable time for subsequent treatment.

Although not achieving statistical significance, the intervention demonstrated a trend toward reduced hospital length of stay. The average length of hospital stays is a critical issue for the high-quality development of hospitals. It not only enhances operational efficiency but also improves patient experience and reduces costs, thereby helping to alleviate the

issues of difficulty and high costs in accessing healthcare services.²⁹ Currently, the calculation and management of the average length of hospital stays have become key indicators for assessing medical service quality and efficiency.²⁹ According to national statistics, the average length of hospital stay in China was 9.2 days in 2021, demonstrating a continuous downward trend in recent years.³⁰ This study was conducted at a tertiary hospital, and our intervention group demonstrated a 0.7-day reduction in average hospital stay duration compared to the control group, although this difference did not reach statistical significance. This trend suggests potential benefits that warrant further investigation in future studies with larger sample sizes to determine clinical significance.

Patient compliance and satisfaction serve as crucial indicators for ensuring the effectiveness of nursing interventions.³¹ The intervention group showed significantly higher scores in patient compliance and nursing satisfaction as measured by PSQ-18 compared to the control group, indicating that the bundled management based on feedforward control significantly contributed to enhancing the patient's care experience and improving the quality of nursing services. Following adequate education and psychological support, patients demonstrated enhanced cooperation with healthcare providers, maintained a regular lifestyle and medication routine, thereby reducing the risk of disease recurrence and complications.

This study has several limitations. As a retrospective study, the sample size was determined by patient availability during the study period rather than a priori power calculation, and data were collected from a single center, which may limit the generalizability of findings to broader populations and healthcare settings. The non-randomized allocation of patients based on nursing protocols may introduce selection bias, despite balanced baseline characteristics. The relatively short study period (8 months) may not capture long-term outcomes, and the lack of blinded assessment for subjective measures such as anxiety and satisfaction scores could potentially influence results. Additionally, cost-effectiveness analysis was not performed, which is crucial for healthcare policy decisions. Future research should focus on conducting multi-center randomized controlled trials with larger sample sizes to validate these findings across diverse settings. Long-term follow-up studies are needed to assess sustainability of outcomes and impact on TB treatment completion rates. Economic evaluation studies comparing cost-effectiveness versus standard care would provide valuable insights for healthcare administrators, and adaptation of this bundle management approach for other TB complications warrant further investigation.

Conclusion

In summary, bundle management based on feedforward control in the care of patients with pulmonary TB and hemoptysis was associated with shortened duration of hemoptysis, and a reduce the incidence of recurrent and massive hemoptysis, as well as lower risks of asphyxiation and surgery, improved the psychological state of patients, and enhanced their compliance and satisfaction with nursing care. However, several limitations should be acknowledged, including the retrospective design, small sample size, single-center setting, and relatively short follow-up period. This approach may offer valuable insights and methods for clinical nursing, but requires further validation through multicenter prospective trials before broader implementation. Future studies with larger sample sizes and longer follow-up periods are warranted to confirm these findings and evaluate the long-term effects on patient prognosis and quality of life.

Data Sharing Statement

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Statement

This retrospective study was approved by the Ethics Committee of The First People's Hospital of Changde City (Approval number: 2025-115-01). Due to the retrospective nature of the study, the requirement for informed consent was waived by the ethics committee. All patient data were collected and analyzed in accordance with the principles of the Declaration of Helsinki.

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Disclosure

The authors declare no conflicts of interest.

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