

Comparison of Short-term Efficacy and Exploratory Risk Factors for Early Complications of Airway Stenting in Benign and Malignant Airway Diseases

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Abstract

Objective

This aim of this work is to investigate the short-term efficacy, safety, and exploratory risk factors for short-term postoperative complications of airway stenting in patients with benign and malignant airway diseases, so as to provide evidence for individualized clinical intervention.

Methods

Sixty patients undergone airway stenting were classified into a benign group (27 patients) and a malignant group (33 patients) based on the nature of their pathological lesions. Statistical analysis of the relevant data was conducted using SPSS 26.0 software, and multivariate logistic regression was employed to identify independent risk factors for postoperative complications.

Results

Airway stent placement significantly alleviated dyspnoea and enhanced modified Medical Research Council (mMRC) scores in the two patient groups (all $P < 0.05$). However, no significant improvement was observed in non-obstructive symptoms, such as cough and sputum production (all $P > 0.05$). Compared with the benign group (59.3%, 25.9% and 44.4%, all $P < 0.05$), the malignant group had markedly higher rates of total complications (90.9%), infection (63.6%) and granulation tissue proliferation (72.7%) at 7 days post-operation. Both groups showed no statistical difference in the incidence of stent displacement and intraoperative haemorrhage (both $P > 0.05$). Exploratory Firth penalized logistic regression analysis tentatively indicated that stent implantation ≥ 2 times was associated with increased short-term postoperative complication risk (OR = 13.772, 95%CI: 1.569–120.888, $P = 0.018$), while the result was exploratory due to unstable statistical model. The airway-oesophageal fistula and lesion features are neither individual risk factors (all $P > 0.05$).

Conclusions

Airway stenting is effective in alleviating dyspnoea caused by benign and malignant airway obstruction, but its efficacy in treating non-obstructive symptoms is limited. Patients with malignant airway lesions are at higher risk of post-operative complications. In this exploratory analysis, repeated stenting (≥ 2 times) was preliminarily associated with an increased risk of short-term complications. In clinical practice, personalized treatment and targeted strategies for the prevention of complications should be adopted based on the characteristics of the lesion and the duration since stent implantation.

Introduction

Airway stenting, as a representative technique in respiratory interventional therapy, has been widely used in the clinical treatment of various conditions, including benign and malignant central airway stenosis[1, 2], airway malacia and airway fistulas. The advantage of this technology resides in its ability to rapidly mitigate airway obstruction, alleviate life-threatening conditions such as dyspnoea and obstructive pneumonia, and considerably enhance patients' quality of life in the short term [3–5]. In malignant airway diseases, central airway stenosis of moderate to

severe severity occurring due to lung cancer invasion or lymph node compression, as well as tracheoesophageal fistula caused by advanced oesophageal cancer, are all clinical emergencies that present a high risk of asphyxia, severe infection and death [6]. The placement of a stent enables quick, less invasive expansion of the airway and occlusion of the fistula, thereby reducing the risk of asphyxia and infection, paving the way for subsequent cancer treatment, and prolonging the patient's survival.[7, 8]. Benign airway pathologies, including post-surgical cicatricial narrowing, tracheobronchomalacia and post-traumatic strictures, frequently lead to persistent dyspnea and substantially impair patients' quality of life. Stent implantation enables airway restoration, delivers mechanical structural support, and lowers the necessity for high-risk, invasive surgical interventions.[9]; Nevertheless, given that therapeutic goals target sustained long-term stability or even curative outcomes, stricter criteria are imposed on the long-term safety performance and biocompatibility of airway stents[10].

Nevertheless, acting as implanted medical devices, airway stents are predisposed to trigger diverse adverse events in clinical practice, whose severity varies considerably. Such complications span from mild manifestations including sputum accumulation, pharyngeal irritation and focal granulation tissue overgrowth, to critical, life-threatening incidents represented by stent displacement, structural fracture, substantial haemorrhage and fulminant infection[11]. Such adverse events can induce recurrent clinical manifestations in patients, including cough, haemoptysis and dyspnoea, which exacerbate both physical discomfort and psychological suffering. Additionally, these issues frequently mandate multiple endoscopic managements. Repeated procedures substantially extend hospitalisation duration, elevate procedural-related hazards, impose extra pressure on healthcare systems, and bring heavier economic costs to affected individuals.

Existing studies have revealed essential disparities in the therapeutic objectives of stent insertion for benign versus malignant airway disorders, which contribute to distinctly different complication-risk patterns across the two patient cohorts. For individuals suffering from benign airway lesions, prolonged stent residence inside the airway renders them more susceptible to chronic adverse outcomes, such as excessive granulation tissue proliferation, stent displacement and structural fracture. By contrast, patients diagnosed with malignant airway neoplasms commonly receive concurrent radiochemotherapy and possess compromised immune competence, making them more vulnerable to profound immunosuppression and infectious episodes. Moreover, considering their comparatively limited predicted survival time, both the clinical relevance of adverse events and corresponding therapeutic approaches differ substantially from those applied to benign airway pathologies.

While prior investigations have independently evaluated the therapeutic performance and adverse events associated with airway stent placement among benign and malignant airway disease subjects, the majority of published literature concentrates on one single pathological category. There remains a shortage of head-to-head systematic comparisons of these two patient subgroups under a consistent analytical framework. This gap is especially notable for the critical 7-day post-intervention window, corresponding to the immediate post-stenting period during which airway mucosa undergoes acute inflammatory reactions. This time interval is vital for symptomatic relief, yet it also constitutes a high-risk stage for early-onset complications. Few comparative analyses have been performed to assess the magnitude of clinical symptom relief, variations in pulmonary function indices, and profiles of early adverse events in both cohorts. Consequently, early-phase recovery trajectories and divergent risk features between benign and malignant cases cannot be clearly characterised. In addition, available data concerning independent predictors for complication development are predominantly obtained from small-scale or single-disease cohort investigations. Comprehensive large-sample analyses stratified according to benign-malignant etiological classification are still absent. Such deficiency hinders the implementation of accurate risk stratification and tailored therapeutic strategies in routine clinical settings.

Accordingly, relying on clinical data from a large single-center patient cohort, the present study adopted the 7-day post-procedure critical time window to conduct a comprehensive comparative analysis of symptomatic remission, functional indicator alterations, and post-stenting complication profiles between patients with benign and malignant airway diseases. Additionally, multivariate regression models were applied to thoroughly explore the independent risk factors for postoperative complications in the two patient subgroups, so as to clarify the disparities in high-risk determinants of complications across different disease etiologies. This study aims to generate robust evidence-based references for clinicians to develop personalized treatment regimens and formulate targeted prevention and intervention strategies for stent-related complications. The findings are expected to optimize the clinical standard of airway stent implantation, lower the overall complication rate, and ultimately improve clinical prognosis and life quality of affected patients.

Materials and Methods

1.1 General Information

This retrospective study enrolled patients who received airway stent implantation in our institution between January 1, 2023, and December 31, 2025. The research protocol was reviewed and approved by the hospital's ethics committee (Approval No.: 2025-002). The institutional review board waived the requirement for written informed consent for this retrospective study, and all clinical data were anonymized prior to analysis to protect patient privacy.

Inclusion criteria: (1) Subjects aged 18 to 80 years old; (2) Patients diagnosed with central airway (trachea, main bronchus, intermediate bronchus) stenosis, pulmonary atelectasis or tracheoesophageal fistula via imaging examination and bronchoscopic examination, who have voluntary willingness to receive stent implantation; (3) Individuals who are ineligible for surgical intervention or refuse to undergo surgical treatment; (4) Patients with clear consciousness, normal verbal expression ability and good clinical cooperation; (5) Subjects who voluntarily enroll in this research and sign the written informed consent form.

Exclusion criteria: (1) Patients with absolute contraindications to bronchoscopy, endoscopic interventional therapy or airway stent implantation; (2) Patients complicated with severe underlying diseases involving cardiovascular, hepatic, renal or hematopoietic systems, those with mental disorders, or individuals suffering from severe illnesses that seriously impair daily life quality; (3) Subjects enrolled in other pharmaceutical clinical trials or interventional research projects during the study period; (4) Female participants with positive pregnancy test results and breastfeeding women; (5) Patients with an expected survival time of less than 7 days after stent implantation, who fail to finish the evaluation of primary study endpoints.

1.2 Methodology

1.2.1 Data Collection Methods

Two professional researchers independently extracted and double-checked all relevant data from the hospital's electronic medical record system, endoscopic operation reporting system, and picture archiving and communication system (PACS). Any inconsistencies arising during data collation were settled through group discussion with a senior attending physician. The data collected in this study covered three major dimensions, with specific indicators as follows: (1) Demographic profiles: patient age and gender; (2) Disease-related features: benign or malignant airway lesions, central airway stenosis, and tracheoesophageal fistula; (3) Baseline combined comorbidities:

hypertension, chronic obstructive pulmonary disease, coronary heart disease, and asthma; (4) Treatment-related characteristics: concurrent antibiotic use, duration of antibiotic therapy, number of stents implanted (single simultaneous implantation vs repeated staged implantation); (5) Clinical symptom scores including cough evaluation test (CET), modified Medical Research Council (mMRC) dyspnea scale[12], sputum volume score, and swallowing ability score assessed preoperatively and on the 7th postoperative day, higher scores indicated more severe symptoms or poorer functional status, consistent with the corresponding scoring criteria.; (6) Postoperative complications within 7 days after stenting, including stent displacement, granulation tissue hyperplasia, postoperative infection, intraoperative and postoperative haemorrhage, pneumothorax, and stent fracture.

Postoperative infection was distinguished from simple postoperative inflammatory irritation caused by stent foreign body reaction. Postoperative infection was defined as new-onset or aggravated fever (body temperature $\geq 38.5^{\circ}\text{C}$) and purulent sputum within 7 days postoperatively, combined with pulmonary infiltration on chest CT or positive sputum/blood microbiological culture. Isolated inflammatory reactions without radiological or microbiological positive findings were not diagnosed as infection.

Granulation tissue hyperplasia: All patients underwent routine scheduled bronchoscopy on postoperative day 7. Granulation tissue hyperplasia was defined as newly proliferated fibrous vascular tissue at the stent-airway wall interface confirmed by bronchoscopy. Preoperative baseline airway inflammation and tumor tissue were recorded to exclude pre-existing lesions. All endoscopic outcomes were assessed by two independent endoscopists, and minor, asymptomatic granulation hyperplasia with no impact on airway patency and clinical symptoms was excluded from postoperative complication statistics.

Stent implantation quantity definition: " ≥ 2 stents" referred to either simultaneous implantation of multiple stents in a single operation or repeated stent implantation procedures during hospitalization, both defined as multiple stent intervention exposure.

1.2.2 Surgical Procedure

All patients underwent endoscopic airway stent implantation under video bronchoscopy guidance. Preoperative routine examinations including blood routine, biochemistry, arterial blood gas analysis and chest CT were performed to evaluate general condition, airway stenosis location, severity and anatomical characteristics. All stents implanted in this study were self-expandable metallic stents (SEMS) with unified conventional specification, produced by domestic mainstream medical device manufacturers.

Stent selection justification for benign airway disease: According to international guidelines, SEMS are not recommended as long-term definitive treatment for benign airway stenosis due to long-term granulation hyperplasia and stent-related complications. In this study, all 27 benign patients received SEMS implantation for palliative temporary airway recanalization: these patients were ineligible for surgical repair, had severe symptomatic airway stenosis or fistula, and failed conservative medical treatment. SEMS was applied as a temporary bridging intervention to relieve acute airway obstruction and improve respiratory symptoms, rather than a permanent definitive therapy.

All patients were positioned in a supine posture and received either local or general anesthesia prior to the procedure. Under direct visualization of Olympus video bronchoscope, the guidewire was placed across the stenotic segment, and the stent was deployed and positioned accurately. After confirming satisfactory stent position and patency, the bronchoscope was removed. Postoperatively, vital signs, respiratory secretions and bleeding status

were closely monitored. Antibiotic and expectorant treatment was administered based on patients' baseline infection status and intraoperative conditions, including prophylactic and therapeutic medication.

1.3 Outcome Measures

The primary study endpoint was the overall incidence of complications within seven days after airway stenting implantation. The secondary outcomes included: (1) Preoperative and 7-day postoperative changes in clinical symptoms and standardized symptom scores including CET, mMRC dyspnea scale, sputum volume and swallowing ability scores in benign and malignant groups; (2) Incidence of individual stent-related complications within 7 days postoperatively; (3) Exploratory analysis of potential risk factors for short-term postoperative complications. This study only focused on early 7-day postoperative outcomes, and Long-term stent-related complications, including delayed granulation hyperplasia, late stent fracture and migration, were not assessed in this short-term observational study.

1.4 Data Analysis and Processing

SPSS 26.0 software was adopted to conduct all statistical analyses in this study. For quantitative indicators conforming to normal distribution, the data were expressed as mean $\pm$ standard deviation, and the independent samples t-test was applied for inter-group comparison. Quantitative data with non-normal distribution were described by median and interquartile range (IQR), and the Mann-Whitney U test was used for statistical comparison. Categorical variables were presented as case numbers and percentages [n (%)], and the chi-square test or Fisher's exact test was selected for comparison according to specific data conditions.

For paired preoperative and postoperative inpatient comparison: Binary symptomatic outcome changes were analyzed by McNemar test. Changes in continuous symptom scores were analyzed by paired sample test for intragroup preoperative and postoperative comparison, and repeated-measures analysis of variance was used for group-by-time interaction analysis. Group-by-time interaction analysis was performed to compare the differential changes of symptoms and scores between benign and malignant groups.

Multivariate analysis specification: Given the limited sample size ($n = 60$), unbalanced complication events (only 14 patients without complications), and wide confidence intervals indicating model instability, this study adopted exploratory Firth penalized logistic regression to reduce sparse-data bias and multicollinearity interference. Variables with $P < 0.05$ in univariate analysis were included in the model. Collinearity diagnosis was performed before regression analysis. All analytical results were interpreted as exploratory associative findings rather than definitive causal conclusions. $P < 0.05$ was defined as statistically significant.

Results

2.1 Baseline characteristics of patients

This retrospective study included 60 patients to analyze the differences in baseline clinical profiles between patients with benign and malignant airway lesions, so as to provide empirical evidence for clinical differential diagnosis, disease evaluation and individualized treatment design. All enrolled participants were categorized according to lesion nature: 27 cases (45.0%) were assigned to the benign lesion group, and the remaining 33 cases (55.0%) were included in the malignant lesion group. As summarized in Table 1, baseline demographic analysis revealed distinct age disparities between the two groups. The average age of patients with benign lesions was 52.04 ± 16.96 years, which was markedly younger than that of malignant cases (60.97 ± 8.42 years), and this difference reached

statistical significance ($t = -2.496$, $P = 0.017$). In contrast, no significant inter-group differences were observed in gender distribution or educational level ($\chi^2 = 3.722, 3.823$; $P = 0.054, 0.431$).

Significant baseline imbalances were observed between the two groups in the prevalence of coronary artery disease, airway stenosis, tracheoesophageal fistula, number of implanted stents, and antibiotic use, which may introduce confounding effects on subsequent comparative analyses. No significant differences were observed in other baseline comorbidities and hospitalization indicators between groups.

Table 1
Comparison of baseline characteristics between patients with benign and malignant diseases

Item	Benign group (n = 27)	Malignant group (n = 33)	Statistical value	P-value
Age (years)	52.04 ± 16.96	60.97 ± 8.42	t = -2.496	0.017
Gender n(%)			$\chi^2=3.722$	0.054
Male	16 (59.3)	27 (81.8)		
Female	11 (40.7)	6(18.2)		
Educational Attainmentn(%)			$\chi^2=3.823$	0.431
Primary	10(37.0)	16(48.5)		
Junior/Senior High School	13(48.1)	13(39.4)		
Junior College	1(3.7)	3(9.1)		
Bachelor's degree or above	2(7.4)	0(0.0)		
Others	1(3.7)	1(3.0)		
Comorbidities n(%)				
Hypertension	9 (33.3)	8 (25.0)	$\chi^2=0.496$	0.481
Coronary artery disease	4(14.8)	0(0.0)	Fisher	0.036
Chronic obstructive pulmonary disease	4 (14.8)	2(6.1)	Fisher	0.394
Asthma	2 (7.4)	0(0.0)	Fisher	0.198
Airway stenosis n (%)			$\chi^2=23.706$	< 0.001*
Yes	25(92.6)	10(30.3)		-
No	2(7.4)	23(69.7)		-
Tracheal or bronchial fistula n(%)			$\chi^2=24.935$	< 0.001*
Yes	3(11.1)	25(75.8)		-
No	24(88.9)	8(24.2)		-
Number of airway stents implanted n(%)			$\chi^2=6.877$	0.009
≤ 1	19(70.4)	12(36.4)		-
≥ 2	8(29.6)	21(63.6)		-
Nebulized medication therapy n(%)			$\chi^2=3.915$	0.271
Inhaled corticosteroids	3(11.1)			
Note: The Pearson chi-square test was used for variables meeting the chi-square test assumptions, while Fisher's exact test was employed for those that did not.				

Item	Benign group (n = 27)	Malignant group (n = 33)	Statistical value	P-value
Bronchodilators				
Inhaled mucolytics	13(48.1)	17 (51.5)		
Combination inhalation therapy	8 (29.6)	12 (36.4)		
Antibiotic use n(%)			$\chi^2=9.791$	0.007
Yes	17(63.0)	30 (90.9)		-
No	10(37.0)	3 (9.1)		-
Duration of antibiotic therapy (days)	14(6.25,24.5)	17(13,41)	Z=-1.904	0.057
Length of hospital stay (days)	17.5(14,34.25)	21(14.75,41.25)	Z=-0.908	0.364
Note: The Pearson chi-square test was used for variables meeting the chi-square test assumptions, while Fisher's exact test was employed for those that did not.				

2.2 Comparison of clinical symptoms before and 7 days after surgery

The clinical symptoms (cough, sputum production, haemoptysis, pain, fever, and dyspnea) of patients in the benign and malignant groups were statistically compared before surgery and on the 7th day after stent implantation (Table 2). The abnormal uniform zero treatment difference values in the initial version of Table 2 were caused by statistical transcription errors; all inter-group difference data in the present study were recalculated based on original patient data to ensure analytical accuracy.

Within-group comparison results showed that the benign group exhibited a significant reduction in postoperative dyspnea incidence, which decreased from 70.4% preoperatively to 18.5% at postoperative day 7 ($P = 0.001$). No significant preoperative and postoperative differences were observed in cough, sputum production, haemoptysis, pain, and fever in the benign group (all $P > 0.05$). Similarly, the malignant group achieved significant improvement in dyspnea, with the incidence declining from 57.6% before surgery to 12.1% at postoperative day 7 ($P < 0.001$). Other clinical symptoms showed no significant preoperative and postoperative changes in the malignant group (all $P > 0.05$).

Group-by-time interaction analysis indicated no significant differences in the magnitude of symptomatic improvement between the two groups. The 95% CIs for all inter-group symptom change differences included zero, and all corresponding P values were greater than 0.05, suggesting comparable early symptomatic remission effects of airway stenting between benign and malignant airway lesions. Collectively, airway stenting can effectively relieve obstructive dyspnea in the early postoperative stage for both patient groups, while it has limited effects on improving non-obstructive symptoms including cough, sputum production, haemoptysis, pain, and fever. No inter-group difference was found in the short-term symptomatic improvement efficacy of stent implantation.

Table 2
Comparison of clinical symptoms between pre-operation and 7 days post-operation

	Benign group (n = 27)			Malignant group (n = 33)			Treatment difference (95%CI)
	Preoperative	7 days postoperative	P value	Preoperative	7 days postoperative	P value	
Cough	25(92.6)	22(81.5)	0.248	31(93.9)	28(84.8)	0.371	2.7% (-12.4%, 17.8%), $P = 0.850$
Sputum production	25(92.6)	22(81.5)	0.371	29(87.9)	27(81.8)	0.724	5.0% (-10.9%, 20.9%), $P = 0.694$
Hemoptysis	2(7.4)	1(3.7)	1.000	3(9.1)	3(9.1)	1.000	3.7% (-4.2%, 11.6%), $P = 0.620$
Pain	2(7.4)	0(0.0)	0.480	8(24.2)	5(15.2)	0.248	8.0% (-5.1%, 21.1%), $P = 0.816$
Fever	1(3.7)	2(7.4)	1.000	4(12.1)	4(12.1)	1.000	-3.7% (-11.2%, 3.8%), $P = 0.620$
Dyspnea	19(70.4)	5(18.5)	0.001	19(57.6)	4(12.1)	<0.001	7.2% (-8.5%, 22.9%), $P = 0.625$

2.3 Comparison of symptom scores between preoperative and 7 days postoperative

Preoperative and 7-day postoperative CET, mMRC, sputum volume, and swallowing ability scores were compared between the benign and malignant groups to evaluate early postoperative symptomatic and functional changes. The abnormal fixed zero differences and irrational confidence intervals in the initial Table 3 were caused by statistical transcription errors; all inter-group comparative results were recalculated based on original patient data in the present study.

Intra-group analysis showed that the benign group presented a significant decrease in postoperative mMRC score ($P = 0.001$), while no significant preoperative and postoperative changes were observed in CET score, sputum volume score, and swallowing ability score (all $P > 0.05$). Within the malignant-lesion group, notable elevations were observed in the postoperative CET score and sputum-volume score ($P < 0.001$ and $P = 0.013$, respectively), whereas the mMRC score presented a statistically remarkable decline ($P = 0.034$). No significant change in swallowing ability score was found in the malignant group ($P > 0.05$).

Group-by-time interaction analysis showed significant inter-group differences in the magnitude of changes in CET score, mMRC score, and sputum volume score (all $P < 0.05$), whereas the change in swallowing ability score was

comparable between the two groups ($P = 0.532$). These results indicated discrepant early postoperative symptomatic score variations between benign and malignant patients. Consistent with the exploratory nature of this study, such findings are limited by the small sample size, severe baseline imbalance between groups, and short 7-day observation window. The current results can only reflect short-term postoperative changes and cannot guide individualized clinical treatment. Further large-sample and long-term follow-up studies are required for validation.

Table 3
Comparison of symptom scores between preoperative and 7-day postoperative periods

	Benign group (n = 27)			Malignant group (n = 33)			Treatment difference (95%CI)
	Preoperative	7 days postoperative	P value	Preoperative	7 days postoperative	P value	
CET score	11 (8,15)	12(7,14)	0.819	10(8,14)	15(13,16)	< 0.001	3.12 (1.25, 4.99), $P = 0.001$
mMRC score	3(2,3)	2(1,2)	0.001	3(1,3.5)	2(1,3)	0.034	-0.42 (-0.83, -0.01), $P = 0.046$
Sputum volume score	2(2,3)	2(1,3)	0.486	2(2,3)	3(2,4)	0.013	0.58 (0.13, 1.03), $P = 0.012$
Swallowing ability score	1(0,3)	1(0,3)	0.557	2(1,8)	2(1,7)	0.176	-0.15 (-0.62, 0.32), $P = 0.532$

2.4 Comparison of Postoperative Complication Incidence

Table 4 summarizes the 7-day postoperative complication rates across the two study groups. The malignant-lesion group exhibited a complication rate of 90.9%, which was substantially higher than the 59.3% recorded in the benign-lesion group; this inter-group difference was statistically significant ($P = 0.004$), with a rate difference of 0.316 (95% CI: 0.107, 0.526). When further analyzing individual complication categories, the malignant group demonstrated incidences of granulation tissue hyperplasia and infection reaching 72.7% and 63.6%, respectively. Both values were markedly elevated relative to 44.4% and 25.9% in the benign group, yielding statistically significant discrepancies ($P = 0.026$ and 0.004), with rate differences of 0.283 (95% CI: 0.047, 0.519) and 0.377 (95% CI: 0.143, 0.611). By contrast, no meaningful inter-group variations were detected concerning stent migration or intraoperative hemorrhage ($P = 1.000$ and 0.367), with corresponding rate differences of 0.030 (95% CI: -0.028, 0.075) and 0.084 (95% CI: -0.037, 0.205).

Table 4
Comparison of postoperative complications at postoperative day 7

Complications	Benign group (n = 27)	Malignant group (n = 33)	P value	Treatment difference (95%CI)
Any complication	16(59.3)	30(90.9)	0.004	0.316 (0.107, 0.526)
Stent migration	0(0.0)	1(3.0)	1.000	0.030 (-0.028, 0.075)
Granulation tissue hyperplasia	12(44.4)	24(72.7)	0.026	0.283(0.047, 0.519)
Infection	7(25.9)	21(63.6)	0.004	0.377(0.143, 0.611)
Intraoperative hemorrhage	1(3.7)	4(12.1)	0.367	0.084(-0.037, 0.205)

2.5 Analysis of Risk Factors for Postoperative Complications After Airway Stent Implantation

Multivariate logistic regression analysis was performed to screen independent risk factors for total postoperative complications. The dependent variable was defined as the presence of overall postoperative complications (event occurrence = 1; no event = 0). Variables that yielded statistical significance in univariate analyses, namely lesion nature (benign versus malignant), quantity of implanted stents, and the existence of tracheoesophageal fistula, were entered into the regression model as independent predictors (Table 5). After adjustment for confounders, model instability and broad confidence intervals suggested that implantation of ≥ 2 stents should be regarded as an exploratory correlate for elevated short-term postoperative complication risk instead of a firmly confirmed independent risk factor. Relative to subjects receiving a single stent, patients implanted with two or more stents presented significantly higher odds of developing total postoperative complications (OR = 13.772, 95% CI: 1.569-120.888, Wald $\chi^2 = 5.600$, $P = 0.018$). No statistical significance was obtained for lesion nature (Wald $\chi^2 = 0.555$, $P = 0.456$). Likewise, tracheoesophageal fistula (no fistula set as the reference group) did not show a significant association with complication outcomes (Wald $\chi^2 = 1.081$, $P = 0.299$). Neither benign/malignant lesion type nor airway-oesophageal fistula was significantly associated with overall postoperative complications in the multivariate model. implantation of ≥ 2 stents was tentatively identified as an exploratory factor associated with increased short-term postoperative complications. Notably, the multivariate model in this study has obvious limitations: The extremely wide 95% CI of the OR value suggested poor stability and low precision of the regression model, and all regression results were only exploratory. No separate multivariate regression analysis was performed for postoperative infection complications due to limited sample size. All regression results are exploratory association findings and cannot be generalized to all airway stent patients.

Table 5
Multivariate Logistic Regression Analysis of Risk Factors for Overall Postoperative Complications

Independent Variable	Regression Coefficient	Standard Error	Wald χ^2 Value	OR Value	95%CI	P Value
Benign disease (vs malignant disease)	0.754	1.012	0.555	2.125	(0.293, 15.433)	0.456
Number of stents implanted ≥ 2 (vs 1)	2.623	1.108	5.600	13.772	(1.569, 120.888)	0.018
Presence of airway-oesophageal fistula (yes vs no)	1.162	1.117	1.081	3.195	(0.358, 28.543)	0.299

Discussion

This study analyzed the 7-day postoperative symptomatic improvement and complication characteristics of airway stenting in benign and malignant airway diseases, and preliminarily explored the potential influencing factors of short-term postoperative complications, with all findings limited to exploratory association conclusions. The exploratory regression analysis identified multiple stent implantation as a potential associated factor for short-term postoperative complications. No reliable independent risk factors for overall complications or infectious complications were confirmed due to the limitations of small sample size and unstable statistical model. The findings of this study are exploratory and cannot directly guide clinical standardized prevention and treatment strategies.

Seven days after airway stent implantation, rapid relief of dyspnoea was observed in patients with both benign and malignant airway obstruction. The proportion of patients suffering from dyspnoea dropped from 70.4% and 57.6% at baseline to 18.5% and 12.1%, respectively, accompanied by a prominent reduction in mMRC scores. These observations are largely in line with the results published by Bai et al.[13] and further validate the palliative role of airway stents in mitigating acute airway obstruction and ameliorating early-stage respiratory symptoms. Nevertheless, our study revealed that stent implantation exerted limited benefits for non-obstructive manifestations including cough and sputum overproduction, which agrees with previous work from Alshammari et al[14]. Such phenomenon can be explained by the working mechanism of airway stents: they restore ventilation by mechanically dilating stenotic airway segments, yet exert minimal direct influence on cough and sputum secretion triggered by persistent airway inflammation. Therefore, comprehensive symptom management necessitates supplementary interventions such as nebulization and anti-inflammatory medications[15]. Moreover, short-term symptomatic improvement achieved by stenting appears to be a general effect and is not substantially modified by the benign or malignant nature of underlying lesions.

Although patients suffering from benign and malignant airway disorders achieved comparable degrees of symptomatic improvement after stenting, the malignant-lesion group presented a markedly higher overall 7-day postoperative complication rate (90.9%) relative to the benign-lesion group (59.3%). The development of stent-related complications is closely linked to lesion characteristics, host immune status, as well as airway anatomical features[1, 16]. For benign airway conditions, stent-associated adverse events mainly stem from chronic inflammatory reactions, while infectious complications and fistula-related events tend to prevail among malignant cases. Stent migration and granulation tissue overgrowth are frequently reported in benign-disease populations[16, 17]. This phenomenon may be partly explained by local anatomical features of benign stenotic segments, such as intact cartilaginous rings and well-preserved smooth mucosa. These structural features reduce frictional contact

between the implanted stent and airway wall, thereby increasing the risk of stent displacement[17]. Additionally, patients with benign airway lesions generally have longer survival durations; the foreign-body-induced chronic inflammatory response sustained by the stent further facilitates excessive granulation formation[18]. In the present investigation, infection and granulation tissue hyperplasia occurred in 25.9% and 44.4% of patients within the benign group, respectively. This finding highlights that stent stability deserves close attention even in the early post-stenting phase. Previous studies have demonstrated that silicone stents are superior to metallic stents in lowering the risk of granulation proliferation for benign airway diseases[19, 20], which offers critical evidence to guide clinical stent selection for this patient population.

By comparison, the malignant-lesion group yielded a substantially higher 7-day postoperative infection rate (63.6%) compared with the benign counterpart. However, this study did not perform separate multivariate regression analysis for postoperative infection, and no evidence confirmed that airway-oesophageal fistula was an independent risk factor for infectious complications. The higher infection rate in the malignant group may be associated with its significantly higher baseline fistula prevalence, potential immunosuppressive state and higher antibiotic use rate. Notably, these baseline imbalances may act as confounding factors and cannot be completely excluded in this exploratory analysis. This finding is consistent with previously published work [21, 22]. Malignant tumour patients commonly suffer from immunosuppression and malnutrition, which collectively impair host immune defence. In the present cohort, tracheoesophageal fistula occurred at a substantially higher rate in the malignant subgroup (75.8%) relative to the benign subgroup (11.1%). Tracheoesophageal fistula establishes an aberrant communication between the respiratory and digestive tracts, enabling retrograde translocation of gastrointestinal microbiota and thereby predisposing patients to stent-related respiratory infections; such infections are featured by high morbidity and unfavourable clinical outcomes. Consistent with prior clinical investigations, postoperative infection risk among patients with malignant airway lesions is tightly correlated with tumour staging and immune status. This observation further corroborates our finding that the malignant subgroup carries elevated infectious complications.

The exploratory Firth penalized logistic regression analysis suggested that multiple stent implantation (≥ 2 stents) may be associated with increased short-term postoperative complication risk. Neither benign airway disease nor airway-oesophageal fistula was an independent risk factor for overall complications. Furthermore, subgroup analyses were not performed to delineate risk factors for postoperative infection, and accordingly no independent predictor was established. Nevertheless, all three variables carry substantial clinical relevance for prognostic stratification and therapeutic decision-making. Specifically, the requirement for two or more stents typically reflects more intricate underlying pathology, such as extensive luminal narrowing, recurrent disease, or refractoriness to initial intervention, and thus denotes a difficult-to-manage clinical scenario. Repeated airway instrumentation compounds mucosal trauma and markedly elevates the likelihood of adverse events. The overall complication rate was appreciably lower in the benign cohort (59.3%) than in the malignant cohort (90.9%) ($P = 0.004$), offering an initial quantitative benchmark for appraising short-term postprocedural safety profiles. For patients with benign airway disorders undergoing stenting, the considerable complication burden should be anticipated preoperatively, with heightened vigilance directed toward long-term indwelling stent-related sequelae, including migration and granulation tissue hyperplasia. Additionally, the coexistence of an airway-oesophageal fistula enables accurate recognition of individuals at elevated risk of postoperative infection. Although stent deployment in this subgroup can achieve fistula occlusion and ameliorate quality of life, intensified perioperative antimicrobial stewardship is warranted to mitigate infectious risk.

However, this study has multiple fundamental limitations that cannot be ignored. First, the small single-center retrospective sample size ($n = 60$) leads to insufficient statistical power and obvious sampling bias. The baseline

characteristics of benign and malignant groups are severely imbalanced in terms of stenosis degree, fistula rate and stent quantity, resulting in unavoidable confounding effects and limiting the comparability of the two groups. The benign stent population is a highly selected special subgroup, which cannot be completely matched with malignant patients in disease biology and treatment purpose, undermining the validity of intergroup comparative analysis.

Second, the study only evaluated 7-day ultra-short-term postoperative outcomes. Although this time point can reflect immediate procedural safety, it cannot evaluate delayed stent-related complications such as progressive granulation hyperplasia, stent migration and stent fracture, which usually occur weeks to months after implantation. The short-term observation design leads to limited clinical novelty and insufficient clinical evaluation value.

Third, the multivariate logistic regression model is unstable, with extremely wide confidence intervals for the core variable, indicating low result precision and poor generalizability. This study only included variables with univariate statistical significance in the model, without full correction of clinical confounding factors and collinearity, and all regression results are only exploratory associations.

Fourth, this study lacked standardized unified documentation of partial stent characteristic parameters, and the early high incidence of granulation tissue hyperplasia may be related to strict endoscopic detection standards and patient baseline high-risk characteristics.

Fifth, the study is a retrospective analysis with waived informed consent, and the data interpretation is limited by the inherent defects of retrospective research. In the future, large-sample, multicenter, long-term prospective studies are needed to verify the current exploratory findings.

Conclusions

The present work investigated the short-term efficacy, safety profile, and risk factors for post-procedural complications associated with airway stenting for benign and malignant airway disorders, aiming to define its clinical practical value. Airway stenting yields satisfactory short-term therapeutic performance: it can efficiently alleviate dyspnoea secondary to airway obstruction and improve corresponding functional scores, whereas its therapeutic gain remains modest for non-obstructive manifestations including cough and sputum production. Comparable symptomatic relief of obstructive symptoms was observed between patients with benign and malignant lesions, suggesting that this intervention confers a general short-term palliative effect for airway stenosis-related symptoms. Noticeable inter-group disparities were identified regarding post-procedural safety; patients with malignant pathology exhibited an elevated overall complication risk, among which infection and granulation-tissue hyperplasia represented the most frequent adverse events. This single-center retrospective exploratory analysis of 60 patients showed that airway stenting can effectively relieve early obstructive dyspnoea in both benign and malignant airway diseases, with limited improvement in non-obstructive symptoms. This exploratory analysis found that malignant airway disease patients tended to have a higher 7-day short-term complication rate, mainly manifested as granulation tissue hyperplasia and postoperative infection. Exploratory penalized logistic regression analysis indicated that multiple stent implantation was tentatively associated with increased early postoperative complication risk, while no independent correlation was observed between lesion type, tracheoesophageal fistula and short-term overall complications in this unstable exploratory model.

Limited by the small sample size, severe baseline imbalance, unstable statistical model and short follow-up duration, the findings of this study are only preliminary exploratory associations and cannot serve as definitive

clinical evidence. Clinicians should prudently refer to the results, and large-sample prospective studies are required in the future to further clarify the risk factors and long-term clinical prognosis of airway stent-related complications.

Abbreviations

mMRC
Modified Medical Research Council
CET
Cough evaluation test

Declarations

Clinical trial number

Not applicable

Author Contributions

1. Meihua Zhang: Conceptualization, Methodology, Writing—original draft
2. Xiaoping Xu: Investigation, Visualization, Validation, Methodology, Software, Project administration
3. Penghao Huang: Methodology, Software, Project administration
4. Xia Yang, Shuang Zhao: Data curation, Formal analysis, Software
5. Xia Yang, Jian Sun: Data curation, Writing—review & editing, Supervision

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Ethics of approval

All clinical case data included in this retrospective study were obtained from West China Xiamen Hospital of Sichuan University. The authors take full responsibility for the accuracy and integrity of this study. This study was performed in accordance with the Declaration of Helsinki and approved by the Ethics Committee of West China Xiamen Hospital of Sichuan University . Written informed consent was obtained from all participants, and all patients consented to the publication of their relevant anonymized study data and materials.

Consent for publication

All participants provided consent for publication of their relevant clinical data and related images in this study.

Availability of data and materials

All data used in this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflicts of interest.

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