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Long-term outcomes and predictors of recurrence after interventional bronchoscopic dilation for post-intubation tracheal stenosis: a 24-month cohort study

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Abstract

Background: Benign tracheal stenosis (BTS) is a challenging condition in interventional pulmonology, with recurrence remaining a major limitation of endoscopic treatment. We aimed to evaluate clinical outcomes and safety of endoscopic treatment for acquired BTS and to describe recurrence over 24 months of follow-up.

Methods: We conducted a retrospective cohort study at a tertiary-care hospital, including adults with BTS who underwent endoscopic airway recanalization. The primary outcome was first stenosis recurrence within 24 months. Recurrence-free survival was estimated using the Kaplan–Meier method. Associations between clinical and anatomical characteristics and time to recurrence were evaluated using Cox proportional hazards models.

Results: A total of 490 patients were included, with a mean age of 54.9 ± 11.7 years; 62.2% were male. COVID-19-associated orotracheal intubation was the etiology in 70.0% of cases. Stenosis was predominantly subglottic (41.8%) or located in the upper trachea (31.2%), and 56.9% were classified as complex stenoses. Myer–Cotton grade III stenosis was present in 58.0% of patients. The index endoscopic strategy consisted of cryotherapy plus dilation in 68.0% and electrocautery plus dilation in 32.0%. The most frequent adverse events were bronchospasm (8.4%), hypoxemia (7.8%), reintubation (6.9%), and vocal cord paresis or paralysis (6.3%). Recurrence increased progressively from 6.9% at 3 months to 15.3% at 6 months, 27.6% at 12 months, 34.9% at 18 months, and 41.6% at 24 months. Median time to first recurrence was 8.9 months (IQR, 3.9–15.3). Recurrence-free survival was 92.9% at 3 months, 84.9% at 6 months, 72.7% at 12 months, 65.5% at 18 months, and 59.4% at 24 months. Absence of malacia ($p=0.009$) and simple stenosis ($p<0.001$) were associated with higher recurrence-free survival. Among patients with recurrence, 16.7% required open surgery or tracheal resection, 11.3% required stent placement, and 8.8% underwent tracheostomy.

Conclusions: In patients with ETB treated with endoscopic intervention, recurrence progressively increased during follow-up, reaching 41.6% at 24 months, with a recurrence-free survival of 59.4%. The presence of malacia and greater stenosis complexity were associated with lower recurrence-free survival.

Introduction

Tracheal stenosis is a central airway obstruction that may be either benign or malignant (1). Benign tracheal stenosis (BTS) most commonly results from prolonged endotracheal intubation or tracheostomy, although it may also be associated with autoimmune diseases, chronic infections, obesity, and other underlying conditions (1, 2). It is estimated that 4%–13% of intubated patients develop this complication, although the true prevalence may be higher because mild cases or those presenting with nonspecific symptoms may remain undiagnosed (1–4). Pressure-related injury from the endotracheal tube can cause mucosal ischemia, ulceration, and cartilage damage, followed by inflammation, fibrosis, and scar remodeling, ultimately resulting in a significant reduction in airway caliber (4, 5). The increase in

the number of patients requiring prolonged mechanical ventilation during the COVID-19 pandemic was accompanied by greater recognition of post-intubation tracheal and subglottic stenosis (5, 6).

BTS may exhibit considerable heterogeneity in terms of location, length, degree of obstruction, presence of malacia, and extent of scar tissue involvement (1, 3). Prognosis largely depends on the location, extent, and severity of the lesion, as well as the therapeutic approach employed (4). In this regard, tracheal recanalization using endoscopic techniques has demonstrated efficacy in restoring airway patency, improving functional outcomes, and facilitating decannulation, thereby contributing to medium-term survival (1, 7, 8). Endoscopic techniques include mechanical or balloon dilation, resection or ablation of scar tissue using different energy sources, cryotherapy, and, in selected cases, stent placement. However, recurrence is common and may require repeated procedures or surgical resection and reconstruction in some patients (9, 10).

Dilation provides immediate restoration of luminal caliber but may be insufficient when dense scar tissue or complex stenosis is present, and recurrence remains one of the major limitations of endoscopic treatment (4–7). Cryotherapy, on the other hand, has gained an increasingly important role in interventional bronchoscopy because of its ability to achieve tissue ablation and remodeling through a thermal profile distinct from that of electrosurgical techniques (4). Similarly, electrocautery can be used to perform radial incisions or targeted resection of scar tissue before dilation (2, 10, 11).

In Latin America, and particularly in Colombia, endoscopic recanalization has become an established safe and effective alternative for the management of post-intubation benign tracheal stenosis. However, evidence regarding recurrence-free survival following endoscopic intervention remains limited, as does evidence identifying lesion characteristics, such as stenosis complexity and the presence of malacia, that may influence clinical outcomes (12, 13). Therefore, the aim of this study was to evaluate the clinical outcomes and safety of endoscopic dilation strategies combined with cryotherapy or electrocautery in patients with acquired tracheal stenosis, as well as to describe the cumulative incidence of recurrence, time to first recurrence, and need for subsequent interventions during follow-up of up to 24 months.

Methods

Study Design and Population

A retrospective cohort study was conducted at a tertiary-care hospital and included adult patients diagnosed with ETB who underwent endoscopic treatment between January 2014 and November 2025. The primary objective was to evaluate patient outcomes after endoscopic treatment, with particular emphasis on stenosis recurrence and time to first recurrence during follow-up of up to 24 months.

Eligibility Criteria

Patients ≥ 18 years of age with a confirmed diagnosis of ETB were included. ETB was defined as an acquired, nonmalignant narrowing of the tracheal or subglottic airway documented by endoscopic evaluation. Patients who underwent an endoscopic airway recanalization procedure during the study period were eligible for inclusion. Patients with stenosis of malignant etiology or insufficient information to determine outcomes after the index procedure or to establish the presence or absence of recurrence during follow-up were excluded.

Variables and Data Collection

Sociodemographic and clinical variables were collected, including age, sex, body mass index (IMC), and arterial hypertension. The etiology of stenosis was classified according to a history of orotracheal intubation associated with COVID-19 infection or orotracheal intubation for other causes. Anatomical characteristics of the stenosis included location, length, minimum pre-treatment diameter, degree of obstruction, presence of malacia, and cartilage involvement. Stenosis location was classified as subglottic, upper, middle, or lower tracheal.

Stenosis severity was classified according to the Myer–Cotton grading system: grade I, ≤ 50% obstruction; grade II, 51%–70%; grade III, 71%–99%; and grade IV, complete obstruction (14, 15). Lesions were classified as simple or complex according to their anatomical characteristics. A simple stenosis was defined as a short lesion (≤ 1 cm), limited to the mucosa or submucosa, without cartilage involvement. Complex stenoses were defined as lesions > 1 cm, with cartilage involvement, or associated with structural abnormalities of the airway, including malacia (14, 16).

Procedure-related complications and those occurring within the first 48 hours after the intervention were recorded. Evaluated complications included bronchospasm, hypoxemia, reintubation, vocal cord paresis or paralysis, unplanned admission to the intensive care unit, pneumomediastinum or emphysema, pneumothorax, mucosal tear, bleeding, transient desaturation, and laryngeal or tracheal edema. Complications were classified according to the timing of presentation as intraoperative or immediate, with the latter defined as complications occurring within the first 48 hours after the procedure.

Endoscopic Procedure Characteristics

For the index procedure, procedure duration, technique used, airway diameter after dilation, and percentage of residual obstruction were recorded. The index endoscopic strategy was classified into two groups: cryotherapy plus dilation or electrocautery plus dilation. For procedures involving cryotherapy, the number of cycles, duration of each cycle, and total application time were recorded. For procedures involving electrocautery, the incision pattern was recorded according to the classification used at the institution. During follow-up, the use of silicone stents and the occurrence of stent migration were recorded when applicable.

Outcomes

The primary outcome was first recurrence of stenosis during the 24 months following the index endoscopic procedure. Recurrence was defined as the reappearance of a clinically relevant stenosis during follow-up requiring a new endoscopic or therapeutic intervention. The recurrence date was defined as the date on which the event was first documented.

Time to first recurrence was calculated from the date of the index procedure to the date of first recurrence. Patients who did not experience recurrence were censored at the last available evaluation or upon completion of 24 months of follow-up. Among patients who experienced recurrence, the degree of obstruction at the time of the event and subsequent interventions were recorded, including repeat endoscopic interventions, stent placement, tracheostomy, and open surgery or tracheal resection.

Patients were followed for a maximum of 24 months after the index procedure. Follow-up information was obtained from clinical records, endoscopic reports, and subsequent procedures documented in the medical record. For each patient, the date of the index procedure, the date of first recurrence when applicable, and the date of the last available evaluation for patients who remained recurrence-free were recorded.

Sample Size

Census sampling was performed, including all patients who met the eligibility criteria and underwent endoscopic treatment during the study period. No a priori sample size calculation was performed because of the retrospective and census-based nature of the study.

Statistical Analysis

Data were collected and managed using Research Electronic Data Capture (REDCap) (17). Statistical analyses were performed using Stata version 17.0 (StataCorp, College Station, TX, USA) (18). Quantitative variables were summarized using the mean and standard deviation (DE) when they had an approximately normal distribution, and the median and interquartile range (RIC) when the distribution was non-normal. Categorical variables were expressed as absolute frequencies and percentages.

The distribution of quantitative variables was assessed using the Shapiro–Wilk test. Between-group comparisons were performed using the Student's t-test or Mann–Whitney U test for quantitative variables, as appropriate, and the chi-square test or Fisher's exact test for categorical variables (19).

The probability of remaining recurrence-free was estimated using the Kaplan–Meier method (20). Time zero was defined as the date of the index endoscopic procedure. First recurrence-free survival curves were graphically displayed, and the probabilities of remaining recurrence-free at 3, 6, 12, 18, and 24 months were estimated, with corresponding 95% confidence intervals.

Recurrence-free survival curves were compared using the log-rank test according to clinical, anatomical, and procedure-related characteristics, including sex, age > 60 years, arterial hypertension, chronic kidney disease, ischemic heart disease, history of orotracheal intubation associated with COVID-19, cartilage involvement, presence of malacia, stenosis complexity, Myer–Cotton classification, and index endoscopic technique.

The association between baseline and anatomical characteristics of stenosis and time to first recurrence was assessed using Cox proportional hazards models. Results were expressed as hazard ratios (HR) with 95% confidence intervals (IC95%). For the multivariable analysis, variables with clinical relevance and biological plausibility were considered, prioritizing those related to structural airway characteristics, particularly malacia, stenosis complexity, cartilage involvement, and degree of obstruction. The index endoscopic technique was also considered as the exposure variable of interest.

Because of the relationship between some anatomical variables, alternative models were evaluated to avoid overfitting and collinearity. Sensitivity analyses were performed using different specifications of variables related to structural airway involvement. The proportional hazards assumption was assessed using Schoenfeld residuals. Survival analysis results were reported as HR with IC95%. A p-value < 0.05 was considered statistically significant. No imputation of missing data was performed; for each analysis, records with available information for the corresponding variables were used.

Results

General Characteristics

A total of 490 patients were included, with a mean age of 54.9 ± 11.7 years and a male predominance (62.2% [305/490]); the mean IMC was 28.5 ± 4.2 kg/m². Arterial hypertension was present in 35.5% (174/490) of patients (Table 1). The etiology of stenosis was orotracheal intubation associated with COVID-19 in 70.0% (343/490) of cases and orotracheal intubation for other causes in 30.0% (147/490). Stenosis was primarily located in the subglottic region (41.8% [205/490]), followed by the upper (31.2% [153/490]) and middle trachea (19.6% [96/490]). The median stenosis length was 20.5 mm (RIC: 15.2–24.9), with a median minimum pre-treatment diameter of 4.7 mm (RIC: 3.3–6.4). Most patients had Myer–Cotton grade 3 stenosis (58.0% [284/490]), followed by grade 2 (40.2% [197/490]) and grade 1 (1.8% [9/490]); 56.9% (279/490) were classified as having complex stenosis.

Table 1
General characteristics.

Variable, %(n)	**100% (490)**
Age years, mean(SD)	54.9 ± 11.7
Men, n(%)	62.2% (305/490)
BMI kg/m², mean(SD)	28.5 ± 4.2
Smoking, n(%)	16.5% (81/490)
Arterial hypertension, n(%)	35.5% (174/490)
Diabetes mellitus, n(%)	34.9% (171/490)
COPD/asthma, n(%)	15.9% (78/490)
Stenosis etiology, n(%)	
Post-intubation	30.0% (147/490)
Post-intubation (COVID-19)	70.0% (343/490)
Prior tracheostomy	69.0% (338/490)
Days of intubation, mean(SD)	15.6 ± 7.1
Number of intubations, mean(SD)	1.1 ± 0.3
Baseline stridor, n(%)	69.0% (338/490)
Stenosis location, n(%)	
Subglottic	41.8% (205/490)
Lower tracheal	7.3% (36/490)
Mid-tracheal	19.6% (96/490)
Upper tracheal	31.2% (153/490)
Vocal cord-to-stenosis distance mm, me(IQR)	23.9 [15.4–30.3]
Stenosis length mm, me(IQR)	20.5 [15.2–24.9]
Minimum pre-treatment diameter mm, me(IQR)	4.7 [3.3–6.4]
Pre-treatment obstruction %, mean(SD)	72.4 ± 11.9
Myer–Cotton, n(%)	
Grade 1	1.8% (9/490)
Grade 2	40.2% (197/490)
Grade 3	58.0% (284/490)

Variable, %(n)	100% (490)
Simple stenosis, n(%)	43.1% (211/490)
Complex stenosis, n(%)	56.9% (279/490)
Mixed morphology, n(%)	29.0% (142/490)
Concentric cicatricial morphology, n(%)	71.0% (348/490)
Malacia/cartilage involvement, n(%)	11.0% (54/490)
No malacia/cartilage involvement, n(%)	89.0% (436/490)
Active granulation, n(%)	29.0% (142/490)
Baseline mMRC, mean(SD)	2.7 ± 0.7
Baseline FEV1 L, mean(SD)	1.8 ± 0.5
Baseline FEV1% predicted, mean(SD)	57.9 ± 14.5
Baseline FVC L, mean(SD)	2.5 ± 0.6
Baseline FVC % predicted, mean(SD)	69.8 ± 16.4
Baseline FEV1/FVC %, mean(SD)	75.8 ± 25.5
Baseline PIF L/min, mean(SD)	96.5 ± 28.1

Notes: SD, standard deviation; me, median; IQR, interquartile range; s, seconds; BMI, body mass index; COPD, chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019; FEV1, forced expiratory volume in the first second; FVC, forced vital capacity; IQR, interquartile range; mMRC, modified Medical Research Council; PIF, peak inspiratory flow; SD, standard deviation.

Data are presented as mean ± SD, median [IQR], or n (%) as appropriate.

Procedural Characteristics

Dilation procedures had a mean duration of 41.5 ± 12.0 minutes, a mean post-dilation airway diameter of 13.0 ± 1.4 mm, and a mean residual obstruction of 27.3 ± 7.3% (Table 2). The index technique consisted of cryotherapy plus dilation in 68.0% (333/490) of patients and electrocautery plus dilation in 32.0% (157/490). Among procedures involving cryotherapy, the median number of cycles was 2.0 (RIC: 0.0–3.0), with a median duration of 5.0 seconds per cycle (RIC: 0.0–10.0) and a median total cryotherapy application time of 15.0 seconds (RIC: 0.0–20.0). Electrocautery interventions included different incision patterns, corresponding to codes 1, 2, and 3 in 31.8% (156/490), 45.3% (222/490), and 22.9% (112/490) of cases, respectively.

Table 2
Characteristics of the procedure

Variable, %(n)	**100% (490)**
Index technique, %(n)	
Cryotherapy + dilation	68.0% (333/490)
Electrosurgery + dilation	32.0% (157/490)
Procedure duration min, me(IQR)	41.5 ± 12.0
Post-dilation diameter mm, me(IQR)	13.0 ± 1.4
Residual obstruction %, me(IQR)	27.3 ± 7.3
Number of cryotherapy cycles, me(IQR)	2.0 [0.0–3.0]
Seconds per cryotherapy cycle, me(IQR)	5.0 [0.0–10.0]
Total cryotherapy time s, me(IQR)	15.0 [0.0–20.0]
Post-procedure stay days, me(IQR)	1.0 [0.0–2.0]
Intralesional corticosteroid, %(n)	28.2% (138/490)
Mitomycin C, %(n)	15.1% (74/490)
Technical success, %(n)	100.0% (490/490)
Immediate clinical improvement, %(n)	98.2% (481/490)
Cryotherapy, %(n)	68.0% (333/490)
Electrosurgery incisions, %(n)	
1	31.8% (156/490)
2	45.3% (222/490)
3	22.9% (112/490)

Notes: me, median; IQR, interquartile range; s, seconds.

Data are presented as mean ± SD, median [IQR], or n (%) as appropriate.

Complications

The most frequent adverse event was bronchospasm, observed in 8.4% (41/490) of patients, followed by hypoxemia in 7.8% (38/490), reintubation in 6.9% (34/490), vocal cord paresis or paralysis in 6.3% (31/490), and unplanned admission to the intensive care unit in 5.9% (29/490) (Table 3). Pneumomediastinum or emphysema occurred in 5.5% (27/490) of patients and pneumothorax in 2.7% (13/490). Among intraoperative complications, documented in 11 patients, superficial mucosal tears

occurred in 36.4% (4/11), moderate bleeding controlled endoscopically in 36.4% (4/11), and transient desaturation in 27.3% (3/11). Among immediate complications occurring within the first 48 hours, documented in 23 patients, bronchospasm was the most frequent event (43.5% [10/23]), followed by transient laryngeal or tracheal edema (26.1% [6/23]).

Table 3
Complications and safety events

Variable, %(n)	**100% (490)**
Significant bleeding, n(%)	2.2% (11/490)
Perforation/rupture, n(%)	0.4% (2/490)
Pneumothorax, n(%)	2.7% (13/490)
Pneumomediastinum/emphysema, n(%)	5.5% (27/490)
Hypoxemia, n(%)	7.8% (38/490)
Bronchospasm, n(%)	8.4% (41/490)
Vocal cord paresis/paralysis, n(%)	6.3% (31/490)
Unplanned ICU admission, n(%)	5.9% (29/490)
Reintubation, n(%)	6.9% (34/490)
Urgent tracheostomy, n(%)	1.2% (6/490)
Death ≤ 30 days, n(%)	0.0% (0/490)
Type of operative complication, n(%)	
Transient desaturation	27,3% (3/11)
Superficial mucosal tear	36,4% (4/11)
Moderate bleeding controlled endoscopically	36,4% (4/11)
Type of immediate complication ≤ 48 h, n(%)	
Bronchospasm	43,5% (10/23)
Transient laryngeal/tracheal edema	26,1% (6/23)
Mild post-procedural bleeding	17,4% (4/23)
Transient hypoxemia	13,0% (3/23)
Type of delayed complication 3–30 days, n(%)	
Symptomatic granulation	23,5% (4/17)
Lower respiratory tract infection	11,8% (2/17)
Secretion retention	35,3% (6/17)
Persistent pain/odynophagia	29,4% (5/17)

Notes: ICU, intensive care unit; h, hours.

Data are presented as n (%).

Table 4
Recurrence, reinterventions, and subsequent treatments

Variable, % (n)	**100% (490)**
Recurrence at 3 months, % (n)	6.9% (34/490)
Recurrence at 6 months, % (n)	15.3% (75/490)
Recurrence at 12 months, % (n)	27.6% (135/490)
Recurrence at 18 months, % (n)	34.9% (171/490)
Recurrence at 24 months, % (n)	41.6% (204/490)
Time to first recurrence, me(IQR)	8.9 [3.9–15.3]
Obstruction at recurrence %, mean(SD)	65.0 ± 11.3
Symptoms at recurrence, % (n)	84.3% (172/204)
Repeat therapeutic bronchoscopy, % (n)	74.5% (152/204)
Number of reinterventions at 24 months	0.5 ± 0.8
Time to first reintervention, months	9,20 [5,20–14,70]
Subsequent stent, % (n)	11.3% (23/204)
Subsequent silicone prosthesis, % (n)	2.0% (10/490)
Subsequent tracheostomy, % (n)	8.8% (18/204)
Open surgery/resection, % (n)	16.7% (34/204)
Time to surgery, mean(SD)	11.6 ± 5.9
Mortality at 12 months, % (n)	1.2% (6/490)
Mortality at 24 months, % (n)	2.4% (12/490)
Cause of death: respiratory, % (n)	100.0% (12/12)

Notes: SD, standard deviation; me, median; IQR, interquartile range.

Data are presented as n (%), mean ± SD, or median [IQR], as appropriate.

Recurrence, Reinterventions, and Subsequent Treatments

Recurrence increased progressively during follow-up, from 6.9% (34/490) at 3 months to 41.6% (204/490) at 24 months. Recurrence rates were 15.3% (75/490) at 6 months, 27.6% (135/490) at 12 months, and 34.9% (171/490) at 18 months. The median time to first recurrence was 8.9 months (RIC: 3.9–15.3), with a mean degree of obstruction of 65.0 ± 11.3%. Among patients with recurrence, 11.3%

(23/204) subsequently required stent placement, 8.8% (18/204) underwent tracheostomy, and 16.7% (34/204) required open surgery or resection. The mean time to surgery was 11.6 ± 5.9 months. Silicone stent placement was documented in 2.0% (10/490) of the overall cohort. Mortality was 1.2% (6/490) at 12 months and 2.4% (12/490) at 24 months; all recorded deaths were respiratory-related.

Kaplan–Meier Analysis

First recurrence-free survival decreased progressively over the 24-month follow-up period, from 92.86% (IC95%: 90.19–94.82) at 3 months to 84.87% (81.37–87.75) at 6 months, 72.68% (68.49–76.41) at 12 months, 65.51% (61.08–69.56) at 18 months, and 59.42% (54.86–63.67) at 24 months (Fig. 2). The absence of malacia (Fig. 3; $p = 0.009$) and simple stenosis (Fig. 4; $p < 0.001$) were associated with higher recurrence-free survival. Recurrence-free survival according to Myer–Cotton classification is shown in Fig. 5.

Discussion

In patients with ETB who underwent endoscopic treatment, the probability of remaining free from first recurrence progressively decreased during the 24-month follow-up period, reaching 59.4% at the end of follow-up. Recurrence was evident within the first few months and was accompanied by a clinically relevant proportion of patients requiring additional interventions, including stent placement, tracheostomy, or open surgery. The presence of malacia and classification of the stenosis as complex were associated with lower recurrence-free survival. These findings suggest that, although endoscopic treatment allows immediate restoration of airway caliber, the durability of the treatment effect is strongly influenced by the structural characteristics of the lesion. Our results characterize the temporal pattern of recurrence and provide complementary information to previous series.

In our population, 70% of stenoses were associated with COVID-19-related intubation, and most lesions were in the subglottic or upper tracheal regions, with a predominance of Myer–Cotton grade III lesions and a substantial proportion of complex stenoses. This pattern is consistent with studies conducted during the pandemic, in which COVID-19-associated post-intubation stenoses were characterized by complex lesions and tracheal involvement that frequently required surgical treatment (21, 22). A recent review reported that severe COVID-19 may increase the frequency and complexity of tracheal stenosis because of the combined effects of the inflammatory response, prolonged mechanical ventilation, reintubation, and other factors related to critical illness (23). More recently, a propensity score-adjusted cohort study found that patients with COVID-19-associated post-intubation stenosis more frequently required airway resection to achieve definitive treatment compared with patients with non-COVID-19-related etiologies (81.4% vs. 42.4%; $p < 0.001$) [24]. These findings support the possibility that post-COVID-19 stenoses represent a particularly complex phenotype, potentially related not only to the duration of intubation but also to factors inherent to critical illness, mucosal injury, and altered wound healing.

The association between stenosis complexity, the presence of malacia, and recurrence observed in our study is clinically plausible and consistent with the literature on interventional treatment of benign

tracheal stenosis (25–27). In a retrospective cohort of 132 patients, Dalar et al. observed that complex stenoses required a considerably greater number of bronchoscopic procedures and had a lower success rate than simple stenoses; the overall success rate for complex lesions was 69.8%, compared with 100% for simple lesions (25). These findings support the importance of anatomical classification in selecting the therapeutic strategy and anticipating the need for repeat interventions or surgery (25, 26). In our survival analysis, the difference associated with stenosis complexity was not limited to the immediate response to the procedure but was also manifested as a lower probability of remaining recurrence-free during follow-up.

The endoscopic strategy used in this cohort combined dilation with a tissue-modification modality, primarily cryotherapy or electrocautery (3, 4, 27). A systematic review published in 2023 identified only five studies involving a total of 67 patients treated with cryotherapy; 29 were treated with cryotherapy alone and 38 with cryotherapy followed by balloon dilation. Although most patients experienced clinical improvement and a low frequency of complications was reported, the authors highlighted the limited quantity and heterogeneity of the available evidence (4). In our cohort, the use of cryotherapy plus dilation in 68% of procedures represents a considerably larger experience than that described in the literature specifically addressing this modality and provides relevant information on its use in real-world clinical practice. However, this greater utilization should not be interpreted as evidence of superiority over electrocautery, since treatment selection was not randomized and baseline patient and lesion characteristics may have influenced the choice of treatment (3, 4, 27).

Recurrence-free survival decreased from 92.9% at 3 months to 59.4% at 24 months. The subsequent need for surgery in 16.7% of patients who experienced recurrence and for tracheostomy in 8.8% demonstrates that a proportion of patients may progress from an initially endoscopic approach to more invasive strategies. This pattern is consistent with studies showing that endoscopic treatment may be effective as an initial or bridging strategy, whereas surgery may provide greater durability in appropriately selected patients (3, 4, 25, 27). A meta-analysis including eight studies and 1,627 patients found a lower recurrence rate after open surgical treatment compared with endoscopic interventions; however, the authors noted that this difference was not consistent across all subgroups and that interpretation should account for differences in the anatomical and clinical characteristics of patients undergoing each strategy [27]. Management should therefore be individualized and multidisciplinary, considering anatomical complexity, the presence of malacia, and recurrence risk from the outset when defining the therapeutic strategy and follow-up approach.

Limitations

The limitations of this study include its retrospective observational design based on electronic clinical records, which may result in missing information, heterogeneity in the quality of documentation, and residual confounding from unmeasured variables, thereby limiting the generalizability of the findings to other healthcare settings. Additionally, the relatively low number of events during follow-up reduces statistical power and the precision of the estimates, as reflected by the wide confidence intervals. Finally,

no imputation of missing data was performed, and analyses were based on records with available data, an approach that may reduce efficiency and introduce bias if missingness was not random. Therefore, these findings should be interpreted cautiously and corroborated in prospective, multicenter studies with standardized collection of covariates and, when feasible, specific and adjudicated outcomes.

Conclusion

In patients with ETB treated with endoscopic intervention, recurrence progressively increased during follow-up, reaching 41.6% at 24 months, with a recurrence-free survival of 59.4%. The presence of malacia and greater stenosis complexity were associated with lower recurrence-free survival. Among patients who experienced recurrence, some required additional interventions, including stent placement, tracheostomy, or open surgery.

Declarations

Authors' contributions

JEH, JAEF, JTA and ETQ contributed substantially to the study design, data analysis and interpretation, and manuscript writing. JEH and ETQ had full access to all study data and takes responsibility for data integrity as well as for accuracy of the included data analysis and, especially, any adverse effects. All authors read and approved the final manuscript.

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Data availability: The data supporting our findings are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was conducted in accordance with the principles of the current Helsinki Declaration, as well as local, regional, and international regulations pertaining to clinical research, including Colombian Law on Biomedical Research. Ethical approval was obtained from the Medical Ethics Committee of the Clínica de Alta Tecnología Oncólogos del Occidente (approval number 202601). Prior to participating in the study, all participants provided written informed consent, and the confidentiality of their data was strictly maintained throughout the study.

Consent for publication: Not applicable

Competing interests: The authors declare that there are no competing interests associated with the manuscript.

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Figures

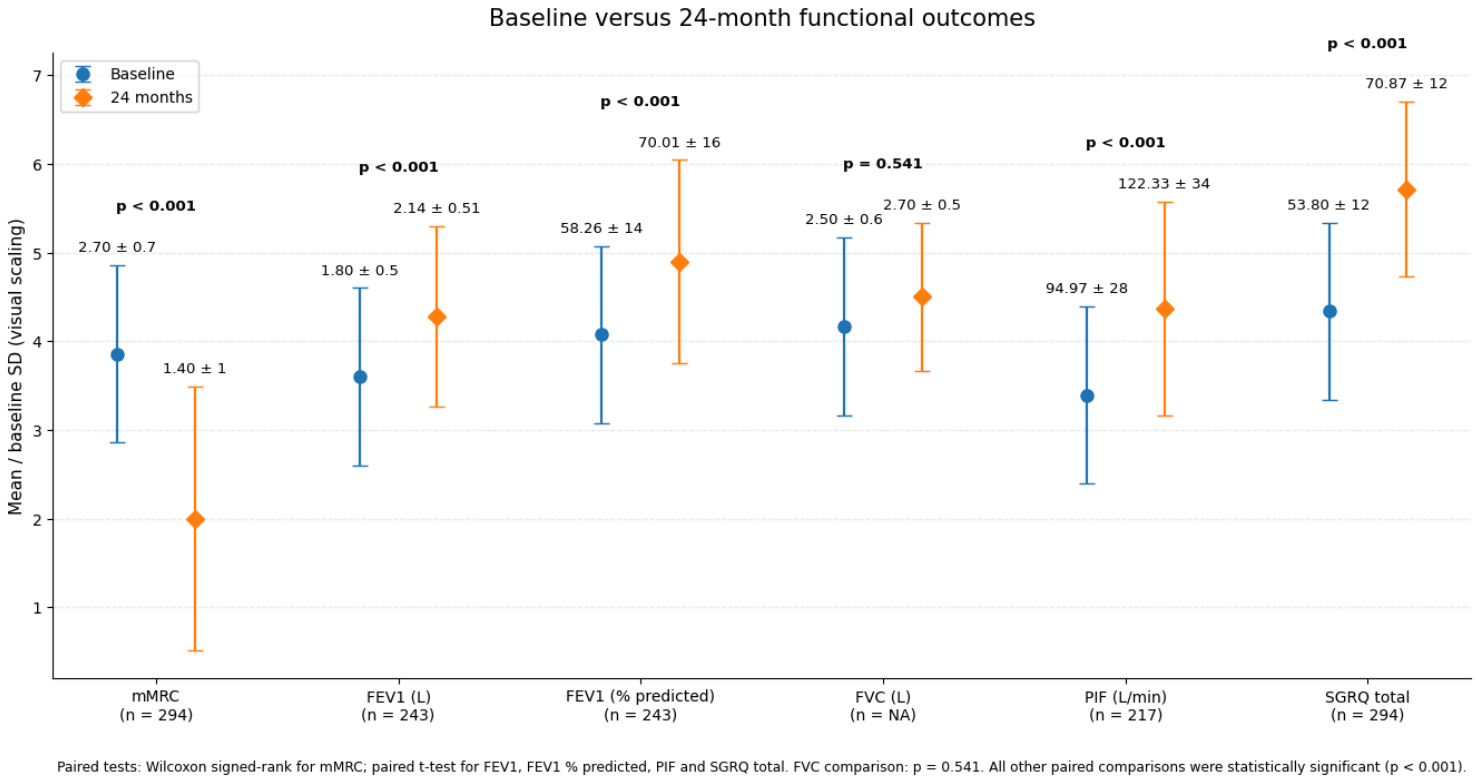


Figure 1

Functional outcomes at 24-month follow-up.

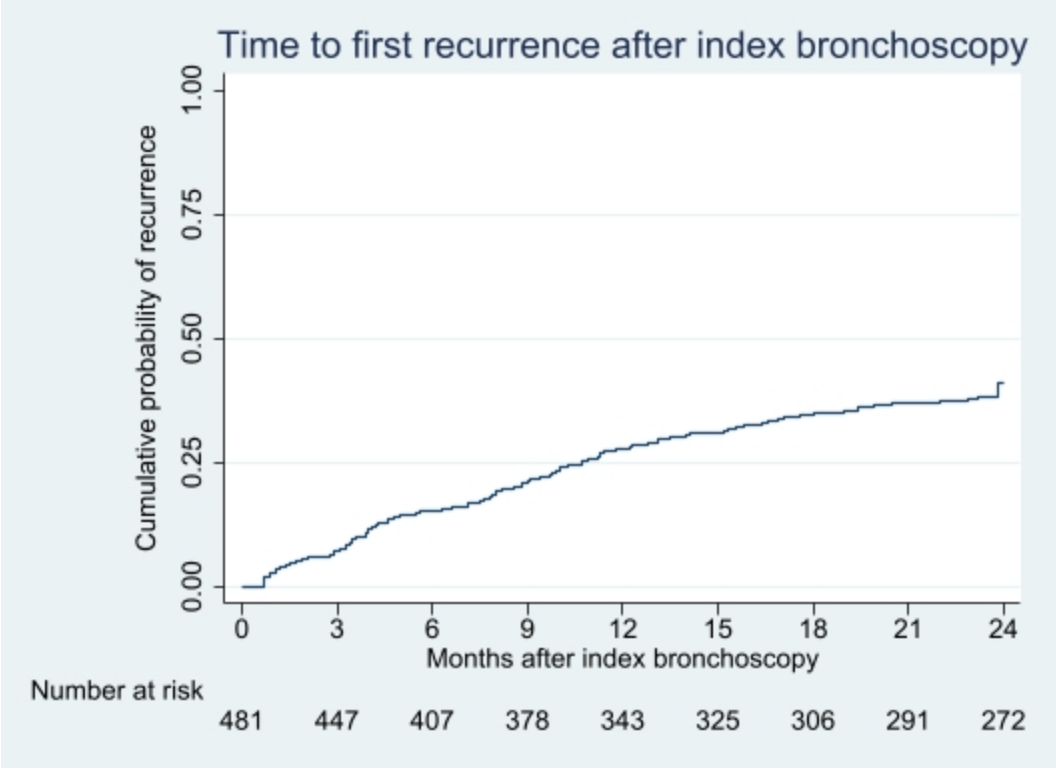


Figure 2

Overall survival.

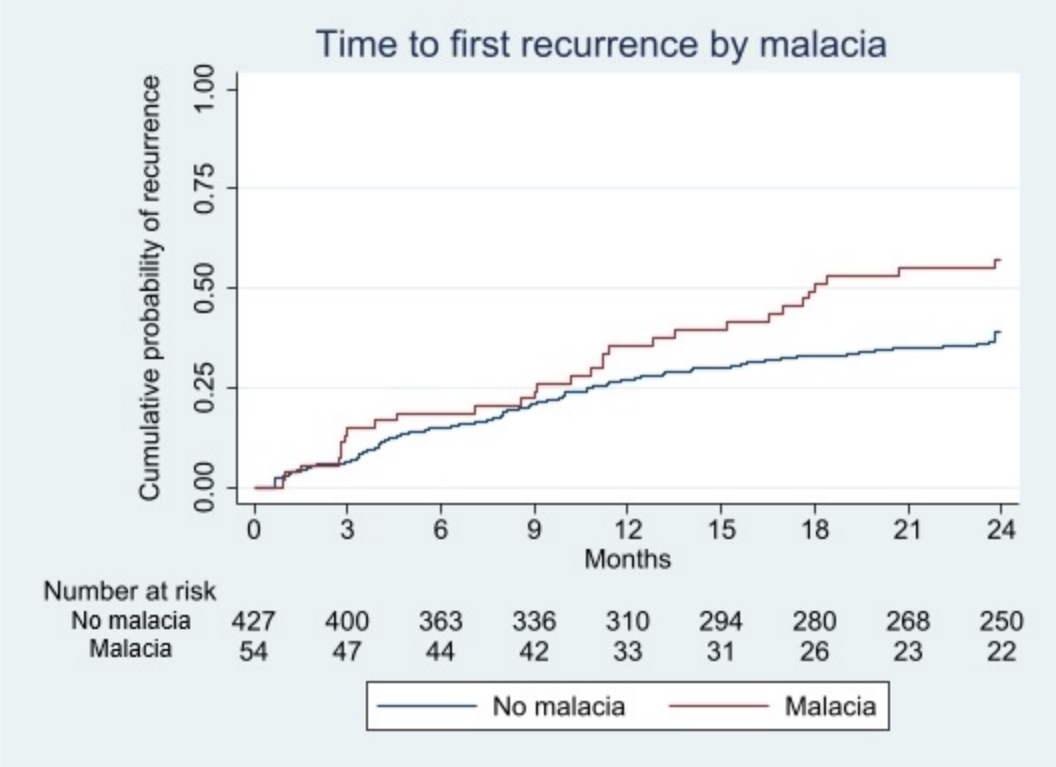


Figure 3

Survival by malacia

*log rank test 0.011.

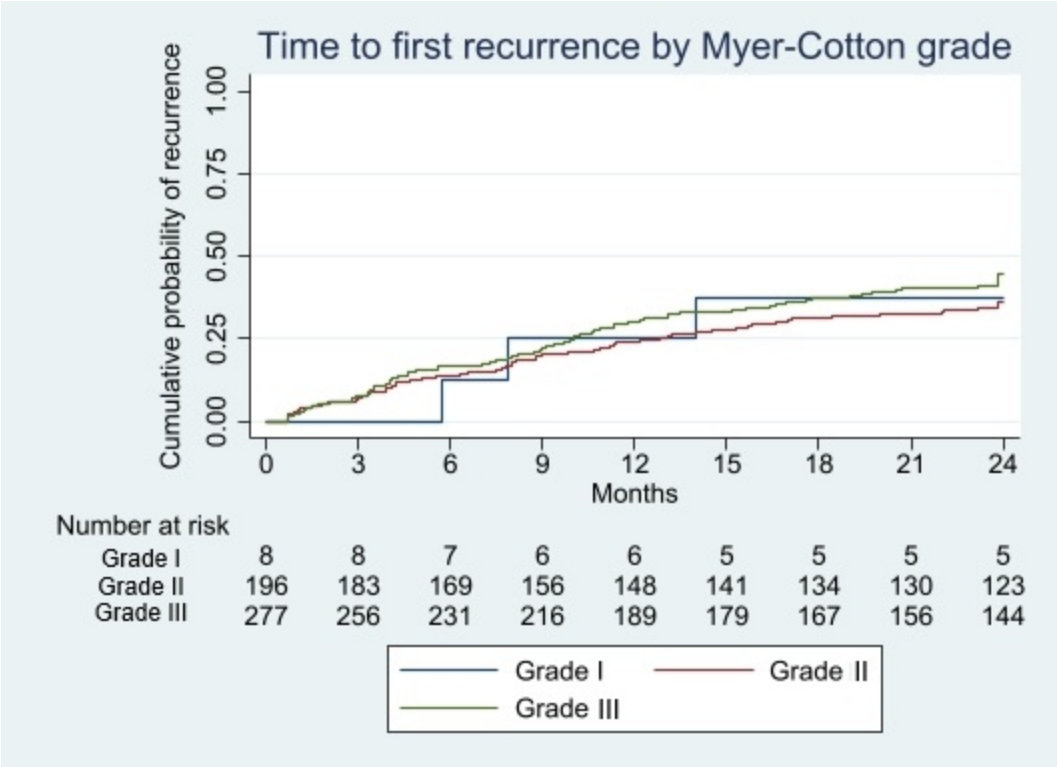


Figure 4

Survival according to stenosis complexity.

*log rank test <0.001.

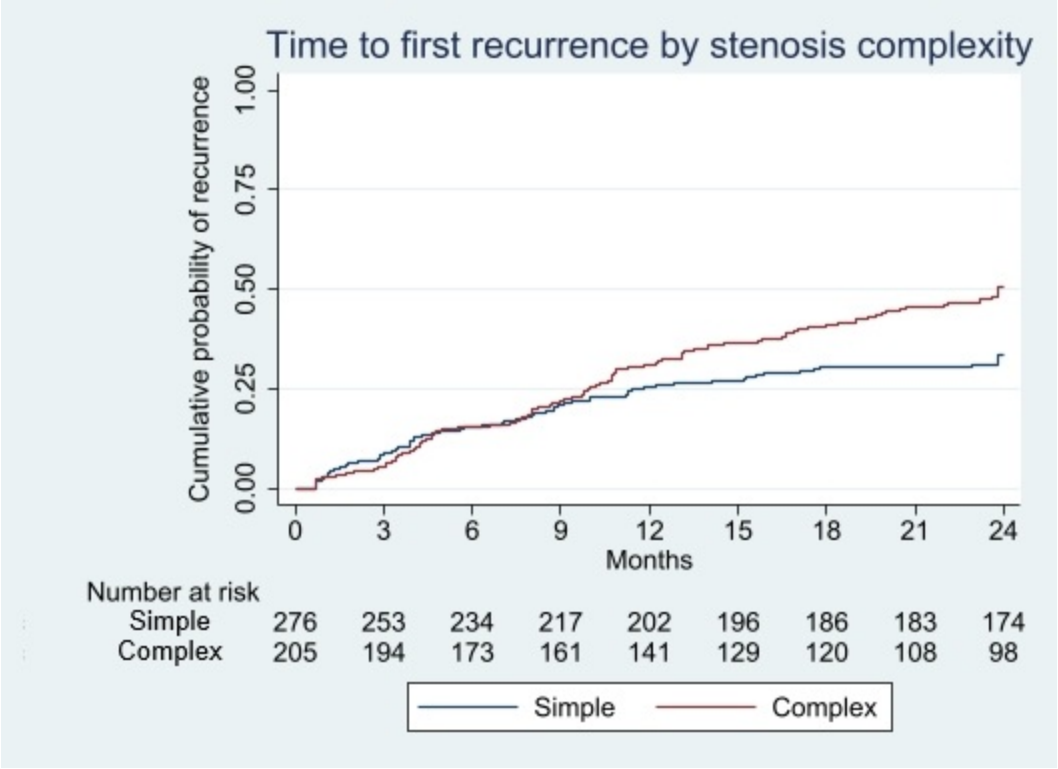


Figure 5

Survival by Myer-Cotton

*log rank test 0.293.