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Stricture classification of pediatric esophageal strictures (SCOPES): A novel tool to predict response to endoscopic therapy

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Abstract
Objectives: Esophageal anastomotic stricture is a common complication following esophageal atresia (EA) repair. While multiple endoscopic therapies exist, predicting individual stricture response remains challenging. Existing classification systems focus primarily on luminal diameter and do not account for complex physical characteristics of the stricture. We developed and evaluated a novel endoscopic scoring tool, stricture classification of pediatric esophageal strictures (SCOPES), to determine if physical features are predictive of treatment response. In addition to its predictive utility, SCOPES aims to standardize the description of and improve communication of stricture morphology across providers and institutions.
Methods: A retrospective cohort study was conducted on EA patients treated at a tertiary referral center between 2019 and 2024. Patients with ≥2 endoscopies and documented SCOPES scores were included. The SCOPES tool categorizes strictures based on diameter, length, scar band intrusion, symmetry, and presence of diverticula. Multivariable mixed-effects regression models were used to analyze associations between SCOPES characteristics and the primary outcome of number of therapeutic endoscopies within 6 months.
Results: Seventy patients (238 endoscopies) met inclusion criteria. In multivariable analysis, symmetric strictures and those with highly intrusive scar bands were significantly associated with a greater number of therapeutic endoscopies within 6 months. Two complications were observed, both managed without long-term sequelae.
Conclusions: The SCOPES classification tool identifies physical stricture features that significantly influence response to endoscopic therapy. Circumferential symmetry and scar tissue protuberance were associated with higher treatment burden, suggesting these characteristics may guide therapeutic decision-making. SCOPES may aid in individualizing endoscopic management of pediatric esophageal strictures and warrants prospective validation.

KEYWORDS
anastomotic narrowing, balloon dilation, interventional endoscopy, risk stratification, scoring system

1 | INTRODUCTION

Anastomotic stricture following esophageal atresia (EA) repair has been consistently described as the most common cause of esophageal stricture in the pediatric population[1] and is one of the most common complications experienced by children with surgically repaired EA.[2] Common endoscopic therapies for these strictures include dilation, intralesional steroid injection (ISI), use of mitomycin C, stenting, and electrocautery incisional therapy (EIT). However, response of strictures to endoscopic therapies can be unpredictable and many require repetitive endoscopic interventions.[3]

There has been great interest in developing predictive scoring tools that prognosticate the binary outcome of development of stricture requiring any dilation, with several tools previously described purely based on diameter(s) of various segments of the esophagus.[4–8] However, no tool exists to predict behavior of a stricture in response to endoscopic therapy. Existing stricture classification systems do not consider any complex physical features of the stricture such as circumferential asymmetry or scar tissue protuberance

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(Figure 1), which we hypothesize may play a role in response of stricture to endoscopic therapy.

We have developed a novel stricture classification system that considers multiple physical stricture characteristics with the aim of predicting response to endoscopic therapy, using features such as stricture diameter, scar tissue protuberance, association with diverticulum, defined as a prestenotic post-surgical outpouching, and circumferential asymmetry.

In this study, we evaluate the predictive capability of our novel stricture scoring system in a cohort of pediatric anastomotic strictures treated at our international EA referral center. We hypothesize that physical stricture characteristics influence treatment burden following initial endoscopic therapy.

What is Known

- Anastomotic stricture is a common pediatric complication following esophageal atresia repair.
- Stricture response to standard therapeutic interventions is unpredictable.
- Existing stricture classification tools focus solely on diameter and lack predictive capability for therapy response.

What is New

- Our study describes a novel stricture classification tool that considers multiple anatomic stricture characteristics.
- Our study analyzes the predictive capability of this novel stricture classification tool in pediatric anastomotic strictures.

2 | METHODS

2.1 | Ethics statement

This study was approved by the Institutional Review Board (IRB) at Boston Children's Hospital, and all procedures were conducted in accordance with the national ethical standards. Informed consent was obtained from the parents or legal guardians of all individual participants included in the study.

2.2 | Overview and patients

An institutional review board-approved retrospective review of patients with EA treated in the Esophageal and Airway Treatment (EAT) Center at Boston Children's Hospital was performed. Eligibility is determined as follows: for the years 2019 through 2024, any patient with a stricture classification recorded in our prospectively collected database, who has EA, and who has at least two endoscopies at our institution—one endoscopy for initial stricture classification and stricture therapy, and one for follow up for response to endoscopic stricture therapy—were eligible for inclusion in analysis. All strictures included in this study were post-surgical anastomotic strictures related to EA/tracheoesophageal fistula repair. No other etiologies were included. Patients who did not have a follow-up esophagogastroduodenoscopy (EGD) at our institution were excluded. Patients who did not have a documented stricture classification score were excluded (Figure 2).

2.3 | Stricture classification of pediatric esophageal strictures (SCOPES) tool

The SCOPES tool accounts for the following physical characteristics of a stricture as judged by its endoscopic appearance:

- Stricture diameter
- Stricture length
- Degree of scar band intrusion in four quadrants
- Circumferential symmetry
- Presence of diverticular outpouching

The endoscopist scores the stricture at the beginning of every endoscopy before any intervention is performed according to these physical characteristics. Degree of intrusion of the anastomotic scar into the lumen fell into one of the following categories: imperceptible or nearly imperceptible scar band intrusion into the central lumen (A), intrusion into the central lumen greater than imperceptible but smaller than the width of the closed pediatric biopsy forceps (<1.8 mm, B), or intrusion into the central lumen greater than the width of the closed pediatric biopsy forceps (>1.8 mm, C) (Figure 1). Symmetry was defined as an anastomosis with all four quadrants assigned to the same letter category for degree of intrusion of the scar band (e.g., AAAA, BBBB, or CCCC); all other strictures were considered asymmetric. If a stricture was associated with a diverticulum, a "*" was added to the associated quadrant (e.g., AAAA* or AC*BB). See Figure 1 for example classifications. Internal agreement on scoring was ensured by having the four providers involved in performing these procedures review eight sets of example images of strictures and independently rate them. Anastomotic diameter was measured by the endoscopist during each procedure before therapeutic intervention and is recorded in the operative note. Anastomotic inner diameter was measured by using visual benchmarks/references such as the known diameter of the endoscope, and the known widths of open and closed biopsy forceps.[9]

2.4 | Data collection

Data was abstracted by manual review of the medical record and from an endoscopy research database actively maintained by the Boston Children's Hospital Esophageal and Airway Treatment team since August 2019. Recorded data included patient demographics, age at time of procedure, type of atresia, dates of endoscopies, stricture classification (SCOPES) value, number of and time intervals between endoscopic stricture therapies, initial anastomotic stricture diameter, anastomotic stricture diameter measured at follow up endoscopy, types of endoscopic therapies employed (balloon dilation, EIT, ISI), and complications from endoscopy.

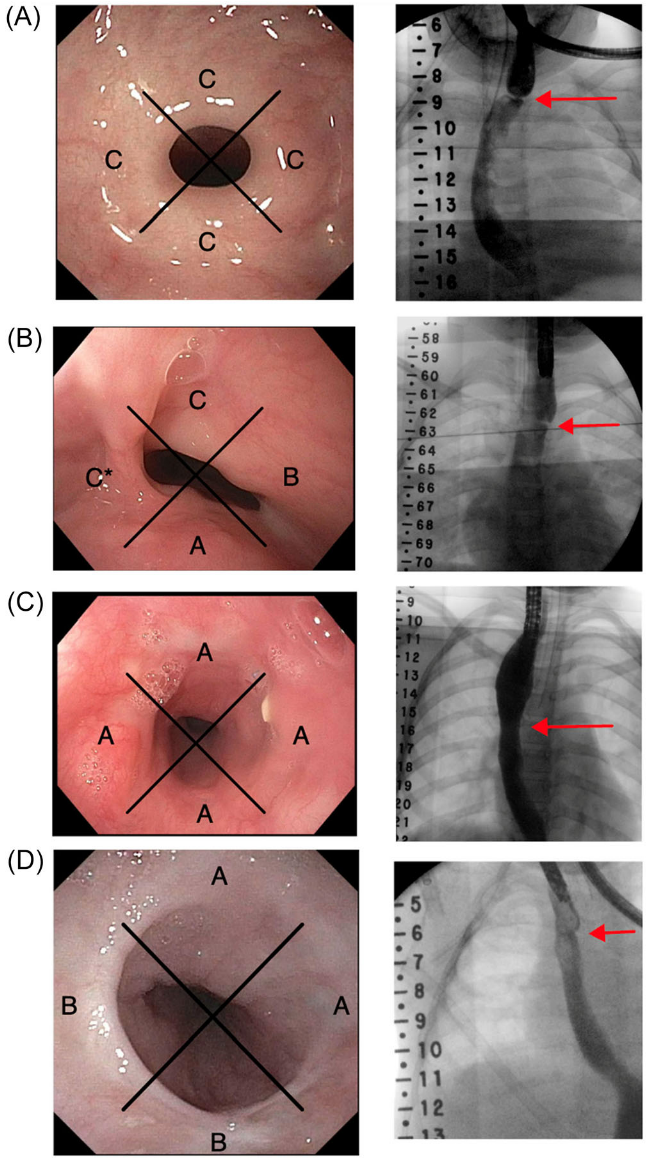

FIGURE 1 Classification of example anastomoses. (A) Symmetric stricture 4 mm diameter × 3 mm in length with significantly intrusive scar band circumferentially (e.g., intrusion exceeding width of a closed biopsy forcep). (B) Asymmetric stricture 15 mm diameter × 5 mm in length with significantly intrusive scar band on left lateral wall seen visually and as a filling defect on left side of anastomosis on fluoroscopic imaging. (C) Symmetric 10 mm diameter × 5 mm in length anastomosis, with no grossly perceptible intrusive scar bands. (D) Asymmetric 8 mm diameter × 2 mm in length anastomosis, with mildly intrusive scar bands (e.g., less intrusive than the width of a closed biopsy forcep) on the left lateral and posterior walls.

2.5 | Total therapies within 6 months of initial therapeutic endoscopy

To assess the relationship between stricture characteristics and treatment outcomes, we used the total number of therapeutic endoscopies a patient received within the first 6 months following the initial procedure as the primary outcome measure. This variable was calculated by summing all therapeutic endoscopies (e.g., balloon dilation, ISI, EIT) performed within 6 months of the initial SCOPES-scored therapeutic endoscopy for each patient. The same value was then assigned to all EGDs associated with that patient to allow for mixed-effects modeling. This measure served as a proxy for treatment burden and was the primary method used to assess the effectiveness of therapeutic maneuvers. Our design intentionally evaluates a defined 6-month therapeutic window, allowing us to compare treatment burden across patients using an outcome that reflects care delivered within a consistent and clinically relevant timeframe.

2.6 | Statistical analyses

Continuous data are presented as medians and interquartile ranges (IQR), and categorical data are presented as frequencies and percentages. In order to evaluate the independent associations between type of therapy, asymmetry, and treatment burden (number of therapeutic endoscopies within 6 months), multivariable mixed-effects regression modeling was implemented in order to account for multiple serial measurements over time within the same patient. A sensitivity analysis was also performed stratified by asymmetry. Mixed-effects median regression was implemented to analyze total therapies within 6 months of initial therapeutic endoscopy as a continuous outcome. Results are presented as adjusted regression coefficients or odds ratios with 95% confidence intervals (CIs) and *p*-values. Stata software (version 18.1, StataCorp LLC) was used for all analyses, and a two-tailed $p < 0.05$ are considered statistically significant.

3 | RESULTS

3.1 | Descriptive analysis

A total of 70 EA patients (33 female) were identified who had at least one SCOPES-scored, therapeutic endoscopy for esophageal anastomotic stricture. 124/238 EGDs had a diagnosis of long gap EA. The 70 patients had 238 total endoscopic evaluations (Table 1).

3.2 | Predictors of therapeutic maneuver effectiveness

To determine if a stricture′s physical characteristics were predictive of effectiveness of therapeutic endoscopic maneuvers (e.g., dilation) used to treat the stricture, mixed-effects linear regression modeling was performed.

Multiple stricture characteristics from the SCOPES scoring system were identified to be significantly predictive of endoscopic treatment outcomes. In multivariable analyses, the stricture′s starting diameter, presence of a significantly intrusive scar band, and degree of symmetry were each significantly associated with outcome of treatment burden as judged by total number of endoscopies required to treat the stricture within the first 6 months (Table 2). More intrusive scar bands required more endoscopic sessions than less intrusive scar bands (coefficient 1.35, 95% CI [0.25, 2.45], $p = 0.017$); symmetric strictures required more endoscopic

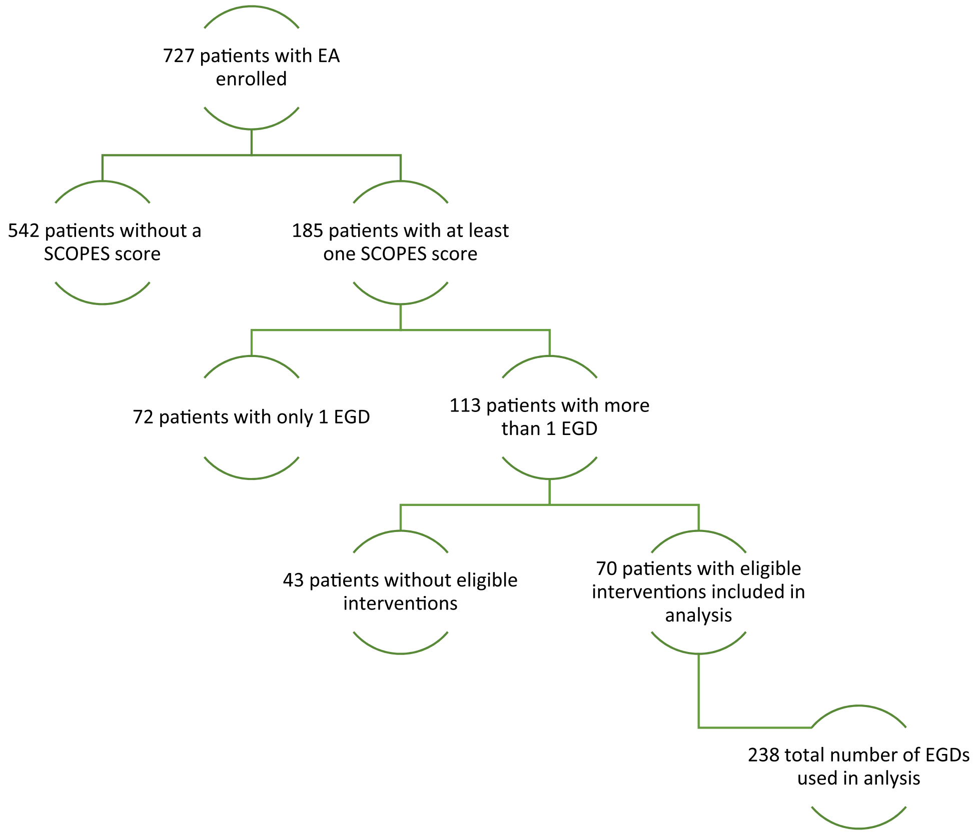

FIGURE 2 Study enrollment. EGD, esophagastroduodenoscopy; SCOPES, stricture classification of pediatric esophageal strictures.

sessions compared to asymmetric strictures (coefficient 1.12, 95% CI [0.11, 2.13], $p = 0.03$).

3.3 | Complications from endoscopy

Two procedures were associated with complications following endoscopy. The first was a contained extra-esophageal leak, managed conservatively with overnight inpatient observation and no intervention; follow-up endoscopy confirmed resolution of the leak. The second was a perforation with free-flowing contrast, for which Esophageal Vacuum-Assisted Closure (EVAC) was placed. Although EVAC was initiated, definitive surgical repair of the perforation was performed 4 days later during a previously scheduled, unrelated thoracotomy that had been planned for surgical management of tracheomalacia.

4 | DISCUSSION

The current study examines the utility of a stricture classification tool (SCOPES) that is applied in real-time during endoscopy. We found that multiple physical stricture characteristics are statistically significantly associated with treatment burden, as measured by total numbers of therapeutic endoscopies required in the first 6 months to treat stricture. The use of such a stricture classification system that accounts for these physical characteristics in real-time decision making for specialists treating esophageal anastomotic stricture has not previously been published. Starting diameter, circumferential symmetry, and scar tissue protuberance were all found to be significantly associated with treatment burden, with some characteristics—such as symmetry—correlating with increased total number of therapeutic endoscopies, and others—such as starting diameter—correlating with decreased total number of therapeutic endoscopies.

There have been multiple prior attempts at developing stricture classification systems that predict whether a child will develop a stricture[5,7] or need at least one dilation for stricture,[6,8] typically based on various fluoroscopically imaged ratios of diameters of the stricture itself and the upper and lower esophageal pouches. There are no stricture classification systems which use endoscopic gross appearance of the stricture as an endoscopist may be expected to encounter in real time during an endoscopy, and no previously described system which prognosticates outcome after dilation. In the current study, we describe use of several readily ascertainable physical characteristics of a stricture including its starting diameter,[10] its circumferential symmetry, and degree of scar intrusion into the esophageal lumen as compared to the width of standard biopsy forceps. Use of a visual reference such as the biopsy forceps has been previously shown to enhance reproducibility and accuracy of esophageal stricture dimension measurements during endoscopy.[9]

Compared to previous stricture classification systems, our system considers multiple physical characteristics of the

TABLE 1 Patient, anastomosis, and stricture characteristics and treatment modalities.

Variable	*n* (%) or median (IQR)
Number of unique patients	70
Age at EGD (months)	13.7 (8.3, 31.1)
Time between EGD (months)	13 (2, 44)
Number of delta diameter measurements	238
# of therapeutic endoscopies prior to initial EGD	1 (0, 4)
Outside hospital EA repair	31/70 (44%)
Type of anastomosis	
Foker growth induction—esophagus to esophagus	86/238 (36.1%)
Stricture resection—esophagus to esophagus	27/238 (11.3%)
Nonspecific esophageal atresia/tracheoesophageal fistula repair	125/238 (52.5%)
Diagnosis long or short gap	
Long gap	124/238 (52.1%)
Short gap	114/238 (47.9%)
Starting stricture length (mm)	5 (3, 8) $n = 226$
Starting diameter (mm)	9 (6, 12)
Balloon dilation stricture treatment	177/238 (74.4%)
Steroid injection and balloon dilation stricture treatment	65/238 (27.3%)
EIT and balloon dilation stricture treatment	46/238 (19.3%)
Significantly intrusive scar band	64/148 (43.2%)
Symmetric	63/148 (42.6%)
Diverticulum association	43/148 (29.1%)

Abbreviations: EA, esophageal atresia; EGD, esophagastroduodenoscopy; EIT, electrocautery incisional therapy; IQR, interquartile range.

anastomosis, including scar tissue protuberance and circumferential symmetry. For many surgical esophageal anastomoses, there can be asymmetry around the circumference and/or scar tissue protuberance at the healed surgical connection which may affect a stricture′s response to mechanical dilation or other endoscopic therapies; the development of such circumferential asymmetry or scar tissue protuberance may be due to multiple factors including how the anastomosis was initially sutured, individual variations in wound healing, effect from previous dilations, and prior history of leak or perforation. We found in the multivariable analysis of the physical characteristics captured in the SCOPES score that symmetric strictures required more therapies within 6 months compared to asymmetric strictures. Similarly, strictures with a highly intrusive scar band also required more therapies within 6 months compared to strictures with less intrusive degrees of scar (Table 2). Symmetry and scar band intrusiveness may play important roles in determining initial outcome as well as durability of the response to dilation therapy due to a number of factors that include plasticity of the scar band tissue and circumferentially uniform distribution of scar tissue, which may respond more favorably to the radial forces applied equally in all directions by mechanical dilators. Starting diameter also demonstrated a significant negative impact on effectiveness of endoscopic therapy, a finding consistent with expectations (Table 2). As the starting diameter of the anastomotic stricture increases, the potential for further enlargement diminishes.

Presence of a diverticulum did not independently predict therapeutic response in our analysis, but we find that this feature remains clinically relevant as pre-stenotic post-surgical diverticula can contribute to dysphagia and may enlarge over time if not addressed. While not predictive of treatment burden, diverticular anatomy remains an important component of endoscopic assessment and may hold clinical significance outside the scope of this study.

While bolstered by relatively large numbers of endoscopies and patients for an overall rare disease, our study is limited by its retrospective and nonrandomized design, which can introduce potential biases in the selection and assessment of patients. We did not assess functional outcomes of therapy such as feeding behavior and tolerance, which are crucial for a comprehensive evaluation of treatment efficacy. Biomechanical metrics obtained through technologies such as EndoFLIP (Medtronic) could provide objective and potentially more sensitive measures of esophageal distensibility; however, these data were not routinely collected during the study period and therefore could not be incorporated into our analysis. Similarly, the degree of balloon waist appreciated on fluoroscopy when performing fluoroscopic wire-guided dilation may serve as an additional indicator of stricture rigidity; however, this variable was not consistently documented across procedures, limiting its inclusion in our study. Although the SCOPES classification system demonstrated reproducibility among the endoscopists involved, it has not yet been separately validated, which could affect the generalizability. Our referral center performs a large number of specialized long-gap EA repairs and stricture resections that have a higher propensity for stricture development than routine primary anastomoses. Thus, our findings may not be generalizable to centers with different case composition. Due to low numbers of observed complications, statistical analysis was unable to be performed to understand if stricture characteristics are associated with likelihood of complication from endoscopic therapeutic maneuvers.

Understanding the impact of readily ascertainable physical features of stricture on that stricture′s behavior can help clinicians predict if and how a stricture will respond to endoscopic dilation and other treatments. We have found that scar tissue protuberance and circumferential symmetry are important characteristics in predicting stricture response to endoscopic therapy. Predictive tools that aid the endoscopist in more accurately prognosticating response to therapy are critical in moving the field toward more personalized and effective treatment strategies for esophageal anastomotic stricture.

TABLE 2 Univariate and multivariable mixed-effects linear regression analysis of total therapies within 6 months.

	Univariate analysis		Multivariable analysis (Model F) ($n = 114$)	
Variable	Coefficient (95% CI)	*p*-value	Adjusted coefficient (95% CI)	*p*-value
Type of anastomosis				
Foker—esophagus to esophagus	Reference		Reference	
Stricture resection—esophagus to esophagus	−0.58 (−1.89, 0.74)	0.388	−0.05 (−1.33, 1.23)	0.939
Nonspecific esophageal atresia/tracheoesophageal fistula repair	−0.46 (−1.21, 0.29)	0.228	0.69 (−0.42, 1.8)	0.221
Starting stricture length	0.05 (−0.07, 0.17)	0.411	−0.02 (−0.14, 0.11)	0.772
Starting diameter	−0.34 (−0.44, −0.25)	<0.001*	−0.3 (−0.45, −0.14)	<0.001*
# of therapeutic endoscopies prior to initial EGD	−0.006 (−0.077, 0.066)	0.879	0.024 (−0.048, 0.096)	0.506
Age at EGD	−0.012 (−0.018, −0.006)	<0.001*	−0.001 (−0.011, 0.009)	0.868
Diagnosis long gap	0.33 (−0.38, 1.04)	0.357	1.18 (0.11, 2.24)	0.03*
Balloon dilation stricture Tx	2.25 (−1.12, 5.61)	0.19	0.32 (−2.47, 3.1)	0.823
Steroid injection stricture Tx	1.16 (0.44, 1.88)	0.002*	−0.04 (−0.89, 0.81)	0.928
Electrocautery incisional therapy stricture Tx	−0.12 (−0.93, 0.69)	0.769	−0.31 (−1.46, 0.84)	0.592
Stricture score				
All A/A*	Reference		Reference	
Contains at least one B/B* without C/C*	−0.87 (−2.01, 0.26)	0.131	0.07 (−1.01, 1.16)	0.892
Contains at least one C/C*	−0.12 (−0.99, 0.74)	0.778	1.35 (0.25, 2.45)	0.017*
Symmetric	1.25 (0.5, 1.99)	0.001*	1.12 (0.11, 2.13)	0.03*
Diverticulum association	−0.54 (−1.37, 0.28)	0.194	0.35 (−0.59, 1.3)	0.459

Note: Mixed-effects modeling was implemented to account for multiple measurements (deltas) per patient with medical record number as a random effect.
Abbreviations: CI, confidence interval; EGD, esophagastroduodenoscopy.
*Statistically significant.

5 | CONCLUSION

In conclusion, the SCOPES classification system's focus on circumferential symmetry and scar tissue protuberance offers valuable insights and can assist endoscopists in guiding their clinical approach and setting expectations for anastomotic stricture treatment. Further large-scale, prospective randomized studies are needed to confirm these findings.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Individual deidentified participant data will be shared upon request and pending IRB approval.

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