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Unlocking the secrets of esophageal motility: how ineffective motility influences dysphagia and LES function following robotic hiatal hernia repair

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Abstract

Background Ineffective Esophageal Motility (IEM) is often identified during preoperative evaluations for anti-reflux surgery (ARS). Concerns regarding postoperative dysphagia may lead to hesitancy in offering surgery to these patients. This study compares postoperative dysphagia rates and lower esophageal sphincter (LES) function in patients with IEM versus those with normal esophageal peristalsis (NIEM).

Methods We conducted a retrospective review of patients who underwent high-resolution manometry and robotic ARS between March 2011 and January 2024. Patients were classified as NIEM or IEM based on manometry, with IEM sub-stratified into non-severe (NSIEM: ≥ 50% to < 70% ineffective swallows) and severe (SIEM: ≥ 70% ineffective swallows). Postoperative dysphagia rates were assessed at 3, 6, and 12 months. LES function was evaluated using endoscopic impedance planimetry (Endo FLIP). Patients requiring reoperation were excluded.

Results A total of 633 patients met inclusion criteria: IEM (n = 97) and NIEM (n = 536). IEM patients were more likely to be male ($p < 0.001$) and less likely to be Hispanic ($p < 0.001$). Dysphagia rates did not differ significantly between groups at any time point. Subgroup analysis of NIEM, NSIEM, and SIEM revealed a significant difference in mild dysphagia at 12 months ($p = 0.041$), associated with preoperative dysphagia. However, the incidence of new-onset dysphagia at 12 months was not impacted by IEM. Preoperatively, IEM patients had larger LES cross-sectional areas (93.46 ± 43.32 vs. 76.7 ± 41.36 mm^2, $p = 0.009$), higher pressure (25.49 ± 35.89 vs. 23.97 ± 8.26 mmHg, $p = 0.009$), and greater distensibility indices (4.78 ± 2.53 vs. 3.63 ± 2.42 mm^2/mmHg, $p < 0.001$). Post-repair, IEM patients showed greater reductions in CSA and distensibility index compared to NIEM patients.

Conclusion Patients with IEM had positive outcomes after ARS, with no significant differences in overall dysphagia rates compared to NIEM. Although mild long-term dysphagia was more common in IEM patients, it appears that these symptoms persist from before the surgery, suggesting that these patients tend to have similar long-term outcomes to patients without IEM.

Keywords Ineffective esophageal motility (IEM) · Anti-reflux surgery (ARS) · Dysphagia · Endo FLIP · Lower esophageal sphincter (LES) function · Hiatal hernia repair

Gastroesophageal reflux disease (GERD) is a common condition impacting many people globally, often diminishing quality of life. Although lifestyle changes and proton pump inhibitors (PPIs) serve as the primary treatments, some patients do not respond to these medical therapies and may need surgical intervention. Anti-reflux surgery (ARS) is considered the gold standard for managing these patients, aimed at restoring the function of the lower esophageal sphincter (LES) to prevent acid reflux [1]. Nonetheless, in those with concurrent esophageal motility disorders like ineffective esophageal motility (IEM), there is caution about using ARS due to concerns about an increased risk of postoperative dysphagia.

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IEM, categorized by the Chicago Classification system, is defined by ineffective peristaltic contractions (distal contractile integral < 450 mmHg) in 50% or more of swallows during high-resolution manometry (HRM), alongside LES relaxation (integrated relaxation pressure [IRP] < 15 mmHg). It may arise from a mix of neural dysfunction (either primary or secondary), muscular dysfunction (possibly due to chronic acid exposure damaging esophageal smooth muscle), or it can be idiopathic with no discernible cause [2, 3]. Clinically, IEM can manifest with typical GERD symptoms, dysphagia, or may even be asymptomatic in otherwise healthy individuals.

IEM is one of the prevalent esophageal motility disorders identified in preoperative assessments for GERD patients, yet its clinical importance is still debated. Some research suggests that IEM may make patients more susceptible to dysphagia following fundoplication, as weakened peristaltic function could hinder esophageal clearance after surgery. Therefore, some surgeons may hesitate to recommend ARS for patients with IEM, worrying that a tighter LES could worsen swallowing challenges. In situations where IEM is diagnosed preoperatively, surgeons might take a modified approach, such as opting for a partial or looser fundoplication, to mitigate the risk of postoperative swallowing difficulties [4–6]. Nevertheless, despite these considerations, the true effect of IEM on post-fundoplication dysphagia remains unclear and requires further exploration.

High-resolution manometry (HRM) is the standard for diagnosing esophageal motility disorders, providing a thorough assessment of peristaltic function [7]. However, HRM does not measure the real-time biomechanical properties of the LES, which are crucial for esophageal function. Endoscopic impedance planimetry (Endo FLIP) is an innovative technique that offers real-time evaluations of LES and esophageal biomechanics, including distensibility, compliance, pressure, and cross-sectional area (CSA). Recent studies suggest that Endo FLIP may offer beneficial intraoperative insights that assist surgical decision-making, particularly for patients with esophageal motility disorders [8, 9]. Nonetheless, its role in preoperative and postoperative LES evaluation in IEM patients undergoing ARS is still largely unexplored.

This study aims to assess postoperative dysphagia rates and changes in LES function in patients with IEM compared to those with normal esophageal motility (NIEM) after ARS. Additionally, we investigate whether the severity of IEM (Severe IEM (SIEM) vs. Non-Severe IEM (NSIEM)) influences dysphagia outcomes, providing valuable insights to inform surgical decisions for GERD patients with coexisting motility disorders.

Materials and methods

A retrospective analysis examined patients who received robotic anti-reflux surgery (ARS) at a single tertiary care center between March 2011 and January 2024. The study was approved by the institutional review board (IRB 19-05020206) and adhered to ethical standards for retrospective clinical research. The cohort consisted of patients undergoing robotic Nissen, Toupet, Dor, and Hill fundoplications, LINX magnetic sphincter augmentation, or transoral incisionless fundoplication (TIF) for medically resistant gastroesophageal reflux disease (GERD). Inclusion criteria mandated that patients had undergone an index ARS with available preoperative high-resolution manometry (HRM), while exclusions comprised those with prior anti-reflux surgeries, bariatric procedures, redo fundoplications, or missing preoperative HRM data. Patients without intraoperative Endo FLIP assessments or those with unsuccessful Endo FLIP measurements due to technical issues were also excluded from the sub-analysis.

Data on demographics and perioperative details were gathered from electronic medical records, including age, sex, ethnicity, race, body mass index (BMI), and comorbidities such as diabetes, hypertension, and coronary artery disease. Preoperative diagnostic tests included upper endoscopy, barium esophagram, HRM, 48-h BRAVO pH monitoring (Medtronic, Minneapolis, USA), and gastric emptying studies where clinically relevant. Patients were categorized into two primary cohorts based on preoperative HRM results: those with normal esophageal peristalsis (NIEM) and those with ineffective esophageal motility (IEM). The IEM group was further divided into two subcategories: SIEM, indicating ≥ 70% ineffective swallows with a normal integrated relaxation pressure (IRP), and NSIEM, indicating 50% to 70% ineffective swallows with a normal IRP.

Preoperative symptom profiles were categorized into typical GERD symptoms—such as regurgitation and heartburn—and atypical GERD symptoms, which included chronic cough, throat clearing, hoarseness, and chest pain. The severity of dysphagia was assessed using a validated scoring system.

Surgical technique

All robotic anti-reflux surgeries were conducted by a single fellowship-trained minimally invasive foregut surgeon at Weill Cornell Medical College/New York-Presbyterian Medical Center in New York, NY. The procedures utilized the da Vinci robotic platform (Intuitive Surgical Inc., Sunnyvale, CA) and adhered to established techniques [10,

11]. Patients were positioned in a 30-degree reverse Trendelenburg position, with five working ports inserted 13 cm below the xiphoid process in a linear arrangement. A Genzyme liver retractor elevated the liver, and intra-abdominal insufflation was consistently maintained at 10 mmHg throughout the procedure.

Surgical dissection commenced with the division of the gastrohepatic ligament, followed by the identification and mobilization of the right and left crura. The short gastric vessels were divided up to the angle of His, facilitating complete mobilization of the esophagus. The esophagus and vagus nerves were encircled using a Penrose drain, continuing dissection until a tension-free intra-abdominal esophageal length of 3–5 cm was achieved. The hiatal defect was subsequently closed posteriorly with a 3–0 V-Loc running suture, reinforced with interrupted 3–0 silk sutures as needed.

Mesh reinforcement was selectively applied using Phasix ST®, particularly in patients with large hiatal hernias or compromised diaphragmatic tissue integrity. In instances of significant esophageal shortening, Collis gastroplasty was performed to attain sufficient intra-abdominal esophageal length. Relaxing incisions were made as necessary to enable a tension-free hiatal closure. The type of fundoplication performed (Nissen, Toupet, Dor, Hill, LINX, or TIF) was determined by preoperative discussion with patients and was not modified intraoperatively.

Flip planimetry

In this dataset, a subgroup of patients (n = 299; IEM n = 56, NIEM n = 243) underwent Endo FLIP assessment, analyzed using FLIP-Analytic software (Crospon, Galway, Ireland). Endo FLIP employs a flexible catheter equipped with 16 impedance planimetry sensors contained within a compliant balloon. Once placed under endoscopic guidance, the balloon is filled with fluid to evaluate intra-balloon pressure, diameter, and distensibility index (DI) at the gastroesophageal junction. Our Endo FLIP technique has been detailed in earlier publications [8, 12]. All measurements were taken at 10 mmHg intra-abdominal insufflation with 30 mL of fluid in the balloon while patients were positioned at a 30° reverse Trendelenburg. The parameters recorded pre-procedure/post-induction and after fundoplication included cross-sectional area (CSA) (mm^2), intra-balloon pressure (mmHg), high-pressure zone length (HPZ) (cm), distensibility index (DI) (mm^2/mmHg), and minimum diameter (mm).

Post-operative follow-up

Postoperative dysphagia was evaluated using the Bazaz dysphagia score, a recognized method for measuring swallowing function both before and after ARS [13]. This scoring framework classifies the severity of dysphagia as follows: 0 (no dysphagia with liquids or solids), 1 (mild dysphagia—no trouble swallowing liquids, occasional difficulties with solids), 2 (moderate dysphagia—rare issues with liquids, some difficulty with specific solid foods), and 3 (severe dysphagia—minimal difficulty with liquids, frequent problems with solids). Clinical records, which included patient-reported symptoms and dietary tolerance, were reviewed to validate these scores. Dysphagia outcomes were assessed at 3 months, 6 months, and over 12 months post-surgery to monitor symptom progression. Dysphagia resolution was identified as a postoperative Bazaz score of 0 in patients who experienced dysphagia before surgery. Persistent dysphagia was described as preoperative dysphagia continuing postoperatively, regardless of its severity. Specifically, persistent mild dysphagia was defined as patients who reported mild dysphagia (Bazaz score = 1) preoperatively and continued to report mild dysphagia at the 12-month follow-up, with no change in symptom severity. The same validated Bazaz scale was used pre- and postoperative assessments, allowing for consistent symptom grading across time points. New-onset or worsening dysphagia refers to cases where dysphagia was not present before surgery but emerged afterward, or when existing dysphagia intensified after the procedure. Considering the variability in postoperative dysphagia presentations, we analyzed symptom progression over time to understand if early postoperative dysphagia ameliorated or continued. Dysphagia outcomes were compared among NIEM, NSIEM, and SIEM patients to assess if preoperative esophageal motility dysfunction impacted swallowing after fundoplication function.

Statistical analysis

Statistical analyses were conducted using GraphPad Prism Version 10.3.0 (461). Continuous variables were presented as mean ± standard deviation (SD) or median with interquartile range (IQR), while categorical variables were shown as counts (percentages). For data that followed a normal distribution, paired t tests were utilized, whereas non-normally distributed data were evaluated with the Mann–Whitney test. Categorical variables were analyzed using Pearson's chi-square test or Fisher's exact test. Univariate analyses were used to compare demographic, clinical, intraoperative, and postoperative outcomes between motility subgroups. Statistical significance was set at an alpha level 0.05, with p values less than 0.05 deemed significant.

Results

Patient selection and demographics

A total of 633 patients met the inclusion criteria and underwent robotic ARS from March 2011 to January 2024. A flow diagram of patient inclusion and exclusion is presented in Fig. 1. Among them, 536 patients (84.7%) were categorized as NIEM, while 97 patients (15.3%) were identified as IEM. Within the IEM group, 46 patients (47.4%) fell under NSIEM, and 51 patients (52.6%) were classified as SIEM, based on preoperative HRM findings. The mean percentage of ineffective swallows was recorded at 9.6% for NIEM patients, 54.9% for NSIEM patients, and 80% for SIEM patients (Fig. 2).

Baseline demographic and clinical characteristics largely mirrored each other between groups; however, notable differences were evident. IEM patients were considerably more likely to be male (54.6% vs. 33.8%, $p < 0.001$) and less likely to be Hispanic (2.1% vs. 20.7%, $p < 0.001$) compared to NIEM patients. No significant differences were observed in other demographic aspects such as age, body mass index (BMI), smoking status, or significant comorbidities (Table 1).

Preoperative evaluations were routinely conducted for all patients, which included barium esophagram, HRM, upper endoscopy, and pH testing when clinically justified. Every patient had a barium esophagram; 48 h BRAVO pH testing was carried out in 453 patients, gastric emptying studies were done in 215 patients, and upper endoscopy was performed on 436 patients.

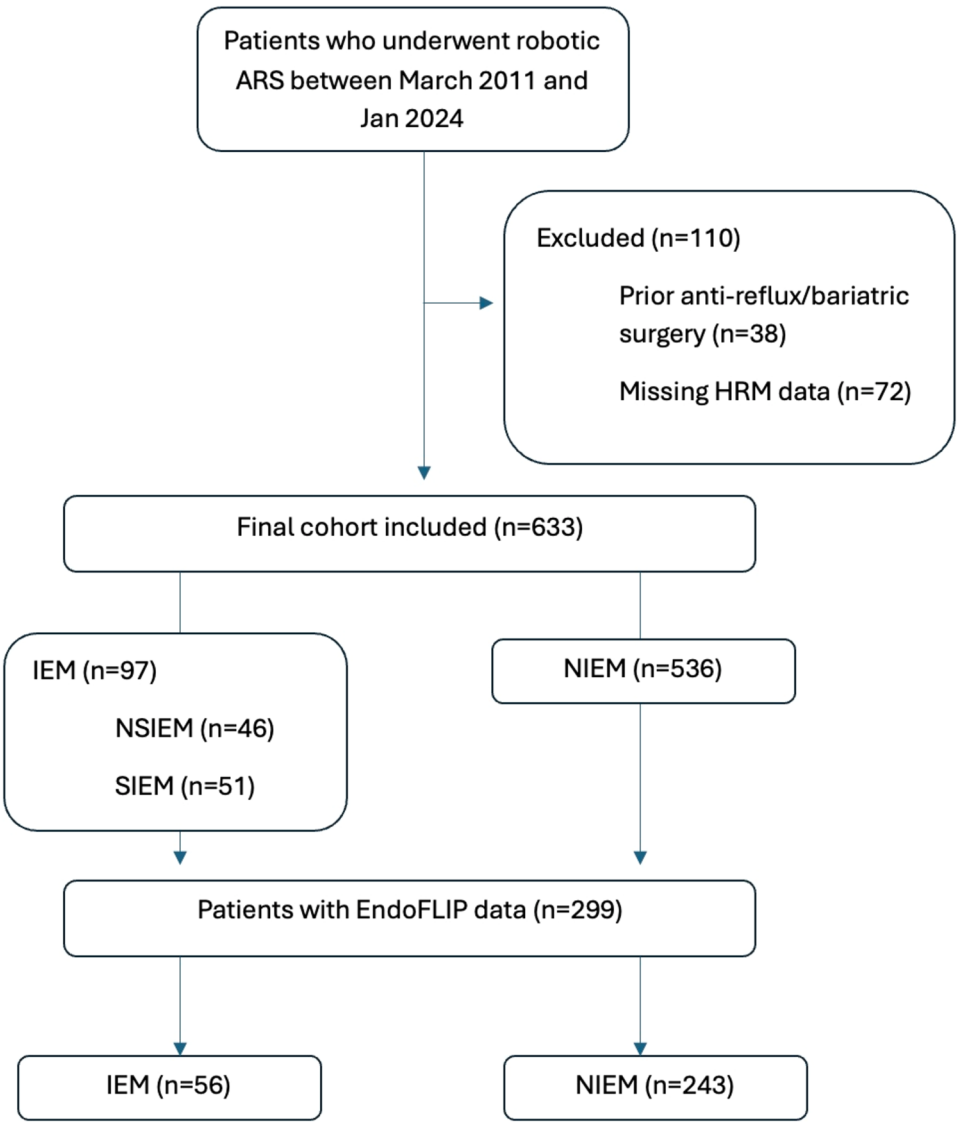

Fig. 1 CONSORT-style flow diagram showing inclusion and exclusion of patients and stratification by esophageal motility status and Endo FLIP assessment

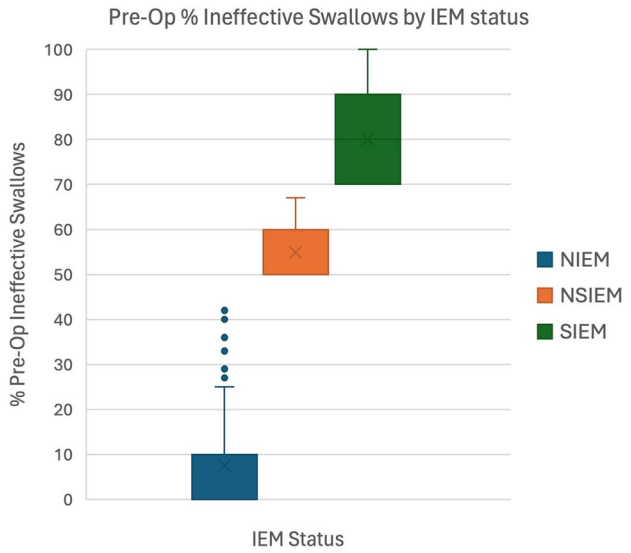

Fig. 2 Preoperative percentage of ineffective swallows across IEM, NSIEM, and NIEM groups

In assessing objective GERD severity and esophageal function, IEM patients exhibited a higher rate of symptom correlation in BRAVO pH testing (76.9% vs. 65.8%, p = 0.047) and were more likely to have erosive esophagitis discovered during upper endoscopy (68.4% vs. 45.8%, p = 0.0004). These results indicate that, despite their motility dysfunction, IEM patients presented objective evidence of reflux-related disease severity on par with NIEM patients.

Intraoperative variables, including the type of fundoplication carried out, did not show significant differences between the groups. The patients underwent various ARS procedures, such as Nissen, Toupet, Dor, Hill, LINX, and transoral incisionless fundoplication (TIF), with no statistically significant differences in procedure type based on esophageal motility status. Operative duration and mesh utilization were comparable between the two cohorts (Table 2).

Table 1 Pre-operative characteristics

	IEM (*n* = 97)	Non-IEM (*n* = 536)	*p* value
Age (years)	51.58 ± 16.74	53.33 ± 15.71	0.332
Female (%)	44 (45.36)	355 (66.23)	**< 0.001**
Race/ethnicity n (%)			
White	68 (70.1)	368 (68.66)	0.813
African American	10 (10.31)	98 (18.3)	0.057
Asian	1 (1.03)	10 (1.87)	> 0.99
Hispanic	2 (2.06)	57 (10.6)	**< 0.001**
Body mass index (Kg/m^2)	27.11 ± 4.88	28.17 ± 6.54	0.134
Comorbidities n (%)			
Diabetes	11 (11.34)	105 (19.59)	0.063
Hypertension	24 (24.74)	208 (38.81)	0.651
Coronary artery disease	8 (8.25)	26 (4.85)	0.216
Pre-operative symptoms n (%)			
Heartburn	66 (68)	368 (68.7)	0.906
Regurgitation	59 (60.8)	290 (54.1)	0.271
Bloat/gas	26 (26.8)	127 (23.69)	0.524
Atypical	44 (45.36)	272 (50.75)	0.381
GERD-HQRL	36.32 ± 18.41	32.42 ± 18.12	0.246
Dysphagia, n = 623	n = 96	n = 527	
Presence	46 (47.92)	258 (48.96)	0.912
Mild	12 (12.5)	61 (11.57)	0.733
Moderate	18 (18.75)	68 (12.9)	0.147
Severe	16 (16.67)	129 (24.48)	0.115

Bold values represent results that are statistically significant

Values are presented as n (%) and mean ± SD

GERD-HQRL Gastroesophageal reflux disease—health-related quality of life

Table 2 Peri- and intra-operative characteristics

	IEM (*n* = 97)	Non-IEM (*n* = 536)	*p* value
Barium swallow			
Delayed food	12 (12.37)	104 (19.4)	0.063
Emptying			
Hiatal hernia size (cm)	4.163 ± 2.437	5.841 ± 2.841	0.222
Dysmotility	33 (34)	211 (39.4)	0.365
BRAVO findings n = 453	n = 78	n = 375	
DeMeester score	41.9 ± 37.93	37.08 ± 32.83	0.214
Symptom correlation	60 (76.92)	243 (64.8)	**0.047**
Gastric emptying n = 215	*n* = 24	*n* = 191	
Abnormal	8 (33.33)	91 (47.64)	0.201
Upper endoscopy n = 436	*n* = 76	*n* = 360	
Erosive esophagitis	52 (68.42)	165 (45.83)	**< 0.001**
Intra-operative characteristics			
Fundoplication type n (%)			
Toupet	53 (54.6)	274 (51.11)	0.324
Nissen	33 (34)	161 (30.03)	> 0.99
Hill	7 (7.22)	60 (11.12)	0.166
LINX	3 (3)	30 (5.5)	0.456
Dor	0 (–)	3 (0.6)	> 0.99
TIF	1 (1)	8 (1.5)	> 0.99
Mesh use	60 (61.9)	346 (64.5)	0.642
Operative time (mins)	126.4 ± 48.71	119.9 ± 30.92	0.410

Bold values represent results that are statistically significant

Values are presented as n (%) and mean ± SD

TIF transoral incisionless fundoplication

Table 3 Endo FLIP parameters at different time points

	IEM ($n=56$)	Non-IEM ($n=243$)	p value
Pre-repair			
Cross-sectional area (mm^2)	93.46 ± 43.32	76.7 ± 41.36	**0.009**
Pressure (mmHg)	25.49 ± 35.89	23.97 ± 8.262	**0.009**
High-pressure zone length (cm)	1.44 ± 0.8107	1.72 ± 0.9162	0.054
Distensibility index (mm^2/mmHg)	4.78 ± 2.53	3.63 ± 2.42	**< 0.001**
Minimum diameter (mm)	10.63 ± 2.538	9.55 ± 2.638	**0.011**
Post-fundoplication			
Cross-sectional area (mm^2)	44.26 ± 23.2	42.88 ± 20.41	0.881
Pressure (mmHg)	37.4 ± 35.83	34.31 ± 11.34	0.186
High-pressure zone length (cm)	3.15 ± 0.8905	3.17 ± 0.8349	0.799
Distensibility index (mm^2/mmHg)	1.43 ± 0.9196	1.31 ± 0.8052	0.222
Minimum diameter (mm)	7.2 ± 1.861	7.18 ± 1.677	0.926
Change			
Cross-sectional area (mm^2)	51.57 ± 42.61	33.8 ± 39.89	**0.008**
Pressure (mmHg)	− 9.92 ± 10.66	− 10.3 ± 11.31	0.516
High-pressure zone length (cm)	− 1.47 ± 1.33	− 1.42 ± 1.061	0.413
Distensibility index (mm^2/mmHg)	3.43 ± 2.323	2.32 ± 2.318	**< 0.001**
Minimum diameter (mm)	3.74 ± 2.984	2.4 ± 2.707	**0.007**

Bold values represent results that are statistically significant

Values are presented as mean ± standard deviation

Flip planimetry findings

Endo FLIP measurements were analyzed intraoperatively for both groups, with pre-repair and post-fundoplication (post-repair) measurements for both IEM and NIEM patients (Table 3). Pre-repair, IEM patients showed significantly higher values in cross-sectional area (CSA) (93.46 ± 43.32 mm^2 vs. 76.7 ± 41.36 mm^2, p = 0.009), distensibility index (DI) (4.78 ± 2.53 mm^2/mmHg vs. 3.63 ± 2.42 mm^2/mmHg, p < 0.001), minimum diameter (10.63 ± 2.54 mm vs. 9.55 ± 2.64 mm, p = 0.011), and intra-balloon pressure (25.49 ± 35.89 mmHg vs. 23.97 ± 8.26 mmHg, p = 0.009). Meanwhile, there was no significant difference in high-pressure zone (HPZ) length between the groups (1.44 ± 0.81 cm vs. 1.72 ± 0.92 cm, p = 0.054).

Endo FLIP parameters (including CSA, DI, minimum diameter, pressure, and HPZ length) did not significantly differ between IEM and non-IEM patients at the post-repair time point. However, when assessing the change from pre- to post- repair, IEM patients exhibited significantly greater reductions in CSA (51.57 ± 42.61 mm^2 vs. 33.8 ± 39.89 mm^2, p = 0.008), DI (3.43 ± 2.32 mm^2/mmHg vs. 2.32 ± 2.32 mm^2/mmHg, p < 0.001), and minimum diameter (3.74 ± 2.98 mm vs. 2.4 ± 2.71 mm, p = 0.007). The intra-balloon pressure and HPZ length changes from pre-repair to post-repair evaluations were not statistically significant in either cohort (Fig. 3).

Gastroesophageal symptoms and dysphagia outcomes

Preoperatively, the occurrence of typical and atypical GERD symptoms, along with dysphagia severity, was similar across all cohorts (Table 1). There were no notable differences in the occurrence of heartburn, regurgitation, or atypical symptoms between NIEM and IEM patients. Likewise, baseline dysphagia severity showed no significant variation between groups. Follow-up data were available for 35 IEM, 39 NSIEM, and 289 NIEM patients at 3 months; 19 IEM, 24 NSIEM, and 191 NIEM patients at 6 months; and 9 IEM, 9 NSIEM, and 118 NIEM patients at 12 months. These sample sizes are reflected in Table 4.

Postoperatively, the occurrence and severity of dysphagia continued to be comparable among the groups (NIEM, NSIEM, and IEM patients) at 3 and 6 months. However, at 12 months, subgroup analysis indicated a statistically significant difference in the prevalence of mild dysphagia among NIEM, NSIEM, and SIEM patients (p = 0.041) (Table 4). Furthermore, persistent mild dysphagia, characterized by symptoms that were mild preoperatively and remained so postoperatively, also exhibited significant differences between the groups (p = 0.024). In contrast, the rate of new-onset dysphagia at 12 months showed no significant differences between the three cohorts. (Fig. 4).

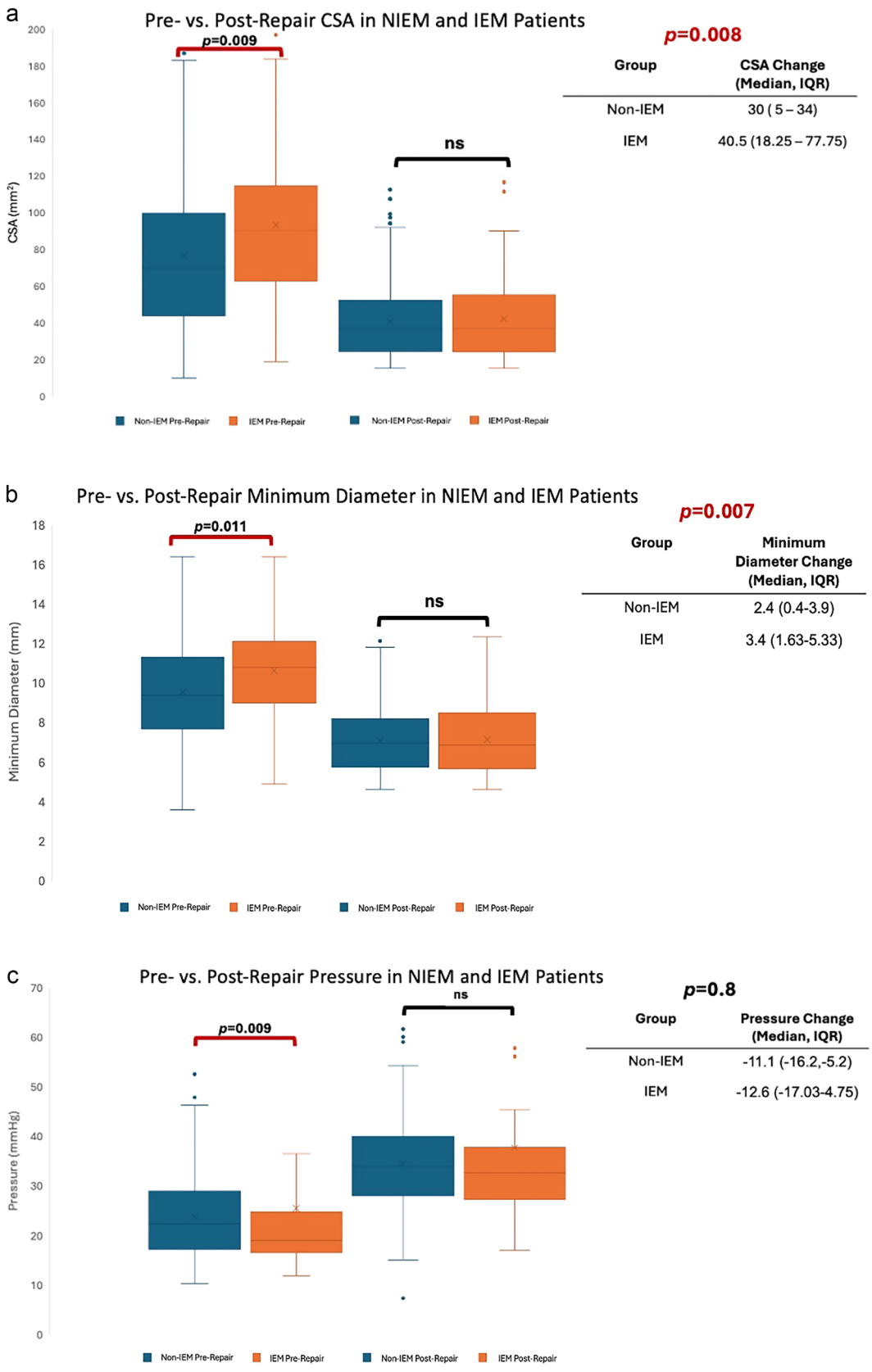

Fig. 3 Changes in endo FLIP parameters, including **a** cross sectional area, **b** minimum diameter, **c** pressure, **d** distensibility index, **e** high pressure zone, from pre- to post-repair time points in IEM and non-IEM patients

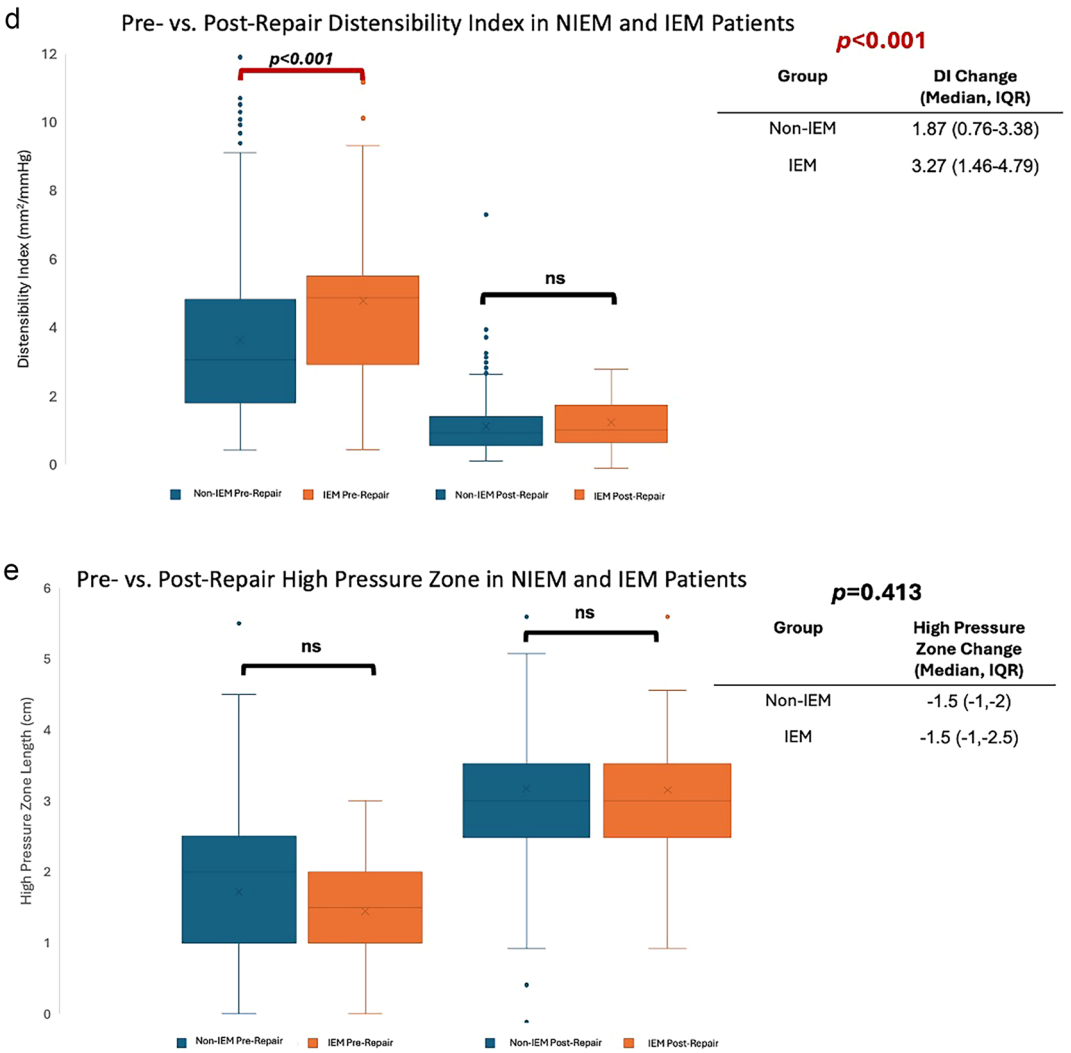

Fig. 3 (continued)

Discussion

ARS continues to be the primary surgical option for GERD in patients who experience ongoing symptoms despite medical treatment. Nonetheless, the occurrence of IEM has caused worries about the risk of postoperative dysphagia, making some doctors reluctant to suggest surgery for these patients. This study aimed to assess whether IEM status affects dysphagia outcomes after fundoplication and to explore how the severity of IEM impacts these results. We also sought to evaluate the initial LES function in patients with IEM compared to those without Endo FLIP and to analyze anticipated changes in LES post-surgery. Our results show that although IEM patients demonstrate unique changes in LES biomechanics after ARS, neither the presence nor severity of IEM significantly affects dysphagia outcomes post-surgery. These findings imply that IEM should not prevent patients from undergoing ARS and emphasize the potential of Endo FLIP in enhancing surgical decision-making.

Our analysis showed that IEM patients displayed considerably higher intraoperative pre-repair Endo FLIP measurements for CSA, DI, pressure, and minimum diameter than NIEM patients, indicating a more flexible and compliant sphincter. While post-repair, IEM patients exhibited more substantial reductions in CSA, DI, and minimum diameter, reflecting a more significant constricting effect on the gastroesophageal junction post-ARS. Importantly, all post-repair LES function metrics were similar between IEM and NIEM patients, indicating that ARS effectively normalizes LES function in those with IEM. While our study demonstrated significant reductions in DI post-fundoplication, it is noteworthy that the mean post-repair DI values for both IEM and non-IEM patients were below the thresholds

Table 4 Post-operative dysphagia outcomes

3-months post-op, n (%)	Severe IEM ($n=35$)	Non-severe IEM ($n=39$)	Non-IEM ($n=289$)	p value
Presence	11 (31.4)	12 (30.7)	102 (35.3)	0.827
Mild	7 (20)	8 (20.5)	74 (25.6)	0.701
Moderate	2 (5.7)	2 (5.1)	18 (6.2)	0.785
Severe	2 (5.7)	2 (5.1)	10 (3.5)	0.404
6 months post-op, n (%)	Severe IEM ($n=19$)	Non-Severe IEM ($n=24$)	Non-IEM ($n=191$)	p value
Presence	4 (21)	7 (29.2)	45 (23.5)	0.835
Mild	1 (5.3)	2 (8.3)	29 (15.2)	0.093
Moderate	1 (5.3)	3 (12.5)	9 (4.7)	0.417
Severe	2 (10.5)	2 (8.3)	7 (3.6)	0.128
12 months post-op, n (%)	Severe IEM ($n=9$)	Non-Severe IEM ($n=9$)	Non-IEM ($n=118$)	p value
Presence	4 (44.4)	5 (55.6)	30 (25.4)	0.068
Mild	1 (11.1)	4 (44.4)	13 (11)	**0.041**
Moderate	2 (22.2)	1 (11.1)	15 (12.7)	0.323
Severe	1 (11.1)	0 (-)	2 (1.7)	0.349

Bold values represent results that are statistically significant

Values are presented as n (%). Sample sizes reflect the number of patients with available dysphagia follow-up at each time point

previously associated with optimal postoperative outcomes. Specifically, Su et al. reported that a post-fundoplication DI between 2.0 and 3.5 mm^2/mmHg was associated with lower rates of postoperative dysphagia and improved reflux symptom control. In contrast, DI values below 2.0 mm^2/mmHg were linked to higher dysphagia risk and need for intervention [14]. In our cohort, although the mean DI values were below this threshold, we observed generally low rates of postoperative dysphagia across all groups. These findings are similar to those reported in prior studies evaluating postoperative DI after fundoplication, where low post-repair DI values did not necessarily correlate with increased dysphagia [15]. We did not directly correlate DI with dysphagia outcomes in this analysis, but this will be an essential focus for future studies. Further research is warranted to determine whether intraoperative Endo FLIP measurements can effectively predict postoperative symptom improvement or persistence. Additionally, efforts are needed to define clinically meaningful DI thresholds, as the optimal values for guiding surgical outcomes have yet to be clearly established.

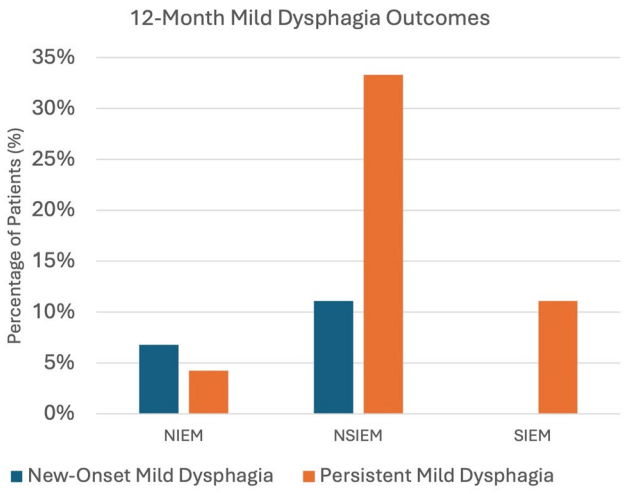

Fig. 4 12-month post-operative persistent vs. new-onset mild dysphagia by IEM status

These results shed light on the physiological characteristics of the LES and its adaptive behavior post-surgery, reaffirming ARS's role in restoring LES competence regardless of preoperative motility status. Moreover, Endo FLIP provides valuable real-time biomechanical insights into LES function, which are unattainable through manometry alone, illustrating its potential as a supplementary tool in intraoperative decisions. As Endo FLIP has been included in the diagnostic framework for achalasia, future research could investigate its use to aid HRM in enhancing the diagnosis of motility disorders like IEM. Additional studies are warranted to develop standardized intraoperative Endo FLIP parameters and predict postoperative changes, which would assist in optimizing surgical strategies and informing tailored fundoplication methods. Improving our understanding of Endo FLIP's role in intraoperative assessment and surgical choices may result in more personalized treatment approaches for GERD patients with coexisting motility disorders.

Furthermore, we found no significant differences in postoperative dysphagia rates between IEM and NIEM patients at 3, 6, and 12 months. Notably, at 12 months, subgroup analysis showed a significant difference in the prevalence of mild dysphagia ($p=0.041$), with persistent mild dysphagia also achieving statistical significance ($p=0.024$). However, the rate of new-onset dysphagia did not differ between the two groups, indicating that IEM patients are not at greater risk for developing new dysphagia after surgery. This contradicts the idea that IEM patients are likely to experience poor

outcomes following ARS and suggests that surgical recommendations should not be based solely on motility findings.

Our results are consistent with previous research indicating that IEM does not markedly affect postoperative dysphagia rates. For instance, Addo et al. showed that IEM patients who underwent laparoscopic anti-reflux surgery attained substantial symptom relief and quality-of-life enhancements similar to those with normal esophageal motility. While dysphagia improvement was less striking in the IEM group, IEM was not associated with an elevated risk of postoperative dysphagia [16]. In a similar vein, Laliberte et al. carried out a retrospective study examining dysphagia outcomes in IEM patients post-Nissen fundoplication. They found no significant rise in postoperative dysphagia rates compared to patients with normal motility. Most patients with preoperative dysphagia experienced symptom resolution, and none required reoperation or any intervention beyond early recovery. These findings contribute to growing evidence that complete wraps may be well-tolerated in IEM patients, challenging the traditional preference for partial fundoplication [17]. Our findings support this, as patients with IEM demonstrated acceptable postoperative outcomes despite undergoing a range of fundoplication types.

In our study, the wrap type was determined preoperatively and not modified intraoperatively. While this contrasts with prior strategies that adapt the wrap based on intraoperative findings, which may limit generalizability, it allows for a more consistent evaluation of outcomes based on planned surgical approach. As this dataset was collected retrospectively, it provides a foundation for future studies aimed at identifying which intraoperative or perioperative metrics, including Endo FLIP, could guide personalized wrap selection.

Nevertheless, many surgeons have shifted away from Nissen fundoplication because of the heightened risk of postoperative bloating, leading to its decreased usage compared to earlier years. [18, 19]. However, further research is required to fine-tune patient selection criteria and identify factors that might enhance postoperative results for IEM patients undergoing ARS. Thorough preoperative assessments using objective perioperative data are essential for customizing surgery for optimal reflux management and esophageal clearance.

Our study builds on these insights by incorporating Endo FLIP to evaluate LES biomechanics objectively. This methodology provides novel information about how LES compliance and distensibility adapt postoperatively in IEM patients. It yields supplementary data to support surgical decision-making and further refine patient selection in managing GERD alongside concurrent motility issues.

The findings from our study present crucial clinical implications for managing GERD patients with IEM who are candidates for anti-reflux surgery. The similar postoperative dysphagia rates in IEM and NIEM patients indicate that IEM should not be seen as a contraindication to ARS, reinforcing the notion that surgical interventions can be appropriately applied to this demographic. Additionally, the normalization of LES function in IEM patients post-surgery underscores the potential of ARS to restore esophageal mechanics, likely contributing to better symptom relief. By integrating Endo FLIP, our study introduces a new perspective on assessing LES physiology, illustrating its worth in quantifying intraoperative alterations in LES compliance and distensibility. These findings support the viability of Endo FLIP as an adjunct to HRM for preoperative evaluations and intraoperative surgical planning. Future research should establish standardized Endo FLIP thresholds to enhance surgical decision-making, refine criteria for patient selection, and tailor fundoplication techniques based on the unique attributes of each patient's esophagus physiology.

This study has several limitations. Being a retrospective analysis, there is a potential for selection bias that could affect the findings. Moreover, it was conducted at a single center with one surgeon, which may restrict the generalizability of the results to other institutions and surgical approaches. The follow-up duration was limited, which hinders the evaluation of long-term postoperative outcomes beyond the study period. Additionally, the smaller sample size at the 12-month follow-up may reduce the strength of conclusions drawn from long-term dysphagia outcomes. We did not perform a formal sensitivity analysis comparing patients lost to follow-up with those who completed follow-up, which is a limitation. As such, we cannot exclude the possibility that follow-up attrition introduced bias in the 12-month results. In addition, a post hoc power analysis comparing the two subgroups with the largest observed difference in mild dysphagia prevalence at 12 months (NIEM: 11% vs. NSIEM: 44.4%) yielded a power of 73.1%, suggesting that this subgroup analysis may have been underpowered.

Furthermore, the study lacked sufficient power to evaluate specific anti-reflux procedures, including LINX, Dor, or transoral incisionless fundoplication (TIF), restricting conclusions on dysphagia outcomes across various surgical methods. Although a validated dysphagia scoring tool was used, patient-reported symptoms can vary due to differences in perception and reporting, potentially leading to some heterogeneity in the outcome assessment. Future research must involve larger, multi-institutional cohorts and long-term objective follow-up measures to substantiate these findings further.

Several research pathways should be pursued to enhance the management of GERD in patients with IEM. First, a prospective study that employs intraoperative Endo FLIP guidance to customize the type of fundoplication for IEM patients could clarify whether adapting the wrap based on real-time LES biomechanics leads to better postoperative results. Second, randomized controlled trials (RCTs) that

compare surgical strategies in IEM patients would provide high-quality evidence for optimizing treatment algorithms and patient selection criteria. Furthermore, integrating Endo FLIP into standardized surgical workflows requires additional investigation. Our study illustrates that Endo FLIP offers significant insights into LES function intraoperatively; however, its impact on surgical decision-making—primarily when used alongside HRM and clinical assessment—needs further validation. Future research should aim to establish optimal Endo FLIP thresholds that could facilitate intraoperative adjustments to enhance patient outcomes.

In addition, as our comprehension of esophageal motility disorders progresses, Endo FLIP may contribute to refining the diagnostic criteria for IEM. With its capability to evaluate LES distensibility and compliance in real-time, further studies could investigate its use as a complement to HRM for better classification and diagnosis of IEM. This approach could result in a more thorough assessment of esophageal function, improving patient selection and personalized treatment strategies.

Conclusion

Our study provides important insights into the impact of IEM on postoperative outcomes following anti-reflux surgery. We found that IEM status does not significantly influence postoperative dysphagia rates, reinforcing that IEM should not be considered a contraindication to ARS. Furthermore, our findings demonstrate that LES biomechanics, as assessed by Endo FLIP, normalize postoperatively in IEM patients, suggesting that ARS effectively restores LES function in this population. By incorporating Endo FLIP, we add a novel dimension to the understanding of esophageal physiology, highlighting its potential as an adjunct to HRM in both preoperative evaluation and intraoperative surgical decision-making. Future research should focus on refining patient selection criteria, establishing standardized Endo FLIP thresholds, and further exploring its role in optimizing surgical planning for GERD patients with motility disorders.

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Declarations

Conflict of interest Dr. Rasa Zarnegar is a consultant for Intuitive, Medtronic, and Beckton-Dickenson. Drs. Maria Alqamish, Anjani Turaga, Niloufar Salehi, Gala Cygiel, Hala Al Asadi, Benjamin Greenspun, Brendan M Finnerty, and Thomas J Fahey III have no conflicts of interest or financial ties to disclose.

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