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Comparison of endoscopic ultrasound-directed transgastric endoscopic retrograde cholangiopancreatography outcomes using various technical approaches

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ABSTRACT

Background and study aims Roux-en-Y gastric bypass presents an anatomic challenge for patients needing ERCP. EUS-directed transgastric ERCP (EDGE) offers high clinical success but carries considerable risk of adverse events (AEs) with no standardized technical approach. In our study, we review the safety and efficacy of our various EDGE technical approaches.

Patients and methods A retrospective single-center study of all patients who underwent EDGE procedures between February 2018 and November 2019. Primary outcomes included comparing the technical and clinical success, AEs, and lumen-apposing metal stent (LAMS) migration rates per access route (gastrogastric vs jejuno-gastric), number of procedure stages (single-stage vs two-stage), and stent size (15 mm vs 20 mm). Secondary outcomes included LAMS migration characteristics and management.

Results Thirty-two EDGE procedures were performed in 29 patients, including 17 single-stage and 15 two-stage procedures, 23 gastrogastric, and nine jejuno-gastric routes, fourteen 15-mm and 17 20-mm LAMS. Overall technical and clinical success rates were 96.9 % and 87.1 %, respectively, without any significant difference between groups. The overall AE rate was (34.4 %) and was significantly lower in the 20-mm LAMS group compared to the 15-mm group (17.6 % vs 57.1 %, $P = 0.03$). Compared to two-stage procedures, there was no significant difference in AEs with single-stage procedures (35.3 % vs 33.3 %, $P = 0.33$). The LAMS migration rate was (25 %) with no significant difference between groups. Most migrations were around the index procedure and managed endoscopically (62.5 %).

Conclusions EDGE offers high clinical success rates but AE rates remain significant. In our series, a 20-mm LAMS resulted in a significantly lower AE rate than the 15-mm LAMS. Large multicenter studies are recommended to identify technical factors leading to an optimal EDGE procedure.

Introduction

With the rising prevalence of morbid obesity and Roux-en-Y gastric bypass (RYGB) surgeries in the United States, altered gastrointestinal anatomy has been posing remarkable technical challenges to performing urgent or elective endoscopic retrograde cholangiography (ERCP) or pancreatobiliary endoscopic ultrasound (EUS) interventions for various indications [1,2]. Several surgical and endoscopic procedures have recently been implemented to technically overcome these anatomical challenges and successfully perform pancreatobiliary interventions in these patients, with various reported success and adverse event (AE) rates [3,4]. Commonly performed procedures include laparoscopy-assisted ERCP (LA-ERCP), balloon enteroscopy-assisted ERCP (BE-ERCP), and EUS-directed transgastric ERCP (EDGE). LA-ERCP was one of the first developed procedures that achieved remarkable technical and clinical success rates but was associated with longer procedure duration and hospital length of stay, higher cost, and notable AE rates [4–6]. BE-ERCP has been commonly performed over the last few years, with overall better safety profile but inferior technical and clinical success rates compared to LA-ERCP or EDGE [3,4,7]. EDGE, a recently introduced minimally invasive endoscopic technique, creates a gastro-gastric (GG) or jejuno-gastric (JG) fistula via a lumen-apposing metal stent (LAMS) to access excluded stomach under EUS guidance and facilitate ERCP execution [8]. Despite limited literature, available EDGE data are promising in terms of achieving impressive technical and clinical success rates and a safety profile comparable to LA-ERCP but with shorter procedure duration and hospital stay [8–11]. EDGE's technique-related AEs include LAMS migration, perforation, bleeding, and weight loss. Given the absence of a standardized EDGE approach regarding access route, procedure stages (single-stage vs two-stage), or stent size, it is unclear if certain approach carries a higher risk of AEs compared to the other.

In our study, we share the EDGE experience of multiple advanced endoscopists at a single US tertiary care referral center focusing on overall efficacy and safety along with comparison data by access route, number of procedure stages, and stent size.

Patients and methods

This study was approved by the institutional review board for human research at Baylor College of Medicine. This was a retrospective single-center study that included all consecutive patients ≥ 18 years with a history of RYGB surgery who underwent an EDGE procedure performed by one of our four advanced endoscopists for pancreatobiliary indications between February 2018 and November 2019 at Baylor St. Luke's Medical Center (BSLMC), Houston, Texas, United States. The primary outcomes included comparing the technical and clinical success, AEs, and LAMS migration rates per access route (GG vs JG), number of procedure stages (single-stage vs two-stage), and stent size (15 mm vs 20 mm). Secondary outcomes included LAMS migration characteristics and management.

EDGE procedure

All procedures were performed by one of four advanced endoscopists at BSLMC who were familiar with EDGE technique at the time of the study. All procedures were performed under both general endotracheal anesthesia and total intravenous anesthesia.

Creation of gastrogastric or JG fistula

An initial endoscopic exam was first performed with a traditional front-viewing gastroscope or a standard therapeutic linear echoendoscope (EG-3870UTK; Pentax, Montvale, New Jersey, United States) for examination of the gastric pouch, gastrojejunal anastomosis, and proximal jejunal limb. The echoendoscope was then used to identify the excluded stomach adjacent to the pouch stomach or proximal jejunal limb. Under echoendoscopic guidance, a 19G or 22G needle (Expect Slimline; Boston Scientific, Marlborough, Massachusetts, United States) was used to puncture the excluded stomach. A mixture of contrast (ISOVUE-M) and water was then injected to distend the gastric remnant with the goal o fgastric wall separation of 6 cm to accept the LAMS delivery system. A 15-mm or 20-mm cautery-enhanced LAMS (AXIOS; Boston Scientific, Marlborough, Massachusetts, United States) was then deployed under echoendoscopic and fluoroscopic guidance, creating a GG or JG fistula. The choice between 15 mm or 20 mm was based on endoscopist preference or stent availability, especially after the introduction of a 20-mm LAMS in mid-2018. Two of the four endoscopists in our study used both size stents while two used only 15-mm stents. Following fistula creation, the stent was serially dilated with a through-the-scope (TTS) balloon dilator (Controlled Radial Expansion Balloon Dilation Catheter; Boston Scientific, Marlborough, Massachusetts, United States). In all cases in which the single-stage approach was elected, the LAMS was dilated to 15 mm to 20 mm, based on the stent size.

Performance of ERCP or diagnostic EUS

The choice to perform ERCP or diagnostic EUS during the same session as fistula creation or during a second session was operator- and procedure-dependent. ERCP was preferred during the initial session if the indication was urgent, i.e. cholangitis. There was a tendency to perform ERCP during a second session if the fistula was JG, or if the angle of the LAMS in the lumen following deployment was deemed to be unfavorable. All ERCPs were performed using a duodenoscope (ED34-i10T; Pentax, Montvale, New Jersey, United States) via the newly created fistula. ERCP with cholangioscopy was performed, if indicated, in addition to traditional cholangiography. Diagnostic EUS was performed using a linear echoendoscope (EG-3870UTK; Pentax, Montvale, New Jersey, United States).

Removal of lumen-apposing metal stent

Removal of the LAMS with an endoscopic grasper (Raptor Grasping Device; Steris, Mentor, Ohio, United States) was performed in all patients with successful fistula creation. The length of time to before LAMS removal varied from 3 to 8 weeks, based on endoscopist performance or a patient's clini-

cal condition. The LAMS was left for a longer period of time if clinically needed. The decision to close the fistula was based on endoscopist preference. Closure of the fistula was performed with placement of an over-the-scope clip (OTSC) system (Ovesco Endoscopy, Cary, North Carolina, United States), traditional endoclips, or endoscopic suturing.

Data collection

A search of Epic and Provation electronic health records was performed to identify patients who met our inclusion criteria. Eligible patients' electronic charts were subsequently reviewed, and their data were collected into a REDCap database. Collected data included baseline patient characteristics (e. g., age, gender, ethnicity, body mass index), procedure characteristics (e. g., indication, access route, stent size, number of procedure stages, technical and clinical success, AEs), and follow-up data (e. g., stent removal time, delayed AEs, weight change).

Definitions

Technical success was defined as access to the excluded stomach following LAMS placement. Clinical success was defined as successful performance of ERCP or EUS, either at the index procedure (single stage) or after fistula maturation (two-stage). AEs were classified according to the American Society of Gastrointestinal Endoscopy (ASGE) lexicon for endoscopic AEs severity grading [12].

Statistical analysis

Summary data were expressed as median (interquartile range: P25-P75) or mean ± standard deviation. Frequencies and percentages were calculated using the REDCap software's basic descriptive statistics. For between-group comparisons, we used Fisher's exact test for categorical variables and ANOVA for continuous variables using GraphPad software. Nominal *P* values are reported; $P<0.05$ was considered significant. Post-hoc power calculations were additionally performed for primary outcomes among compared groups.

Results

The final group included 29 patients who underwent a total of 32 EDGE procedures between February 2018 and November 2019. One patient underwent a total of three EDGE procedures while another underwent a total of two EDGE procedures.

Baseline patient characteristics (N = 29)

Baseline patient characteristics are presented in ▶**Table 1**. The median patient age was 57 years. There were 26 women (89.7%) and three men (10.3 %). Of the 29 patients, there 21 were White (72.4 %), six were African American (20.7 %), and two were Hispanic (6.9 %). Median baseline BMI and weight were 29.5 kg/m^2 and 77.4 kg, respectively.

Overall procedure characteristics (N = 32)

Overall procedural characteristics are presented in ▶**Table 2**. Of the 32 EDGE procedures, 25 were performed for biliary indications (78.1 %) while seven were for pancreatic indications (21.9 %). The intended procedure was ERCP in 30 cases (93.75%) and EUS in the remaining two (6.25 %). Seventeen procedures were performed in a single stage (53.1 %) and 15 were performed in two stages (46.9 %).

▶**Table 1** Baseline patient characteristics.

Factor	Overall statistics (N = 29)
Age (years)	57 [51,62.25]
Gender	
▪ Female	26/29 (89.7 %)
▪ Male	3/29 (10.3 %)
Ethnicity	
▪ White	21/29 (72.4 %)
▪ African American	6/29 (20.7 %)
▪ Hispanic	2/29 (6.9 %)
Baseline BMI (kg/m^2)	29.5 [23,31.4]
Baseline weight (Kg)	77.4 [63.6,89.9]
Statistics presented as median [P25,P75] or Frequency (%)	

BMI, body mass index.

The GG route was used in 23 procedures (71.9 %) while the JG route was used in the remaining nine cases (28.1 %). Regarding stent size, 15-mm stents were used in 14 cases (43.8 %) while 20-mm stents were used in 17 cases (53.1 %). Of the 14 cases in which 15-mm stents were used, nine were before the availability of 20-mm stents while five were afterwards. Technical success was achieved in 31 of 32 cases (96.9 %) while clinical success was achieved in 27 of these 31 cases (87.1 %). The technically failed procedure was due to intraprocedural perforation requiring surgical gastric repair. This patient underwent a successful EDGE procedure 3 months later. On the other hand, the four clinically failed procedures were due to three cases of proximal LAMS migration with fistula closure by second-stage procedure and one case of malignant duodenal stenosis. These failed cases were managed with intraoperative ERCP, LAMS replacement with subsequent successful EDGE, clinical monitoring, and percutaneous biliary drainage, respectively.

In our study, two patients underwent repeat EDGE procedures during the study. The first patient had a technically failed first EDGE procedure and underwent a subsequent successful EDGE procedure 3 months later. The second patient had chronic pancreatitis and recurrent pancreatic duct stone formation and underwent a total of three EDGE procedures over our study duration. Following a clinically successful first EDGE procedure with stent removal, the patient represented 8 months later with recurrent symptomatic pancreatic duct stone formation warranting a second EDGE procedure. The second EDGE procedure clinically failed at its second stage due to LAMS migration warranting LAMS removal and a repeat two-stage EDGE procedure later.

▶ **Table 2** Procedure characteristics.

Factor	Overall statistics (N = 32)
Indication	
▪ Biliary	25/32 (78.1 %)
▪ Pancreatic	7/32 (21.9 %)
Intended procedure	
▪ ERCP	30/32 (93.75 %)
▪ EUS	2/32 (6.25 %)
Number of procedure stages	
▪ Single stage	17/32 (53.1 %)
▪ Two stage	15/32 (46.9 %)
Access route	
▪ Gastrogastric	23/32 (71.9 %)
▪ Jejuno-gastric	9/32 (28.1 %)
Stent size	
▪ 15 mm	14/32 (43.8 %)
▪ 20 mm	17/32 (53.1 %)
▪ Undocumented	1/32 (3.1 %)
Technical success	31/32 (96.9 %)
Clinical success	27/31 (87.1 %)[1]
Index procedure characteristics	
Index procedure setting	
▪ Outpatient	23/32 (71.9 %)
▪ Inpatient	9/32 (28.1 %)
Duration of index procedure (min)	34 [22.5,41.5]
Admission at index procedure	12/32 (37.5 %)
Reason for admission at index procedure:	
▪ Transfer from outside hospital for symptomatic choledocholithiasis or cholangitis	5/12 (41.7 %)
▪ Already admitted patients	4/12 (33.3 %)
▪ Intraprocedural AE (perforation)	1/12 (8.3 %)
▪ Expedited inpatient second stage procedure	1/12 (8.3 %)
▪ Monitoring	1/12 (8.3 %)
Length of stay for admitted patients after index procedure (days)	5 [2.75,6.25]
Second procedure characteristics	
Days between procedures for two stage procedures	22 [15.25,33.75]
Duration of second procedure if applicable (min)	23 [13,30.5]
Admission at second stage procedure	2/15 (13.3 %)
Reason for admission at second stage procedure	
▪ Already admitted patient.	1/2 (50 %)
▪ Worsening pancreatic stones symptoms warranting urgent inpatient procedure.	1/2 (50 %)
Length of stay for admitted patients at second procedure (days)	18 [18,18]
Stent removal procedure characteristics	
Stent status	
▪ Removed at later date without complication	19/32 (59.4 %)
▪ Kept for future procedures	6/32 (18.8 %)
▪ Removed due to complication	6/32 (18.8 %)
▪ Kept after distal migration to excluded stomach	1/32 (3.1 %)
Days to stent removal if applicable	52 [41.25,68.25]
Duration of stent removal procedure (min)	8 [7.5,12]
Weight change from baseline at stent removal (kg)	-0.9 [-1.5,0.5]
Need for fistula closure at LAMS removal	6/32 (18.8 %)
▪ Over-the-scope clip	4/6 (66.7 %)
▪ Endoclip	2/6 (33.3 %)

Statistics presented as median [P25,P75] or frequency (%).
ERCP, endoscopic retrograde cholangiopancreatography; EUS, endoscopic ultrasound; AE, adverse event.
[1] Denominator only included patients with technically successful procedure.

Most index procedures were done on an outpatient basis (23/32, 71.9 %) while the remaining were inpatient (9/32, 28.1%). Of the patients who had 23 outpatient index procedures, three were immediately admitted following the procedure for AE management, expedited second-stage procedure, and monitoring, respectively. The median index procedure duration and length of stay for admitted patients were 34 minutes [IQR 22.5,41.5] and 5 days [2.75,6.25], respectively.

Regrading two-stage procedures, the median duration between two-stage procedures and procedure duration were 22 days [IQR: 15.25,33.75] and 23 minutes [13,30.5], respectively. Most second-stage procedures were done on an outpatient basis (13/15, 86.7 %). The two inpatient procedures were expedited procedures for admitted patients with worsening symptoms.

Regarding stents status following procedures, 19 were removed at later date without complications (59.4 %), six were kept for possible future procedures (18.8 %), six were removed due to AEs (18.8 %), and one was kept after distal migration to excluded stomach with fistula closure (3.1 %). If applicable, median days to stent removal were 52 days [IQR: 41.25,68.25] with median weight change of –0.9 kg [IQR –1.5,0.5]. Median

▶ **Table 3** Adverse events.

Factor	Overall statistics (N = 32)
Overall AEs	11/32 (34.4 %)
Severe AEs	3/32 (9.4 %)
▪ Perforation with LAMS migration requiring surgery	2/32 (6.25 %)
▪ Post-sphincterotomy bleeding requiring ICU admission	1/32 (3.125 %)
Moderate AEs	2/32 (6.25 %)
▪ Abdominal pain due to LAMS migration requiring endoscopic removal	1/32 (3.125 %)
▪ Delayed gastro-gastric fistula formation requiring endoscopic closure	1/32 (3.125 %)
Mild AEs	6/32 (18.75 %)
▪ Uncomplicated LAMS migration	5/32 (15.6 %%)
▪ Admission for uncomplicated abdominal pain control	1/32 (3.125 %)
Index procedure AEs	6/32 (18.75 %)
Severe AEs	3/6 (50 %)
▪ Intraoperative perforation with LAMS migration requiring surgery	
▪ Post-procedural perforation with LAMS migration requiring surgery	
▪ Post-sphincterotomy bleeding requiring ICU admission	
Moderate AEs	1/6 (16.7 %)
▪ Abdominal pain due to LAMS migration requiring endoscopic removal	
Mild AEs	2/6 (33.3 %)
▪ Intraoperative LAMS migration requiring endoscopic adjustment	
▪ Intraoperative distal LAMS migration requiring LAMS replacement	
Second-stage procedure AEs	3/15 (20 %)
Mild AEs	
▪ Admission for uncomplicated abdominal pain control	1/3 (33.3 %)
▪ Uncomplicated proximal LAMS migration with fistula closure	2/3 (66.7 %)

index, second-stage, and stent removal procedure durations were 34 minutes, 23 minutes, and 8 minutes, respectively. Six cases required fistula close after stent removal (18.8 %) using OTSC in four of these and Endoclip in the remaining two.

▶ **Table 3** (Continuation)

Factor	Overall statistics (N = 32)
LAMS removal procedure AEs	1/19 (10.5 %)
Mild AEs	
▪ Uncomplicated distal LAMS migration to excluded stomach	1/19 (10.5 %)
1-year follow-up AEs	1/32 (3.125 %)
Moderate AEs	
▪ Gastro-gastric fistula formation requiring endoscopic closure	
Management setting of AEs	
▪ Admission for AE management	6/11 (54.5 %)
▪ Outpatient management	4/11 (36.4 %)
▪ Already admitted patient	1/11 (9.1 %)
Length of stay for inpatient AE management (days)	7 [5.5,12]
Overall LAMS migration management	8/32 (25 %)
▪ Removed endoscopically at 2nd stage due to uncomplicated proximal migration	2/8 (25 %)
▪ Removed surgically due to severe complication	2/8 (25 %)
▪ Removal endoscopically due to complicated proximal migration	1/8 (12.5 %)
▪ Replaced endoscopically during single stage procedure after distal migration	1/8 (12.5 %)
▪ Adjusted endoscopically during single stage procedure after distal migration	1/8 (12.5 %)
▪ Kept in place after migration to excluded stomach with fistula closure	1/8 (12.5 %)

Statistics presented as median [P25,P75] or frequency (%).
AE, adverse event; LAMS, lumen-apposing metal stent; ICU, intensive care unit.

Adverse events

Detailed AE data are presented in ▶ **Table 3**. Overall there were 11 AEs (34.4 %), including three severe (9.4 %), two moderate (6.25 %), and six mild AEs (18.75 %).

Regarding the three severe AEs, oe patient who underwent a single-stage EDGE using a 15-mm gastrogastric LAMS developed intraprocedural perforation during LAMS balloon dilation. This patient underwent same day exploratory laparotomy for surgical repair of gastric defect, LAMS removal, and temporary feeding jejunostomy tube placement. This patient underwent successful EDGE 3 months later. One patient who underwent a single-stage successful outpatient EDGE using a 15-mm gastrogastric LAMS represented the same day with severe abdominal pain and hemodynamic instability due to acute peritonitis. This patient underwent urgent exploratory laparotomy during

which distal LAMS migration and bilious leak from the gastric pouch were noted, requiring surgical gastric repair and LAMS removal. One patient on apixaban who underwent a single-stage inpatient EDGE using a 15-mm GG LAMS developed hemodynamically significant post-sphincterotomy bleeding 2 days following his procedure. He required transfusion of packed red blood cells and prothrombin complex concentrate, admission to the intensive care unit, and successful endoscopic hemostasis using Gold Probe.

Regarding the two moderate AEs, one patient was readmitted with abdominal pain 5 days following the index procedure of a planned two-stage EDGE using a 20-mm gastrogastric LAMS. Repeat endoscopy revealed proximal LAMS migration to the stomach pouch with fistula closure. The LAMS was removed endoscopically, and the patient underwent a subsequent intraoperative ERCP. One patient who underwent a two-stage EDGE using a 15-mm gastrogastric LAMS developed a gastrogastric fistula that was identified in the setting of chronic abdominal pain and weight loss workup following LAMS removal. This fistula failed to close with OTSC and required subsequent endoscopic suturing.

There were six mild AEs, including five uncomplicated LAMS migrations and one readmission for uncomplicated abdominal pain following two-stage EDGE.

Of the 11 patients who had AEs, six required admission for inpatient management (54.5%), four were managed as outpatients (36.4%), and one was already an inpatient (9.1%). The median length of stay for inpatient AE management was 7 days [IQR 5.5,12].

LAMS migration

Detailed characteristics of all eight LAMS migration cases are presented in ▶**Table 4**. There were equal rates of proximal (4/8, 50%) and distal migrations (4/8, 50%). Regarding timing of migration, five were identified around the index procedure (62.5%), two around the second-stage procedure (25%), and one around the stent removal procedure (12.5%). Regarding severity of AEs related to LAMS migration, there were two severe (25%), one moderate (12.5%), and five mild AEs (62.5%).

Of the eight LAMS that migrated, three were removed endoscopically (37.5%), two were removed surgically (25%), one was replaced endoscopically (12.5%), one was adjusted endoscopically (12.5%), and one was kept in place after distal migration to the excluded stomach with fistula closure (12.5%).

Outcomes comparison

A comparison of outcomes by access route, number of procedural stages, and stent size are presented in ▶**Table 5**, including post-hoc power calculations.

Access route

There was no statistically significant difference in technical (95.7% vs 100%, $P>0.99$) or clinical success (86.4% vs 88.9%, $P>0.99$) or LAMS migration rates (26.1% vs 22.2%, $P>0.99$) between the GG (n=23) and JG (n=9) groups. Although it did not reach statistical significance, the GG group had higher overall-rate of AEs (39.1% vs 22.2%, $P=0.44$) and more weight loss after stent removal (–1.15 kg vs 0.6 kg, $P=0.09$) compared to the JG group.

Number of procedure stages

There was no statistically significant difference between single-stage (n=17) and two-stage (n=15) procedures in terms of technical success (94.1% vs 100%, $P>0.99$), clinical success (93.8% vs 80%, $P=0.33$), overall AEs (35.3% vs 33.3%, $P>0.99$), LAMS migration (29.4% vs 20%, $P=0.69$), or weight change after stent removal (–0.3 kg vs –1.1 kg, $P=0.66$).

LAMS size

There was no statistically significant difference in technical success (92.9% vs 100%, $P=0.45$), clinical success (92.3% vs 82.4%, $P=0.61$), or weight change after stent removal (–0.25 kg vs –1.1 kg, $P=0.35$) between the 15-mm (n=14) and 20-mm stent groups (n=17). On the other hand, the 15-mm stent group had a statistically significantly higher overall rate of AEs (57.1% vs 17.6%, $P=0.03$) compared to the 20-mm stent group. Although it did not reach statistical significance, the 15-mm stent group also had a higher rate of LAMS migration (35.7% vs 17.6%, $P=0.41$).

When comparing the 15-mm stent group outcomes before (n=9) and after (n=5) the availability of 20-mm stents, there was no statistically significant difference in technical success (88.9% vs 100%, $P>0.99$), clinical success (100% vs 80%, $P=0.3$), or overall AE rates (44% vs 80%, $P=0.3$), respectively.

Learning curve

When comparing the outcomes of the first half of procedures (n=16) to the second half (n=16), there was no statistically significant difference in technical success (93.8% vs 100%, $P>0.99$), clinical success (86.7% vs 87.5%, $P>0.99$), stent migration (37.5% vs 12.5%, $P=0.2$), or overall AE rates (43.8% vs 25%, $P=0.45$), respectively.

Discussion

RYGB is currently one of the most performed bariatric surgeries in the United States. Gallstone formation and its related diseases are common delayed complications of rapid weight loss following bariatric surgeries that increase demand for pancreatobiliary interventions [13, 14]. Our study highlights the efficacy and safety of EDGE as a minimally invasive endoscopic intervention that facilitates ampullary and pancreatic head access in RYGB patients. Given the absence of a standardized technical approach, our study included various technical approaches to the EDGE procedure in terms of access route (GG vs JG), number of procedural stages (single-stage vs two-stage), and stent size (15 mm vs 20 mm).

Our overall technical and clinical success rates were 31/32 (96.9%) and 27/31 (87.1%), respectively. The technically failed procedure in our cohort was due to intraprocedural perforation during LAMS balloon dilation after deployment, which was successfully managed surgically and with a subsequent successful EDGE procedure. On the other hand, four procedures failed clinically due to proximal LAMS migration with fistula closure

▶ **Table 4** LAMS migration characteristics.

Case	Indication	LAMS successfully placed	Access route	Single or two stage	Stent size	Clinical success	Timing of migration	Nature of Migration	Clinical outcome
1	Symptomatic choledocholithiasis without cholangitis.	Yes	Gastro-gastric	Single stage	15 mm	Yes	Discovered at stent removal procedure, 62 days following placement	Distal migration into excluded stomach with closure of pouch stomach	Patient being serially monitored without adverse sequelae
2	Symptomatic choledocholithiasis without cholangitis.	Yes	Jejuno-gastric	Single stage	15 mm	Yes	Migrated during single stage ERCP	Distal migration during passage of the duodenoscope s/p repositioned using rat tooth forceps	No adverse events
3	Symptomatic choledocholithiasis without cholangitis.	Yes	Gastro-gastric	Single stage	15 mm	Yes	Migrated same day following index procedure and causing severe pain	Distal migration into bypassed stomach	Peritonitis requiring surgery.
4	Malignant biliary obstruction	Yes	Gastro-gastric	Single stage	15 mm	No	During index procedure	Distal migration into remnant stomach during passage of the duodenoscope s/p LAMS replacement	Clinically unsuccessful due to malignant duodenal stenosis requiring percutaneous biliary drainage. Stent was not removed.
5	Symptomatic choledocholithiasis without cholangitis.	Yes	Gastro-gastric	Two stages	20 mm	No	Discovered 5 days following index procedure after readmission for abdominal pain	Proximal migration into pouch stomach with fistula closure	LAMS removal endoscopically and underwent subsequent intraoperative ERCP
6	Chronic abdominal pain with biliary dilation on imaging.	Yes	Gastro-gastric	Two stages	20 mm	No	Discovered at second stage procedure, 35 days following placement	Proximal migration into pouch stomach with fistula closure s/p stent removal.	Referred for laparoscopy-assisted ERCP which she declined s/p clinical monitoring.
7	Chronic pancreatitis with pancreatic duct stones	Yes	Jejuno-gastric	Two stages	20 mm	No	Discovered at second stage procedure, 37 days following placement	Uncomplicated proximal migration into jejunal loop.	LAMS replacement with subsequent clinical success
8	RUQ abdominal pain with biliary dilation and abnormal liver function tests.	No	Gastro-gastric	Single stage	15 mm	N/A	During index procedure	Proximal migration during LAMS balloon dilation leading to perforation.	Gastric surgical repair with subsequent successful EDGE

LAMS, lumen-apposing metal stent; RUQ, right upper quadrant.

by a second-stage procedure in three cases, and malignant duodenal stenosis in the remaining case. Although it did not reach statistical significance, our two-stage procedures had a lower clinical success rate than single-stage due to LAMS migration with a second procedure (80 % vs 93.8 %, $P = 0.33$). However, we did not identify any statistically significant difference in technical or clinical success rates associated with stent size or access route, which supports the feasibility of transjejunal approach.

Despite its success, EDGE carries a remarkable rate of AEs. Including ERCP-related complications, the overall rate of AEs in our study was 11/32 (34.4 %), which was slightly higher than in a recently published systematic review (47/169, 27.8 %) [15]. Excluding ERCP-related complications, our overall rate of AEs remained slightly higher than reported in the literature

▶ **Table 5** Outcomes comparison.

	Gastro-gastric route (N = 23)	Jejuno-gastric route (N = 9)	*P* value	Post-hoc power	Single stage (N = 17)	Two stages (N = 15)	*P* value	Post-hoc power	15-mm stent (N = 14)	20-mm stent (N = 17)	*P* value	Post-hoc power
Factor	Statistics	Statistics			Statistics	Statistics			Statistics	Statistics		
Technical success	22/23 (95.7 %)	9/9 (100 %)	> 0.99	1.8 %	16/17 (94.1 %)	15/15 (100 %)	> 0.99	13.4 %	13/14 (92.9 %)	17/17 (100 %)	0.45	21 %
Clinical success	19/22 (86.4 %)	8/9 (88.9 %)	> 0.99	3.3 %	15/16 (93.8 %)	12/15 (80 %)	0.33	20.6 %	12/13 (92.3 %)	14/17 (82.4 %)	0.61	10.8 %
Overall AEs	9/23 (39.1 %)	2/9 (22.2 %)	0.44	12.6 %	6/17 (35.3 %)	5/15 (33.3 %)	> 0.99	3.3 %	8/14 (57.1 %)	3/17 (17.6 %)	0.03	63.7 %
▪ Mild AE	4/23 (17.4 %)	2/9 (22.2 %)	> 0.99	5.6 %	3/17 (17.6 %)	3/15 (20 %)	> 0.99	3.7 %	4/14 (28.6 %)	2/17 (11.8 %)	0.36	21.9 %
▪ Moderate AE	2/23 (8.7 %)	0/9 (0 %)	> 0.99	4.5 %	0/17 (0 %)	2/15 (13.3 %)	0.21	34.5 %	1/14 (7.1 %)	1/17 (5.9 %)	> 0.99	3.5 %
▪ Severe AE	3/23 (13 %)	0/9 (0 %)	0.54	8.9 %	3/17 (17.6 %)	0/15 (0 %)	0.22	38.9 %	3/14 (21.4 %)	0/17 (0 %)	0.08	51.8 %
LAMS migration	6/23 (26.1 %)	2/9 (22.2 %)	> 0.99	3.8 %	5/17 (29.4 %)	3/15 (20 %)	0.69	8.6 %	5/14 (35.7 %)	3/17 (17.6 %)	0.41	20.8 %
Weight change (kg)	−1.15 [−3.4, −0.28]	0.6 [−0.03,1.3]	0.09	NA	−0.3 [−1.3, 0.6]	−1.1 [−1.6, 0.5]	0.66	NA	−0.25 [−0.9, 0.7]	−1.1 [−2.3, 0.15]	0.35	NA

Statistics presented as mean ± SD, or frequency (%) or median [P25,P75].
AE, adverse event; LAMS, lumen-apposing metal stent.

(31.25% vs 24.26 %), which could be due to our various technical approaches, learning curve of multiple providers, and deficiency in standardized reporting of AEs in the literature. In our study, we had two severe EDGE-related AEs (6.25 %) due to perforation requiring urgent surgical intervention, which was higher than the rate in recent literature (3/169, 1.8 %) [15]. Both of our cases had migration of 15-mm GG stents around the index procedure and did well with surgical repair. One of them developed GG separation, likely due to lack of recognition of the leading tip of the LAMS being in the gastric wall rather than the lumen. The patient had a previous gastric sleeve surgery that likely contributed to diminished gastric distention. Following the separation, the bypassed stomach could not be brought closer to the pouch, and thus, the patient was sent for surgery. Despite this, the patient had a successful EDGE later.

In our study, more than half the AEs (6/32, 18.75 %) occurred around the index procedure, including all severe AEs. Although most of our index procedures were done on outpatients, the prior finding might advocate for hospitalizing these patients for short-term monitoring following index procedures. On the other hand, LAMS migration played a major role in our overall EDGE-related AEs (8/32, 25 %) including all severe, 50 % of moderate, and 83 % of mild AEs. The management of LAMS migration was done on a case-by-case basis based on AE severity and whether endoscopic salvage was possible, as we highlighted in ▶ **Table 4**. This included surgical removal in 25 % of migration cases and endoscopic interventions in 62.5 %. One patient had asymptomatic distal LAMS migration to the excluded stomach with fistula closure and has been clinically monitored without removal attempts. We did not encounter significant weight loss by stent removal time in our patients (median −0.9 kg, IQR: −1.5,0.5).

There have been continuous efforts to identify factors associated with EDGE-related AEs and LAMS migration to optimize technical approach. Given the various technical approaches in our study, we retrospectively compared our AE and LAMS migration rates per access route, number of procedure stages, and stent size. Regarding access route, our transjejunal cases had statistically insignificantly lower AE rates (22.2 % vs 39.1 %, $P = 0.44$), although a recent retrospective multicenter study found a significantly lower rate of index procedure AEs with transjejunal access compared to transgastric (4.5 % vs 15.2 % respectively, $P = 0.027$) [16]. Although our study could be underpowered, we did not identify any significant difference in AE or LAMS migration rates between single-stage and two-stage procedures (35.3 % vs 33.3 %, $P > 0.99$) and (29.4 % vs 2 %, $P = 0.69$), respectively. These findings might support the decision to perform ERCP at the index procedure for time-sensitive indications like acute cholangitis if benefits of earlier intervention outweigh the procedural risks. An important finding in our study is that 15-mm stents were associated with significantly higher AE rates compared to 20-mm stents (57.1 % vs 17.6 %, *P*

= 0.03 %). The 15-mm stent group also had double the LAMS migration rate in the 20-mm group but that did not reach statistical significance (35.7 % vs 17.6 %, $P = 0.41$). Because the 15-mm stents were the only stents used before the introduction of the 20-mm stents in the latter half of 2018 and to account for the learning curve, we compared the overall AE rate in the 15-mm stent group before and after the availability of the 20-mm stents and did not find a significant difference (44 % vs 80 %, $P = 0.3$). Similarly, a recent US multicenter study found a higher intraprocedural stent migration rate with 15-mm LAMS compared to 20-mm LAMS in single-stage EDGE [17]. Those researchers also suggested that LAMS dilation and fixation following deployment could also decrease the LAMS migration rate. We believe that our study adds to recent published data that would advocate for wider use of 20-mm LAMS in EDGE procedures. We think that the learning curve might have also played a role in our overall AE rates, as the first half of the procedures had higher AE rates compared to the second half (43.8 % vs 25 %, $P = 0.45$), although that did not reach statistical significance, possibly due underpowering of the study.

The strengths of our study include various technical approaches, procedural indications, and including multiple providers. On the other hand, our study could be underpowered to detect significant differences in certain outcomes among our groups, which is the main limiting factor along with the retrospective study design.

Conclusions

In conclusion, our study supports the high clinical success of EDGE procedures while also highlighting its common AEs. In our series, the 20-mm LAMS offered a significantly lower AE rate than the 15-mm LAMS, which could support wider use. Although our small study could be underpowered, single-stage EDGE procedures were not associated with a significantly higher AE rate, which might support its utilization for time-sensitive indications. Future large multicenter studies are warranted to identify technical factors leading to optimal EDGE procedures.

Competing interests

Dr. Othman is a consultant for Boston Scientific, Olympus Corporation of America, Lumendi, ConMed, Apollo, and AbbVie. Dr. Raijman is a consultant for Boston Scientific Corporation, ConMed, Microtech, Pentax, GI Supplies, Ambu, and co-owner of Endorx. Dr. Abidi is a consultant for ConMed.

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