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Impedance planimetry (EndoFLIPTM) and surgical outcomes after Hill compared to Toupet fundoplication

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Abstract

Introduction Endoluminal functional lumen imaging probe (EndoFLIP) provides a real-time assessment of gastroesophageal junction (GEJ) compliance during fundoplication. Given the limited data on EndoFLIP measurements during the Hill procedure, we investigated the impact of the Hill procedure on GEJ compliance compared to Toupet fundoplication.

Methods Patients who underwent robotic Hill or Toupet fundoplication with intraoperative EndoFLIP between 2017 and 2022 were included. EndoFLIP measurements of the GEJ included cross sectional surface area (CSA), intra-balloon pressure, high pressure zone length (HPZ), distensibility index (DI), and compliance. Subjective reflux symptoms, gastroesophageal reflux disease-health related quality of life (GERD-HRQL) score, and dysphagia score were assessed pre-operatively as well as at short- and longer-term follow-up.

Results One-hundred and fifty-four patients (71.9%) had a Toupet fundoplication while sixty (28%) patients underwent the Hill procedure. The CSA [27.7 ± 10.9 mm^2 vs 42.2 ± 17.8 mm^2, $p < 0.0001$], pressure [29.5 ± 6.2 mmHg vs 33.9 ± 8.5 mmHg, $p = 0.0009$], DI [0.9 ± 0.4 mm^2/mmHg vs 1.3 ± 0.6 mm^2/mmHg, $p = 0.001$], and compliance [25.9 ± 12.8 mm^3/mmHg vs 35.4 ± 13.4 mm^3/mmHg, $p = 0.01$] were lower after the Hill procedure compared to Toupet. However, there was no difference in post-fundoplication HPZ between procedures [Hill: 2.9 ± 0.4 cm, Toupet: 3.1 ± 0.6 cm, $p = 0.15$]. Follow-up showed no significant differences in GERD-HRQL scores, overall dysphagia scores or atypical symptoms between groups ($p > 0.05$).

Conclusion The Hill procedure is as effective to the Toupet fundoplication in surgically treating gastroesophageal reflux disease (GERD) despite the lower CSA, DI, and compliance after the Hill procedure. Both procedures led to DI < 2 mm^2/mmHg with no significant differences in dysphagia reporting (12–24) months after the procedure. Further studies to elucidate a cutoff value for DI for postoperative dysphagia development are still warranted.

Keywords EndoFLIP · The Hill procedure · Toupet · GERD · Impedance planimetry

The Hill fundoplication was first introduced by Dr. Lucius D. Hill in 1967. It is defined as restoration of the gastroesophageal anti-reflux barrier by reducing any hiatal hernia and anchoring the gastroesophageal junction (GEJ) via its normal attachment to the pre-aortic fascia superior to the celiac trunk, thereby re-creating and providing an anatomical reconstruction of the gastroesophageal valve, unique from other types of fundoplication [1, 2]. This firm fixation reduces re-herniation which is the most common cause of failure in anti-reflux surgery. It has been suggested that it does not raise the lower esophageal sphincter pressure, making the procedure appropriate for patients with poor esophageal motility [1, 3].

The Hill fundoplication has been shown to be a highly effective procedure, with a marked improvement in quality of life and freedom from heartburn, regurgitation, and dysphagia at long-term follow-up when compared to the conventional Nissen fundoplication [2–7]. It has been suggested in the literature that partial fundoplication results in less post-operative dysphagia, less gas bloating symptoms,

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and lower reoperation rates compared to Nissen fundoplication [8–10]. However, there are multiple different partial fundoplications, and there is limited understanding of which type of partial fundoplication leads to better control of reflux post-operatively [8].

Endoluminal functional imaging probe (EndoFLIP) is a catheter-based probe with a compliant balloon that can be inflated with saline to a fixed volume that provides a three-dimensional image of esophageal lumen [11, 12]. It has been used to evaluate GERD by evaluating the function of the GEJ [13] and the GEJ distensibility [14]. Recently, EndoFLIP has been proposed as a tool to tailor fundoplication intraoperatively, leading some surgeons to track intraoperative measurements [15–17]. However, there is limited data on EndoFLIP measurements during the Hill procedure in comparison to Nissen and Toupet fundoplication. Hence, the aim of our study was to assess outcomes and to report our experience in performing EndoFLIP during the Hill procedure, comparing these results to those of Toupet fundoplication.

Materials and methods

Data collection

A retrospective review of a prospectively maintained database of patients who underwent an index Hill or Toupet fundoplication with concomitant intraoperative EndoFLIP between October 2017 and August 2022 was performed. Patients who underwent previous fundoplication and those with failed EndoFLIP monitoring intra-operatively were excluded from the study. Baseline patient demographics and preoperative symptomatology including typical and atypical (hoarseness, throat clearing, globus sensation, sore throat, chronic cough, or non-cardiac chest pain) GERD symptoms and the presence of bloat and dysphagia were reported.

The results from pre-operative workup including high-resolution manometry (HRM), barium esophagram, endoscopy (EGD), and pH monitoring with BRAVO (Medtronic, Minneapolis, USA) were recorded. Intra-operative details including the need for Collis esophageal lengthening procedure, crural relaxing incision, and the use of mesh were also collected.

Postoperative typical and atypical GERD symptoms, dysphagia scores, and scores from the Gastro-Esophageal-Reflux Disease-Health-Related Quality of Life (GERD-HRQL) questionnaire, a validated questionnaire consisting of GERD-related questions, scored from 0 (no symptoms) to five (symptoms are incapacitating to daily activity), were obtained at 3–6 months and again at 12–24 months post-surgery. Similarly, patients are encouraged to obtain post-operative barium esophagogram at routine time interval (6, 12, and 24 months) or for recurrent symptoms. The physicians would determine the need for post-operative endoscopy and BRAVO pH monitoring based on findings and symptoms selectively.

Each patient received either Toupet or Hill fundoplication based on patient preference. This study was approved by the Weill Cornell Medicine institutional review board (IRB 19-05,020,206).

Surgical technique

Our technique for robotic ARS had been described previously [18, 19]. All procedures were performed by a single fellowship-trained minimally invasive foregut surgeon at Weill Cornell Medical College/New York-Presbyterian Medical Center, New York, NY utilizing the da Vinci Xl (Intuitive Surgical Inc., Sunnyvale, CA) robot. Fellows and chief residents participated in all procedures performed at this center.

For both procedures, patients were placed supine in a 30-degree reverse Trendelenburg position with arms tucked at the sides and foot boards in place. The trocars were placed in a linear fashion 13 cm inferior to the xiphoid process: two 8-mm ports-each 8 cm apart to the right of midline, one 8-mm port in the midline, and two 8-mm ports each 8 cm apart to the left of midline. A Genzyme liver retractor was used to retract and elevate the left lobe of the liver from the field. First, the gastro-hepatic ligament was divided then the right and left crura were dissected to isolate the esophagus along with the anterior and posterior vagus nerves using Penrose drain. Short gastric vessels were taken if Toupet was performed. The angle of His was identified and esophageal mobilization was pursued until 5 cm of tension-free intra-abdominal length could be obtained. The hiatal hernia was reduced, and diaphragmatic crus were reapproximated using a 3–0 V-Loc suture (Covidien, New Haven, Connecticut) and interrupted 3–0 silk sutures. Phasix ST mesh (Bard, Warwick, RI) and Collis procedure were performed based on surgeon and patient preference and based on the characteristics of the repair. Typically, in patients with weaker diaphragms after hiatal hernia reduction, mesh was employed. In cases of foreshortened esophagus, Collis procedure was performed to ensure adequate intraabdominal esophageal length. These procedure modifications will affect the diaphragmatic repair. However, our aim is to assess the wrap type and its contribution to the compliance of GEJ and EndoFLIP measurements. The Hill procedure was accomplished by pexying the anterior and posterior stomach to the crus complex or to the mesh/crus complex when mesh was employed using silk sutures and ensuring secure fixation of GEJ to its normal intra-abdominal location, Toupet fundoplication was performed with three sutures on either

side of the esophagus to secure the wrap, posterior pexy was then performed by suturing the posterior fundus to inferior crus with three sutures then anterior pexy was performed from the esophagus to the right and left crus.

FLIP planimetry

All patients were assessed using the EndoFLIP™ EF-325N catheter and data was reviewed with FLIP-Analytic software (Crospon, Galway, Ireland). At the distal end of the catheter exists a soft balloon with 16 electrodes placed 5 mm apart through which AC voltage is conducted. This provides an 8-cm-long field for volume-controlled measurements at the level of GEJ.

Our technique for performing EndoFLIP™ during ARS had been previously described [18–20]. For both procedures, all measurements were performed at 10 mmHg intra-abdominal insufflation pressure with 30 mL of conductive solution within the catheter balloon while the patient was positioned in 30° reverse Trendelenburg position. The catheter was placed trans-orally across the GEJ under direct visualization and the balloon was allowed to equilibrate for 45–60 s prior to each measurement, until stabilization of readings on the display. Cross-sectional area (CSA) (mm^2), intra-balloon pressure (mmHg), high pressure zone length (HPZ) (cm), distensibility index (DI) (mm^2/mmHg), and compliance (mm^3/mmHg) were obtained pre-procedure/post-induction, post-hiatal repair, and post-fundoplication.

Clinical follow-up

All patients were scheduled for clinical follow-up within 3 weeks of surgery for their first post-operative visit, again at short-term (3–6 month) and longer-term follow-up (12–24 month) post-operatively. At these time points, patients were evaluated for typical and atypical GERD symptoms, dysphagia, and gas-bloat sensation. Gastroesophageal reflux disease-health related quality of life questionnaire (GERD-HRQL) was distributed at the same time. Dysphagia was interpreted according to Bazaz et al. scoring system [21]. Dysphagia symptoms were classified as no dysphagia (no difficulty swallowing liquid or solids), mild dysphagia (no difficulty swallowing liquids but rare difficulty swallowing solids), moderate dysphagia (no or rare difficulty swallowing liquids, occasional difficulty swallowing specific solid food), or severe dysphagia (no or rare difficulty swallowing liquids but frequent difficulty swallowing solids). Patients were identified as having new or worsening dysphagia if their dysphagia score post-operatively exceeded their score pre-operatively.

Statistical analysis

Statistical analysis was performed using GraphPad Prism Version 9.3.1 (350) (GraphPad software, LLC, San Diego, CA). Continuous variables were described as median with interquartile range or mean ± standard deviation. Categorical variables were described as percentages. Paired t-test was used for normally distributed variables, whereas Mann–Whitney test was used for non-normally distributed variables. Chi-square test was used for categorical variables. Statistical significance was evaluated at the 0.05 alpha level and 95% confidence intervals were computed to assess the precision of the obtained estimates.

Results

Patient demographics

Between October 2017 and August 2022, a total of 214 patients met the inclusion criteria. Among them, 154 patients (71.9%) underwent Toupet fundoplication, and 60 patients (28%) underwent the Hill procedure.

Patients who underwent the Hill procedure were younger (46 ± 16 vs 55 ± 16, $p = 0.0007$) and less likely to have hypertension (10% vs 32.4%, $p = 0.0008$) compared to the group that underwent Toupet. Additionally, the Hill procedure patients had smaller hiatal hernia sizes as measured by pre-operative barium swallow (2.4 ± 0.6 cm vs 5.3 ± 2.3 cm, $p = 0.02$) (Table 1). Notably, Collis gastroplasty (11% vs 0%, $p = 0.001$) and relaxing incision (7.7% vs 0%, $p = 0.02$) were performed only during Toupet fundoplication. Mesh was used more frequently during the Hill procedure (96.6% vs 74%, $p = 0.0002$) (Table 1). Conducting a sub analysis to assess the impact of these factors on outcomes in this subset of patients was not possible due to the limited sample size. Additional larger studies are needed.

Impedance planimetry (EndoFLIP) findings

EndoFLIP measurements from both procedures are shown in Table 2. The CSA [27.7 ± 10.9 mm^2 vs 42.2 ± 17.8 mm^2, $p < 0.0001$], pressure [29.5 ± 6.2 mmHg vs 33.9 ± 8.5 mmHg, $p = 0.0009$], DI [0.9 ± 0.4 mm^2/mmHg vs 1.3 ± 0.6 mm^2/mmHg, $p = 0.001$], and compliance [25.9 ± 0.4 mm^3/mmHg vs 35.4 ± 13.4 mm^3/mmHg, $p < 0.0001$] were lower after the Hill procedure compared to Toupet. There was no difference in post-fundoplication HPZ between procedures [Hill: 2.9 ± 0.4 cm, Toupet: 3.1 ± 0.6 cm, $p = 0.15$].

The median for the mean change in LES parameters at each step of the surgery was assessed (Table 3). The decrease in CSA [− 14.13 IQR (− 12.63, − 15.6) mm^2 vs − 3.6 IQR (− 2.7, − 4.63) mm^2, $p = 0.0005$] and DI

Table 1 Patient pre- and intra-operative characteristics

Subjects (*n*)	Hill (*n* = 60)	Toupet (*n* = 154)	*p*-value
Mean age (years)	46 ± 16	55 ± 16	0.0007
Female, *n* (%)	34 (56.6)	85 (55.1)	0.84
Body mass index (kg/m^2)	25.3 (22.4–28.4)	27.1 (24.3–30.4)	0.07
Race, *n* (%)			
White	39 (65)	101 (65.5)	0.93
Black	2 (3.3)	8 (5.1)	0.56
Hispanic	4 (6.6)	12 (7.7)	0.77
Asian	1 (1.6)	3 (1.9)	0.89
Other	14 (23.3)	30 (19.4)	0.53
Comorbidities, *n* (%)			
Hypertension	6 (10)	50 (32.4)	0.0008
DM	4 (6.6)	17 (11)	0.52
Coronary artery disease	1 (1.6)	13 (8.4)	0.07
Respiratory diseases	12 (20)	19 (12.3)	0.15
GERD-HRQL score	33.5 (20–53.5)	34 (22–55)	0.99
Symptoms, *n* (%)			
Typical	55 (91.6)	140 (90.9)	0.86
Atypical	28 (46.6)	66 (42.8)	0.66
Bloat/gaseous sensation	20 (33.3)	44 (28.5)	0.5
Manometry findings	56 (93.3)	119 (77.2)	0.005
LES length (cm)	2.4 (1.9–3)	2.3 (1.9–2.7)	0.5
LES pressure (mmHg)	24.2 (14.3–33)	18.3 (9.8–30.9)	0.12
Distal contractile integral (mmHg-s-cm)	1404 (786.1–2328)	1180 (478.2–2109)	0.26
BRAVO findings, *n* (%)	55 (91.6)	122 (79.2)	0.04
Percent time in reflux	10.1 (6.6–15.9)	9.5 (5.5–12.9)	0.24
DeMeester score	33.8 (20.9–48.7)	34 (21–46.4)	0.49
Symptom correlation (SAP), *n* (%)	37 (67.2)	69 (54.8)	0.17
Barium swallow, *n* (%)	47 (78.3)	116 (75.3)	0.72
Reflux, *n* (%)	28 (59.5)	54 (46.5)	0.13
Hiatal hernia, *n* (%)	24 (51)	64 (55.1)	0.63
Hiatal hernia size (cm)	2.4 ± 0.6	5.3 ± 2.3	0.02
Dysmotility, *n* (%)	20 (42.5)	39 (33.6)	0.28
Endoscopy Findings, *n* (%)	60 (100)	149 (96.7)	0.32
Esophagitis, *n* (%)	23 (38.3)	61 (40.9)	0.72
Hiatal hernia, *n* (%)	31 (51.6)	95 (63.7)	0.1
Barret's esophagus, *n* (%)	1 (1.6)	7 (4.6)	0.3
Intra-operative characteristics			
Collis procedure, *n* (%)	0 (0)	17 (11)	0.001
Mesh use, *n* (%)	58 (96.6)	114 (74)	0.0002
Relaxing incisions, *n* (%)	0 (0)	12 (7.7)	0.02
Intra-operative HH size	3.5 ± 0.8	3.6 ± 1.2	0.77
Length of stay (days)	1 (0–2)	0 (0–1)	0.44

Values presented as *n* (%), mean ± standard deviation and median (IQR)

LES lower esophageal sphincter

[− 0.62 IQR (− 0.54, − 0.69) mm^2/mmHg vs − 0.41 IQR (− 0.35, − 0.46) mm^2/mmHg, $p = 0.01$] from hiatal hernia closure to post-fundoplication was higher after the Hill procedure, but the increase in pressure was lower [2 IQR (1.97–2) mmHg vs 6.1 IQR (5.8–6.39) mmHg, $p < 0.0001$] compared to Toupet fundoplication.

In both procedures, the majority of the changes in LES parameters occurred as a result of hiatal hernia closure

Table 2 Mean LES parameters through surgery

	Hill	Toupet	*p*-value
Pre-repair			
Cross-sectional area (mm^2)	74.6 ± 37.1	82.9 ± 41	0.18
Pressure (mmHg)	21.9 ± 6	22.4 ± 7.6	0.61
High-pressure zone length (cm)	1.6 ± 0.8	1.5 ± 0.8	0.61
Distensibility (mm^2/mmHg)	3.7 ± 2.1	4.1 ± 2.3	0.22
Compliance (mm^3/mmHg)	91.7 ± 41.9	118.5 ± 63.3	0.01
Post-hiatal closure			
Cross-sectional area (mm^2)	41.8 ± 16.4	45.9 ± 23.6	0.24
Pressure (mmHg)	27.5 ± 6.3	27.8 ± 6.8	0.78
High-pressure zone length (cm)	2.4 ± 0.6	2.5 ± 0.8	0.46
Distensibility (mm^2/mmHg)	1.6 ± 0.7	1.7 ± 0.9	0.45
Compliance (mm^3/mmHg)	44.3 ± 17.9	49.7 ± 20.5	0.18
Post-fundoplication			
Cross-sectional area (mm^2)	27.7 ± 10.9	42.2 ± 17.8	< 0.0001
Pressure (mmHg)	29.5 ± 6.2	33.9 ± 8.5	0.0009
High-pressure zone length (cm)	2.9 ± 0.4	3.1 ± 0.6	0.15
Distensibility (mm^2/mmHg)	0.9 ± 0.4	1.3 ± 0.6	0.001
Compliance (mm^3/mmHg)	29.5 ± 12.8	35.4 ± 13.4	0.01

Values presented as mean ± standard deviation

(Fig. 1). Compared to Toupet fundoplication, the Hill procedure had a significantly higher percent contribution to the change in CSA (30% vs. 9%, $p = 0.04$), DI (25% vs. 14.2%, $p = 0.04$) and compliance (23.7% vs 14.9%, $p = 0.04$) but a lower contribution to pressure change (36.3% vs. 53%, $p = 0.02$) post-LES augmentation.

Surgical outcomes

A higher percentage of patients who underwent the Hill procedure reported new onset or worsening dysphagia (22.5% vs 8.3%, $p = 0.04$) during the short-term follow-up period, that resolved during 12–24 months after surgery (14.2% vs 12%, $p = 0.78$) (Tables 4 and 5).

The results of post-operative barium swallow and EGD showed no significant differences in the rates of hiatal hernia recurrence between the procedures. Similarly, there were no significant differences in the post-operative DeMeester score (Hill: 10.5 (2.1–30.9), Toupet: 4.8 (1.1–18.2), $p = 0.32$) or the percentage of patients with abnormal DeMeester score (25% vs 7%, $p = 0.05$) between the two groups (Table 6).

Discussion

Anti-reflux surgery (ARS) has slowly been transitioning to procedures that provide optimal symptoms relief while mitigating side effects [22]. The Nissen fundoplication, which was deemed the gold standard, has been associated with significant side effects including gas bloat, inability to vomit or burp, and flatulence [22, 23]. Moreover, data supporting similar long-term clinical outcomes for Toupet fundoplication, Hill fundoplication, and LINX have led clinicians to consider these as feasible alternatives [4, 5, 8, 23–25].

Table 3 Mean change in LES parameters through surgery

	Hill	Toupet	*p*-value
Pre-repair to post-hiatal closure			
Cross-sectional surface area (mm^2)	− 32.76 (− 27.39, − 38.14)	− 37 (− 34.13, − 40)	0.29
Pressure (mmHg)	5.6 (5.45, 5.75)	5.33 (5.21, 5.46)	0.07
High-pressure zone (cm)	0.79 (0.73, 0.85)	0.95 (0.93, 0.96)	0.01
Distensibility (mm^2/mmHg)	− 2 (− 1.73, − 2.46)	− 2.43 (− 2.19, − 2.68)	0.25
Compliance (mm^3/mmHg)	− 47.34 (− 40.83, − 53.87)	− 68.72 (− 59.72, − 77.83)	0.1
Post-hiatal closure to post-wrap			
Cross-sectional surface area (mm^2)	− 14.13 (− 12.63, − 15.63)	− 3.67 (− 2.7, − 4.63)	0.0005
Pressure (mm Hg)	2 (1.97, 2)	6.1 (5.8, 6.39)	< 0.0001
High-pressure zone (cm)	0.54 (0.5, 0.58)	0.58 (0.55, 0.6)	0.21
Distensibility (mm^2/mm Hg)	− 0.62 (− 0.54, − 0.69)	− 0.41 (− 0.35, − 0.46)	0.01
Compliance (mm^3/mmHg)	− 14.85 (− 12.57, − 17.14)	− 12.12 (− 11.41, − 12.82)	0.11
Pre-repair to post-wrap			
Cross-sectional surface area (mm^2)	− 46.89 (− 40, − 53.7)	− 40.73 (− 36.73, − 44.64)	0.24
Pressure (mmHg)	7.6 (7.49, 7.72)	11.43 (11.26, 11.6)	< 0.0001
High-pressure zone (cm)	1.33 (1.23, 1.43)	1.53 (1.49, 1.56)	0.03
Distensibility (mm^2/mmHg)	− 2.72 (− 2.27, − 3.16)	− 2.85 (− 2.55, − 3.14)	0.69
Compliance (mm^3/mmHg)	− 62.19 (− 53.4, − 71)	− 83 (− 72.44, − 93.8)	0.1

Values presented as median of mean change (IQR)

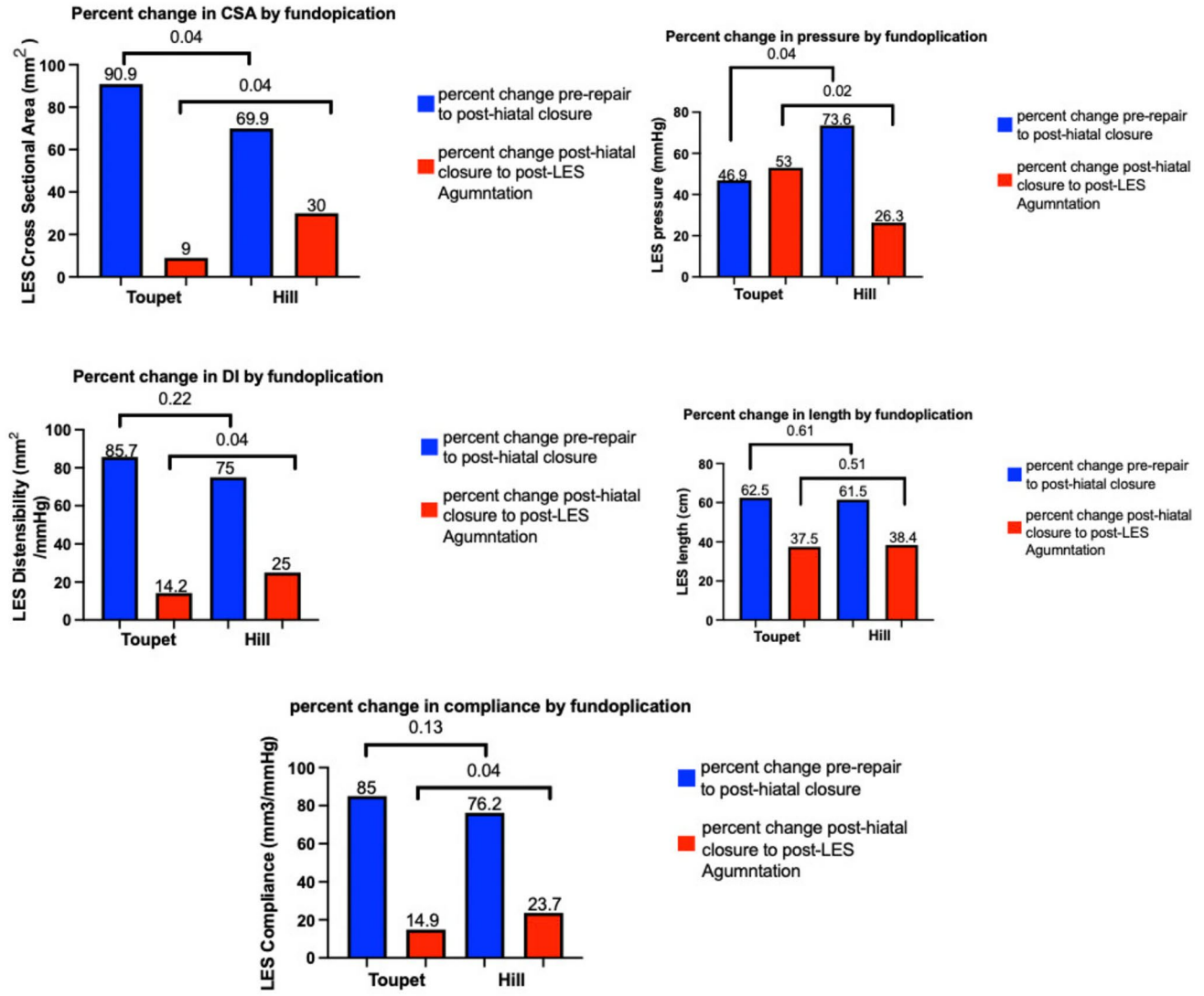

Fig. 1 Percent change in LES parameters through surgery (Hill vs Toupet). *LES* lower esophageal sphincter

In our previous studies, we investigated the sequential changes in FLIP values during ARS in Nissen and Toupet fundoplications. We observed consistent decreases in CSA, DI, and compliance as well as increases in HPZ length regardless if Nissen or Toupet fundoplication was performed. Notably, we also demonstrated that that hiatal hernia repair had the greatest impact on the gastroesophageal junction (GEJ) measurements compared to the wrap step itself [18, 19]. In our current study, we compared the sequential changes in FLIP values during the Hill and Toupet procedures. While both procedures had a similar percentage contribution to the changes in the GEJ parameters after hiatus closure, we found that the Hill procedure had a greater influence on decreasing DI (25% vs 14.2%, $p = 0.04$) and compliance (23.7% vs 14.9%, $p = 0.04$) during the augmentation of the lower esophageal sphincter (LES). As a result, the final values of DI and compliance were significantly lower in the Hill procedure compared to Toupet fundoplication. This observation suggests that each fundoplication technique may have a varying effect on FLIP values and GEJ characteristics.

The lower DI after the Hill procedure likely led to increased incidence of short-term dysphagia in this subset of patients which was found to resolve one to two years after surgery. This finding is consistent with prior studies that indicated a correlation [16, 26, 27]. Interestingly, contrary to prior studies that correlated the final DI value and the occurrence of post-operative dysphagia, suggesting final DI < 2 mm^2/mmHg is a predictor of increased dysphagia [16], our current study indicates that both procedures result in lower DI (< 2 mm^2/mmHg) without any significant differences in dysphagia development during two-years follow-up.

Table 4 Typical, atypical symptoms and GERD-HRQL post-operatively

	Hill	Toupet	*p*-value
Preoperative, *n* (%)	*n* = 60	*n* = 154	
Heartburn	49 (81.6)	110 (71.4)	0.12
Regurgitation	35 (58.3)	94 (61)	0.75
Bloat/gas	19 (31.6)	44 (28.5)	0.65
Atypical	28 (46.6)	66 (42.8)	0.66
GERD-HRQL	33.5 (20–53.5)	34 (22–55)	0.93
(3–6) month follow-up, *n* (%)	*n* = 40 (66.6)	*n* = 106 (68.8)	
Heartburn	5 (12.5)	19 (17.4)	0.61
Regurgitation	2 (5)	5 (4.5)	> 0.999
Bloat/gas	5 (12.3)	15 (14.1)	> 0.999
Atypical	10 (25)	16 (14.6)	0.22
GERD-HRQL	3 (2–6)	7 (3–9)	0.06
(12–24) month follow-up, *n* (%)	*n* = 42 (70)	*n* = 108 (70.1)	
Heartburn	7 (16.6)	20 (18.5)	> 0.999
Regurgitation	7 (16.6)	13 (12)	0.43
Bloat/gas	5 (11.9)	22 (20.3)	0.34
Atypical	11 (26.1)	14 (12.9)	0.08
GERD-HRQL	3 (0–5)	4 (2–9)	0.5

Values presented as *n* (%) or median (IQR)

Table 5 Dysphagia rate post-operatively

	Hill	Toupet	*p*-value
Pre-operative	*n* = 60	*n* = 154	
Dysphagia	21 (35)	71 (46.1)	0.12
Mild	4 (19)	25 (35.2)	0.16
Moderate	12 (57.1)	35 (49.2)	0.52
Severe	5 (23.8)	11 (15.4)	0.37
(3–6) month follow-up, *n* (%)	*n* = 40 (66.6)	*n* = 106 (68.8)	
Dysphagia (any)	12 (30)	25 (23.5)	0.52
Mild	6 (50)	14 (56)	> 0.999
Moderate	6 (50)	11 (44)	> 0.999
Severe	0 (0)	0 (0)	> 0.999
New onset/worsening dysphagia	9 (22.5)	9 (8.3)	0.04
(12–24) month follow-up, *n* (%)	*n* = 42 (70)	*n* = 108 (70.1)	
Dysphagia (any)	9 (21.4)	21 (19.4)	0.82
Mild	7 (77.7)	14 (66.6)	0.32
Moderate	2 (22.2)	8 (38)	0.67
Severe	0 (0)	0 (0)	> 0.999
New onset/worsening dysphagia	6 (14.2)	13 (12)	0.78

Values presented as n (%)

This aligns with other studies that have shown post-fundoplication DI values typically around 1 mm^2/mmHg, was associated with favorable symptom resolution after surgery [28]. The rational for this longer duration of dysphagia resolution in the Hill procedure requires further investigation and likely is related to the differences in these two techniques and their respective effects on the LES compliance. Although, in this study, we were unable to establish an absolute value for DI for dysphagia postoperatively. Further studies are required to better elucidate a correlation and its potential impact on long-term dysphagia is warranted.

Patients with typical and atypical symptoms had significant symptomatic improvement compared to pre-operative levels highlighting the effectiveness of these procedures in the management of reflux. Clearly, patients who underwent either procedure had improvement in their GERD-HRQL score throughout the follow-up period. However, this improvement in the GERD-HRQL score was not influenced by their final DI values, which aligns with findings from other studies that have reported no correlation between the final DI and the GERD-HRQL score [16, 29]. This may be attributed to the technique employed in ARS, where the restoration of the normal intra-abdominal position of the GEJ plays a more critical role in creating an effective anti-reflux barrier. As a result, it can reduce the reporting of typical symptoms associated with GERD, regardless of the final GEJ distensibility [16]. Additionally, upon evaluating the objective recurrence of GERD, we observed no significant differences in the DeMeester score or the recurrence of reflux or hiatal hernia as determined by the barium swallow after either procedure. These findings further support the notion that the Hill procedure represents a favorable option for the surgical treatment of GERD and maybe like Toupet fundoplication.

There are several limitations associated with this study. First, all procedures were performed by one robotically trained foregut surgeon and further studies among multiple centers may be important to confirm validity and adoption of technique. Additionally, the assessment of post-operative outcomes relied solely on GERD HQRL score, dysphagia scores, and barium swallow results, but did not include pH testing or endoscopy unless clinically indicated which would further determine surgical success. This could explain the insignificantly higher percentage of Hill patients with abnormal DeMeester score compared to those who underwent Toupet fundoplication (25% vs 7%, $p = 0.05$) likely due to small sample size of symptomatic patients who underwent BRAVO. However, this was not the primary aim of this study. Further larger-scale studies are warranted. These limitations should be taken into consideration when interpreting the findings of this study.

Our study shows that the Hill procedure is as effective to the Toupet fundoplication in surgically treating

Table 6 Post-operative test results

	Hill	Toupet	*p*-value
Barium swallow, *n* (%)	43 (71.6)	113 (73.3)	0.86
Reflux	6 (13.9)	14 (12.3)	0.79
Dysmotility	22 (51.1)	56 (49.5)	> 0.999
Delayed emptying	8 (18.6)	30 (26.5)	0.4
Hiatal hernia	6 (13.9)	9 (7.9)	0.36
Mean Hiatal hernia size	1.9 ± 0.6	3.4 ± 0.8	0.002
Median time to barium swallow, (months)	5.3 (2.5–7.4)	6.2 (2.5–9.1)	0.36
EGD, *n* (%)	24 (40)	56 (36.3)	0.63
Hiatal hernia	2 (8.3)	6 (10.7)	> 0.999
BRAVO findings	14 (58.3)	25 (44.6)	0.33
Median DeMeester score	10.5 (2.1–30.9)	4.8 (1.1–18.2)	0.32
Abnormal DeMeester score	6 (25)	4 (7.1)	0.05
Median time to endoscopy, (months)	7.9 (4.2–14.6)	8.4 (4.4–17.2)	0.91
Re-operation	4 (6.6)	5 (3.2)	0.27

Values presented as n (%), mean ± SD and median (IQR)

gastroesophageal reflux disease (GERD), despite the differing effects of each fundoplication on intraoperative measurements of GEJ's CSA, DI, and compliance. We observed no significant differences in the resolution of typical and atypical symptoms, and GERD-HRQL score between the two procedures. The lower CSA and DI during the Hill procedure appears to contribute to the increased risk of short-term (3–6 months) dysphagia, which appears to resolve within 12–24 months. Notably, both procedures led to final DI of less than 2 mm^2/mmHg with no significant differences in dysphagia two years after surgery suggesting the need to establish an absolute DI value for dysphagia development postoperatively. Clinicians may consider discussing these short-term risks with patients electing to proceed with the Hill procedure pre-operatively. Further studies to elucidate the subgroup that had short-term dysphagia are warranted.

Declarations

Disclosures Dr. Rasa Zarnegar works as a consultant for Bard (BD) and Intuitive/Medtronic. Drs. Hala Al Asadi, Haythem Najah, Rodrigo Edelmuth, Jacques A. Greenberg, Teagan Marshall, Niloufar Salehi, Yeon Joo Lee, Maria Cristina Riascos, Brendan M. Finnerty, Thomas J. Fahey III have no conflicts of interest or financial ties to disclose.

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