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Impedance planimetry (EndoFLIP™) reveals changes in gastroesophageal junction compliance during fundoplication

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Abstract

Introduction Compliance is the ability of a hollow organ to dilate and increase volume with an increase in pressure, an accurate representation of food bolus transit through the gastroesophageal junction (GEJ). Impedance planimetry system can calculate compliance (change in volume over pressure) and distensibility (cross-sectional area over pressure) of the GEJ. We aim to describe the changes in compliance during anti-reflux surgery and hypothesize that compliance is a better predictor of patient outcomes than distensibility (DI).

Methods and procedures A review of a prospectively maintained quality database was performed. Patients with FLIP measurements during laparoscopic fundoplication between August 2018 and June 2021 were included. GEJ compliance and DI were measured after hernia reduction, cruroplasty, and fundoplication. Patient-reported outcomes were collected through standardized surveys up to 2 years after surgery. A scatter plot was used to identify a correlation between compliance and DI. Comparisons of measurements between time points were made using paired *t*-tests. Spearman's correlation coefficients (ρ), Wilcoxon rank-sum, and chi-square tests were used to evaluate associations between measurements and outcomes.

Results One hundred and forty-four patients underwent laparoscopic fundoplication. Compliance is strongly associated with DI ($r = 0.96$), and a comparison of measurements showed similar trends at specific time points during the operation. After hernia reduction, compliance at the GEJ was 168 ± 74 mm^3/mmHg, cruroplasty 79 ± 39 mm^3/mmHg, and fundoplication 90 ± 33 mm^3/mmHg (all comparisons $p < 0.05$). GEJ compliance of 80–92 mm^3/mmHg after fundoplication was associated with the best patient-reported outcome scores. A compliance of ≤ 79 mm^3/mmHg had the highest percentage of patients who reported dysphagia.

Conclusions Compliance and DI are strongly associated displaying the same directional change during anti-reflux surgery. GEJ compliance of 80–92 mm^3/mmHg revealed the best patient-reported outcome scores, and avoiding a compliance ≤ 79 mm^3/mmHg may prevent postoperative dysphagia. Therefore, GEJ compliance is an underutilized FLIP measurement warranting further investigation.

Keywords EndoFLIP · Impedance planimetry · Fundoplication · GERD · Outcomes

Laparoscopic fundoplication is the surgical management for medical refractory GERD [1–3]. However, patients are hesitant to undergo surgery due to concerns of postoperative side effects. These side effects may be due to an overly tight fundoplication leading to gas-bloat and dysphagia or persistent dysphagia requiring dilation or reoperation. Surgeons continue to modify operative techniques to enhance the patient's postoperative quality of life. These techniques include a partial versus complete fundoplication, shorter wrap around the esophagus, creating a fundoplication over different bougie sizes, or mobilization of fundus for a wrap without undue tension [1, 4].

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The endoluminal functional lumen imaging probe (EndoFLIP™) impedance planimetry system can quantify the effects of gastroesophageal junction (GEJ) modification. Recent literature included objective measurements of the GEJ after each critical step in anti-reflux surgery. These measurements, such as the distensibility of the restored GEJ, have been correlated to patient outcome [5–7]. The cross-sectional area (CSA) of multiple planes at the GEJ is defined through volumetric distension of a catheter balloon, which allows for the calculation of the distensibility index as the minimum CSA divided by the balloon pressure. The FLIP system can challenge the GEJ through intraluminal distension allowing for measurement and calculation of compliance by dividing the change in volume over the intraluminal pressure one centimeter above and below the minimum diameter [8–10]. Therefore, compliance within this context is the ability of a hollow organ to dilate and increase in volume with an increase in pressure, an accurate representation of food bolus transit or reflux through the GEJ. We describe our institutional experience in utilizing impedance planimetry to observe the changes in GEJ compliance during anti-reflux surgery and hypothesize that GEJ compliance is a better predictor of patient outcomes than the distensibility index (DI).

Methods

Data collection

An institutional review board approved study utilizing a prospectively maintained quality database was queried for all patients undergoing laparoscopic fundoplication and FLIP evaluation between August 2018 and June 2021. Research fellows prospectively maintain the database by collecting clinical data on patients who present to our clinic with gastroesophageal chief complaints. Clinical data includes preoperative (e.g., demographics, symptomatology), perioperative (e.g., intraoperative complications, blood loss), and postoperative data (e.g., follow-up visits, readmission rates).

Operative protocol

Before laparoscopic fundoplication, all patients completed a comprehensive esophageal work-up, which included an esophagram or CT scan, manometry, acid-reflux testing (impedance or BRAVO study, unless the patient had a symptomatic paraesophageal hernia), and upper endoscopy.

Our practice utilizes manometry and FLIP to decide which fundoplication a patient will receive. A patient will receive a Nissen fundoplication after demonstrating normal motility (peristalsis > 80% along with no hypercontractile disorders such as Diffuse Esophageal Spasm or Jackhammer Esophagus based on Chicago Classification v3.0) and a distensibility index of greater than 7.0 mm^2/mmHg after hernia reduction, otherwise a Toupet fundoplication is performed. A single surgeon performed all fundoplications within this study.

The operation starts with the hiatal dissection leading to the reduction of the hiatal hernia, then the crura are approximated with permanent sutures. Paraesophageal hernias are repaired with a biochemical mesh in a rectangular configuration that is placed posteriorly and secured with three permanent sutures into a horizontal mattress closure. The FLIP balloon or a bougie (52 to 60 French) is carefully inserted through the GEJ under laparoscopic vision before creating the wrap. For a Nissen fundoplication, the posterior fundus was tacked to the crus, and apical stitches are placed between the esophagus and fundus bilaterally. Three interrupted permanent sutures, each grasping a partial-thickness bite of the esophagus while preserving both vagus nerves results in a floppy fundoplication. Then permanent suture is used for the posterior gastropexy to the median arcuate ligament for both fundoplications. Toupet fundoplication begins with two coronal sutures incorporating fundus, crus, and the esophagus and are placed bilaterally with permanent sutures. Four additional sutures, two on each side, are placed about a centimeter inferior to each other incorporating fundus and esophagus.

FLIP system and protocol

The EndoFLIP system comprises (EF-100, Medtronic) of a 240 cm long catheter with a 3 mm outer diameter along with 17 impedance planimetry electrode sensors that span a distance of 8 cm (EF-325 catheter) at regular 5 mm intervals. Measurements were recorded after hernia reduction, crural closure, and fundoplication, this included: minimum diameter (D_{min}), cross-sectional area (CSA), intra-balloon pressure, and distensibility index (DI). DI is calculated by dividing the minimum CSA over the peak balloon pressure. We adhered to recently published intraoperative FLIP protocols and analyzed the 40 mL balloon fill without pneumoperitoneum measurement [11, 12]. Video data were acquired from each operation and available for post hoc analysis with the FLIP-Analytic software (Crospon, Galway, Ireland).

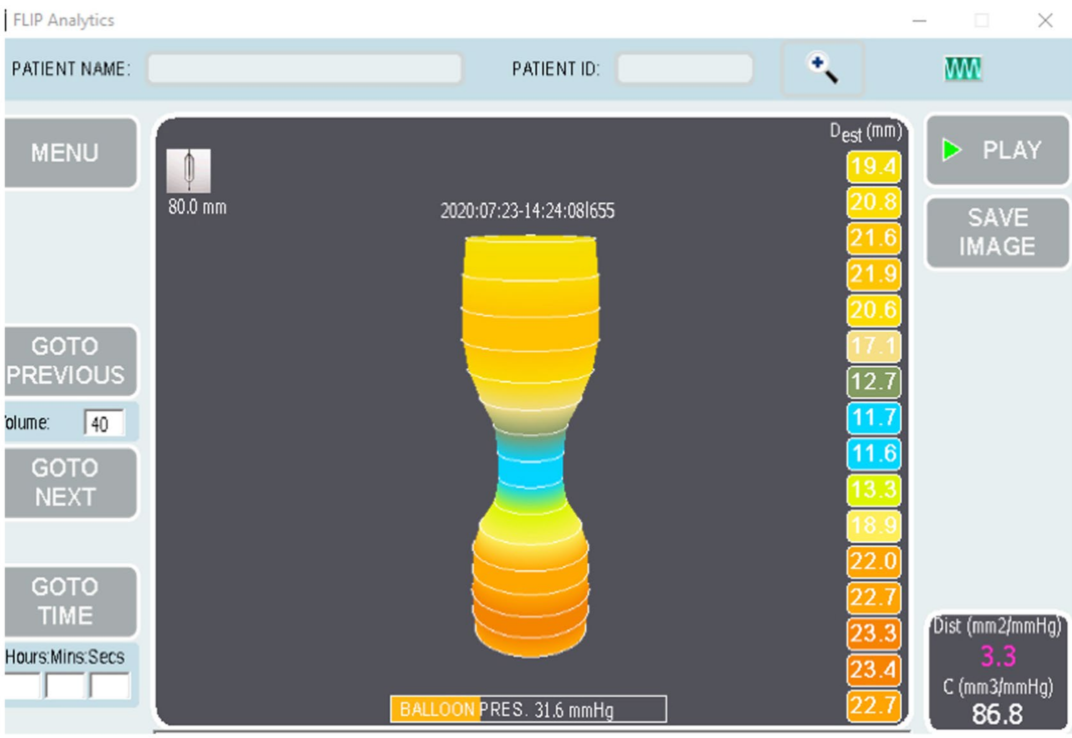
FLIP GEJ compliance calculation

After the catheter is appropriately placed, straddling the GEJ, the real-time hourglass image will display on the FLIP interface. The FLIP system will calculate compliance by dividing change in volume over change in pressure. Volume of a cylinder is calculated as $V = \pi r^2 h$ (r = radius, h = height). The FLIP system recognizes the volume of a cylinder being created by five selected electrodes, with the center electrode as the minimum diameter, so four 5 mm segments (in the EF-325 catheter) are included in the calculation. The mean diameter of each segmental plane is first computed, so the mean radius can be identified, then volume can be calculated. Each segment will have a corresponding volume, $V = \pi r_{mean}^{2} h_{segment}$, where the sum of each segmental volume is the total volume to be used in the compliance computation (Fig. 1). Compliance (mm^3/mmHg) = total volume/balloon pressure. Manual calculation is required when compliance is not displayed on the FLIP interface due to the balloon not being centered on the GEJ or low balloon pressure.

Clinical follow-up

All patients return for follow-up within three weeks after the operation. Quality of life questionnaires are distributed in person or electronically at three weeks, 6 months, 1 year, and 2 years. The questionnaires include the Reflux Symptom Index (RSI), Gastroesophageal Reflux Disease-Health Related Quality of Life Questionnaire (GERD-HRQL), and Dysphagia Score. RSI assesses for "atypical" reflux symptoms such as asthma, cough, laryngitis, or globus sensation. An RSI score > 13 represents severe reflux [13]. The GERD-HRQL evaluates for "typical" reflux symptoms, such as heartburn or regurgitation [14]. In general, a higher QOL score indicates worse symptomatic disease. The gas-bloat score is extrapolated from the GERD-HRQL question #7, the response range from a

(a)



(b)

Dest (mm)	Dmean (mm)	Segment Volumes (SV, mm^3) = $\Pi r^2 h$
12.7	12.2	584.492
11.7	11.65	532.980
11.6	12.45	608.692
13.3	16.1	1017.914
18.9		Compliance (mm^3/mmHg) = sum of SV ÷ balloon pressure
BP (mmHg) = 31.6		**86.837**

Dest (estimated diameter, mm), Dmean (average diameter of segment), BP (balloon pressure), SV (segment volumes), r (radius of mean diameter, mm), h (height of segment, 5 mm)

Fig. 1 **a** FLIP system calculation of compliance, **b** manual calculation of compliance score of 0 (no symptoms) to 5 (symptoms are incapacitating). Dysphagia score measures the severity of dysphagia on a five-point scale from 1 (I am able to eat a normal diet/no dysphagia) to 5 (I am unable to swallow anything/total dysphagia). Questionnaire responses are recorded in a prospectively maintained quality database.

Statistical analysis

Descriptive statistics were used to summarize the results, including mean with standard deviation, median with interquartile range, and frequency with percentage. Spearman's correlation coefficients were used to describe the association between compliance and DI. Comparisons of measurements between time points were made using paired t-tests. Wilcoxon rank-sum and chi-square tests were used to evaluate associations between FLIP measurements and outcomes. Receiver operating characteristic (ROC) curves, with dichotomized one and 2-year QOL scores, were used to find optimal upper and lower cutoff values for determining an ideal range for compliance. RSI greater than 13 was used to select an upper cutoff and Dysphagia Score > 1 was used to select a lower cutoff. The optimal cutoffs were selected based on the smallest distance form where sensitivity (SENS) and specificity (SPEC) equal one. All statistical analysis was performed using SAS 9.4 (SAS Institute, Cary, NC) with two-tailed tests and statistical significance set at $p < 0.05$.

Results

Patient demographics

Between August 2018 and June 2021, 144 patients underwent laparoscopic fundoplication and had FLIP evaluation. Patients received laparoscopic Nissen fundoplication or Toupet fundoplication (22% vs 78%, respectively). Indications for surgery included GERD and/or paraesophageal hernia. All fundoplications were created over a bougie, a traditional stiff bougie was used for 64% while the FLIP catheter was used as a bougie in 36% of the cases. Patient preoperative, perioperative, and postoperative details are shown in Table 1.

GEJ compliance and DI has the same directional change during fundoplication

Compliance of the GEJ had a strong, positive association with DI ($r = 0.96$, $p < 0.001$, Fig. 2). This was seen in the total cohort along with subgroup analyses of Nissen and Toupet patients. Therefore, the higher the compliance, the higher the distensibility index and vice versa. Upon comparing compliance and DI at all time points during the operation, both measurements display similar trends. The highest values for DI and compliance were after hernia reduction. Both DI and compliance decreased to their lowest values after crural closure, then slightly increased after fundoplication (Table 2). This trend is apparent when separating the group into Nissen and Toupet fundoplication. Each subsequent change in DI or compliance between the different time points in the operation was statistically significant. The DI and compliance after Nissen and Toupet fundoplication do not differ between procedures (Table 2).

Nissen patients have a larger DI and compliance change from hernia reduction to fundoplication than Toupet patients due to a larger DI and compliance at hernia reduction. The

Table 1 Patient demographics

Total patients, *N*	144
Age, years [mean ± SD]	68 ± 12
Body mass index [mean ± SD]	29.5 ± 4.1
Male [*N* (%)]	53 (36.8)
Current or former smoker [*N* (%)]	61 (42.4)
ASA class 3 or 4 [*N* (%)]	67 (46.5)
Dysmotility [*N* (%)]	53 (36.8)
Hiatal hernia type [*N* (%)]	
None	35 (24.3)
I	21 (14.6)
II	1 (0.7)
III	82 (56.9)
IV	5 (3.5)
Operating room time, min [mean ± SD]	127 ± 32
Estimated blood loss, ml [median (Q1–Q3)]	10 (5–20)
Fundoplication TYPE [*N* (%)]	
Nissen	32 (22.2)
Toupet	112 (77.8)
Bougie-assisted [*N* (%)]	93 (64.6)
Mesh use [*N* (%)]	89 (61.8)
Intraoperative complication [*N* (%)]	2 (1.4)
Length of stay, days [median (Q1–Q3)]	1 (1–1)
Pain at discharge, VAS [median (Q1–Q3)]	1 (0–3)
Medication stopped, days [median (Q1–Q3)]	2 (1–3)
Return to activities of daily living, days [median (Q1–Q3)]	4 (3–7)
30 day mortality [*N* (%)]	0 (0.0)
30 day complication [*N* (%)]	8 (5.6)
30 day emergency department visit [*N* (%)]	13 (9.0)
30 day readmission [*N* (%)]	10 (6.9)
Off proton pump inhibitor [*N* (%)] (*N* = 125)	112 (89.6)
Follow-up, months [median (Q1–Q3)]	5 (1–16)

Dysmotility (esophageal peristalsis < 80% along with hypercontractile disorder such as Diffuse Esophageal Spasm, or Jackhammer Esophagus based on Chicago Classification v3.0)

SD standard deviation, *ASA* American Society of Anesthesiologists, *VSA* visual analog scale

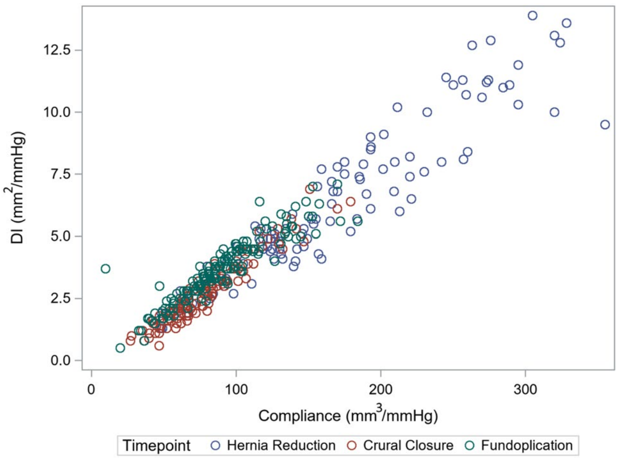


Fig. 2 Scatter plot of DI and compliance—strong association ($r = 0.958$, $p < 0.0001$)

percentage change of DI from hernia reduction to fundoplication in the total cohort show that DI decreased by a mean of 33 ± 35% compared to a larger decrease in compliance of 39 ± 27% ($p < 0.0001$). This difference was seen in Toupet patients (27 ± 35 versus 34 ± 27, percentage decrease of DI versus compliance, $p < 0.0001$), however not in Nissen patients (58 ± 16 versus 58 ± 16, $p = 0.59$). The percent reduction for DI (27 ± 35 versus 58 ± 16, $p < 0.0001$) and Compliance (34 ± 27 versus 58 ± 16, $p = 0.0001$) are significantly different between Toupet and Nissen, respectively (Table 2).

Impedance planimetry suggests a potential ideal compliance range after fundoplication for good patient outcomes

ROC curves identified compliance values of 80 (SENS = 67%, SPEC = 65%) and 92 (SENS = 54%, SPEC = 61%) as optimal cutoffs to define an ideal range where postoperative symptoms of dysphagia and reflux were both low. Patients were separated into three groups, compliance of ≤ 79, 80–92, and ≥ 93 mm³/mmHg (low, ideal, high compliance). At 1-year follow-up, patients in the ideal group reported the lowest RSI, GERD-HRQL, and gas-bloat score compared to the other two groups (Table 3). These patients had better symptomatic control of their atypical and typical GERD symptoms after fundoplication, however, these differences were not seen upon 2-year follow-up. The tight compliance group had the highest rate of dysphagia out of the three groups at one or 2-year follow-up (low 21.4% vs. ideal 8.3% vs. high 6.5%, $p = 0.199$), however this was not shown to be statistically significant.

An analysis of compliance after each type of fundoplication showed potential compliance thresholds that were associated with patient-reported outcomes. For Nissen

Table 2 FLIP measurements of all fundoplications

	All Mean ± SD	Nissen Mean ± SD	Toupet Mean ± SD	*p*-Value Nissen vs. Toupet
Hernia reduction	*N* = 119	*N* = 22	*N* = 97	
DI	6.5 ± 3.3	8.7 ± 2.7	6.0 ± 3.2	< 0.001
Compliance	168 ± 74	204 ± 64	160 ± 74	0.009
Crural closure	*N* = 134	*N* = 30	*N* = 104	–
DI	2.8 ± 1.3[a]	3.5 ± 1.5[a]	2.6 ± 1.2[a]	0.005
Compliance	79 ± 39[a]	92 ± 33[a]	75 ± 26[a]	0.009
Fundoplication	*N* = 144	*N* = 32	*N* = 112	–
DI	3.7 ± 1.3[a,b]	3.6 ± 1.3[a]	3.7 ± 1.3[a,b]	0.459
Compliance	90 ± 33[a,b]	86 ± 0 [a]	92 ± 33[a,b]	0.350
Change from hernia reduction to fundoplication	*N* = 119	*N* = 22	*N* = 97	–
DI	−2.8 ± 3.2	−5.3 ± 2.3	−2.3 ± 3.1	< 0.001
Compliance	−78 ± 70	−124 ± 61	−68 ± 68	< 0.001
Percentage decrease from hernia reduction to fundoplication		*N* = 22	*N* = 97	
DI		58 ± 16	27 ± 35[c]	
Compliance		58 ± 16	34 ± 27[c]	

Compliance (mm³/mmHg), distensibility index (mm²/mmHg)

[a] *p*-value vs. hernia reduction, $p < 0.001$

[b] *p*-value vs. crural closure, $p < 0.001$

[c] Significant difference percentage change of hernia reduction to fundoplication between DI and compliance, $p < 0.001$

Table 3 Quality of life by fundoplication compliance

	All	Compliance at fundoplication			*p*-Value
		≤ 79	80–92	≥ 93	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Preop	*N* = 80	*N* = 32	*N* = 10	*N* = 38	
RSI	17.0 ± 10.6	19.6 ± 10.5	12.2 ± 10.4	16.0 ± 10.4	0.104
GERD-HRQL	14.1 ± 9.6	15.6 ± 11.0	10.9 ± 8.3	13.4 ± 8.6	0.422
Gas/bloat	2.0 ± 1.4	2.1 ± 1.3	2.7 ± 1.7	1.7 ± 1.4	0.114
Dysphagia score	1.3 ± 0.8	1.4 ± 0.8	1.4 ± 1.0	1.2 ± 0.8	0.240
1 year	*N* = 48	*N* = 15	*N* = 9	*N* = 24	
RSI	6.7 ± 7.0	6.7 ± 6.4	1.8 ± 1.6	8.6 ± 7.8	0.014[a,b]
GERD-HRQL	3.7 ± 3.5	4.7 ± 4.3	1.2 ± 1.4	4 ± 3.2	0.019[a,b]
Gas/bloat	1.8 ± 1.1	2.1 ± 1.1	0.9 ± 0.9	2.0 ± 0.9	0.015[a,b]
Dysphagia score	1.1 ± 0.4	1.2 ± 0.4	1.1 ± 0.3	1.1 ± 0.4	0.605
2 years	*N* = 37	*N* = 16	*N* = 7	*N* = 14	
RSI	6.6 ± 7.8	7.5 ± 9.2	6.0 ± 7.6	5.8 ± 6.7	0.938
GERD-HRQL	3.4 ± 3.8	4.5 ± 4.7	4.1 ± 4.3	1.8 ± 1.8	0.383
Gas/bloat	1.5 ± 1.3	1.6 ± 1.3	2.1 ± 1.9	1.1 ± 1.1	0.408
Dysphagia score	1.1 ± 0.3	1.2 ± 0.4	1.0 ± 0.0	1.0 ± 0.0	0.124

SD standard deviation, *RSI* Reflux Symptom Index, *GERD-HRQL* Gastroesophageal Reflux Disease-Health Related Quality of Life

[a] ≤ 79 vs. 80–92 $p < 0.05$

[b] ≥ 93 vs. 80–92 $p < 0.05$

fundoplication, a compliance of ≥ 100 mm^3/mmHg ($N = 4$) at the GEJ led to a better GERD-HRQL (1.3 ± 1.0 versus 5.8 ± 4.4, $p = 0.045$) and gas-bloat score (1.0 ± 0.8 versus 2.5 ± 1.2, $p = 0.040$) compared to a compliance of < 100 mm^3/mmHg ($N = 10$) upon 2-year follow-up. GEJ compliance of ≥ 100 mm^3/mmHg after Nissen fundoplication had better symptomatic control of GERD. Patients reported a higher dysphagia score when the GEJ compliance was < 52 ($N = 2$) compared to ≥ 52 mm^3/mmHg ($N = 12$) (1.5 ± 0.7 versus 1.0 ± 0.0, respectively, $p = 0.014$). Compliance of ≥ 52 mm^3/mmHg may avoid postoperative dysphagia after Nissen fundoplication. For Toupet fundoplication, patients reported a worse RSI score when the GEJ compliance was ≥ 93 ($N = 20$) compared to < 93 mm^3/mmHg ($N = 19$) (9.5 ± 8.3 versus 4.4 ± 5.9, respectively, $p = 0.023$). Toupet patients had worse control of atypical GERD symptoms when the GEJ compliance was ≥ 93 mm^3/mmHg.

Discussion

Patients with GERD have an incompetent sphincter due to inappropriate transient relaxation, permanent relaxation, or increased intra-abdominal pressure. Flow through the GEJ is proportional to the opening radius to the fourth power. A change in the GEJ diameter can have a profound impact on the amount of acid-reflux into the esophagus. A fundoplication aims to restore the anti-reflux barrier by decreasing this diameter, however postoperative dysphagia continues to plague patients after surgery. A short and floppy fundoplication continues to be the technique echoed in operating rooms across the world based on work by DeMeester et al. [1] Impedance planimetry through the use of EndoFLIP is a recent technology that can objectively measure the effects of fundoplication on the GEJ.

FLIP can calculate the “tightness” of the GEJ, known as the distensibility index, before and after anti-reflux surgery. The distensibility index is calculated by dividing the minimum CSA over the intra-balloon pressure. This quantitative value has provided surgeons an opportunity to reflect on how to fine-tune critical steps in anti-reflux surgery with the goal of optimizing patient outcomes. Su et al. proposed an ideal final DI range for good outcomes between 2 and 3.5 mm^2/mmHg at 30 mL balloon fill. After 1 year, patients with a final DI < 2.0 mm^2/mmHg reported significantly more gas-bloat and dysphagia [12]. Turner et al. reported that a decrease in the minimum diameter of the GEJ less than 0.15 mm or a decrease in CSA less than 1.5 mm^2 at 30 mL balloon fill correlated with severe heartburn symptoms 6 or more months following surgery [6]. Both studies demonstrate the utility of intraoperative impedance planimetry in quantifying the tightness of the lower esophageal sphincter, even though study methodologies differed. A 2013 consensus collected data from multiple institutions and reported a small study that showed compliance decreasing from crural repair to fundoplication, these measurements were reported at 30 mL balloon fill with pneumoperitoneum [10]. The current study follows an updated consensus intraoperative FLIP protocol and incorporates patients from previous published work [5, 11]. Compliance during anti-reflux surgery was categorized into different ranges associated with patient outcomes.

There are subtle differences between compliance and the distensibility of a hollow organ. In this context, distensibility refers to the intrinsic elastic properties of the GEJ, and compliance reflects the buffering function of the hollow walled organ. GEJ compliance can be measured with FLIP, as the catheter balloon inflates the surrounding area increases in volume with an increase in pressure, simulating food bolus transit or reflux in real-time. Measuring compliance would better our understanding of how the GEJ functions. Since the distensibility index is computed from a single plane, the minimum CSA, and compliance from several segments above and below the minimum CSA, we hypothesized that compliance would be a better predictor of postoperative outcomes.

Our study found that compliance and distensibility are strongly associated with each other ($r = 0.96$), in a sense providing similar information through different biomechanical interpretations. The distensibility index provides an objective measure of GEJ tightness, while compliance represents the GEJ's ability to accommodate passage of food, liquid, or gas. Compliance and DI followed the same trends throughout an anti-reflux operation. Therefore, if the DI is increased, so was compliance and vice versa. So a tighter lower esophageal sphincter is also a stiffer one, and a loose sphincter is a more compliant one. Peak DI and compliance values were after hernia reduction and trough values after crural closure, then slightly increased after fundoplication. These trends were similar when each type of fundoplication was analyzed separately.

Patients who received a Nissen fundoplication had a DI greater than seven after hiatal dissection due to our operative protocol. This explains the larger decrease in DI and compliance from hernia reduction to crural closure and hernia reduction to fundoplication when comparing Nissen and Toupet patients. However, both groups demonstrated the same decreasing trend in DI and compliance. The percentage reduction of DI and compliance from hernia reduction to fundoplication in Nissen patients were similar. However, the percentage change of compliance from hernia reduction to fundoplication was significantly larger compared to percentage change in DI for Toupet patients. We would expect a similar percentage reduction in DI and compliance given their strong association. This may be the result of the different anatomical configurations of the differing fundoplications. In the patients selected to have a Nissen fundoplication, DI and compliance after hernia reduction are significantly higher, representing a looser and highly compliant sphincter. A 360° wrap employs the fundus for more GEJ coverage, remaining taut, dramatically reducing DI and compliance, a mean reduction of approximately two times compared to a 270° wrap. The lower esophageal sphincter pressure is significantly increased after a Nissen fundoplication, which can represent a tighter and stiffer sphincter [4]. As a result, venting of swallowed air may be difficult, even though final measurements were similar to Toupet fundoplications. The reduction in transient lower esophageal relaxation in Nissen compared to Toupet alters gastric belching patterns, leading to some patients having supragastric belching in a futile attempt to vent the stomach [15]. With that said, impedance planimetry is a quantitative platform to understand the biomechanical properties of the GEJ while considering the differing types of fundoplications.

Analyzing both types of fundoplication together revealed a possible ideal compliance range within our study. The ideal range had the lowest patient-reported outcome scores after 1 year follow-up, so these patients reported the best symptomatic control of their GERD symptoms after fundoplication. Also, the low compliance group had the highest percentage of patients with dysphagia at one or 2-year follow-up. However, this finding was not statistically significant. One would expect a more compliant GEJ would have a lower gas-bloat score. However, our data does not show that the patients with the highest compliance have lower gas-bloat. This may be due to combining Nissen and Toupet patients in the analysis. The cohort had a majority of patients who had a Toupet fundoplication. Also, Toupet fundoplication has been shown to have decreased gas-bloat syndrome [4]. Therefore, we recognize that even though impedance planimetry provided insightful information, it needs to be applied in a specific context. This led to separate small subgroup analyses of compliance in Nissen and Toupet fundoplication separately to patient outcomes, each had specific thresholds for different postoperative quality life scores. Nissen patients with a GEJ compliance of ≥ 100 mm^3/mmHg had less gas-bloat syndrome and better symptomatic control of GERD. GEJ compliance of ≥ 52 mm^3/mmHg is suggested to avoid postoperative dysphagia. In Toupet patients, a GEJ compliance of ≥ 93 mm^3/mmHg had worse control of atypical GERD symptoms. Our analysis did not reveal one measurement being a better predictor of patient outcomes over the other. Therefore, we currently suggest that compliance data be considered supplemental to the distensibility index when assessing the effectiveness of an anti-reflux operation.

There are several limitations to our study. First, this is a single institution review of a prospectively maintained database with a small group of patients. We believe that the continued collection of patient outcomes and FLIP data will result in more refined compliance ranges that predict patient outcomes. Second, the FLIP system did not compute all compliance values, so post hoc analysis and computation were done by hand as outlined in the methods. A research fellow is in each case collecting FLIP measurements, however due to catheter malfunction, inexperience of fellow, or loss of data, values may not be recorded after hernia reduction or crural closure. There is typically time at the end of the case to ensure collection of fundoplication measurements. Third, our surgical practice selectively performs Nissen fundoplication due to Toupet fundoplication achieving adequate symptomatic control of GERD along with decreased postoperative side effects [4]. This is the basis of our protocol as we continue to study the differences between each fundoplication. As a result, there is a majority of Toupet fundoplications in our cohort, which may inadvertently affect our analysis. All fundoplications in our study were created over a bougie per our operative protocol, which resulted in slight dilation of the lower esophageal sphincter and increase in DI and compliance after fundoplication. Therefore, our results may not be generalizable due to the difference in operative technique. Finally, there is a lack of objective data in GERD resolution, such as postoperative acid monitoring or endoscopy, unless clinically indicated.

Conclusion

GEJ compliance and DI are strongly associated with each other and follow similar trends through an anti-reflux operation. When analyzing Nissen and Toupet fundoplication together, GEJ compliance of 80–92 mm^3/mmHg revealed the best patient-reported outcome scores, and avoiding a compliance ≤ 79 mm^3/mmHg may prevent postoperative dysphagia. Compliance is an underutilized FLIP measurement warranting further investigation during anti-reflux surgery.

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Declarations

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