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The impact of pneumoperitoneum on esophagogastric junction distensibility during anti-reflux surgery

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Abstract

Objective We aimed to quantify the contribution of pneumoperitoneum on compliance of the esophagogastric junction (EGJ) during anti-reflux surgery.

Background Compliance of the EGJ is reduced with anti-reflux surgery. EndoFLIP® planimetry can be used to assess dynamic changes of EGJ compliance intraoperatively. It is unclear how pneumoperitoneum impacts intraoperative measurements by EndoFLIP® and the implications thereof on validity of the results. Therefore, determining variability in EndoFLIP® measurements based on pneumoperitoneum is warranted to establish guidelines to interpret clinical outcomes.

Methods Primary anti-reflux surgery was performed on 39 consecutive patients with pathologic reflux. Intraoperative EGJ measurements including distensibility index (DI), cross-sectional area (CSA), and intrabag pressure were collected using EndoFLIP® at 0, 10, and 15 mmHg of intraperitoneal pressure. Data were acquired pre-procedure, post-hiatal hernia repair, and post-LES augmentation with fundoplications.

Results Patients underwent Nissen (13.2%), Toupet (68.4%), LINX (10.5%), or Hill-fundoplications (7.9%). There was no difference between 0 and 10 mmHg of pneumoperitoneum in CSA, pressure, or DI measurements pre-procedure; however, there was a difference between 0 and 15 mmHg in pressure ($p=0.016$) and DI ($p=0.023$) measurements. After LES augmentation, 10 mmHg intraperitoneal pressure reduced DI, though the absolute difference is small (2.0 vs. 1.5 mm^2/mmHg, $p=0.002$).

Conclusion Pneumoperitoneum affected EGJ distensibility at 15 mmHg, but not 10 mmHg, of insufflation prior to anti-reflux procedures. After anti-reflux surgery, there was a significant variance between 0 and 10 mmHg of pneumoperitoneum in pressure and distensibility. The change in pressure appears linear and needs to be considered if procedural modifications are performed based on intraoperative findings and when evaluating clinical outcomes.

Keywords EndoFLIP · Impedance planimetry · Pneumoperitoneum · Distensibility · GERD

Gastroesophageal reflux disease (GERD) is a symptom of increased compliance of the esophagogastric junction (EGJ) [1]. Functional lumen imaging probe (FLIP) measures compliance using impedance planimetry, a dynamic technique that combines measurements of resistance to balloon distention with geometric reconstruction. Distensibility of the esophagogastric junction has been correlated with compliance [2]. Increased compliance of the EGJ, in the case of GERD, means its ability to resist backflow is impaired [3]. It is modulated by multiple physiologic mechanisms, including strength of the diaphragmatic crura, displacement of the LES, pressures in the abdominal and thoracic cavity, as well as drugs and lifestyle factors (i.e., obesity, smoking, and body posture) [4–8]. Anti-reflux surgery decreases compliance of the EGJ and is one possible mechanism for prevention of reflux [9]. Other explanations for reduction of reflux after anti-reflux procedures include repositioning of the LES intra-abdominally and creation of a flap-valve [10].

FLIP planimetry for esophageal disorders has been extensively studied as an adjunct to high-resolution

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manometry (HRM) to allow for improved differentiation of incongruent symptomology and diagnostic studies [11]. The dynamic evaluation of the EGJ for cross-sectional area has also been shown not to require collaboration of the patient, therefore calibration during breathing and swallowing are not essential and anesthesia is permissible [12]. As the role of FLIP planimetry has evolved, the dynamic evaluation of the EGJ during anti-reflux surgery has been explored to determine characteristics that could guide clinicians in real-time to reduce postoperative long-term dysphagia from a "tight EGJ" or persistent reflux from a "loose EGJ". FLIP provides a numerical measurement of EGJ distensibility as the ratio of cross-sectional area to pressure and is a reproducible method of quantifying EGJ compliance [1].

Normal values of esophageal distensibility in healthy volunteers during endoscopy have reported a median EGJ distensibility index (DI) of 5.8 mm^2/mmHg, with none of these volunteers having a DI less than 2.8 mm^2/mmHg, using a 16 cm FLIP and a median balloon fill volume of 60 mL [13]. Pneumoperitoneum for conventional laparoscopic procedures has shown to reduce cross-sectional area (CSA) and pressure at the EGJ, and a significant decrease in DI and therefore compliance [14]. That study, however, reports a median DI of 1.4 mm^2/mmHg using balloon fill volumes of 30 and 40 mL in patients without reported subjective reflux symptoms. Other studies have set a DI of 2.0 mm^2/mmHg as a target to reduce postoperative dysphagia and bloating at 0 mmHg intra-abdominal pressure. However, there are potential limitations to these findings, including the need to drop pneumoperitoneum to 0 mmHg intraoperatively, as well as the small number of patients in the follow-up period. Moreover, standardized questionaries used in the study have shown no difference in patients based on final DI. As such, there is controversy on target DI during anti-reflux with no consensus on the appropriate normative values or the intra-abdominal pressure for FLIP planimetry [15, 16]. This leads to difficulty adopting real-time feedback from FLIP planimetry intraoperatively, due to unclear guidelines. The contribution of pneumoperitoneum to calculations of DI may falsely reassure a surgeon that the wrap is adequate when it may not have reached the target range.

Although pneumoperitoneum can change EGJ distensibility, there is scant evidence on the extent of its influence intraoperatively and the consequences on the applicability of the results obtained across different pneumoperitoneum pressures. We aimed to determine the impact of these varying levels on FLIP planimetry of the EGJ during anti-reflux procedure. We built an ex vivo experimental model to understand contribution of pneumoperitoneum on FLIP measurement exclusive of patient-dependent factors.

Methods

FLIP planimetry

The EndoFLIP® EF-325N catheter was used for this study, with the EndoFLIP II system (Medtronic's, Minneapolis, MN). This catheter has a soft balloon at the distal end, with 16 electrodes spaced 5 mm apart, to provide an 8-cm-long image field for volume-controlled measurements. The catheter was utilized to measure minimum cross-sectional area (CSA_{min}) (mm^2) and pressure (mmHg) of the EGJ across a voltage gradient in a cylindrical balloon after distention with 30 mL of balanced saline solution. Distensibility is calculated as a function of minimum CSA/ pressure and defined as mm^2/mmHg. Catheter was calibrated and zeroed to atmospheric pressure prior to use.

Experimental model

To understand the underlying mechanics of insufflation and its effects on the variance of EndoFLIP measurements, we developed a distensible closed system to mimic the abdominal cavity (Fig. 1). This model was connected to a conventional insufflation system (Karl-Storz, Tuttlingen, Germany) using a 12 mm laparoscopic trocar. The EndoFLIP 325 catheter was introduced into the closed system via a laparoscopic port. Different rigid and soft tubes, mimicking the EGJ, with lengths up to 3.4 cm and of varying cross-sectional areas, were placed in the center of EndoFLIP catheter to obtain an hourglass image. The EndoFLIP catheter was inflated to 30 cc and allowed to stabilize for 60 s. Chamber pressure was increased from 0 to 15 mmHg at 5 mmHg increments. CSA_{min} and balloon pressures were recorded at each

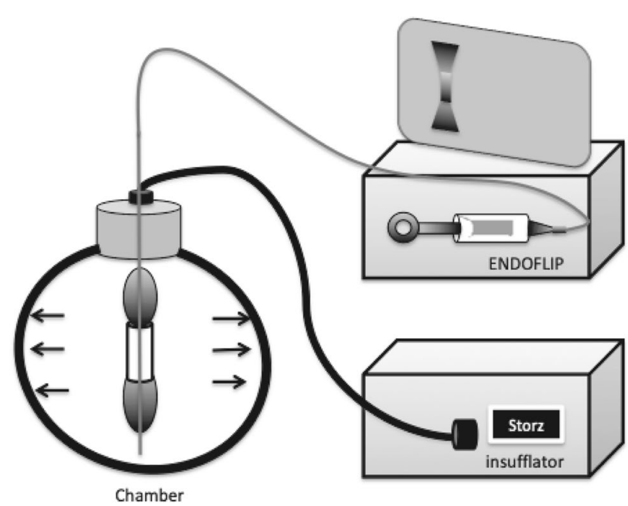

Fig. 1 Schematic diagram of ex vivo experimental model

insufflation pressure. Distensibility was calculated based on these variables.

Clinical method

This is a retrospective review of a prospectively maintained database of consecutive patients who underwent robotic-assisted hiatal hernia repair with biosynthetic mesh and sphincter augmentation between April 2019 and March 2020. All data were collected under an Institutional Review Board approved protocol. We included all patients that had EGJ distensibility assessed using EndoFLIP® with measurements taken in real-time at 0, 10, and 15 mmHg pre-procedure, prior to any manipulation of the EGJ. Procedures were tailored to the preoperative HRM, presence of bloating, and patient preference and they included: Nissen, Toupet, Hill, and magnetic (LINX) sphincter augmentation. Patients had FLIP planimetry evaluation at three key steps: pre-procedure, post-hiatal hernia repair, and post sphincter augmentation. Exclusion criteria were based on availability of the EndoFLIP® catheters and system, failure of data acquisition post hoc, and patients that we could not perform all the parameters at all time-points.

Data pertaining to baseline demographics, symptoms, co-morbidities, and indications for surgery were collected. Type of sphincter augmentation, length of stay, and readmission rates were documented. Detailed history, endoscopy, esophageal manometry, esophagram, and BRAVO pH probe monitoring (Given Imaging, Yokneam, Israel) or pH impedance studies were also included as part of diagnostic evaluation.

All procedures were performed at a tertiary academic medical center: New York-Presbyterian Hospital/Weill Cornell Medicine. The procedures were all performed on the da Vinci Xi System (Intuitive Surgical Inc., Sunnyvale, CA) by one foregut surgeon (RZ). The technique utilized for robotic anti-reflux surgery at our institution was previously described [17]. The intraperitoneal pressure was maintained using Airseal (ConMED, Utica, NY) for all procedures. The LINX procedure was always performed in conjunction with hiatal hernia repair and placed anterior to the posterior vagus.

The EndoFLIP® catheter was placed transorally across the EGJ after general anesthesia and patient positioning in 30-degree reverse Trendelenburg. During the procedure, anesthesia maintained continuous skeletal paralysis using TOF-Watch® monitor and all measurements were taken in the same position. Ventilation was not held for measurements. The catheter was inflated and position confirmed by identification of an hourglass image on the EndoFLIP® display and visual feedback on the robotic display. The EGJ was identified as narrowest cross-sectional area and centered on the display for subsequent readings, thereby correlating with the hourglass image. The balloon was inflated for 45–60 s until stabilization of readings on the display. Representative still images of the EndoFLIP® measurements were acquired and stored for comparison of each key step: pre-procedure, post-hiatal repair and crural closure, and post-LES augmentation. Separate measurements were acquired and stored at intraperitoneal pressures of 0, 10, and 15 mmHg. During the procedure, the insufflation was fully evacuated for 0 mmHg readings. All measurements were allowed to equilibrate prior to recording and based on our prior study [18].

Post-procedurally, the data were acquired with FLIP-Analytic software (Crospon, Galway, Ireland). Measurements of CSA_{min} and pressure were collected for each key step at 0 and 10 mmHg of intraperitoneal pressure. Pre-repair data at the start of the case were collected at 0, 10, and 15 mmHg. The DI was calculated based on these measurements.

Data were analyzed with statistical software (GraphPad Prism 0.3.0). Continuous variables are described as mean or median with 95%-confidence intervals. Categorical variables are described as percentages. Paired *t* test was used for intragroup bivariate analysis for normally distributed variables. For intergroup comparison, a Mann–Whitney test was performed. Linear regression was performed where applicable. All of the analyses were considered statistically significant at a two-tailed p value of < 0.05.

Results

There were 103 patients that underwent anti-reflux surgery between April 2019 and March 2020. Of these, 39 patients met inclusion criteria and had pre-repair FLIP planimetry at 0, 10, and 15 mmHg. The majority of patients were female (64.1%) and white (69.2%) (Table 1). Patients had subjective symptoms of GERD, with regurgitation (71.8%) and heartburn (87.2%) being the most common. Most patients also had pathological reflux on pH monitoring with an average DeMeester score of 33 (normal < 14.72). Patients underwent Nissen (13.2%), Toupet (68.4%), LINX (10.5%) or Hill (7.9%) as part of sphincter augmentation for anti-reflux surgery.

We compared FLIP planimetry at intraperitoneal pressures of 0, 10 and 15 mmHg pre-repair (Table 2). There was no difference in minimum cross-sectional area (CSA_{min}) measurements as intraperitoneal pressures increased (Fig. 2a). Significant differences were only observed in pressure and DI between 0 and 15, but not between 0 and 10 mmHg (Fig. 2B, C). At 15 mmHg of insufflation, EGJ median pressure increased from 20 to 25 mmHg ($p = 0.016$) and median DI decreased from 5.7 to 4.1 mm^2/mmHg ($p = 0.023$).

Sixteen patients had FLIP planimetry performed at key steps in the procedure at 0 and 10 mmHg of pneumoperitoneum and all had underwent Toupet fundoplications.

Table 1 Characteristics of 39 study patients including demographics, GERD symptoms, co-morbidities and procedure details

Characteristics	$N = 39$
Female	64.1% (25)
Age (years)	51.4 (21–89)
BMI	26.7 (19.3–35.84)
Race	
White	69.2% (27)
Hispanic	12.8% (5)
African American	7.7% (3)
Other	5.1% (2)
Asian	2.6% (1)
Unknown	2.6% (1)
Duration of symptoms (years)	8.5 (0.3–30)
Regurgitation	71.8% (28)
Heartburn	87.2% (34)
Bloating	17.9% (7)
Atypical	28.2% (11)
GERD score	35.4 (5–71)
DeMeester score	33.0 (2.6–69.3)
Co-morbidities	
Diabetes mellitus	15.3% (6)
Hypertension	28.2% (11)
Coronary artery disease	7.6% (3)
Fundoplication type	
Nissen	13.2% (5)
Toupet	68.4% (27)
LINX	10.5% (4)
Hill	7.9% (3)
Intra-abdominal length (cm)	3.75 (3–5)
Collis	5.1% (2)
Relaxing incisions	5.1% (2)
Length of stay (days)	0.83 (0–2)
Readmission 30 day	5.1% (2)

Means values are calculated and ranges are included where applicable

We performed subgroup analysis on these patients comparing effect of insufflation pre-repair, after hiatal hernia repair, and after sphincter augmentation (Table 3). Again, we found no difference in CSA_{min} between 0 and 10 mmHg among all stages of the procedure (Fig. 3A), consistent with the larger dataset. There was a significant increase in EGJ pressure due to increased pneumoperitoneum after hiatal hernia repair and sphincter augmentation. Compared to no insufflation, EGJ intrabag pressure at 10 mmHg insufflation increased from 24.5 to 30.4 mmHg ($p = 0.0005$) after hiatal hernia repair, and from 29.3 to 35.5 mmHg ($p = 0.002$) after sphincter augmentation (Fig. 3B). This change in EGJ pressure, however, translated to small changes in DI. After hiatal hernia repair, there was no statistically significant change with pneumoperitoneum (2.9 vs. 2.4 mm^2/mmHg, $p = 0.25$) (Fig. 3C). However, after sphincter augmentation, there was statistical difference between 0 and 10 mmHg of intraperitoneal pressure (2.0 vs. 1.5 mm^2/mmHg, $p = 0.002$), though the absolute change was small.

To explain the differences in we observed in intrabag pressure measurements throughout the operation, we created an ex vivo system. Different diameters of rigid and soft tubes were tested in a closed chamber with increasing insufflation pressures up to 15 mmHg. Minimum cross-sectional area ranged from 55 to 143 mm^2. EndoFLIP intrabag pressures increased linearly with increasing insufflation pressures in the chamber across all material and diameter (Fig. 4). The linear relationship of the intrabag pressure and pneumoperitoneum can be simplified as $P_x = x + P_0$ mmHg, where P is intrabag pressure and x is the intraperitoneal pressure based on insufflation. In other words, for every 1 mmHg increase in intraperitoneal pressure, the intrabag pressure reading also increased by 1 mmHg.

We compared our clinical findings with our experimental model. The intrabag pressures that we obtained intraoperatively had a similar linear relationship, but the slope was only half that of our ex vivo model (slope = 0.52 vs. 0.98) (Fig. 5A) and increased when we considered only the values obtained post-hiatal hernia repair (slope = 0.66). Interestingly, the slope approached that of our ex vivo model further along in the procedure (Fig. 5B). We noted that DI did not have a linear relationship to pneumoperitoneum (Fig. 5C), likely due to the fact that CSA_{min} did not change throughout the anti-reflux operation.

Table 2 Mean values, confidence intervals and p values of minimum cross-sectional area (CSA), intrabag pressure and distensibility index (DI) measurements at intraperitoneal pressures of 0, 10 and 15 mmHg at the beginning of anti-reflux procedure

	CSA (mm^2)			Pressure (mmHg)			DI (mm^2/mmHg)		
Intraperitoneal pressure (mmHg)	0	10	15	0	10	15	0	10	15
Mean	91	93	89	20	21	25	5.7	4.9	4.1
Confidence interval	(75, 108)	(77, 108)	(73, 106)	(17, 22)	(19, 23)	(22, 27)	(4.3, 7.1)	(3.9, 5.8)	(3.2, 5)
p value		0.96	0.92		0.48	0.016		0.19	0.023

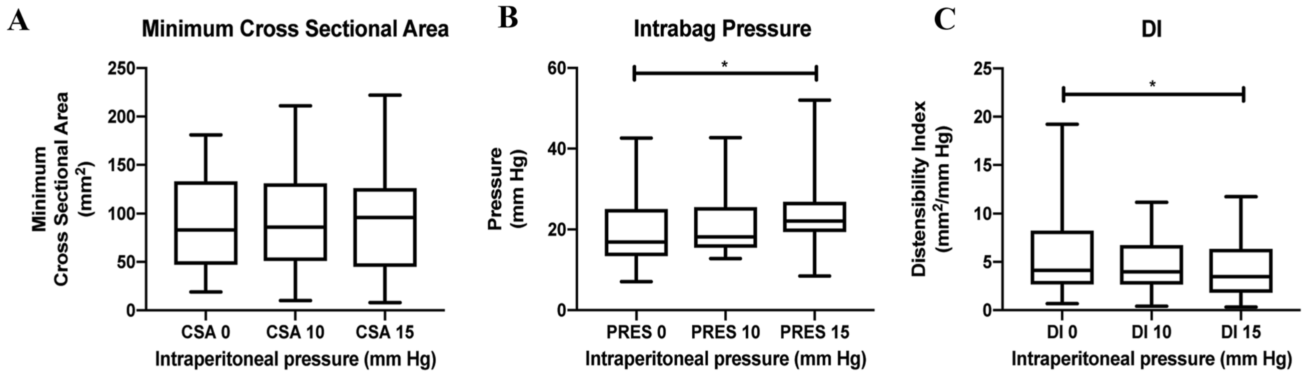

Fig. 2 Measurement of **A** minimum cross-sectional area (CSA), **B** intrabag pressure and **C** distensibility index (DI) at intraperitoneal pressures of 0, 10 and 15 mmHg. Bars denote median values with SEM. Mann–Whitney test was performed among groups where *p* values < 0.05 were considered statistically significant (*)

Table 3 Mean values, confidence intervals and *p* values of minimum cross-sectional area (CSA), intrabag pressure and distensibility index (DI) measurements at intraperitoneal pressures of 0 and 10 mmHg during indicated steps of anti-reflux procedure

	0 mmHg	10 mmHg	*p* value
CSA (mm²)			
Pre-procedure	106.1 (80.6, 131.6)	103.1 (81.3, 124.8)	0.52
Hiatal hernia	73.1 (54.1, 92.2)	68.6 (54.7. 82.4)	0.25
Wrap	56.1 (48.8, 63.3)	54.1 (46.3, 61.8)	0.36
Pressure (mmHg)			
Pre-procedure	21.9 (16.8, 27.1)	23.3 (19.2, 27.5)	0.37
Hiatal hernia	24.5 (20.3, 28.7)	30.4 (26.9, 34)	0.0005
Wrap	29.3 (25.6, 33.1)	35.5 (33.2, 37.7)	0.002
DI (mm²/mmHg)			
Pre-procedure	6 (4.1, 8)	5 (3.6, 6.4)	0.06
Hiatal hernia	2.9 (2, 3.8)	2.4 (1.8, 3)	0.25
Wrap	2 (1.7, 2.4)	1.5 (1.3, 1.8)	0.002

Discussion

We characterized the impact of pneumoperitoneum on EGJ distensibility using FLIP planimetry during anti-reflux procedures. Prior to repair, there was no difference in CSA_{min}, pressure, or distensibility between 0 and 10 mmHg of pneumoperitoneum. However, there was a significant increase in pressure and decrease in distensibility when pneumoperitoneum was increased to 15 mmHg, consistent with previous data [16]. During the procedure, there was no difference in CSA_{min} between 0 and 10 mmHg of insufflation. However, there was a significant increase in pressure measured with 10 mmHg of pneumoperitoneum post-hiatal hernia repair and post sphincter augmentation. These changes contributed to a significant decrease in distensibility with sphincter augmentation. Based on our experimental model and clinical correlates, the changes in observed EndoFLIP pressure are linear and dependent on insufflation pressure. Although there was no observed difference in pressure between 0 and 10 mmHg pre-procedure (in both our main and subgroup

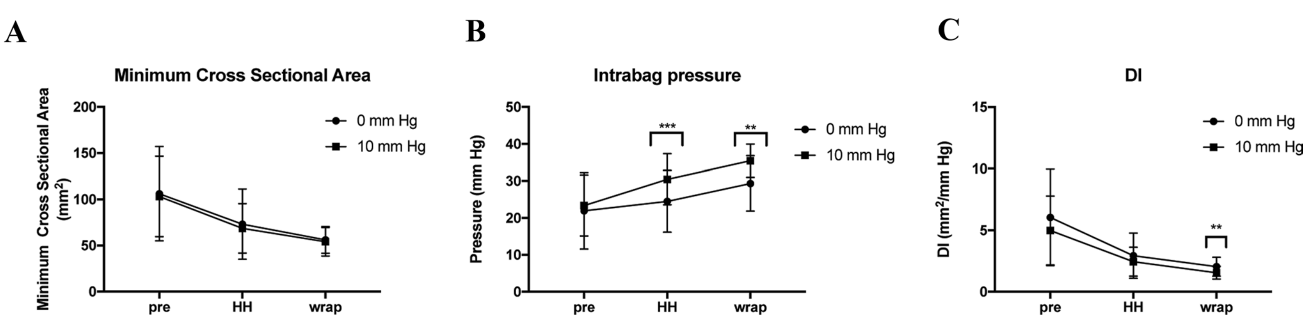

Fig. 3 Measurement of **A** minimum cross-sectional area (CSA), **B** intrabag pressure and **C** distensibility index (DI) at intraperitoneal pressures of 0 and 10 mmHg pre-procedure (pre), after hiatal hernia repair (HH) or post fundoplication (wrap). Error bars denote mean values with SEM. Pair *t* test was performed comparing 0 and 10 mmHg, where *p* values <0.05 (*), <0.001 (**), <0.0001 (***) were considered statistically significant

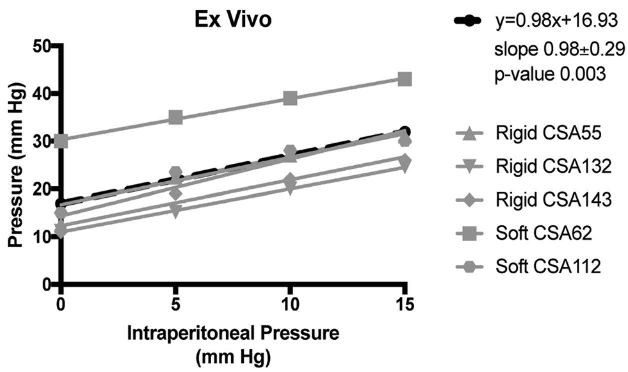

Fig. 4 Linear regression of intraperitoneal pressure against FLIP intrabag pressure measurements using an ex vivo model from (Fig. 1). Four insufflation pressures were used (0, 5, 10 and 15 mmHg). FLIP was inflated across rigid and soft tubing of various diameters with corresponding CSA listed

analyses), there was significant difference after hiatal hernia repair. One potential explanation is that prior to repair, the EGJ is displaced intrathoracically. This location most likely exposes the EndoFLIP® catheter to positive pressure ventilation, and as such, intraperitoneal pressure may not have a significant impact at lower insufflation pressures. However, with mobilization of the EGJ intra-abdominally as the procedure progressed, the slope of the pressure change curves approached that of our ex vivo model. Almost all of the patients in our analysis had a documented hiatal hernia; however, the size of hernia varied across diagnostic modalities (barium swallow, endoscopy, manometry) and precluded more detailed subgroup analysis on its contribution to the impact of pneumoperitoneum.

It is interesting that there was no significant change in CSA_{min} across 0, 10 and 15 mmHg of insufflation or between 0 and 10 mmHg during all steps of the procedure. This suggests that CSA_{min} may reflect an anatomic measurement that is independent of intraperitoneal pressure. Our median preoperative CSA_{min} (89 mm^2) is consistent with prior studies [1]. These findings are contrary to a prior study that showed that CSA_{min} decreased with 13 mmHg of pneumoperitoneum during routine laparoscopic surgeries such as appendectomy and cholecystectomy [14]. These differences may be attributed to the techniques used as patient positions could alter the EGJ position and as such the CSA_{min} [19]. Our study was performed in 30-degree reverse Trendelenburg without variations in positioning for all measurements.

Intrabag balloon pressure is significantly influenced by intra-abdominal pressure and increases in a linear fashion

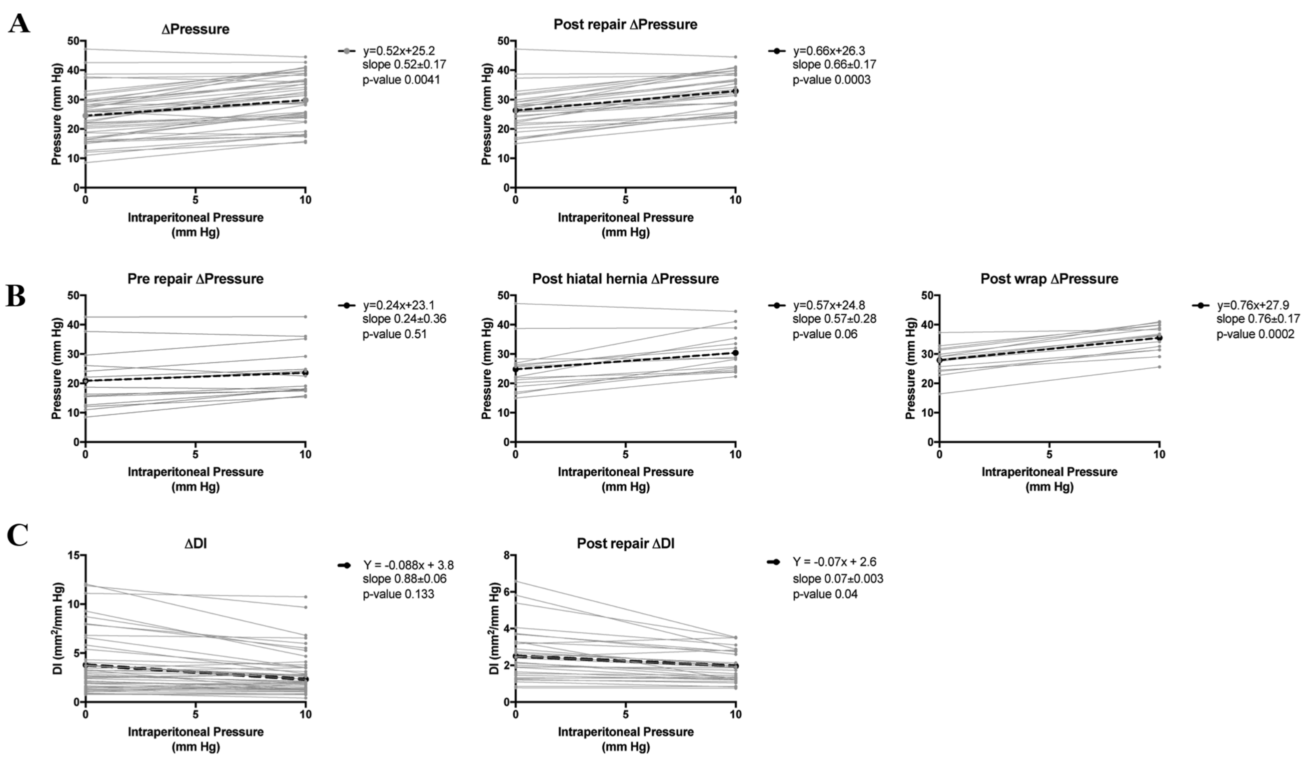

Fig. 5 **A** Linear regression of intraperitoneal pressure (0 and 10 mmHg) and FLIP intrabag pressure measurements all of steps of the procedure, post-repair, and **B** separated by steps of the anti-reflux procedure. P values were calculated by comparing slope to 0. **C** Linear regression of intraperitoneal pressure (0 and 10 mmHg) and distensibility index (DI) measurements all of steps of the procedure, post-repair

with increasing pneumoperitoneum. Both the experimental model and clinical findings confirm these findings. Prior studies that evaluated pneumoperitoneum noted not only a decrease in CSA but also in pressure, which is not consistent with our findings. These differences, similar to the changes identified in CSA, are most likely associated with technique and positioning, rather than reflecting a direct correlation. Changes in CSA and pressure have been observed based on position; however, these findings are in small series and larger standardized studies are required to better elucidate position and planimetry changes at the EGJ [14, 19].

Distensibility after anti-reflux surgery (1.3–2.4 $mm^2/mmHg$) in our study is comparable to the median DI reported for patients without reflux symptoms undergoing laparoscopy (1.4 $mm^2/mmHg$) [14]. Similar to the data from routine laparoscopy, we show a significant difference in EGJ distensibility with pneumoperitoneum after anti-reflux surgery. While this difference is significant, the absolute value of the change is small (0.5 $mm^2/mmHg$), which is reflective of the fact that CSA_{min} is unchanged but pressure significantly increases. Since distensibility may predict one component of a successful repair, a difference of 0.5 $mm^2/mmHg$ may not be substantial clinically if the pre-repair DI is 5–6 $mm^2/mmHg$ and post-repair DI is 1.3–2.4 $mm^2/mmHg$. Target ranges for distensibility are important to potentially reduce the incidence of dysphagia long-term and improve clinical outcomes. Some studies have considered a range of 2.0–3.5 $mm^2/mmHg$ to provide optimal results but these studies did not show a significant difference during follow-up based on the dysphagia score established by the study [15]. Moreover, these datasets are too small to draw significant clinical conclusions. By establishing a linear relationship for pressure and as such a correlation to distensibility, our study attempts to provide ranges of values that could be standardized based on pneumoperitoneum and at 30-degree Trendelenburg, a typical angle for anti-reflux procedures. With such values, real-time clinical applications of EndoFLIP® can become feasible during anti-reflux surgery.

There are some limitations to this study. First, we evaluated FLIP planimetry in real-time and during anti-reflux surgery. Therefore, all procedures were performed at 30-degree Trendelenburg using a robotic platform and may not correlate with flat position. Although some studies have flattened patients to establish difference this approach would be difficult using the robotic platform that is been increasingly utilized by surgeons when performing these procedures [19]. More studies will be required to assess the role of position on measurements. Given that clinicians will require real-time feedback based on FLIP planimetry to modify procedures in the setting of anti-reflux surgery, further studies are warranted to potentially create target ranges for distensibility intraoperatively. Second, linearity at key steps of the operation were based on readings at 0 and 10 mmHg. Given that some clinicians operate at up to 15 mmHg of pneumoperitoneum, we assume that this linear relationship of our models holds above 10 mmHg similar to our ex vivo model. Further studies at higher intra-abdominal pressures may be warranted. Third, while our sample size is comparable to previous FLIP studies, it is limited as a single surgeon at a tertiary referral center performed all these procedures. Larger studies, especially evaluating post sphincter augmentation, should be considered to evaluate for clinical variability. Fourth, while studies have shown differences based on sphincter augmentation, this was beyond the scope of this study as it is underpowered for subgroup analysis. However, previous studies have shown limited differences in sphincter augmentation on distensibility index [18]. And finally, it should be noted that the small differences we observed in pressure measurements between 0 and 10 mmHg at each key step are well beyond the minimum detectable resolutions and ranges of variability of FLIP planimetry. Minimum CSA resolution is reported as 0.8 mm^2, accuracy $\pm$ 0.8 mm^2 and minimum pressure resolution is reported as 0.1 mmHg, accuracy $\pm$ 0.8 mmHg [1].

FLIP planimetry measurements have utility in understanding the dynamic changes at the EGJ during anti-reflux procedures, but there is a lack of standardization as to how the measurements are obtained, especially with regards to pneumoperitoneum. For real-time intraoperative utilization, establishing the impact of these variables unique to anti-reflux surgery is warranted. Our data suggest that pneumoperitoneum impacts pressure, but not CSA, and this relationship appears linear and may be influenced by the location of the EGJ. The change in pressure contributes to significant changes in distensibility, which is one component leading to reflux [9]. If intraperitoneal pressure could influence EGJ distensibility, there may be variation in measurement with end inspiration/expiration during the procedure if part of the EGJ were in the chest. These areas require further investigation and are the goals of future studies.

Therefore, pneumoperitoneum affected EGJ pressure and distensibility and the degree of change was influenced by location of the EGJ based on the step of the anti-reflux procedure. The changes in pressure were linear with respect to intraperitoneal pressure. For optimal utilization, target endpoint EndoFLIP® planimetry measurements should be established intraoperatively and standardized to correlate with clinical outcomes.

Compliance with ethical standards

Disclosures Dr. Zarnegar is a consultant for Bard (BD). Dr Katz is a consultant for Medtronic. Drs. Liu, Stefanova, Finnerty, Schnoll-Sussman, and Fahey have no conflicts of interest or financial ties to disclose.

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