Purpose: Nissen fundoplication is associated with poor long-term durability, as well as dysphasia and gas bloat. We report here the long-term results of modified Belsey fundoplication (Gastroesophageal Valvuloplasty; GEV) performed laparoscopically using a surgical robot.

Methods: Patients who underwent robotic GEV were reviewed retrospectively. Operations were performed by laparoscopy and included robotic dissection of the esophageal hiatus, primary closure of the hiatus, followed by intussusception of a 4 cm segment of the esophagus into the stomach for 270°, and suspension of the fundoplication on the hiatal closure. The results were assessed by postoperative endoscopy, contrast esophagography, a Subjective Symptom Questionnaire (SSQ), and objective Visick grading.

Results: There were 291 patients (156 male, 135 female, mean age 51±14 years). Indications were intractability
Nissen fundoplication (NF) is the most common antireflux procedure. However, NF is associated with poor long-term durability, dysphagia and gas bloat. 1-3 Belsey Mark IV fundoplication (BF) differs conceptually from NF as it creates a valve at the GE junction and suspends the fundoplication on the esophageal hiatus.4,5 BF offers similar reflux control as NF (84%), but has a much lower rate of gas bloat and dysphagia (5%). However, BF is hampered by the need for a thoracotomy, and with the advent of laparoscopy, BF has become largely irrelevant.6 Modified laparoscopic BF or Gastroesophageal Valvuloplasty (GEV) has been reported previously.7 In this report, we present the long-term results of modified Belsey Fundoplication (GEV) performed laparoscopically using a surgical robot.

**INTRODUCTION**

Nissen fundoplication (NF) is the most common antireflux procedure. However, NF is associated with poor long-term durability, dysphagia and gas bloat.1,2 Belsey Mark IV fundoplication (BF) differs conceptually from NF as it creates a valve at the GE junction and suspends the fundoplication on the esophageal hiatus.3,4 BF offers similar reflux control as NF (84%), but has a much lower rate of gas bloat and dysphagia (5%). However, BF is hampered by the need for a thoracotomy, and with the advent of laparoscopy, BF has become largely irrelevant.5 Modified laparoscopic BF or Gastroesophageal Valvuloplasty (GEV) has been reported previously.6 In this report, we present the long-term results of modified Belsey Fundoplication (GEV) performed laparoscopically using a surgical robot.

**MATERIALS AND METHODS**

This study is a retrospective case series analysis of consecutive patients who underwent robot-assisted Belsey Fundoplication (GEV) from January 2003 to November 2008. The indication for surgery was failure of medical therapy and intractability, and secondary pulmonary symptoms of reflux. Inclusion criteria included symptomatic GERD, hiatal hernia of any size, Hill Grade II, III or IV valves, normal esophageal motility, and increased esophageal acid exposure. Patients with prior antireflux or proximal gastrointestinal surgery were excluded.

**Preoperative workup**

All patients were evaluated with a detailed medical history, physical examination, esophagogastroduodenoscopy (EGD), and contrast esophagography. At the time of EGD, the stomach was fully inflated, the endoscope was retroflexed, and the gastroesophageal valve was graded using the Hill Classification (Fig. 1).8 Furthermore, all patients underwent manometry, 24-hour pH and impedance testing, and completed a Subjective Symptom Questionnaire (SSQ) which graded Heartburn, Regurgitation, Dysphagia, and Pain on a scale of 0-3 for a total score of 0-12/patient (Table I).9 In addition, the patients’ symptoms were graded objectively by a nurse practitioner using the Visick Grading system (I-IV)(Table II).10 Patient demographics, comorbidity, history of previous surgical procedures, pre- and postoperative symptoms, operative course, perioperative outcomes
and follow-up data were gathered prospectively in a database.

**Surgical technique**

The procedure is performed on a laparoscopic platform. Preoperative UGI endoscopy is performed and the gastroesophageal junction is examined by the retroflexed endoscope. The gastroesophageal valve is graded by the Hill Classification (Fig. 1). Two laparoscopic CO₂ insufflators are used. Port #1 (Camera Port) is placed inferior to the umbilicus. Pneumoperitoneum is created. The table is placed in a steep reverse Trendelenberg position. Port #2 is placed in the right paraumbilical region at the right mammary line. Port #3 is placed in the left paraumbilical region in the left mammary line. An Endo-Paddle paddle retractor (Medtronic, Norwalk, CT) is introduced through Port #2 and used to place upward traction on the left lobe of the liver. Port #4 is placed in the subcostal region halfway between the umbilicus and the xiphoid just to the left of the midline. This port is aligned with the right limb of the right crus of the diaphragm. Port #5 is placed in the subcostal region two finger breadths to the left and caudad to Port #4. Port #5 is aligned with the left limb of the right crus of the diaphragm.

**Docking of surgical robot and dissection:**

The surgical robot (da Vinci, Intuitive Surgical, Sunnyvale, CA) is docked using a “side docking” technique. A 30-degree down-viewing robotic binocular camera is introduced through Port #1. The right robotic arm with a hook cautery instrument is introduced through Port #3. The left robotic arm with a DeBakey grasper instrument is introduced through Port #2. The entire dissection uses electrocautery and meticulous hemostasis. An endo-Kittner is introduced through Port #5 by the assistant and used to provide appropriate counter-traction and exposure at the esophagogastric junction. The phrenoesophageal ligament is divided. At this point, the right limb (RL) of the right crus is visualized. Lateral traction is applied to the esophagus. The fatty tissue overlying the RL is excised and the RL is followed inferiorly to its junction with the left limb (LL) of the right crus. Next, dissection of the RL is carried out superior to the crural arch and around to the LL of the right crus. The vagal trunks are identified and preserved. At this point, while following the curve of the LL in an oblique caudo-cephalad direction, the left robotic hand is used to encircle the esophagus. A large vessel loop is passed underneath the esophagus and used by the assistant for esophageal traction. Transhiatal dissection is carried out up to the level of the left inferior pulmonary vein. Division of short gastric vessels is not necessary.

**Crural closure:**

Posterior crural closure is accomplished by reapproximating the RL and LL with three 0-Ethibond sutures with 2cm-square absorbable pledgets cut from vicryl mesh (Ethicon, Inc., Sommerville, NJ). The anesthesiologist passes a 60 Fr. bougie into the esophagus. The esophageal hiatus is sized such that the bougie freely traverses the crural opening.

**Modified Belsey fundoplication (gastroesophageal valvuloplasty):**

The gastroesophageal valve is formed by anterolateral intussusception of the esophagus into the stomach from a point halfway on the RL to a point halfway on the LL of the right crus. This creates a 4cm fold of esophagogastric tissue.

Fundoplication is performed by placing only one row of 0-Ethibond sutures between the stomach, the adjacent esophagus, and the corresponding portion of the esophageal crural structure. The previously mobilized vagal trunks are gently moved aside. The first suture is passed through a point 4cm below the GE junction on the greater curve of the stomach, a point 4cm above the GE junction on the right lateral aspect of the esophagus and through the midpoint of the left limb of the crus. The second suture is passed through a point 4cm above the GE junction on the right lateral aspect of the esophagus and through the midpoint of the right limb of the crus. The third and final suture is passed through a point 4cm below the GE junction midway between the greater and lesser curve suture, through a point 4cm above the GE junction on the right lateral aspect of the esophagus and through the top of the crural curve.

| Table I |
| Subjective Symptom Questionnaire (Modified Likert Scale) |
| Symptom   | Score Range |
| Heartburn | 0-3         |
| Regurgitation | 0-3      |
| Dysphagia  | 0-3         |
| Pain       | 0-3         |
| Total Range | 0-12     |

0 = Asymptomatic
1 = Mild Symptoms: aware of symptom but easily tolerated
2 = Frequent Symptoms: interferes with normal activities
3 = Debilitating Symptoms: incapacitating; unable to perform normal activities

| Table II |
| Objective Visick Grading |
| Grade I | Asymptomatic patient |
| Grade II | Mild, intermittent symptoms that are easily controlled by diet |
| Grade III | Moderate symptoms without substantial interference with lifestyle |
| Grade IV | Unsatisfactory outcome and includes all patients with recurrent ulcer |

Grade I: Asymptomatic patient
Grade II: Mild, intermittent symptoms that are easily controlled by diet
Grade III: Moderate symptoms without substantial interference with lifestyle
Grade IV: Unsatisfactory outcome and includes all patients with recurrent ulcer
Placement of the three valvuloplasty sutures results in intussusception of the esophagus into the stomach by 4cm, thereby creating a flap valve. The newly created gastroesophageal valve is inspected by endoscopy and graded using the Hill Classification (Fig. 2). Only a Hill Grade I valve is accepted as a satisfactory result.

**Post-repair protocol:**
An esophagogram with water-soluble contrast was obtained on the first postoperative day. Conditions for discharge included bowel activity and the ability to tolerate a soft diet. Following discharge, patients were seen in the surgical clinic at two weeks, one month, and three months. The patients were followed annually by their gastroenterologist.

**Data analysis:**
The data were prospectively accrued and retrospectively analyzed. Data analyzed included indication for operation, patient age and sex, operative time, morbidity, and death. Immediately after the operation, the technical success of the operation, relief of symptoms, satisfaction with the operation, presence of dysphagia and gas bloat were assessed by the Subjective Symptom Questionnaire and objective Visick Grading.

The study was reviewed and determined to be exempt from institutional review board approval under 45 CFR 46.101 (b).†

## RESULTS

During a 71-month period, 302 patients underwent robotic GE valvuloplasty. Eleven patients (3.6%) were lost to follow-up. In the remaining 291 patients, there were 156 men and 135 women. The mean age was 51 ± 14 years. Indication for surgery was failure of medical therapy in 212/291 patients (73%) and upper respiratory symptoms (cough, hoarseness, bronchospasm) in 79/291 (27%). On Upper GI endoscopy, 183/291 patients (63%) had a Hill Grade IV GE junction, 73/291 (25%) had a Hill Grade III GE junction and the remaining 35/291 (12%) patients were Hill Grade II. On contrast esophagography, 230/291 patients (79%) were diagnosed with a hiatal hernia. All patients had normal esophageal motility and increased acid exposure.

At the time of surgery, exploration of the esophageal hiatus revealed a hiatal hernia in all patients. The mean operative time was 130±52 minutes. In 19/291 (6%), intraoperative post-fundoplication endoscopy revealed an incompetent gastroesophageal valve. In these patients, the valve underwent further repair to achieve a satisfactory Hill Grade I score.

Complications were seen in 61 patients (21%). The pleura was entered in 55/291 (19%) patients. This was treated with closure of the pleural opening and intraoperative evacuation of the pleural space. There was no conversion to an open procedure. A pneumothorax was diagnosed in 5/291 (1.7%) postoperatively. These patients underwent drainage with a 10 Fr. radiographically placed pigtail catheter. One patient had atrial fibrillation (0.3%). There was no mortality.

The mean duration of hospitalization was 2.8±1.7 days. Most patients required two days in the hospital to meet discharge criteria.

**Early (1-12 weeks) postoperative results:**
Immediately after surgery, 221/291 patients (76%) reported dysphagia with regard to solids. Dysphagia was resolved in all patients by the third postoperative week. There was no incidence of gas bloat in the early postoperative period. By 12 weeks, acid-suppression therapy was discontinued in all patients. Five (2%) patients had transient gastroparesis which resolved by the third postoperative month.

**Late follow-up:**
The mean follow-up was 85 ± 7 months. During the follow-up period, the mean score on the SSQ decreased from 8.3 ± 0.6 to 0.7 ± 0.2 (p < 0.05). Ninety-six percent (279/291) of patients scored 0 on the questionnaire and were completely asymptomatic. The remaining patients (4%) had some degree of heart burn and continued acid-suppression therapy. None of the patients reported long-term gas bloat.

Preoperatively, 58/291 patients were objectively graded as Visick III and 231/291 (80%) were Visick IV. By the
end of follow-up, 276/291 (95%) were graded as Visick I and 5% were Visick II. The hiatal hernia recurred in 8/291 patients (2%). Recurrence was documented on Upper GI endoscopy and contrast esophagography. In all instances, the recurrence was in the anterior aspect of the esophageal hiatus. There was no posterior crural disruption.

**DISCUSSION**

The Mark IV fundoplication technique (BF) was first reported by Belsey in 1967.interestingly, Belsey delayed formal publication of the BF for six years before considering that it offered sufficient durability to publish the results. Contrary to the serendipitous discovery of Nissen fundoplication, the surgical strategy adopted by Belsey reflected the culmination of many years of observations in the endoscopy unit and subsequent careful correlation of these findings with the symptoms of the patients. Thereafter, a series of different surgical strategies were undertaken to restore the gastroesophageal junction to a "normal" configuration. BF was the 4th iteration of surgical procedures that attempted to achieve this result by trial and error, careful observation and follow-up. The classic BF relies on the intussusception of a 4 cm length of the esophagus into the stomach approximately 240 degrees of the circumference of the GE junction using 2 rows of mattress sutures. BF has been shown to relieve GERD symptoms and restore normal esophageal acid exposure in 85-95% of patients, while resulting in dysphagia and gas bloat symptom in less than 5% of patients. However, BF has not been widely adopted for the treatment of hiatal hernias and gastroesophageal reflux disease due to several disadvantages, including the complexity of the procedure, difficulty in teaching the procedure, the requirement for a left thoracotomy, and greater familiarity among thoracic surgeons versus abdominal surgeons. The conceptual complexity of the procedure has even resulted in erroneous designation of BF as a partial fundal wrap by surgeons who are more familiar with Nissen fundoplication.

The introduction of laparoscopic Nissen fundoplication by Geagea in 1991 had a profound impact on the management strategy for patients with hiatal hernias and GERD. As a result of the advantages of minimally invasive surgery, fundal wraps such as Nissen and its partial variants have become the most commonly performed antireflux procedures. Fundal wraps date back to the 1950's and 1960's, an era when, based on the observation of a high-pressure zone at the gastroesophageal junction on manometry, it was erroneously concluded that a "sphincter" accounted for the antireflux mechanism. However, it is now believed that the mechanism of gastroesophageal antireflux involves the gastroesophageal valve and not a sphincter, extrinsic compression of the lower esophagus by the crural diaphragm, the intra-abdominal location of the gastroesophageal junction, integrity of the phrenoesophageal ligament, and the acute angle of His. A significant component of the mechanism of gastroesophageal antireflux is the highly complex three-dimensional relationship between the gastroesophageal junction and the esophageal hiatus. The gastroesophageal valve is the 4 cm musculomucosal fold that extends from the greater curve to the lesser curve of the stomach and is created by oblique intussusception of the esophagus into the stomach. In turn, the gastroesophageal valve is suspended on the esophageal hiatus by the phrenoesophageal ligament. External suspension of the valve on the esophageal hiatus prevents kinking and incompetence of the valve in the normal setting. In the normal setting, when the stomach fills with liquid, the pressure results in apposition of the musculomucosal fold, closure of the valve, and prevention of reflux. In turn, when the stomach fills with gas, distension of the stomach results in separation of the muscle mucosal fold and incompetence of the valve, which allows the subject to burp. The relationship of the gastroesophageal valve to the esophageal hiatus is comparable to the relationship of the cardiac mitral valve to the mitral annulus. With a hiatal hernia and stretching of the phrenoesophageal ligament, the esophagus gets pulled out of the stomach much like a telescope being extended, the musculomucosal fold disappears, resulting in GERD.

Curiously, through rigorous observation and trial and error, Belsey recreated what is presently considered to be an antireflux barrier. The BF procedure recreates the mechanism of gastroesophageal antireflux by intussuscepting the esophagus into the stomach, thereby creating a gastroesophageal valve and suspending it on the esophageal hiatus. In a porcine model of GERD, BF has been shown to most closely recreate the normal antireflux mechanism. Furthermore, using the same model, a laparoscopically performed BF has been shown to be feasible.

A pilot study of laparoscopic BF illustrated the complexity of hiatal dissection and fundoplication using conventional laparoscopic instruments. The use of a surgical robot obviates these difficulties. A surgical robot has the advantage of providing high-definition, three-dimensional magnified visualization, and greater instrument maneuverability in a confined space. Through the use of a surgical robot, a long length of the esophagus can be mobilized through the hiatus.

In addition to the use of a robotic laparoscopic platform, the BF was modified such that sutures are taken from the stomach to the esophagus and then through the crural muscle. Only one row of sutures is used. In addition, absorbable pledges made of polyglyactin are used to buttress the sutures and prevent them from tearing through the esophageal and crural muscle.

To clearly communicate the nature of the modified BF procedure, it may be more appropriate to refer to the robotic laparoscopic procedure as gastroesophageal valvuloplasty (GEV). Analogous to the use of pre- and post-repair echocardiography during cardiac valve repair procedures, intraoperative endoscopy is used to provide real-time assessment of the gastroesophageal valve. Based on this assessment, 6% of patients who had unsatisfactory repairs underwent modifications which resulted in a Hill Grade 1 valve before leaving the operating suite. In all instances, the valve needed to be elongated by further intussusception of the esophagus into the stomach at the greater curve.

Surgical procedures on the hiatus are associated with intraoperative complication rates ranging from 6-16%. Pneumothorax due to a pleural defect is a common complication during hernia sac dissection in large and giant hiatal hernia. In this cohort, there were fewer complications than expected, and these were mostly limited to pleural entry as
a result of the extended esophageal mobilization.

Gastroparesis was suspected based on the presence of a bezoar on endoscopy, and confirmed by a gastric-emptying study in 5 patients. In all cases, gastroparesis was transient and may have been the result of traction or transient thermal injury from cautery dissection in the vicinity of the vagus nerves. One of the advantages of the three-dimensional, high-definition visualization during robotic dissection is the clear identification and preservation of the vagal trunk. The left vagal trunk is especially difficult to visualize as it becomes somewhat intramural just above the GE junction. Furthermore, due to the migration of retroperitoneal structures through the hiatus, the vagus nerves are often displaced into abnormal positions, which further illustrates the advantage of better visualization with robotic dissection. Finally, the dexterity of the robotic end-effector allows for encirclement of the esophagus by following the caudo-cranial curve of the left limb of the crus and keeping the vagus nerves constantly in view. It is imperative that the esophagus and the vagal trunks be encircled en bloc. Attempts at encircling the esophagus while traversing the space between the right vagus nerve and the esophageal wall may result in the disruption of vagal branches.

Based on endoscopic observations, the high rate of early dysphagia was attributed to edema resulting from the placement of sutures and esophago-gastric intussusception. This is to be differentiated from the dysphagia resulting from extrinsic esophageal compression due to wrapping the stomach around the esophagus with a fundal wrap. Dysphagia resolved in all patients a few weeks after surgery. Resolution of the inflammatory process most probably accounted for the resolution of dysphagia.

There was no short- or long-term gas bloat. In a porcine model, it has been shown that, after GEV, inflation of the stomach with air results in stretching of the GE junction and incompetence of the valve with resultant evacuation of the excess air. Using the same model, after a circular wrap, inflation of the stomach with air resulted in further tightening of the wrap at the GE junction and retention of air in the stomach. The physiological nature of a valve versus a wrap or a sphincter explains the lack of early or late gas bloat and the ability to burp following GEV.

A multitude of unidimensional and multidimensional questionnaires exist for symptom assessment and monitoring quality of life in GERD. This study used a validated Subjective Symptom Questionnaire that graded Heartburn, Regurgitation, Dysphagia, and Pain on a scale of 0–3, for a total score of 0–12 per patient. Although more complex questionnaires are useful for the diagnosis of GERD and assessment of the nuances of therapy, a streamlined direct questionnaire that grades the important symptoms from the patient’s standpoint before and after surgery is most useful for assessing the success of surgery from the patient’s perspective.

Reoperation for recurrence of the hiatus hernia mostly takes place in the early years after initial surgery with one-, five- and ten-year cumulative reoperation rates of 1.7%, 5.2% and 6.9%, respectively. In this study, although the hiatus was closed primarily and no reinforcing mesh was utilized, recurrence of the hiatal hernia was seen in 2% of the patients. In all instances, at the time of reoperation, the recurrence was in the anterior aspect of the hiatus. There was no disruption of the posterior or crural closure, and all fundoplication sutures were intact. Excessive weight gain in 4/6 patients may explain recurrence of the hiatus due to stretching of the anterior crural arch.

Study Limitations
The following limitations of this study should be considered before drawing definitive conclusions.

The study was retrospective and represented a highly selected group of patients. Furthermore, the study population was heterogeneous and included hiatal hernia of all sizes.

Follow-up was performed by examining clinic records and conducting telephone interviews. Eleven patients (4%) were lost to follow-up. Theoretically, these patients could represent failures of the procedure and the results of the study should be considered in light of this potential error rate.

Another limitation is the observational nature of the study. The surgical outcome is determined using a score that reflects subjective symptoms and the qualitative, yet objective, Visick score. The results of this study therefore have to be interpreted with caution due to the methodological limitations associated with observational studies. To further validate the results of this study, a randomized prospective trial comparing gastroesophageal valvuloplasty and other antireflux procedures is warranted.

In this study, we aimed to assess the long-term results of modified robotic laparoscopic BF fundoplication (GEV) in terms of reflux control and complications. The results show that GEV is a viable minimally invasive means of recreating the normal physiologic antireflux mechanism with a high success rate, low rate of complication, and long-term durability.

The authors have no conflicts of interest to declare.