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The Role of Robotics in Bariatric Surgery

Michelle H. Scerbo[1] · Bashar Alramahi[1] · Melissa M. Felinski[1] · Kulvinder S. Bajwa[1] · Erik B. Wilson[1] · Shinil K. Shah[1,2]

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Abstract
Purpose of Review This article will review the current evidence supporting the use of robotic platforms in bariatric surgery and discuss the technical aspects of robotic platforms in the current bariatric procedures performed.
Recent Findings The use of robotic platforms for minimally invasive bariatric surgery continues to increase. This can be attributed to the perceived advantages of robotic platforms including three-dimensional high-definition visualization, tremor filtration, direct camera control by the primary surgeon, multi-quadrant access, and wristed instruments which make complex and redo surgery potentially easier to perform. Robotic systems may also provide ergonomic advantages in patients with obesity who have significant abdominal wall mass.
Summary Despite a longer operative time, the preponderance of the data suggest robotic surgery is a safe and effective methodology to perform bariatric procedures. The greatest potential for clinical benefit appears to be in revisional bariatric surgery and in patients with higher body mass index. There may also be advantages in the learning curve of these complex procedures. Robotic platform improvement, training, and cost-effective usage may overcome the higher initial costs.

Keywords Robotics · Bariatric surgery · Gastric bypass · Biliopancreatic diversion · Metabolic surgery · Gastrectomy · Ergonomics

This article is part of the Topical Collection on *Bariatric Surgery*.

✉ Shinil K. Shah
shinil.k.shah@uth.tmc.edu

1 Division of Minimally Invasive and Elective General Surgery, Department of Surgery, McGovern Medical School, University of Texas Health Science Center at Houston, 6431 Fannin Street, MSB 4.156, Houston, TX 77030, USA

2 Michael E. DeBakey Institute for Comparative Cardiovascular Science and Biomedical Devices, Texas A&M University, College Station, TX, USA

History

Obesity remains one of the most challenging and growing burdens of health care in recent medicine. Almost 40% of Americans are obese, with a projected increase in prevalence by 33% by 2030 [1]. Bariatric surgery is superior to medical therapy for the treatment of obesity and its related co-morbidities [2, 3]. As a result, the number of bariatric surgeries has increased.

However, bariatric surgery has evolved dramatically since first being introduced as a treatment for obesity approximately seven decades ago. The first operations, jejunoileal bypass [4], and jejunocolic bypass [5], were fraught with morbidities related to the resultant nutritional and vitamin deficiencies, as well as that of open laparotomies on patients with excess weight and significant abdominal wall mass.

As we have come to understand the metabolic derangements that follow bariatric surgery, it has become less morbid [6, 7], more durable [8•], and as a result, more popular. In the year 2018, 252,000 bariatric surgeries were performed. This is a nearly 100,000 increase in less than 10 years (Fig. 1). The American Society for Metabolic and Bariatric Surgery (ASMBS) describes the most common bariatric surgeries to be the sleeve gastrectomy, Roux-en-Y gastric bypass, and duodenal switch/biliopancreatic diversion [9]. The use of robotic surgery has increased tremendously over the last decade, with robotics for general surgical procedures increasing 8.4-fold from 2012 to 2018 [10]. This increase has also been seen for bariatric surgery; 7.7% of gastric bypasses were performed robotically in 2016, increased from only 1.8% from 2007 to 2012 [11].

Development of Robotic Platforms for Surgery

Robotic systems can be classified as active, semi-active, or master–slave. In an active system, the robot works autonomously to perform pre-programmed tasks. The semi-active systems rely on the surgeon to initiate pre-programmed tasks. Master–slave systems are devoid of robot autonomy, relaying the hand movements of the surgeon to the surgical instruments at a distance [12].

In 1998, Guy-Bernard Cadière performed the world's first obesity telesurgery using Mona (Intuitive Surgical, Mountain View, CA) for the placement of a laparoscopic gastric band [13]. Santiago Horgan followed in 2000 with robotically assisted laparoscopic gastric bypass using the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA) [14].

Today, most robotic surgery consists of master–slave systems that include either multiple arms on a patient cart or table-mounted. The current industry leader is the da Vinci Surgical System; however, the next decade will be met with new developments from multiple other ventures, including but not limited to Verb Surgical (Google, Johnson & Johnson, Santa Clara, CA), Medtronic (Minneapolis, MN) and CMR Surgical (Cambridge, United Kingdom).

Laparoscopic Surgery Revolutionized

Surgery on patients with morbid obesity has an increased risk in cardiovascular, pulmonary and thromboembolic adverse events [15]. The large incision used for open surgery increases risk of wound infections and ventral hernias in a patient with morbid obesity [16]. Enlarged or fatty livers and increased visceral fat can make exposure, mobilization and visualization difficult. Laparoscopic surgery mitigates many of these issues. Demonstrating a durable reduced length of stay, postoperative pain and improved postoperative recovery, laparoscopy is now favored as compared to the open technique for bariatric procedures [17].

The laparoscopic technique is not perfect. The straight instruments and two-dimensional images may limit depth perception, cause spatial disorientation, and do not allow large movements in small spaces. The independent motion of the camera decouples the surgeon's eyes and hands, requiring the development of technical skill to adjust to this unnatural visualization.

Conversely, the robotic platform offers improved image quality, a steady, surgeon-controlled camera, and a three-dimensional image with tenfold magnification which may improve depth perception and lessens eye fatigue. The

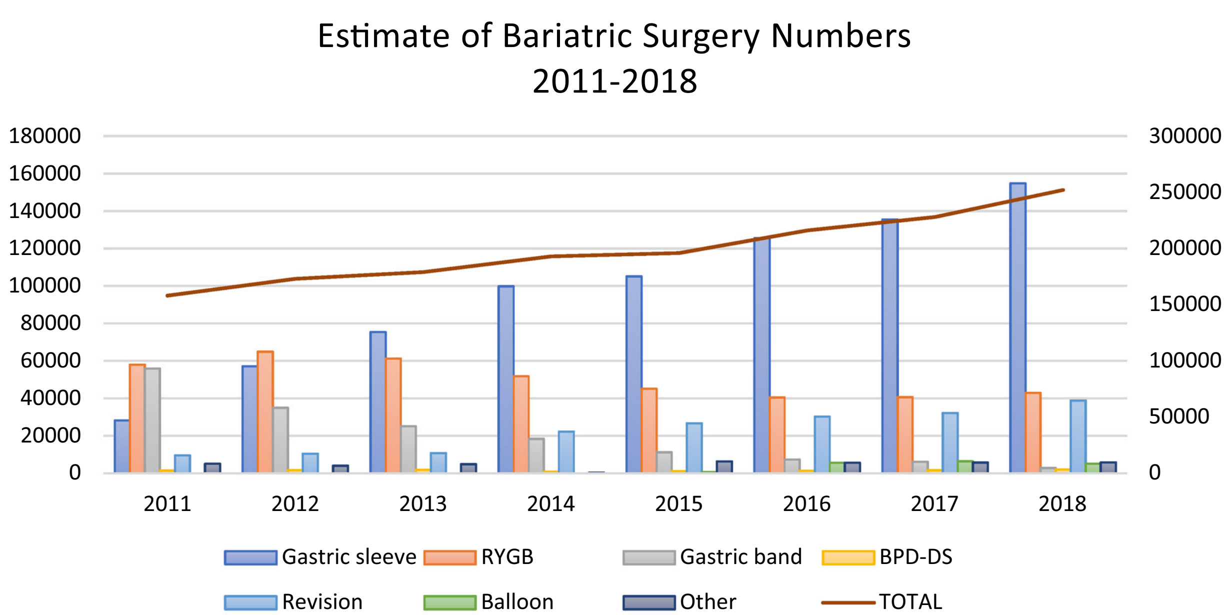

Fig. 1 Total number of bariatric procedures calculated by the American Board of Metabolic and Bariatric Surgery. The left *Y*-axis is the number of each individual procedure, while the right *Y*-axis represents the total number of procedures by year. (RYGB Roux-en-Y Gastric Bypass. BPD-DS Biliopancreatic Diversion-Duodenal Switch). Revision is any bariatric procedure performed following a previous bariatric procedure. Data obtained from https://asmbs.org/resources/estimate-of-bariatric-surgery-numbers

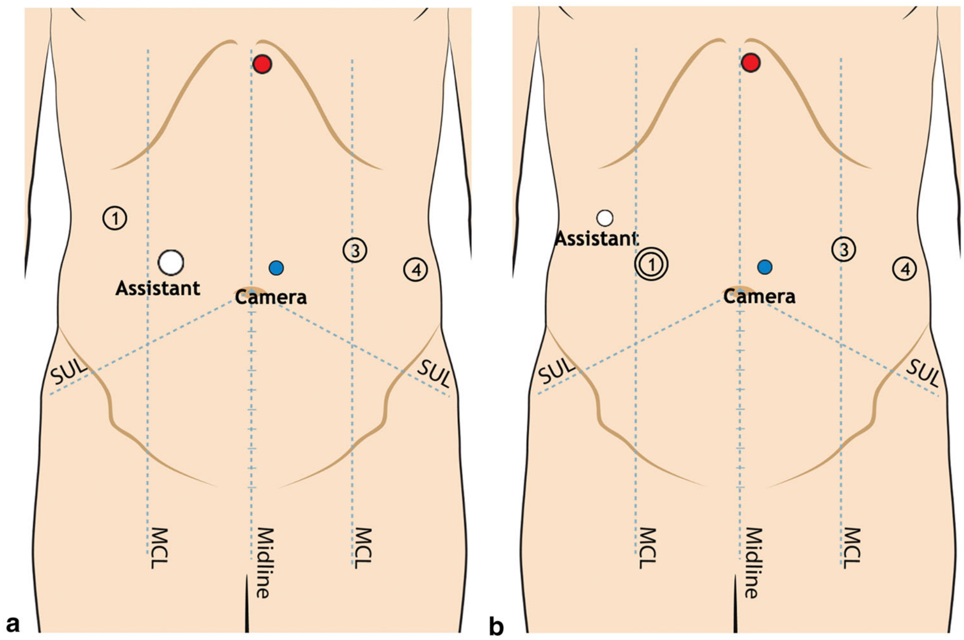

Fig. 2 Robotic port setup when using **a** a hand-held stapler or **b** a robotic stapler. **a** In this configuration, the abdomen is entered in the right upper quadrant, and this port is exchanged for a robotic port. The assistant port is either 12 mm or 15 mm depending on stapler loads. **b** In this configuration, the abdomen is entered in the right upper quadrant, and this port becomes the assistant port. The port in the right mid-abdomen is a 12 mm robotic port with an 8 mm reducer. The 12 mm robotic port with accommodate the robotic stapler

diminution of hand dominance, tremor filtering, precision and speed of motion, and improved range of motion permit fine movements in small spaces. The wristed instruments allow for seven degrees of movement, simulating the motion of the surgeon's wrist, making suturing and knot-tying more similar to open surgery. All of these features facilitate visualization of tight and distant areas such as the hiatus and foregut, which may translate to more efficient surgery for patients undergoing weight loss procedures [18–20].

Robotic surgery is mutually advantageous for the surgeon and patient. The robotic instruments utilize less torque against the abdominal wall, affording for a technically easier and more ergonomic operation, decreasing surgeon fatigue in lengthy and re-operative cases. This has not yet translated to decreased operative time in current studies [11, 21•, 22•, 23, 24•, 25–28]. A few single institutions have found shorter operative times with the robot in patients with a higher BMI, reducing by 14 min for robotic sleeve gastrectomy in patients with a BMI > 50 kg/m^2 [29], or by 1.2 min less per kg/m^2 for gastric bypass [30].

Recent robotic platforms allow multi-quadrant access with ease. Without redocking the robot, the motion of the robot is combined with the motion of the operating table, permitting movement throughout the abdomen when unexpected findings like pelvic small bowel adhesions are encountered [31, 32]. This leads to a purported reduced chance of aborting minimally invasive techniques when an operation is challenging.

There are perceived disadvantages to using the robot. Concerns regarding cost, difficulty with insurance coverage, lack of randomized data, limited tactile and haptic feedback, inappropriately visualizing the anatomy, resulting in a mistaken omega loop [33] or enterotomy, increased anesthetic time, delay in conversion in an emergency, and difficult accessing the patient for cardiopulmonary resuscitation [34] are commonly cited as downfalls to the use of the robot.

The literature comparing laparoscopic and robotic surgery has a generalized theme. As it compares the adoption of a similar technique with a different tool, the multitude of studies that have been completed over the last fifteen years have concluded that robotic is no less safe than laparoscopic bariatric surgery; however, operative time is consistently approximately 30 min longer.

Many early studies reported single-center experience with their adoption of the use of the robot for bariatric surgery and demonstrated varying results from lower rates of conversion, reduced rates of leak, stricture, reoperation and length of stay [35], or the exact converse. More recent literature has utilized the Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) Data Registry, a composite registry of prospective perioperative and 30-day outcomes data from

Table 1 Limitations of the MBSAQIP database

Limitations of MBSAQIP database: exclusion of the following details
Anastomosis technique
Bougie size
Stapler brand
Staple size
Use of buttressing or oversewing staple line
Use of indocyanine green fluorescence
Procedure, operating room, instrument, or facility costs
Docking time
Anesthesia time
Center volume
Robotic platform (i.e., da Vinci Si vs Xi)
Percentage of procedure performed robotically
Long-term information about weight loss
Previous bariatric procedure

The items listed are not included within the database, and therefore cannot be evaluated when comparing robotic techniques

approximately 900 bariatric centers accredited by the ASMBS. The data are aggregated and deidentified of hospital, patient, and provider information. As such, the highest quality data come from evaluation of these databases; randomized controlled trials are difficult to conduct to compare these techniques. Limitations of the MBSAQIP database are listed in Table 1.

Laparoscopic Compared to Robotic Surgery for Primary Cases

The first published study comparing laparoscopic to robotic bariatric surgeries used the Bariatric Outcomes Longitudinal Database, and found an increase in complications and serious adverse events, particularly anastomotic leaks and strictures, along with a longer operative time of 39 min for robotic surgery [11].

Since 2015, many analyses using the large MBSAQIP database have continued to compare laparoscopic to robotic gastric bypass, sleeve gastrectomy, or all bariatric surgeries grouped together. Groups have been compared directly [22•] or after adjusting for co-morbid conditions with propensity matching [36, 37•, 38•] or using logistic regression [21•, 39]. In these large databases, increased operative time with robotic bariatric surgery continues to be seen [23, 24•, 39]. While propensity matched patients by pre-operative co-morbidities continue to show increased rate of conversions and 30-day interventions with robotic surgeries [21•], this was not appreciated in the most recent systematic review of independent comparative studies [24•].

For gastric bypass, the robot has been association with fewer leaks, renal complications, venous thromboembolism [38•], transfusions and length of stay [21•, 38•]. Early analysis showed increased readmissions, mostly for nausea, vomiting, or dehydration, suggesting a higher incidence of stricture rate with hand-sewn compared to stapled gastrojejunal anastomosis. However, this was not observed in this dataset, nor by others specifically investigating that question [40]. In addition, the MBSAQIP database does not collect information regarding anastomosis, so it is impossible to determine a causal relationship between technique and stricture using this database. Nonetheless, no durable impact on unplanned ICU admission, reoperation, intervention, mortality, readmission, stricture, organ or superficial surgical site infection, bleeding, or length of stay has been demonstrated [21•, 23, 24•, 41].

These outcomes are perhaps different for sleeve gastrectomy, with some demonstration of increased leak, surgical site infection, overall morbidity and length of stay with the robotic approach [39].

Finally, evaluation of these adverse events over time have demonstrated an overall reduction of organ-space infections, readmissions and 30-day interventions over just 2 years, implying that robotic primary bariatric surgery continues to improve [22•]. It is imperative to note that in this large database of over 300,000 patients, only approximately 7% of these cases are robotic. Continued use and increased experience will likely shorten the gap between these two techniques, and with higher robotic volumes, a discrete benefit may no longer be of debate.

Laparoscopic Compared to Robotic Surgery for Revisional Cases

Up to 20% of patients that undergo bariatric surgery will experience either failure of weight loss or weight recidivism [42]. Dysphagia, reflux, stricture, erosion, ulceration and gastrogastric fistula have led to conversion rates as high as 65% for vertical banded gastroplasty and 47% for adjustable gastric banding [43]. The rate of revision following a sleeve gastrectomy may be as high as 30% [44]. Fortunately, revisional bariatric surgery is useful for reversing metabolic disease; conversion to gastric bypass from sleeve gastrectomy can achieve 36% improvement in diabetes control and 16% total weight loss [45]. Reasons and options for revisional surgery dependent on previous procedure are displayed in Table 2.

Re-operative bariatric surgery is additionally challenging, as violated tissue planes, dense adhesions and decreased blood supply to these violated tissues contribute to a higher complication rate compared to primary procedures. Laparoscopic revisional bariatric procedures have a leak rate up to 22% [42].

Table 2 Reasons and options for revision and conversion after bariatric surgery

Original surgery	Patient presentation	Options for revision
Adjustable gastric band	Reflux	Longitudinal sleeve gastrectomy
	Erosion	Roux-en-Y gastric bypass
	Weight loss failure/recidivism	Duodenal switch
Vertical banded gastroplasty	Reflux	Roux-en-Y gastric bypass
	Erosion	
	Weight loss failure/recidivism	
	Gastrogastric fistula	
Longitudinal sleeve gastrectomy	Reflux	Revision of sleeve gastrectomy
	Stricture	Roux-en-Y gastric bypass
	Weight loss failure/recidivism	Duodenal switch
	Planned staged procedure	
Roux-en-Y Gastric Bypass	Reflux	Pouch revision
	Stricture	Gastric outlet repair
	Weight loss failure/recidivism	Limb lengthening/biliopancreatic diversion
	Marginal ulcer	
	Failure to thrive	Reversal

Endoscopic options are not included

Our early experience with robotic revisional bariatric surgery saw 25% 90-day readmission rate, 17% complication rate (pain, marginal ulcer, dehydration, nausea/vomiting, obstruction, pneumonia, organ-space infection, gastrostomy complication, or ventral hernia), and 0% mortality, leak, pulmonary embolism and conversion to open [46].

Similar to primary cases, current analysis utilizing the MBSAQIP database demonstrates a longer operative time by 35 min for revisional cases using the robot. Revisional robotic sleeve gastrectomy has been associated with higher rates of reoperation, readmission, intervention, sepsis, organ-space infection, transfusion [28], and ventilator use, which may be a result of increased operative time and not the technique itself [47]. For these reasons, there may be no benefit to using the robot for a revisional sleeve gastrectomy.

Revisional robotic gastric bypass has so far demonstrated comparable overall morbidity, but higher rate of leak [28], fewer respiratory complications, superficial surgical site infections, postoperative bleeding (reflected as transfusion requirement), 30-day serious adverse events, organ-space infections, reoperations and interventions [48].

The evaluation of robotic revisional bariatric surgery is still under investigation; however, it appears the improved visualization of distorted tissue planes with the robot may be more beneficial for gastric bypass than sleeve gastrectomy.

Conversion from Hybrid to Full Robotic Procedures

Over time, robotic procedures have evolved from robotic-assisted laparoscopic to full robotic. Kim et al. described a stepwise graduation to full robotic gastric bypass, prioritizing operative time and patient safety, adding each additional component once they were able to complete the previous steps within their pre-defined time guideline. The jejunojejunostomy was completed robotically first. The gastric pouch was the final step adopted. During their first 26 cases, only the jejunojejunostomy was completed robotically. The next two cases included the gastrojejunostomy, and the remaining 270 cases were completely robotic [49]. Other hybrid approaches include laparoscopically evaluating anatomy to determine feasibility of the operation, division of the omentum, division of the anterior phrenoesophageal ligament [50], lysis of adhesions [26] or

Table 3 Instruments used for adjustable gastric band repositioning

Adjustable gastric band	
Arm 1	Tip-up grasper or Cadière forceps
	Needle driver
Arm 2	Camera
Arm 3	Monopolar shears
	Vessel sealer or harmonic[§]
	Needle driver
Arm 4	Tip-up grasper

[§]if needed

Table 4 Instruments used for longitudinal sleeve gastrectomy

Longitudinal Sleeve Gastrectomy	
Arm 1	Tip-up grasper or Cadière forceps
	Stapler*
Arm 2	Camera
Arm 3	Vessel sealer or harmonic
	Tip-up grasper*
Arm 4	Tip-up grasper

*If using robotic stapler. The tip-up grasper from arm 1 is moved to arm 3 for stapling. In this arrangement, the assistant port is in the right upper quadrant (Fig. 2b)

Table 5 Instruments used for gastric bypass

Gastric bypass	
Arm 1	Tip-up grasper or Cadière forceps
	Stapler[a]
	Needle driver
Arm 2	Camera
Arm 3	Monopolar sheers
	Vessel sealer or harmonic[b]
	Needle driver
Arm 4	Tip-up grasper

[a]If using robotic stapler. The tip-up grasper from arm 1 is moved to arm 3 for stapling. In this arrangement, the assistant port is in the right upper quadrant (Fig. 2b)

[b]If needed

Table 6 Instruments used for duodenal switch

Duodenal switch	
Arm 1	Tip-up grasper or Cadière forceps
	Stapler*
	Needle driver
Arm 2	Camera
Arm 3	Monopolar sheers
	Needle driver
Arm 4	Tip-up grasper

*If using robotic stapler. The tip-up grasper from arm 1 is moved to arm 3 for stapling. In this arrangement, the assistant port is in the right upper quadrant (Fig. 2b)

running the small bowel to mark the site for future anastomosis [51] prior to docking the robot.

Robotic Bariatric Procedures

The principles of patient positioning, abdominal entry, port placement, internal retraction, hiatal hernia repair, use of buttressing and leak testing are the same for all bariatric procedures and will be further described below. Specific portions of each individual operation will then be discussed in separate sections. Instrument selection for each procedure are displayed in Tables 3, 4, 5, 6.

Technique

Patient Positioning

Patients are placed in the supine position, with arms at 90 degrees and a foot board to facilitate steep reverse Trendelenburg. For robotic cases, we place our patients in reverse Trendelenburg at 12°–17°. Forced-air warming blankets are placed over the chest to maintain intraoperative normothermia. The patient is secured to the operating table with straps across the thighs and lower legs to prevent external rotation. It is important to ensure that there is not hyper-flexion of the foot when the patient is in reverse Trendelenburg; this can lead to excessive stress on the midfoot and in the most severe cases can cause fractures.

Abdominal Entry and Port Placement

Entry is obtained in the right upper quadrant using a 5 mm optical trocar. Depending on the robotic platform, an 8 mm or 12 mm camera port is placed to the left of the midline cranial to the umbilicus. Off-midline placement is beneficial as it reduces the risk of hernia by not violating the linea alba and avoids the falciform ligament. Two additional ports are placed in the left abdomen, one lateral at the level of the camera port and another equidistance between the lateral port and the camera port. An additional port is placed in the right mid-abdomen at the level of the camera. If the robotic stapler will be used, this should be a 12 mm port with an 8 mm reducer (Fig. 2a). If a hand-held stapler will be used, this should be a 12 mm or 15 mm port depending on the type of staple loads used (Fig. 2b). Finally, the right upper quadrant port is exchanged for a robotic port. A subxiphoid incision is made for the external liver retractor. Alternatively, an intracorporeal liver retractor can be utilized (such as the FreeHold Trio retractor (FreeHold Surgical, New Hope, PA)). The robot is then docked from the patient's left side, which does not interfere with the anesthesiologist or the ability of the assistant to access the patient from the right side.

Internal Retraction

We prefer to use two right arms and one left arm, allowing for the surgeon to retract and dissect with both the right and left arms.

Hiatal Hernia Repair

The hernia sac is dissected from all mediastinal attachments until the crura are fully exposed and adequate intraabdominal esophageal length is achieved. The posterior crura are reapproximated with permanent sutures. Anterior sutures are placed if needed. A gastric tube is used for sizing during the cruraplasty.

Stapler Use

Robotic or hand-held manual or automatic staplers can be used. Robot setup and port placement should consider which type of stapler will be used.

Buttressing of the Staple Line

The decision to buttress the staple line is surgeon dependent. We prefer absorbable polymer membrane (Seamguard Bioabsorbable staple line reinforcement, Gore, Flagstaff, AZ) as it may reduce staple line leak [52] and bleeding [53]. It is important to note that the use of staple line reinforcement is most strongly suggested in the literature to decrease rate of bleeding; there is no consistent data that demonstrate that it reduces leak rates.

Endoscopic Evaluation and Leak Testing

Methods for performing a leak test of the sleeve gastrectomy, gastrojejunostomy, or duodenoileostomy have been tested mostly after laparoscopic procedures. Air insufflation with endoscopy has been demonstrated as a robust evaluation with a less than 1% leak rate in the cohorts studied [54–57]. Alternatively, air via a nasogastric tube and a blend of methylene blue and indocyanine green (2 mg methylene blue, 5 mg indocyanine green, 100 ml sterile water) is a reliable evaluation that obviates the need for a separate surgeon/endoscopist during robotic procedures [58].

Adjustable Gastric Band

While once one of the most popular bariatric procedures, the utilization of adjustable gastric banding has decreased substantially over the last decade. This abandonment is in part to less durable weight loss, malfunction and need for frequent adjustments. An initial, small (< 30) single-center study reported their experience with robotic adjustable gastric banding, demonstrating a longer operative time and increased cost without reduction in hospital stay compared to a laparoscopic cohort [59]. A larger study (n = 407) found a decreased operative time by ten minutes in patients with a BMI greater than 50 kg/m^2 [60]. Our experience is to reserve the use of the robot for repositioning of a slipped band with concomitant hiatal hernia repair [61]; however, these cases are few as most are converted to another bariatric procedure.

Takedown of Gastric Plication

Using the monopolar shears, the previous gastric plications are taken down until the stomach and band are fully exposed.

Repositioning of Band

A new retrogastric window is created superior to the prior band site. The band is positioned within this window and sutured into place with anterior gastrogastric sutures.

Longitudinal Sleeve Gastrectomy

As the sleeve gastrectomy has demonstrated similar percentage excess weight loss [62], improvement in co-morbidities [63], and avoids the potential complications of marginal ulcer or internal hernia, it has become the most common bariatric procedure over the last decade [9]. Circumstances that make the use of the robot more beneficial for sleeve gastrectomy include for hiatal dissection, hiatal hernia repair, including intracorporeal knot-tying, or larger (> 50 kg/m^2) BMI.

Division of Greater Omentum and Short Gastric Vessels

The gastrocolic omentum is divided off the greater curvature of the stomach using either the Harmonic scalpel (Intuitive Surgical, Sunnyvale, CA) or the Vessel Sealer (Intuitive Surgical, Sunnyvale, CA). The second right arm is used for retraction. This is continued cephalad to divide the short gastric vessels toward the Angle of His until the phrenoesophageal ligament is reached. Crural repair is safe [64], but not mandatory during sleeve gastrectomy, and should be tailored to the patient's symptoms and size of hiatal hernia [65].

Creation of Longitudinal Sleeve Gastrectomy

The sleeve gastrectomy is completed over a fitted tube (36–40 French). Different types of tubes that can be used for sizing include a Bougie, ViSiGi 3D (sized 32–40F, Boehringer Laboratories, Phoenixville, PA), Argyle TM Edlich Gastric Lavage tube (Covidien/Medtronic, Minneapolis, MN), or an esophagogastroduodenoscope (30F). Multiple consensus conferences have recommended the use of a 40F sizing tube. The type and size of stapler used is based on surgeon preference. Generally, thicker stapler loads are used for division of the antrum and gastric body, and thinner stapler loads are used toward the Angle of His.

Roux-en-Y Gastric Bypass

While some the benefit of the robot for sleeve gastrectomy is perhaps limited, the robot has been most vigorously studied for the gastric bypass. The two anastomoses make the procedure more technically difficult, but the improved visualization, three-dimensional view, and wristed instruments make intracorporeal suturing easier to learn with the robot.

Gastric Pouch Creation

The gastric pouch is first created by opening the lesser sac inferior to the left gastric artery. The angle of His is bluntly dissected. A retrogastric tunnel is created to free all posterior attachments. The pouch is then sized over a tube, firing staple loads with staple line reinforcement first transverse to the esophagus and then along the sizing tube until the angle of His is reached.

Omental Division

The omentum is divided if it is thickened and may provide tension on the gastrojejunal anastomosis. The omentum is flipped upwards until the transverse colon is exposed. The end of the omentum is then grasped and brought away from the intestines using the two blunt forceps, and divided using monopolar shears or an energy device until the transverse colon is reached.

Creation of Gastrojejunostomy

Starting at the ligament of Treitz, the small bowel is run distal to approximately 75–100 cm and brought up to the gastric pouch. The posterior outer row is created starting at the corner of the staple line using a running suture and generally follows the inferior boundary of the gastric pouch. Gastrotomy and enterotomy are made with monopolar scissors. The inner row is made starting posteriorly with two 2-0 Vicryl sutures cut to 6 inches and pre-tied together. Alternatively, barbed sutures can be used for the outer, inner, or both rows. Once the posterior row is complete, the sizing tube is advanced through the gastrotomy and enterotomy and the anterior inner row is completed. The anterior outer row is then completed using the remainder of the running suture from the posterior outer row. The sizing tube is then withdrawn and discarded.

Creation of Jejunostomy

Division of Loop The looped jejunum is divided just to the left of gastrojejunostomy with care to not leave a candy-cane. A defect is made in the mesentery and the jejunum is divided with a stapler. The blind end is now the terminal end of the biliopancreatic limb.

Counting and Technique The roux limb is then run 100–150 cm starting the left side of the gastrojejunostomy. The bowel is run in an S-shape to prevent disorientation and the creation of a mistaken omega loop. It is brought to the left upper quadrant near the blind end of the biliopancreatic limb. Ensuring that the Roux limb is longer than the biliopancreatic limb may also help to prevent the creation of a mistaken omega loop (i.e., Roux-en-O anatomy).

Anastomosis Stay sutures are placed from the biliopancreatic to the roux limb at the planned distal aspect of the anastomosis. This segment is brought as high up into the left upper quadrant as much as possible and held into place with the fourth arm. Enterotomies are made on both limbs. The anastomosis is fashioned with a 60 mm stapler and the common enterotomy is closed with a running 2-0 Vicryl suture.

Closure of Mesenteric Defects

The limb of the common channel is flipped to the left to expose the base of the mesentery. The mesenteric defect is closed with a running 2-0 silk suture from the base up to the jejunojejunostomy, ending with an anti-obstruction stitch designed to align the biliopancreatic limb with the roux limb. The decision to close Petersen's defect is as per surgeon's preference.

Biliopancreatic Diversion/Duodenal Switch

Biliopancreatic diversion is completed either with a duodenoileal and ileoileal anastomosis (duodenal switch), or a single looped duodenoileal anastomosis (SADI, SIPS). There is sparse data comparing robotic to laparoscopic techniques. Sudan et al. reported 59 robotic BPD/DS operations with no conversion to open, no leaks, and no mortality [66]. Another single-center study of 179 robotic cases showed decreased leak rates despite longer operative times compared to laparoscopic approach [67].

Technique

Creation of Longitudinal Sleeve Gastrectomy Duodenal switch can either be performed as a planned two stage operation, first with a sleeve gastrectomy and then with the duodenoileostomy after a period of weight loss, or as a single-stage operation. The sleeve gastrectomy is performed in the same manner. If this is a planned two-staged operation, adhesions to the inferior portion of the sleeve are dissected to identify the old staple line.

Dissection and division of duodenum Dissection is continued from the distal staple line to 3 cm beyond the pylorus on the duodenum. The pyloric artery, branching from the gastroduodenal artery, is preserved. All posterior attachments to the pancreas are released. The sizing gastric tube is placed and advanced to the pylorus. The duodenum is then divided with a stapler just past the pylorus.

Running of Ileum Although previous reports have described measuring the ileal loop laparoscopically, marking it with a suture and locating it to the right upper quadrant prior to docking the robot [51], we are able to perform all of these maneuvers robotically when using the coupled table motion. The terminal ileum is identified and the ileum is counted back to 280 cm from the terminal ileum.

Creation of Duodenoileostomy The duodenum is sewn to the ileum with running absorbable suture, creating the posterior outer row. A duodenotomy and ileostomy are made. Similar to the gastrojejunostomy for a gastric bypass, the inner layer is created with two 2-0 Vicryl sutures cut to 6 inches and pre-tied together. Finally, the anterior outer row is completed with the remaining suture from the posterior outer row. This closure is the completion of the procedure if performing a single anastomosis duodenal switch.

Creation of Ileoileostomy The ileum is divided in the afferent limb just past the duodenoileostomy. An ileoileostomy is then created 100 cm from the ileocecal valve, similar to the jejunojejunostomy performed for a gastric bypass.

Closure of Mesenteric Defects The mesenteric defect is closed using a running suture from the base of the mesentery to the ileoileal bypass.

Revisional Bariatric Surgery

While revisional surgery varies depending on the previous and planned surgery, a few principles apply to all revisional cases:

1. Optical trocar entry is sought away from prior surgical incisions to prevent inadvertent injury to visceral structures. While Palmer's point has been regarded as the safest entry point for re-operative surgery, it is avoided in a patient who has had a prior leak from a sleeve gastrectomy or bypass.
2. All plications and adhesions must be fully taken down to restore original anatomy.
3. For gastric bypass, it is imperative to identify and preserve the left gastric artery pedicle. The use of indocyanine green-assisted laser angiography may help facilitate this process in complex revisional cases. In complex cases with significant scarring along the lesser curvature, freeing the greater curvature and then approaching the lesser curve from a lateral to medial approach posterior to the stomach may facilitate dissection and preservation of the left gastric artery.
4. Gastric tube placement into the remnant stomach may be considered if there is concern for emptying of the biliopancreatic limb or need for durable enteral access for supplemental postoperative feeds.

Training and Learning Curve

Robotic certification is not required yet by the American Board of Surgery and graduating residents have varied exposure. Intuitive Surgical (Sunnyvale, CA) offers a robotic training program, which consists of online modules, simulated modules, required number of bedside and console cases, as well as animate labs. Proctoring programs are also available, and there are many robotic fellowships available for post-graduate training. Credentialing is hospital specific, ranging from requiring the certification only to receiving proctoring for the first few cases.

While there is continued debate about the benefit to patients with robotic surgery, the undisputed benefit to the surgeon is the reduced learning curve compared to laparoscopic surgery. The learning curve for robotic sleeve gastrectomy is approximately 10 cases [68]. For gastric bypass, the learning curve is estimated to be between 10–50 cases [69, 70], while laparoscopic is 75–100 [71]. Even better, while proficient after 50 cases, robot users continue to see reduced operative times, conversion rates, and leak rates as they become more experienced [72, 73]. One single center's description of their adoption of the robot for gastric bypass found that operative time

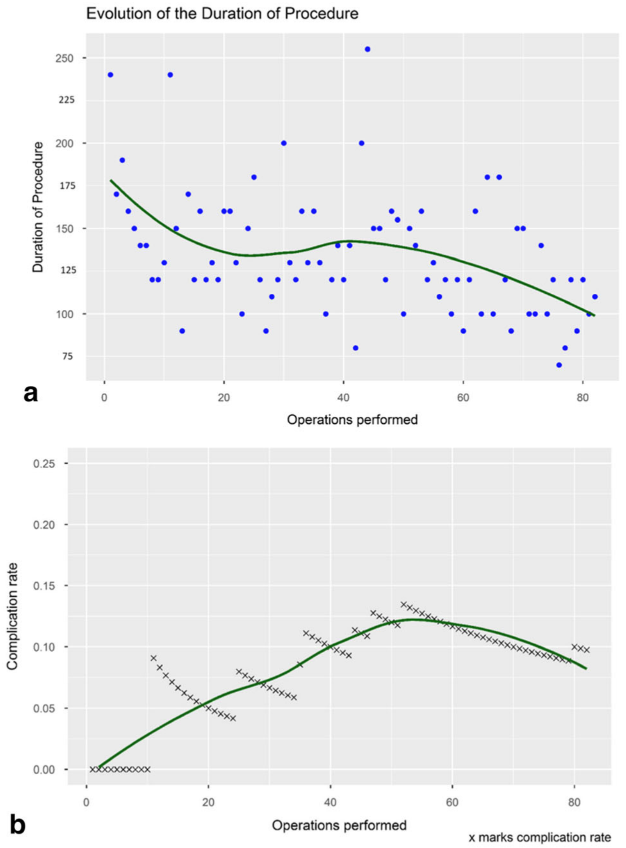

Fig. 3 Improved **a** operative times (cumulative average duration (in min)) and **b** complications for robotic-assisted gastric bypass (from the first patient). From: Ref. [74]

decreased by 30 min after 42 cases and complication rates decreased after 52 cases (Fig. 3) [74].

Financial Considerations

A robotic platform is an expensive investment for a hospital system. In 2012, the purchase cost of the da Vinci was $1–2.3 million, with an annual maintenance fee of $100,000–$170,000 and individual semi-disposable instrument cost of $1300–$3500 ($350/use). A 2010 cost analysis estimated an increased cost of $2900 more than laparoscopic surgery [75]; this has been estimated to be upwards to $3500 more for bariatric procedures alone [60, 76].

Proponents of the robot have challenged these criticism of cost with estimations that the cost of the procedure is perhaps outweighed by persistent reduction in hospital stay, postoperative complications, blood loss, and recovery time [77]. In addition, while "cost" reported in various studies can refer to the overall cost, the cost to purchase the robotic system, or hospital costs generated with the management of complications, studies that compare the cost of the robot for bariatric surgery only, discounting the use of

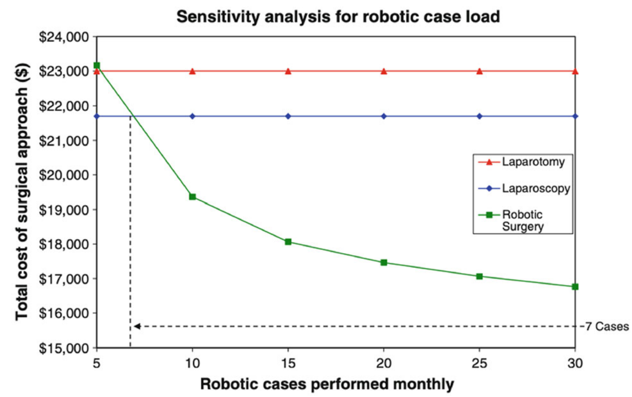

Fig. 4 Reduction in cost for robotic cases as volume increases, compared to stagnant costs for open and laparoscopic cases. From: Ref. [78]

the same robot for surgical procedures should be viewed with caution, as they overestimate the cost of the robot [27].

A predicted reduction in robotic cost could be achieved with high-volume centers (greater than 7 cases per month, Fig. 4), a reduction in complications to zero, a reduction in length of stay, and a reduction in operative time. For example, if operative time could be decreased from 210 to 150 min, this alone could decrease overall cost by $1000 [78]. This can be achieved with a trained and dedicated team that regularly uses the robot, which can reliably operate the robot safely, troubleshoot errors expeditiously, reduce docking time, and exchange instruments readily.

Conclusions

The use of robotics in surgery continues to increase, and bariatric surgery is no exception. Despite a longer operative time of approximately 30 min, robotic surgery is a safe and effective methodology to perform bariatric procedures. These platforms have the greatest potential in complex operations, such as revisional bariatric surgery. The constant improvement of instruments, rigorous training of robotic teams, and cost-effective usage of the robotic platform may overcome the higher initial costs. A faster learning curve with less complications gives the robot an advantage in teaching and may translate into improved outcomes. While the data continue to evolve with our adoption of the robotic platforms, the robot does show advantage for revision gastric bypass and in patients with a higher BMI.

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Compliance with Ethical Guidelines

Conflict of interest Michelle Scerbo, Bashar Alramahi, Melissa Felinski and Kulvinder Bajwa declare that they have no conflicts of interest. Erik Wilson has received speaker, consulting and teaching honorarium from Gore Medical, Apollo Endosurgery, Intuitive Surgical, Ethicon Inc., and Olympus Global. Shinil Shah has received research grant support from Intuitive Surgical.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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