Advances in Laparoscopic Colorectal Surgery

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KEYWORDS

• Laparoscopy • Minimally invasive surgery • Colorectal cancer
• Hand-assisted laparoscopy • Learning curve

KEY POINTS

- Laparoscopic colorectal surgery is safe and oncologically equivalent to open surgery.
- Many short-term and long-term benefits exist for laparoscopic surgery when compared with open surgery.
- Several variations in surgical approach and technique exist, most of which have shown equivalent outcomes in the literature.
- Several patient-specific factors can have an impact on the efficacy of laparoscopic surgery but can be navigated with a safe, thoughtful approach.
- The learning curve for laparoscopic surgery is steep and often requires a strong foundation during surgical training.

INTRODUCTION

When laparoscopic colectomy was first introduced in 1991,[1,2] it did not experience the same level of enthusiasm among practitioners that was given to laparoscopic cholecystectomy. The procedure involved multiple quadrants and was more technically demanding than cholecystectomy. Early fears about port-site metastases[3,4] and potentially inferior oncologic outcomes prevented widespread adoption and ultimately resulted in the conduction of multiple high-quality randomized controlled trials that have now confirmed the safety and efficacy of laparoscopic surgery for colon cancer.[5–10] Current estimates suggest 59% of all elective colectomies are performed laparoscopically,[11] with slight variations based on diagnosis, geography, and hospital setting. Utilization tends to be higher among fellowship-trained colon and rectal surgeons.[12]

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As understanding and experience have evolved, several technical improvements and adaptations have allowed for increased utilization of minimally invasive surgery (MIS). In addition to the more traditional straight multiport laparoscopic surgical (MLS) approaches, many surgeons use robotic-assisted surgery, hand-assisted laparoscopic surgical (HALS), and single-incision laparoscopic surgical (SILS) procedures, all of which fall under the MIS or laparoscopic umbrella. Each of these procedures, although unique, is governed by the same minimally invasive procedural codes (introduced in 2008) and thus reimbursement is no different among these options (including robotics). When compared with open surgery, all these variations in MIS technique maintain similar advantages, including shorter hospital length of stay, shorter duration of narcotic use, decreased pain scores, quicker return of bowel function, decreased rates of ileus, improved rates of surgical site infection, lower incisional hernia incidence (12.9 vs 2.4%), and decreased incidence of adhesive small bowel obstruction (6.1 vs 1.9%).[13–16] The choice between MLS, SILS, and HALS is made based on several surgeon-specific factors, such as personal preference, operative experience, equipment availability, and the skill level of the surgical assistant. Many patient factors also play a role, including prior abdominal surgery (PAS), body habitus, comorbidities, and desired cosmesis. Within each of these approaches, there is considerable variability in the operative steps, with the 2 main approaches medial-to-lateral dissection and lateral-to-medial dissection.

As outlined previously, laparoscopic surgery is oncologically equivalent to open surgery for colon cancer, but significant controversy still exists for the treatment of rectal cancer. In general, laparoscopic low anterior resections and abdominoperineal resections are more technically challenging than colectomy, and experts question whether or not MIS is appropriate for low pelvic cancers. This is discussed in greater detail in Rodrigo Oliva Perez and colleagues' article, "New Strategies in Rectal Cancer," in this issue.

This article provides a summary of the various approaches, including MLS, HALS, and SILS, for segmental colectomies and proctectomy. There is additional discussion of the learning curve for laparoscopic colorectal surgery, surgeon volume, and its relationship to outcomes. Furthermore, the surgical approach to difficult patients, such as those with obesity, prior radiation, or PAS, is discussed.

OPERATIVE STEPS

Patient Positioning

When positioning a patient, the first consideration is whether or not the surgeon requires access to the anus for examination or endoscopy or to allow for a circular stapled anastomosis. Therefore, whenever access to the anus is necessary, including left-sided resections and cases where colonoscopy may be necessary, the patient is placed in lithotomy stirrups, which gives access to the anus and also allows the surgeon and/or assistant to stand between the legs when technically advantageous. For right-sided resections, the patient may be placed supine, although many experts advocate for the use of lithotomy in all cases, because it allows for more versatility.

Laparoscopic colorectal surgery often requires work in multiple quadrants, so tucking both arms at the patient's side (with appropriate padding to prevent nerve injury) is best. Exaggerated Trendelenburg positioning and tilting are also needed at times, so care should be taken to secure the patient to the table and prevent movement during the case. A bean bag is often useful, although some surgeons prefer shoulder pads and tape to secure the patient to the table.

Instruments

Many simple and advanced instruments exist for complex laparoscopic surgery, and their use is often the result of surgeon preference and availability. For colorectal surgery, a high-quality camera is used. Some experts prefer a 0° camera to reduce the assistant's cognitive load, whereas others believe a 30° or 45° camera allows more versatility during a medial-to-lateral approach. Atraumatic graspers are used on the bowel with many acceptable reusable and disposable variants. A laparoscopic suction and irrigation device should be available, and it is best to incorporate this upfront rather than waiting until significant bleeding is experienced. Although most surgeons use monopolar electrocautery in some form, either as a hook or spatula or attached to laparoscopic scissors, the use of a bipolar vessel sealer is also encouraged and can eliminate the need for stapling devices, which require larger ports. Ultrasonic shears can also be used, but they are not able to ligate larger, named vessels, such as the inferior mesenteric artery (IMA), and there is significant lateral thermal spread with these devices, so care should be taken to avoid thermal injury to the bowel.

Ureteral stents can often be placed by urology and can assist with identification and preservation of the ureters during dissection. This is more useful on the left side, where the ureter travels close to the dissection and can be occasionally injured even in the most experienced hands. Ureteral stents are usually unnecessary for experienced surgeons but should be used often during a surgeon's early experience and continue to be useful for all surgeons during difficult cases, such as complicated diverticulitis.

Operative Steps

The first step in all cases is to achieve safe access to the abdomen and establish pneumoperitoneum. The abdomen is then thoroughly explored to identify adhesions, liver disease, spread of cancer, and relevant anatomic landmarks that have an impact on the case. If no problems are discovered, the omentum is then reflected cephalad over the stomach and liver to allow access to the colon and to allow the small bowel to be retracted out of the way.

Right Colectomy

The patient is placed in the Trendelenburg position with the left side tilted downward. The camera is usually placed above the umbilicus. Port placement is at the discretion of the surgeon but often includes two 5-mm ports for the surgeon (eg, left lower quadrant and suprapubic) and an optional 5-mm port for the assistant (eg, epigastric or left upper quadrant).

A medial-to-lateral dissection starts with placing the cecum on tension and retracting it toward the right lower quadrant, which almost always allows for identification of the ileocolic vessels. For most patients, the duodenum can also be visualized through the mesentery, located cephalad to the ileocolic vessels. An incision is made in the visceral peritoneum of the mesocolon, parallel and inferior to the ileocolic artery. Blunt dissection is then used to open the embryologic plane and separate the artery from the underlying duodenum. A high ligation of the ileocolic vessels is then performed with bipolar energy, the mesocolon is retracted anteriorly, and the medial-to-lateral dissection is continued laterally out to the abdominal wall over the top of Gerota fascia as well as cephalad until the hepatic flexure has been separated from the retroperitoneum. The duodenum and head of pancreas are visualized and kept free from harm during this dissection. The right branch of the middle colic artery is also ligated. Next, the terminal ileum is elevated off of the retroperitoneum, and the lateral colonic attachments are divided, connecting the lateral and medial dissection planes. The omentum is

mobilized off the transverse colon, and the hepatic flexure is taken down in a medial-to-lateral fashion. After this, the mobilized and devascularized colon can be extracted through an incision in the abdominal wall for an extracorporeal anastomosis, or an intracorporeal anastomosis can be performed instead.

A laparoscopic lateral-to-medial dissection mirrors that of open surgery and includes medial colonic retraction with incision of the lateral attachments staying slightly medial to the line of Toldt to avoid dissection in the retroperitoneum. As the mobilization continues, care should be taken to identify the duodenum and avoid injury. Similar ligation of mesocolic vessels is performed, and similar options exist for specimen extraction and anastomosis.

Left Colectomy

The patient is placed in lithotomy stirrups and the Trendelenburg position, this time with the right side tilted downward. The camera is usually placed above the umbilicus. Port placement is at the discretion of the surgeon but often includes two 5-mm ports for the surgeon (eg, right lower quadrant and right upper quadrant or possibly suprapubic) and one to two 5-mm ports for the assistant (eg, left lower quadrant and/or left upper quadrant).

A medial-to-lateral dissection starts by elevating the rectosigmoid colon anteriorly, allowing for identification of the IMA and the sacral promontory. The visceral peritoneum of the mesocolon is incised medially at the level of the sacral promontory, allowing entrance into the presacral space. The IMA is elevated anteriorly, and blunt dissection is used to separate the artery from the underlying retroperitoneum. The left ureter must be identified and swept posterior to the dissection to avoid injury. A high ligation of the IMA is performed with bipolar energy, the left mesocolon is elevated anteriorly, and a medial-to-lateral dissection is continued over Gerota fascia to the abdominal wall. For pelvic cases, additional mescolic ligation, including the inferior mesenteric vein at the level of the ligament of Treitz, is necessary to obtain adequate colonic mobility. Next, the lateral attachments are divided to connect the lateral and medial dissection planes. The surgeon should have a low threshold for splenic flexure mobilization, which can be performed with a lateral or medial approach. Most experts recommend routine splenic flexure mobilization.

The site of distal transection is chosen based on pathology, the mesentery is divided, and a laparoscopic linear cutting stapler is used to divide the colon, typically via a 12-mm right lower quadrant incision. Many options exist for extraction, with perhaps the most appealing a low-transverse (Pfannenstiel) incision.

A lateral-to-medial dissection mirrors that of open surgery and includes medial tension on the colon and incision of the lateral attachments staying slightly medial to the line of Toldt to avoid dissection in the retroperitoneum. The left ureter is identified and preserved, and similar vessel ligation is performed.

Low Anterior Resection

A low anterior resection begins similar to a sigmoid colectomy, including mobilization of the left colon and ligation of the IMA. For pelvic cases, routine mobilization of the splenic flexure and routine ligation of the inferior mesenteric vein should be performed to allow adequate mobility.

The pelvic dissection is carried out in a manner similar to open surgery. For women, the uterus often requires elevation, which can be done with fixation suture through the anterior abdominal wall. The assistant elevates the rectum anterior and cephalad, and dissection begins posteriorly in the holy plane, with great care taken not to violate the fascia propria of the mesorectum. Dissection can usually be extended down to the

level of the coccyx posteriorly, after which the lateral dissection is performed bilaterally. This takes a skilled assistant to operate the camera and provide retraction. The anterior dissection is performed last, and for female patients, it is often aided by a retractor within the vagina with anterior tension. Stapling in the deep pelvis is technically challenging, and often the best approach is a linear cutting stapler from a suprapubic port, with an anterior to posterior orientation and an assistant placing cephalad pressure on the perineum.

Conversion

It is important to mention that the quality of dissection and extent of colonic resection should never be compromised to finish the case laparoscopically. Whenever a surgeon determines that the case cannot continue safely in a laparoscopic fashion, immediate conversion to another technique is warranted. Conversion rates remain high for colorectal surgery, including 21% for the 2004 Clinical Outcomes of Surgical Therapy trial[5] and 12% in a more recent study.[11] Conversion from SILS to MLS or MLS to HALS is often useful and can allow a surgeon to safely complete the case with similar benefits to the patient.

SELECTION OF OPERATIVE APPROACH: MULTIPORT LAPAROSCOPIC SURGICAL, HAND-ASSISTED LAPAROSCOPIC SURGICAL, AND SINGLE-INCISION LAPAROSCOPIC SURGICAL

Multiport Laparoscopic Surgical

Straight laparoscopic approaches use multiple laparoscopic ports, with the largest incision that of a small specimen extraction port. This can be made in multiple locations, including a Pfannenstiel incision, lower midline, or the left lower quadrant using a muscle-splitting approach. The former 2 locations can be modified into a slightly larger incision to use one of several commercially available hand ports. This can be used for subsequent specimen extraction and extracorporeal anastomosis.

MLS often requires an experienced surgeon and a capable assistant to complete the case safely. It can be accomplished in a majority of cases, however, and is often the preferred approach for expert surgeons.

Hand-Assisted Laparoscopic Surgical

Depending on the size of a surgeon's hand, HALS may not alter the size of the patient's extraction site, or it may require an additional 2 cm to 3 cm of incision length. The decision to use HALS can be for a variety of reasons. For some surgeons, it is used during the early parts of the laparoscopic learning curve, allowing for tactile feedback and more dexterity during tissue manipulation. It is used by others to replace the need for an experienced assistant, which is often unavailable in certain environments. HALS is also useful as a tool for teaching resident surgeons, allowing for graduated autonomy while not sacrificing complete control of the case. Lastly, HALS is often used to complete a case that would otherwise not be amenable to laparoscopy, including cases with significant adhesions or inflammation, and surgery in morbidly obese individuals.

Bae and colleagues[17] demonstrated in a 2014 retrospective analysis of right colectomies that the HALS approach had similar short-term and oncologic outcomes compared with the traditional laparoscopic approach. The investigators noted that the HALS patients had more advanced disease, which may be a touted benefit but also a source of selection bias. In a 2015 case-matched study looking at oncologic outcomes, Gezen and colleagues[18] showed equivalence in disease-free survival (DFS) and overall survival (OS) among patients treated for adenocarcinoma of the

rectum or sigmoid colon by an open, HALS, or MLS approach. The investigators note a shorter length of stay (LOS) in those who had traditional laparoscopy; however, the HALS patients had more preoperative cardiac and/or hypertensive disease.

The HALS approach is possible for all types of procedures, including proctectomy. Koh and colleagues[19] investigated abdominoperineal resection using the end-colostomy site for hand-access. With a small group of 6 patients, the investigators reported no conversions and a 6.8-day mean LOS with 1 parastomal hernia noted at 13.3-month mean follow-up. In addition to oncologic equivalence, other outcome measures are similar between HALS and MLS. In 2008, Sonoda and colleagues[20] showed similar postoperative rates of incisional hernia, small bowel obstruction, and wound infection between HALS and MLS patients after a 27-month median follow-up. Incisional hernias, in general, may be best prevented for left-sided resections by using the Pfannenstiel incision for extraction site and/or hand access rather than a lower midline incision.[21]

Hand-Assisted Laparoscopic Surgical Versus Open

In addition to comparing HALS and MLS patients directly, there are many comparisons between HALS and open surgical patients. In a 2015 case-matched study with more than 5 years of follow-up, Zhou and colleagues[22] showed that HALS patients had similar lymph node retrieval, margin positivity, locoregional recurrence, DFS, and OS in comparison with open surgical patients. The HALS patients had lower rates of wound infections, earlier tolerance of oral diet, and decreased LOS, which arguably justified the increased operative time. In a much larger case-matched review using the National Surgical Quality Improvement Program database, Benlice and colleagues[23] demonstrated that HALS patients had decreased overall morbidity, surgical site infections, urinary tract infections, ileus, reoperations, readmissions, and LOS in comparison with open surgical patients. This was noted after adjusting for baseline conditions, because the open surgical patients were demonstrably sicker. Finally, HALS for colorectal resection may give obese patients the opportunity for a safe minimally invasive operation, because Myers and colleagues[24] showed that HALS utilization was directly proportional to body mass index, with similar LOS, rate of reoperations, and 30-day mortality rates between the obese and nonobese patients.

Overall, touted benefits of a hand-assist approach include shorter operative times (compared with MLS), and a decreased learning curve – particularly for surgeons who are used to an open approach.[25] It allows a hybrid technique that includes tactile feedback while maintaining the benefits of a minimally invasive approach. Current evidence suggests it is equal to MLS for performing minimally invasive cancer surgery.

Although often found equivalent to MLS, some controversy exists for HALS, and Midura and colleagues'[26] retrospective review showed purely laparoscopic sigmoid colectomies had lower LOS and earlier return of bowel function in comparison to those patients having HALS or laparoscopic mobilization only. Therefore, it is safe to say that 1 technique cannot be universally applied to all patients, and a catered approach is better if the situation and surgeon expertise allows.

SINGLE-INCISION LAPAROSCOPIC SURGERY

SILS tends to be a more technically challenging approach to colectomy. This involves making a single, slightly larger incision and placing a single access port for dissection. There are several commercially available platforms for SILS with similar efficacy. The camera, instrument ports, and specimen extraction can be performed through this incision. Lack of triangulation, instrument collisions, and poor special visualization

are the major challenges of this approach. Nonetheless, some investigators claim that patient benefits warrant the more technically challenging approach.

Papaconstantinou and colleagues[27] reported data comparing SILS, MLS, and HALS for right colectomy, showing benefit with SILS in regard to both postoperative pain scores and LOS. This experienced group demonstrated no significant difference in operative time, rate of conversion, or mean incision lengths between MLS and SILS. In addition, there may be no increased costs for the SILS approach as reported in 2014 case-matched study, where the investigators showed comparable costs between MLS and SILS patients with an finding of shorter operative times and, therefore, decreased anesthesia costs in the SILS patients.[28] An important review of publications on SILS colectomy, covering a 28-year period, demonstrated adequate lymph node harvest, negative margins in all patients, and respectably low morbidity and mortality rates. There was an overall 6.9% conversion rate but only a 1.6% rate of conversion to an open operation,[29] which likely speaks to the high level of surgeon expertise.

SILS studies are often retrospective and there may be a significant amount of selection bias in reporting of these small case series. Furthermore, they are most commonly performed by expert laparoscopists who are skilled in other forms of MIS. Therefore, the SILS technique has not been evaluated with the most rigorous methods and should only be attempted once other forms of MIS have been mastered, particularly for neoplastic indications.

Robotics Versus Laparoscopy

Robotic-assisted MIS has gained traction in recent years as an alternative to laparoscopy. It is extensively covered elsewhere this issue, so discussion in this article is limited to avoid duplication of efforts (See Slawomir Marecik and colleagues' article, "Robotic Colorectal Surgery for Neoplasia," in this issue). The oncologic outcomes, however, for robotic colorectal surgery have been shown equivalent to laparoscopy.[30]

PATIENT RISK FACTORS

Although patient factors may dictate the choice of operative technique, risk factors, including obesity, PAS, and previous pelvic radiation, are not a contraindication to a minimally invasive approach despite adding difficulty for the surgeon.

Obesity

Obesity has been shown to prolong operative times, increase conversion rates, and result in increased length of stay.[31,32] Much of the literature on this topic is the result of nonrandomized, retrospective trials and thus must be interpreted in light of potential bias. Several investigators have examined the effect of obesity on various approaches.

In general, laparoscopic surgery has been shown safe in obese patients. A 2014 retrospective case-matched study demonstrated no difference in short term outcomes between obese patients having a SILS colorectal operation and those obese patients having MLS. Each group (SILS vs MLS) had 37 patients and had similar conversion rates, operating time, hospital length of stay, reoperation, and readmission rates.[33] Mean body mass index was a modest, 34 in the obese group. Similar outcomes were reported for MLS in a 2014 case-matched study, with no difference in the rate of reoperation, intensive care admission, and readmission between obese and nonobese patients.[34] A 2016 systematic review compared 17,895 nonobese and 5754 obese patients, with no significant difference in postoperative morbidity,

anastomotic leakage, reoperation rate, and mortality.[35] Although the obese patients had longer operative times, the lymph node harvests were equivalent overall, and 4 of the studies cited equivalence in OS and DFS.[35] A 2012 meta-analysis showed equivalent lymph node harvest and rate of reoperation for obese patients,[32] but the investigators recognized that some included studies showed increased postoperative morbidity related to cardiopulmonary and/or systemic complications. This may have some relation to the documented longer operative times and higher rates of conversion to an open approach in those patients with obesity.[32]

Although safe, laparoscopic colorectal surgery in obese patients is associated with a higher rate of conversion to open surgery (30% vs 12.7% in one recent study).[36] Longer operative times in obese patients are often noted as well,[31,37] and obese patients usually demonstrate higher rates of wound complications. This may influence surgeons to use HALS as a minimally invasive approach to obese patients, while accepting an open operation in those with PAS or advanced-stage disease and reserving MLS for those with lower-stage disease and virgin abdomens.[38]

As discussed previously, obese patients often have longer operative times, and they can be more difficult to position for surgery. Thus, it is not surprising that obesity has been shown an independent predictor for postoperative peripheral neuropathy in patients having laparoscopic colon surgery.[39]

In summary, obese patients can safely undergo laparoscopic colorectal surgery with similar or even increased advantages compared with normal-sized patients, but these surgeries are more technically challenging, and surgeons can expect longer operative times, increased postoperative morbidity, and a higher potential for conversion to an open operation. Therefore, these cases should be approached with a heightened awareness of the associated risks, and great care should be taken for patient positioning and the operative dissection. A hand-assisted approach can often be advantageous in these difficult patients. Overall, the minimally invasive approaches remain a viable option for obese patients without sacrificing important oncologic outcomes.

Prior Abdominal Surgery

As expected, patients with PAS present challenges to surgeons during any subsequent operation. There are multiple retrospective reviews comparing those patients with and without PAS. A 13-year retrospective cohort study was published by Yamamoto and colleagues[40] that showed patients with PAS having a higher rate of inadvertent enterotomy as well as prolonged recovery and ileus. Retrospective studies frequently report higher rates of wound infections, longer operative times with more frequent conversions, and occasionally higher rates of overall morbidity, but results tend to be mixed.[36,41,42] A recent meta-analysis evaluated 12 retrospective studies and determined that conversion rates and enterotomies were similar between patients with and without PAS.[43] It is likely, however, that differences in conversion rates depend on the extent and location of previous surgery.[44] The results in patients with prior operations for Crohn disease are also mixed and likely reflect the selection bias of different surgeons, with some more aggressive than others in attempting laparoscopic surgery with PAS.[45,46]

Patients requiring urgent or emergent surgery in the immediate postoperative period also technically count as having PAS. These patients often suffer from an anastomotic leak, and, depending on the leak location and severity, it is often feasible, and even preferable, to re-explore these patient laparoscopically. One recent retrospective study showed that laparoscopic reintervention resulted in a lower LOS, lower fascial dehiscence, and a lower mortality when compared with open reintervention.[47]

In summary, laparoscopic colorectal surgery in patients with PAS is safe and feasible but is often more difficult overall. In these situations, surgeons should focus on safe laparoscopic access, typically using a place and technique for access where adhesions are not anticipated, including the left upper quadrant. Published results for these patients are difficult to interpret because of selection bias.

Radiation

Radiated tissue leads to a diminished healing response compared with nonradiated tissue. Animal models support this because Franca and colleagues[48] showed a higher incidence of colorectal anastomotic dehiscence, using a rat model, in those receiving preoperative radiotherapy. Somewhat better outcomes were noted when the interval between radiotherapy and surgery was longer (8 weeks) than in a comparison group (4 weeks). Despite causing this disadvantage, radiation is useful to decrease recurrence in rectal cancer. Geisler and colleagues[49] looked specifically at laparoscopic colorectal surgical outcomes in the irradiated pelvis. Based on a retrospective review of 42 patients (11 having diverting stoma formation and 31 having a resection), there was a 10% conversion rate in the patients having a resection, with an overall average LOS of 5.5 days. Subset analysis noted 2 of 20 patients had an anastomotic leak, and fortunately both were proximally diverted and managed nonoperatively. The reason for radiation is not always for the neoadjuvant treatment of rectal cancer itself. As Buscail and colleagues[50] showed, the patients with prior radiation for prostate cancer (70 Gy) have worse outcomes that those with conventional neoadjuvant radiotherapy for rectal cancer (45 Gy), which supports the concept of considering defunctionalized anastomoses (with proximal stoma) or an end colostomy in this population.

From a staging point of view, the use of radiation correlates with fewer lymph nodes harvested, with results independent of tumor location and tumor stage.[51] Although this does not always have an impact on the plan of care postoperatively, the results help question the requirements regarding rectal cancer staging and the required number of lymph nodes. By knowing the possible effects of surgery in a radiated field, surgeons can ensure optimal oncologic dissection is performed and well vascularized anastomoses are created.

SURGEON VOLUME AND LEARNING CURVES

Technologic advances have led to a multitude of surgical approaches to colorectal disease. Each evolution in surgical technique leads to a new learning curve that must be ascended. This applies to laparoscopy as well as robotics. Even after the technique has been learned, some investigators believe a certain number of ongoing cases is needed to stay proficient. Reports on learning curve vary by the method used to calculate them. As part of some of the aforementioned randomized trials looking at outcomes for laparoscopic surgery, participants had to demonstrate successful performance of 20 procedures, because this was initially considered the learning curve. It was later determined that this was an underestimate. Subsequent study using cumulative sum analysis adjusted for case mix demonstrated that 55 procedures were necessary for right colectomy and 62 procedures for left colectomy to overcome the learning curve.[52] Specialized training programs in colorectal surgery may allow faster achievement of this goal. The learning curve for robotic procedures seems between 20 and 30 cases, during which time, procedures take significantly longer.[53]

To look at surgeon volume and its relationship with quality and cost outcomes, a retrospective study involving approximately 18,000 patients from the University HealthSystem Consortium was conducted. Results showed that high-volume

surgeons, more than 11 colectomies for cancer per year, and medium-volume surgeons, 5 to 11 colectomies for cancer per year, were more likely to use laparoscopy for colon cancer resection than low-volume surgeons, less than 5 colectomies for cancer per year. Compared with operations done by low-volume surgeons, those done by high-volume surgeons had fewer postoperative complications, were less likely to require reoperation, and had direct costs that were nearly $927 lower per patient.[54] A much smaller single-surgeon retrospective review was done for SILS right colectomy, demonstrating significant improvement in operative times between the first 10 cases and the subsequent 10 cases.[55] Similarly, a publication from 2010 showed improvement in operative times for laparoscopic colectomy after the learning curve was completed, defined by the investigators as 40 cases, with no change in rate of conversion, complications, or direct costs during the study period.[56] With regard to the learning curve for total colectomy, Ozturk and colleagues[25] showed that early-experience HALS total colectomy has operative times similar to MLS total colectomy done by surgeons well beyond their learning curve, while having tremendously lower rate of conversion compared with MLS early in learning curve. The investigators conclude that the HALS approach may afford the novice surgeon the chance to complete a minimally invasive colorectal operation in an acceptable operative time.[26] Ozturk and colleagues[25] later showed that a statistically significant decrease in HALS operative time occurs after 50 cases without any change in quality-related outcomes.[57] Other investigators have demonstrated a longer learning curve of more than 100 cases to show an improvement. Pendlimari and colleagues[58] published data showing a statistically significant decrease in mean operating times from 263 to 185 minutes, based on various colorectal resections, with improvements in morbidity, infections, readmissions, and LOS noted after the learning curve.

Given that the learning curve begins in residency, a 2012 survey of colorectal residency graduates focused on a surgeon's comfort level in approaching minimally invasive segmental colectomies after completion of training. With a 51% response rate, the investigators concluded that 10 laparoscopic right colectomies and 30 laparoscopic left colectomies provided colorectal residents with a sufficient number of procedures "very comfortable" on entering practice. Given that 46% and 24% of residents did not reach that number of left and right colectomies, respectively, the investigators comment that the requirements of 50 laparoscopic resections may be adequate, but that further analysis regarding type of segmental colectomy is needed moving forward.[59]

Several barriers exist that limit a surgeon's ability to obtain and then maintain proficiency with laparoscopic colorectal surgery. Most partial colectomies are performed by general surgeons, with less than 12% performed by fellowship-trained colorectal surgeons.[60,61] The average general surgeon, however, performs approximately 11 colectomies per year,[60] with 14 colectomies placing surgeons in the 70th percentile and 23 colectomies placing them in the 90th percentile.[60] Therefore, obtaining proficiency may take as many as 5 years to 10 years of clinical practice. Furthermore, a perceived or realistic lack of hospital equipment and/or qualified surgical assistants may limit the use of laparoscopy in colorectal surgery,[62] which could have a negative impact on a learning curve.

There is certainly not a single number that identifies the moment at which one has passed the learning curve for a particular colorectal operation. It is likely based not only on the number of cases performed but also on the rate at which these cases are done. As more health care subspecialization occurs, colorectal specialists will increase their rate of nonemergent colectomies, at which point, more meaningful learning curve data will be obtained.

SUMMARY

Just as laparoscopy has become an important tool for surgeons in the treatment of neoplasia, open operations continue to play an important role in the treatment of more complex disease, and surgeons must base their approach on several patient-specific and disease-specific factors. Similarly, when a minimally invasive approach has been chosen, the use of MLS, HALS, and SILS must be catered to the situation, and 1 technique is not universally superior. Although a surgeon is ascending the learning curve for laparoscopic surgery, patients with favorable anatomy and disease states should be chosen with safety and oncologic equivalence as major priorities. Surgeons will likely continue to push the boundaries of MIS, and textbooks 20 years from now will contain new and advanced techniques that have been built off of current hard work and innovation.

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