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Laparoscopic Colon Surgery: Past, Present and Future

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In September 1985, Eric Mühe performed the first human laparoscopic cholecystectomy [1]. As is often the case, this revolutionary technique was not readily embraced by the surgical community; however, by 1989, Reddick and Olsen [2] had reported their own experience with the procedure, which would soon become the standard of care for patients with cholelithiasis. By 1992, the early success of minimally invasive surgery of the gallbladder had spread to include a number of first publications on laparoscopic splenectomy, Nissen fundoplication, adrenalectomy, nephrectomy, and appendectomy. Similarly, reports of laparoscopic colon surgery were published in 1991 [3,4], introducing a promising technique for the management of some of the most common abdominal pathologies. Nevertheless, minimally invasive surgical techniques for the colon have not enjoyed as rapid a rise in popularity as many other laparoscopic procedures have throughout the 1990s. Several factors account for this difference, including a steep learning curve for the surgeon, the need for laparoscopic intra-abdominal vascular control, the time required to perform the procedure, the need for larger incisions to retrieve specimens, and concerns over the oncologic safety of the procedure in malignant disease [5]. In this article, we review the current state of laparoscopic colon surgery, focusing on the evidence surrounding its use in malignant and benign disease, and addressing advantages, disadvantages, and common controversies. Finally, we explore several recent technological advances facilitating laparoscopic colon surgery, including hand-assist technologies, hemostatic devices, and new laparoscopic imaging systems.

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Laparoscopic surgery for malignant disease

Port site metastases

In 1993, Alexander and colleagues [6] reported a case of wound recurrence at 3 months following a laparoscopically-assisted right hemicolectomy in a 67-year-old woman who had Dukes' C adenocarcinoma. In a similar fashion, O'Rourke and coworkers [7] described port site recurrences merely 10 weeks following resection of a Dukes' B adenocarcinoma with intent to cure. Overall, greater than 35 cases of port site metastases associated with laparoscopic colon cancer resection were published within a 2-year span of this initial report, including both limited and advanced primary lesions [8]. The true incidence of port site recurrences was unknown at the time, leading Wexner and Cohen [9] to report a series incidence of 6.3% (range 1.5%–21%) among all published cases up to 1995. These data stand in sharp contrast with rates of wound recurrences in colon resections performed via traditional laparotomy. Indeed, a retrospective series by Hughes and colleagues [10] found a rate of 0.81% (CI 0.43%–1.38%) among 1603 patients undergoing traditional open resection between 1950 and 1980, whereas Reilly and coworkers [11] found only 11 cases among 1711 reviewed patients (0.64%, CI 0.32%–1.15%) from 1986 to 1989. Thus, when compared with rates of wound metastases in open resections, early data did seem to indicate that laparoscopic management of colon malignancies compromised oncologic safety, despite the poor quality of the evidence available at the time.

In response to these concerns, the American Society of Colon and Rectal Surgeons recommended that laparoscopic colon resections for malignant disease be limited to formal prospective data collection [12]. The data obtained from these studies were most helpful in determining the true incidence of port site recurrences in minimally invasive colon surgery. In a critical review of the literature from 2001, Zmora and colleagues [8] analyzed a total of 16 series of laparoscopic colorectal resections for carcinoma published between 1993 and 2000, each comprising greater than 50 patients, and found an incidence of port site metastases of less than 1% among 1737 patients. Using a similar methodology, Allardyce [13] found an incidence of 0.85% (CI 0.14%–1.18%) among 1769 patients. More recently, data from well-designed, randomized controlled trials have provided definitive evidence against a higher incidence of port site metastases in laparoscopic colon surgery compared with traditional resection (Table 1). The Clinical Outcomes of Surgical Therapy (COST) study [14], in which 872 patients were randomized to laparoscopically assisted or open colectomy for cancer, reported only two such patients (0.5%) who had wound recurrences within the laparoscopic arm, compared with one for the open arm (0.2%, $P = 0.50$) after a median follow-up of 4.4 years. Similarly, Lacy and colleagues [15] found a single case of port site recurrence within their laparoscopic surgery group ($n = 106$) and none within their open group ($n = 102$) after a median follow-up of

Table 1
Major randomized controlled trials comparing laparoscopic and open surgery for colon cancer

Authors/studies	Year	No. patients (lap/open)	No. centers	Disease site	Conversion rate	Port site metastases	Outcomes	Follow-up
COLOR [22,38]	2005	627/621	Multi (29)	C	19%	-	Short-term, costs	-
Guillou et al [23]	2005	526/268	Multi (27)	C, R	29%	-	Short-term, QoL	-
COST [14,33,55]	2004	435/437	Multi (48)	C	21%	0.5%	Short-term, long-term, QoL, costs	4.4 years
Leung et al [50]	2004	203/200	Single	R, S	23%	0%	Short-term, long-term, costs	4.4 years
Kaiser et al [18]	2004	29/20	Single	C	45%	0%	Short-term, long-term	2.9 years
Hasegawa et al [32]	2003	29/30	Single	C, R	17%	0%	Short-term, immunology	1.7 year
Lacy et al [15]	2002	111/108	Single	C	11%	0.94%	Short-term, long-term	3.6 years
Braga et al [122]	2002	136/133	Single	C, R	5%	0%	Short-term, costs, immunology	1.0 year
Tang et al [123]	2001	118/118	Single	C, R	13%	-	Immunology	-
Curet et al [17]	2000	25/18	Single	C, R	28%	0%	Short-term, long-term	4.9 years
Milsom et al [16]	1998	55/54	Single	C, R	-	0%	Short-term	1.5 years
Schwenk et al [27,31]	1998	30/30	Single	C, R	-	-	Short-term	-
Stage et al [29]	1997	18/16	Single	C	17%	0%	Short-term, immunology	1.2 years

Abbreviations: C, colon, excluding transverse; Multi, multi-center trial; QoL, quality of life; R, rectum; S, sigmoid colon; Single, single-center trial.

43 months. Three additional smaller prospective trials comprising a total of 201 patients randomized between laparoscopic-assisted and open resection for colon cancer found no additional case of port site or wound tumor recurrence [16–18]. As such, the evidence to date indicates that patients undergoing laparoscopic resection of colon malignancies are at no increased risk of port site metastases compared with those undergoing open surgery. It appears that early reports of high rates of port site recurrences were in fact related to surgeon inexperience, and inappropriate handling of the tumor laparoscopically [19].

Adequacy of oncologic resection

The goals of laparoscopic colectomy performed in the setting of colon cancer are the same as for open surgery. Those involve appropriate vessel ligation, adequate resection with 5 cm proximal and distal resection margins, and radical mesenteric lymphadenectomy. In addition, a thorough inspection of the abdominal cavity and liver surface is expected, together with the creation of a reliable anastomosis. Many of these elements have been evaluated in the context of clinical trials. Perhaps the most extensively studied factors have been the number of recovered lymph nodes within surgical specimens and the adequacy of resection margins. A recent meta-analysis [20] reviewed five randomized controlled trials reporting specifically on these issues, and found no significant difference between laparoscopic and open resection groups. Similarly, a Cochrane Collaboration review of 7 trials comprising 688 patients [21] found no difference in the total number of retrieved lymph nodes between the two groups ($P = 0.86$). Recent pathological data from large-scale, randomized controlled clinical studies further support these conclusions. Indeed, the European Colon Cancer Laparoscopic or Open Resection (COLOR) Study Group found identical rates of positive resection margins of 2% between their two groups ($P = 1.0$) [22], whereas the UK Medical Research Council trial of Conventional versus Laparoscopic-Assisted Surgery in Colorectal Cancer (MRC CLASICC) reported nonsignificant positive circumferential resection margins of 7% and 5% ($P = 0.45$) in laparoscopic-assisted and open resections, respectively [23]. In the COST study [14], the median number of recovered lymph nodes was 12 in both study arms, whereas longitudinal resection margins of less than 5 cm were present in only 5% and 6% of laparoscopic and open colectomies, respectively ($P = 0.52$). Despite the lack of good data on other elements of adequate oncologic surgery mentioned earlier, there appears to be no appreciable difference in the oncologic outcomes between laparoscopic and open colectomies for cancer.

Short-term outcomes

Much like other minimally invasive surgical procedures, laparoscopic colon surgery offers numerous short-term benefits, including reduced postoperative pain, potentially improved quality of life, shorter length of stay in

hospital, quicker recovery of bowel function, and potentially, costs savings (see Table 1). These factors can be extremely advantageous for the patient, but must nonetheless be balanced against increased operating time required to perform these procedures. Although the mean increase in operating time seems to approach 1 hour in the literature [24], this value does appear to decrease significantly with surgeon experience [25].

Faster recovery of bowel function is one of the important potential benefits of laparoscopic colon surgery, because this often impacts on the duration of the postoperative hospital stay. Schwenk and colleagues [21] found that first passage of flatus was typically 1.0 day earlier in the laparoscopic colectomy group ($P<0.0001$), whereas passage of first bowel movement was 0.9 days earlier ($P<0.0001$). More recent randomized controlled trials also demonstrated a shorter recovery in bowel function, namely a report by Kaiser and coworkers [18], as well as the recent COLOR trial [22], both of which showed a significant decrease in time to first stool after laparoscopic colectomy. The major criticism associated with these studies is that examiners were not blinded with respect to the procedure performed, thus potentially allowing a positive discriminating bias in favor of patients treated laparoscopically. In addition, several studies failed to standardize the postoperative diet regimen, although Lacy and colleagues [15] used a strict protocol and demonstrated faster initiation of peristalsis and oral intake in patients undergoing laparoscopic colectomy. Despite these limitations inherent to nonblinded trials, objective evidence of improved peristalsis favoring laparoscopic colectomy has been published in the form of animal experiments [26], as well as clinical motility studies involving radio-opaque markers [27] and manometric recordings at the splenic flexure [28]. Thus, high-level evidence indicates that laparoscopic colectomy offers faster bowel function recovery than open surgery.

Numerous randomized controlled trials have demonstrated a significant reduction in pain or analgesic requirements in the immediate postoperative period [14,16,18,22,29–32]. In fact, data from the Cochrane Collaboration meta-analysis by Schwenk and colleagues [21] supports a difference in pain perception limited to the first ($P<0.0001$) and third ($P = 0.0002$) postoperative days, with no statistically significant difference found on postoperative day 2 ($P = 0.16$). In another meta-analysis, Abraham and coworkers [20] found significant advantages for the laparoscopic colectomy group in pain levels at rest and during coughing, from 6 to 8 hours until 3 days postoperatively. More recently, data from the COST study [14] showed that patients treated with laparoscopic colectomy required on average fewer days of both parenteral narcotics (3 versus 4 days, $P<0.001$) and oral analgesics (1 versus 2 days, $P = 0.02$), when compared with open resection. Similarly, short-term outcomes from the COLOR trial [22] showed a lower need for opioid analgesia on postoperative days 2 and 3, as well as a lower need for nonopioid analgesia on postoperative day 1 within the laparoscopy group. When compared with postoperative pain indices, results from quality

of life surveys have been less impressive in demonstrating a difference between patients treated by laparoscopic versus open colon resection. In an interim analysis of the COST trial, Weeks and colleagues [33] administered three different quality of life assessment scales to patients randomized to either laparoscopic-assisted (n = 228) or open colectomy (n = 221). Although the authors did show a significant difference in the number of days of oral and parenteral analgesia requirements, they did not find any significant differences in quality of life indices at 2 days, 2 weeks, and 2 months postoperatively, except for the global rating scale at 2 weeks in favor of the laparoscopic group. Similarly, the authors of the MRC CLASICC trial [23] administered the QLQ-C30 and QLQ-CR38 quality of life questionnaires to patients randomized to laparoscopic-assisted (n = 526) or open surgery (n = 268) for colon cancer. They found very little difference between the two treatment arms at 2 weeks and 3 months follow-up, with most instruments showing equally worse quality of life at 2 weeks, with a return to baseline at 3 months. Despite these disappointing results, it should be noted that the quality of life instruments used in the COST and MRC CLASICC trials were not designed to assess acute to subacute postoperative patients who have potentially curable cancers. Although convenient because of their established validity, all but one of the questionnaires used were taken from the oncology literature, focusing heavily on chronic pain issues. Thus it is possible that meaningful quality of life differences between the two groups may have been missed because of the lack of a more sensitive and appropriate instrument. Therefore, based on the literature available thus far, the superiority of laparoscopic surgery in reducing immediate postoperative pain following colon resection seems evident. On the other hand, short- to medium-term quality of life indices assessed in two randomized controlled trials do not appear to improve with laparoscopic surgery, warranting further investigation using quality of life instruments dedicated for colon cancer surgery.

Length of hospital stay following colorectal surgery is often dependent upon bowel function recovery and the severity of postoperative pain. With the exception of one study [16], all reported randomized studies thus far have shown a shorter length of stay in hospital with laparoscopic colon resection compared with open surgery, with a wide variability in total length of stay between centers [14,15,17,18,22,23,29,31–33]. Although none of these studies were blinded to the treating surgical team, it is unlikely that this overwhelming trend in the literature is the result of an early discharge selection bias in favor of patients treated laparoscopically. A more recent meta-analysis [21] found that the length of stay in hospital was indeed 1.5 days shorter in the laparoscopic group (CI -1.94 to -1.12, $P<0.0001$). It should be noted that patients whose laparoscopic procedure was converted to open had in fact a longer length of stay than those who had conventional open resections, highlighting the importance of identifying this subgroup of patients preoperatively [23]. Nevertheless, there is high-level evidence

indicating that laparoscopy for colon cancer is associated with a shorter stay in hospital compared with laparotomy.

Costs

Direct costs following laparoscopic surgery for colon cancer are generally assumed to be higher than those incurred with equivalent open procedures; however, certain authors have argued that total costs to society may actually be lower for patients receiving laparoscopic surgery, given the improved short-term and potential long-term outcomes associated with the minimally invasive approach. A number of early publications limited to malignant disease have found conflicting data, with all papers reporting higher or similar costs associated with laparoscopic colon resection [34–36]. One of these studies by Philipson and colleagues [35] retrospectively assessed 61 consecutive patients who had undergone either laparoscopic-assisted (n = 28) or open (n = 33) right hemicolectomy for adenocarcinoma. By breaking down total incurred expenditures into direct (operating room, recovery, ward, intensive care unit) and indirect (hospital overhead) costs, but excluding any preoperative or postdischarge expenses, the authors reported a total of $9064 for laparoscopic-assisted procedures versus $7881 for open hemicolectomy ($P<0.001$). It is important to note that this study has significant limitations, including its retrospective nature and the lack of data regarding postdischarge societal costs, which one would predict to be lower in the laparoscopic surgery group. In addition, this report is one of only a handful that failed to show a shorter length of stay in hospital with a laparoscopic approach, a fact which could have substantially increased the hospital costs associated with this group. On the other hand, another retrospective study by Khalili and colleagues [36] reported no significant difference in total costs between the procedures ($P = 0.48$), despite higher operating room costs in the laparoscopic group. More recently, data from a case-controlled series of 150 laparoscopic and 150 open colorectal procedures [37] demonstrated higher operating room expenses associated with laparoscopy. The total direct costs were significantly lower in this same group, however, owing to shorter stay in hospital and lower pharmacy, laboratory, and nursing expenditures. The only costs data available from high-quality, randomized controlled trials have recently been reported in two separate studies. The first one [38], an interim analysis of the European COLOR study, compared 98 cases of laparoscopic colectomy for cancer compared with 112 open cases. In the context of a significantly longer operating room time in the laparoscopic group and a similar length of stay in hospital, Janson and coworkers found significantly higher total primary operation costs (€3493 versus €2322, $P<0.001$) and total cost of first admission (€6931 versus €5375, $P = 0.015$) in the laparoscopic colectomy group compared with the open group; however, productivity loss was greater in the open group (€2579 versus €2181), yielding no statistically significant difference in total

costs between the two groups (€11,660 versus €9814, $P = 0.104$) [38]. On the other hand, the second major trial [39] assessed 512 patients randomized to laparoscopic versus open colectomy for colorectal cancer. The authors reported net extra costs per patient of €125 within the laparoscopic group, related to €1171 in additional operating costs, and savings of €1046 in postoperative complications [39]. Therefore, the data available in the literature do not provide adequate evidence on whether total costs significantly differ between laparoscopy and conventional open surgery in the treatment of colonic malignancy. It appears that costs may differ significantly, depending on health care systems and local practices.

Long-term outcomes

Long-term outcomes following laparoscopic resection for colon cancer—namely tumor recurrence, disease-free survival, and overall survival—are much more challenging to assess than short-term outcomes. Since the inception of minimally invasive techniques for resecting colon cancer, a number of prospective and retrospective case series [40–46], cohort studies [47–49], and randomized controlled trials [18,50] have provided low- to moderate-quality evidence regarding the equivalency of laparoscopic and open colonic resections. The vast majority of comparative studies published thus far have found no significant difference in long-term outcomes between laparoscopic and open resections, and case series have found recurrence and survival data that measure up favorably with accepted rates for traditional colon resections.

In 2002, Lacy and colleagues [15] published one of the first landmark randomized controlled trials comparing laparoscopic-assisted (n = 105) and open resection (n = 101) for colon cancer. The study authors reported tumor recurrence rates of 17% and 27% respectively, with a nonsignificant trend favoring laparoscopic resection ($P = 0.07$). Similarly, based on an intention-to-treat analysis, the overall mortality rates were not significantly different between the laparoscopic and open resection groups (18% versus 26%, $P = 0.14$), but the rates of cancer-related mortality favored the laparoscopic group (9% versus 21%, $P = 0.03$). When analyzed by procedure actually performed, the differences in rates of tumor recurrence, overall mortality, and cancer-related mortality, all became strongly statistically significant in favor of the laparoscopic approach. Interestingly, by analyzing patients based on cancer staging, the Lacy group demonstrated that the overall advantages found with the laparoscopic approach were attributable to a subgroup of patients who had locally-advanced Stage III disease [15]. Indeed, these data by Lacy and coworkers seem to suggest that laparoscopic resections may provide a potential survival advantage for Stage III colon cancer. The mechanism behind these data is speculative at best, but may be related to alterations in immune function with laparoscopy. At least one other large case series has described a similar survival advantage in

locally-advanced disease [51]. Although very interesting and provocative, these results have yet to be replicated in other large-scale randomized studies.

Despite Lacy's report, laparoscopic surgery for malignant disease of the colon has only recently become an acceptable routine procedure, following the publication of long-term outcomes data from the COST study [14]. As stated earlier, this multicenter trial randomized 435 patients to laparoscopic-assisted colectomy and 428 patients to undergo traditional open colectomy. The surgeons participating in this study were required to meet strict adherence criteria, providing video evidence of proficiency in laparoscopic colon surgery. Despite this safeguard mechanism, the conversion rate in this study was 21%. After a median follow-up of 4.4 years, the study authors reported tumor recurrence in 76 and 84 patients ($P = 0.32$) within the laparoscopic and open groups, respectively, with no significant difference noted for time to recurrence and at different stages of disease. Similarly, the 3-year survival rate was 86% for the laparoscopic-assisted group and 85% for the open group ($P = 0.51$), with comparable disease-free survival rates ($P = 0.70$). It is fair to say that the COST study group demonstrated that laparoscopic colectomy for curable cancer is safe and at least equivalent to open resection in experienced hands [14]. The implications of the COST trial results have been far-reaching, including endorsement by American Society of Colon & Rectal Surgeons in a recent position statement [52]. It should be noted that long-term outcomes data from the European COLOR and MRC CLASICC trials had yet to be published at the time of manuscript preparation.

Finally, the issue of conversion to open surgery after attempting laparoscopic resection for colon cancer should be discussed briefly. Indeed, data exist in the literature indicating that patients undergoing attempted laparoscopic resection who are subsequently converted to traditional laparotomy fare substantially worse than either open procedures or laparoscopic resections, both with respect to short- and long-term outcomes. A recent report by Moloo and colleagues [53] reviewing 377 consecutive cases of laparoscopic resections for colorectal cancer described a significantly lower overall 2-year survival rate among converted patients who had curable Stage I through III malignancies, compared with those who had their colectomy completed laparoscopically (75.7% versus 87.2%, $P = 0.0201$). Similarly, recently published short-term data from the multicenter MRC CLASICC trial [23] revealed that converted patients had significantly higher postoperative complication rates, in-hospital mortality, transfusion requirements, and proportion of Dukes' C2 cancers than did completed patients. It is unclear whether these surprising outcomes were the result of an active learning curve documented by the authors throughout this study, or whether this represents a true unexpected outcome. Adverse outcomes associated with conversion have been examined by several additional groups, including a recent report by Casillas and coworkers [54], who used a case-control strategy to

evaluate 51 such converted cases. The authors of this report found no significant short-term outcome differences between their groups of converted and open control patients. Similarly, a recent post-hoc analysis by the COST trial study group [55] reported no significant difference in oncologic outcome after conversion to open surgery, both in terms of overall survival and disease-free survival at 3 years. Thus, although there appear to be conflicting results regarding short-term outcomes, long-term data from one important multicenter randomized trial do not appear to demonstrate any adverse oncologic outcome with conversion to open surgery [55]. Short- and long-term follow-up results from the COLOR and MRC CLASICC trials will have to be released before one can make any further conclusions.

Laparoscopic surgery for benign disease

Inflammatory bowel disease

It is known that patients suffering from inflammatory bowel diseases (IBD) have a high lifetime likelihood of requiring surgery. Specifically, patients who have Crohn's disease (CD) have an 80% overall chance, whereas patients suffering from ulcerative colitis (UC) have a 30% to 40% probability of requiring a colectomy [56]. Given their proportionally younger age and the risk of requiring multiple procedures, patients are increasingly seeking care from specialized colorectal centers offering laparoscopic treatment of IBD. Several short-term benefits similar to those described in colon cancer have been associated with laparoscopic surgery for IBD. In addition, theoretical long-term advantages include fewer adhesions formation, decreased rates of bowel obstruction, decreased likelihood of chronic pain, and decreased incidence of infertility or wound hernias [56,57].

In Crohn's disease involving the colon, the presence of inflammatory changes, thickened mesentery, skip lesions, and fistulas and abscesses makes the laparoscopic approach to surgery particularly challenging. Nevertheless, the indications for surgery remain the same as with open techniques. According to one review [57], up to three different minimally invasive procedures can be performed, including diagnostic laparoscopy, diversion procedures, and bowel resections, which can be approached using pure laparoscopic methods or hand-assisted techniques. Two randomized controlled trials have been published to date [58,59], with numerous small comparative case series [60–66], making it very difficult to assess the superiority of laparoscopic techniques when compared with conventional open outcomes (Table 2). In the first study, Milsom and colleagues [58] randomized 60 patients to elective laparoscopic-assisted (n = 31) or open (n = 29) ileocolic resection for CD. They reported a decreased incidence of minor complications favoring the laparoscopic group (four versus eight, $P < 0.05$), with a significantly faster return to preoperative pulmonary function within this same group (2.5 versus 3.5 days, $P = 0.03$). Interestingly, total morphine

requirements and recovery of bowel function were not significantly different between the two groups, whereas operative time was significantly shorter within the open group (140 ± 45 versus 85 ± 21 minutes, $P<0.0001$). As expected, incision length was substantially shorter within the laparoscopic group (5.3 ± 1.6 versus 12.7 ± 5.5 cm, $P<0.0001$). Recently, a second trial by Maartense and coworkers [59] used a similar comparative strategy with 60 patients who had CD. They reported shorter hospital stays (5 versus 7 days, $P = 0.008$), lower 30-day postoperative morbidity rates (10% versus 30%, $P = 0.028$), and lower total costs over 3 months (€6412 versus €8196, $P = 0.042$) within the laparoscopic resection group. Interestingly, no significant quality of life difference was found between the two groups using the SF-36 Health Survey and the Gastro-Intestinal Quality of Life Index. Based on the data obtained from these two randomized controlled trials, it appears that laparoscopic ileocolic resection for CD is advantageous over open approaches, in addition to providing an apparent cosmetic benefit [67]. It should be noted that the short-term benefits of laparoscopic surgery for CD have also been supported by a recent meta-analysis on the topic [68]. Finally, long-term outcomes following laparoscopic ileocolic resection for CD have simply not been addressed in prospective trials. As such, proposed long-term benefits associated with the laparoscopic approach remain hypothetical, and should not form the basis for choosing this method over a traditional open approach.

The surgical management of UC by minimally invasive methods is complex, and has thus far been limited to highly experienced laparoscopic surgeons working in specialized centers. The three procedures currently performed are laparoscopic subtotal colectomy, total proctocolectomy, and restorative proctocolectomy [69]. As is the case in open surgery, these procedures require the mobilization of the entire colon, as well as the taking of several important vascular pedicles. This area of laparoscopic colon surgery has paralleled the development of operative experience within specialized colorectal centers, and has been facilitated by the evolution of laparoscopic technologies. Many early publications on the topic described significantly worse postoperative outcomes among UC patients treated laparoscopically compared with those receiving traditional open procedures [70], in addition to longer operative times of up to 8 hours [71]. More recently, however, data from case-controlled studies have demonstrated that patients undergoing laparoscopic surgery for UC had no worse outcomes than those receiving open procedures [72], despite operative times that have remained significantly longer in most series (see Table 2). In fact, many groups have documented shorter postoperative stays in hospital by approximately 1 day within their laparoscopic groups [72–74], in addition to superior body image data, and equivalent functional outcomes [74,75]. Larson and colleagues [75] have recently reported comparable functional outcomes at a median follow-up of 13 months, among patients who had undergone laparoscopic (n = 33) and open (n = 33) ileal pouch-anal

Table 2
Major studies of laparoscopic colon resection for benign disease

Authors	Year	Study type	No. patients (lap/open)	Disease site	Conversion rate	Comparative outcomes*
Crohn's disease						
Maartense et al [59]	2006	RCT	30/30	IC	10%	↑ OR time, ↓ hospital stay, ↓ morbidity, ↓ costs
Huilgol et al [66]	2004	CC	21/19	IC	5%	↓ time PO intake, ↓ bowel time, ↓ hospital stay
Msika et al [61]	2001	PNS	20/26	SB, IC, C	0%	↑ OR time, ↓ bowel time, ↓ hospital stay, ↓ complications, ↓ costs
Milsom et al [58]	2001	RCT	31/29	IC	6%	↑ OR time, ↓ pulmonary recovery time, ↓ complications
Ulcerative colitis						
Larson et al [75]	2005	CC	33/33	C	-	No difference in morbidity or functional outcomes
Dunker et al [74]	2001	CC	16/19	C	0%	↑ OR time, ↓ hospital stay, ↓ bowel time, ↑ body image
Hashimoto et al [73]	2001	RCS	11/13	C	0%	↑ OR time, ↓ blood loss, ↓ pain, ↓ hospital stay, ↑ cosmesis
Araki et al [124]	2001	RCS	21/11	C	-	↓ time PO intake, ↓ bowel time, ↑ cosmesis
Marcello et al [72]	2000	CC	20/20	C	0%	↑ OR time, ↓ bowel time, ↓ hospital stay

Diverticular disease						
Alves et al [80]	2005	PNS	163/169	S	15%	↑ OR time, ↓ blood loss, ↓ hospital say, ↓ morbidity
Lawrence et al [79]	2003	RCS	56/215	S	7%	↑ OR time, ↓ hospital stay, ↓ complications, ↓ costs
Dwivedi et al [78]	2002	RCS	66/88	S	20%	↑ OR time, ↓ blood loss, ↓ hospital stay, ↓ time PO intake, ↓ costs
Senagore et al [77]	2002	PNS	61/71	S	7%	↓ hospital stay, ↓ complications, ↓ costs

Abbreviations: CC, case controlled study; IC, ileocolic; OR, operating room; PNS, prospective non-randomized study; RCS; retrospective case series; RCT, randomized controlled trial; SB, small bowel; ↑, increased; ↓, decreased.

* Outcome results are pertaining to the laparoscopic group, relative to the comparison group; non-statistically significant results are omitted.

anastomosis for UC or familial adenomatous polyposis. Despite numerous reports highlighting the safety and feasibility of laparoscopic surgery for UC among expert hands, no comparative randomized trial with open surgery has yet been completed. The current level of evidence in the literature is thus insufficient to conclude the superiority of one approach over another. Nevertheless, it is likely that the minimally invasive approach will continue to gain in popularity among expert laparoscopists, given its clear cosmetic advantages and potentially improved short-term outcomes.

Diverticular disease

In recent years, laparoscopic resection methods have been successfully applied to diverticulitis of the sigmoid colon [76]. Good data exist from a number of nonrandomized studies highlighting the advantages of laparoscopic sigmoid resection in uncomplicated diverticular disease (see Table 2). These benefits include most of the advantageous short-term outcomes associated with laparoscopic colon surgery, and also include decreased postoperative wound and pulmonary complications, as well as lower direct costs [77–79]. Recently, Alves and coworkers [80] published the results of a prospective national study involving 332 consecutive patients undergoing laparoscopic (n = 163) or open (n = 169) elective sigmoid resection for diverticular disease. They reported significantly higher overall morbidity rates within the open group (16.0% versus 31.4%, $P<0.001$), including higher wound complications, abscesses, and fistulas, as well as significantly longer lengths of stay in hospital within this same group. Although this study suffered from a significant patient selection bias associated with its lack of randomization, the study authors did determine that open colectomy was an independent risk factor for morbidity, using a multiple logistic regression analysis model. Therefore, despite the lack of large randomized trials comparing open and laparoscopic sigmoid colectomy for diverticulitis, good evidence exists supporting the use of laparoscopy for elective resections, based on improved short-term outcomes [76]. One should keep in mind, however, that this conclusion does not necessarily hold true for complicated diverticular disease. Some groups have shown significant increases in morbidity and conversion rates associated with laparoscopic resection of complicated diverticulitis [81]. It is recommended that such resections be performed by experienced laparoscopists.

Emerging techniques and technologies

Since the early days of laparoscopic colon surgery, techniques and technologies have evolved to render this procedure more amenable to routine use by general surgeons. Putting aside issues of oncologic safety and outcome equivalency between laparoscopic and open colorectal procedures, it remains that laparoscopic-assisted colectomy is a difficult technique to

adopt for surgeons without advanced minimally invasive surgical training. Conversion rates as high as 29% have been described [23], highlighting the steep learning curve associated with this procedure. Many new techniques and technologies have emerged in an attempt to flatten this learning curve, in part by relying upon skills surgeons have acquired in open surgery.

Hand-assist devices

Simply stated, hand-assisted laparoscopic surgery (HALS) involves the insertion of a hand inside the abdomen during a laparoscopic procedure, while maintaining pneumoperitoneum, to facilitate the procedure. The potential clinical benefits of hand-assist technology in laparoscopic colon surgery are significant. They include the restoration of tactile sensation and proprioception, the ability to perform blunt dissection, the ability to retract organs atraumatically, the ability to apply immediate hemostatic pressure, and a potential reduction in the total number of ports required during surgery. In cases of resection for malignancy, hand-assist devices restore the surgeon's ability to palpate the tumor. In short, hand-assist devices have the potential to provide the operating surgeon with many of the technical advantages of open surgery, while maintaining the short-term benefits of minimally invasive surgery.

Since the early days of laparoscopic colon resections, attempts have been made at inserting a hand inside the abdomen to help with the procedure. The evolution of hand-assisted laparoscopic surgery has paralleled the evolution of technologies to maintain pneumoperitoneum, while allowing for convenient access to the abdomen by a hand or laparoscopic instruments [82]. In 1995, Ou [83] first reported his experience with the hand-assisted technique, whereby he inserted his hand in the peritoneal cavity using a 5 to 6 cm incision and maintained pneumoperitoneum with two stay stitches to tighten the fascia around his hand. Comparing two cohorts of 12 patients each undergoing hand-assisted laparoscopic or open colectomy, Ou reported shorter lengths of stay in hospital for the hand-assisted group (5.6 versus 8.3 days), despite slightly longer total operating time (135 versus 100 minutes). Other groups have also reported their own uncontrolled case series, emphasizing short stays in hospital and the lack of conversion to open resection [84,85].

Based on these early results, a number of hand-access devices have been marketed to facilitate hand-assistance in minimally invasive surgery. So-called "first generation devices" were all built in a similar fashion, including a type of sleeve secured between the abdominal wall and the surgeon's forearm to prevent leakage of carbon dioxide, as well as a circular base designed to adapt to the contour of the abdominal wound [82]. These devices include the Dexterity Pneumo Sleeve (Dexterity Surgical, San Antonio, Texas), Intromit (Applied Medical, Rancho Santa Margarita, California), Handport (Smith & Nephew Endoscopy, Andover, Massachusetts), and Omniport (Advanced Surgical Concepts, Bray, Ireland). These initial designs all

suffered from similar problems, including hand fatigue for the operating surgeon and regular leakage of pneumoperitoneum in as many as 41% to 48% of cases [86,87]. The latter problem specifically resulted in conversion to open surgery in 14% of reported cases in one series [86]. More recently, sleeveless hand-port technology has been introduced on the market, including the Gelport (Applied Medical, Rancho Santa Margarita, California) and LapDisc (Ethicon Endosurgery, Cincinnati, Ohio) devices. These second-generation designs include a wound-contouring system that maintains the system in place, in addition to a reliable lock-on gel or disclike cover top that seals the device shut [82]. Effectively, the self-sealing nature of these new constructs provides a functional ''port'' into the abdomen, allowing the surgeon to insert or withdraw a hand at will. In addition, this property permits the use of laparoscopy trocars, cameras, or instruments, thus maximizing the utility of this port and minimizing the need for additional port sites on the abdominal wall.

Data regarding the validity of HALS in colon surgery now exists in the form of several case series, as well as an increasing number of randomized controlled trials (Table 3). In 1999, the Southern Surgeons' Club Study Group [86] published results of their multicenter prospective study involving 58 patients who underwent HALS, of whom 22 had mixed colon procedures. The average operating time for this subgroup was 157 minutes (94–240 minutes), with a mean length of stay in hospital of 6.4 days. Both figures compare favorably with previously published data from large trials of laparoscopic colectomy [14,22]. In another randomized controlled trial comparing hand-assisted (n = 22) versus standard laparoscopic (n = 18) colorectal resections for a variety of benign conditions and incurable malignancy, the HALS Study Group reported slightly shorter, albeit nonsignificant, operative time for the laparoscopic surgery group (152 ± 66 versus 141 ± 54 minutes, $P = 0.58$) [87]. After removing seven cases of conversion to open surgery from the analysis, operative time became somewhat more favorable for the hand-assisted group (144 versus 152 minutes, $P = 0.70$). Lengths of incision, number of cases converted to open, and stay in hospital were all similar between the two study groups. In another study, Targarona and colleagues [88] randomized 54 patients who had diagnoses of cancer, polyps, or volvulus to hand-assisted or laparoscopic colectomy. Although this group reported similar total anesthetic times, it did find higher conversion rates among laparoscopic patients (7% versus 22%), leading surgeons to find a clear subjective advantage for the hand-assisted procedure in 13 of 54 cases. The authors of this study found no significant difference in length of stay in hospital, requirements for analgesia, overall morbidity rate, oncological features, or costs of the procedures. Although not performed on an intention-to-treat basis, an analysis of interleukin-6 and C-reactive protein inflammatory markers revealed a significantly higher postoperative increase in the hand-assisted colectomy group, highlighting the greater tissue trauma generated by this procedure compared with simple laparoscopy [88].

Table 3
Major studies of hand-assisted laparoscopic surgery in colonic resections

Authors/studies	Year	Study type	Comparison groups	No. patients	Diseases	Comparative outcomes*
Segmental resections						
Chang et al [89]	2005	PNS	HALS versus LAP	66/85	B, M, P	↓ OR time ($P = 0.07$), ↑ incision, ↓ conversion
Kang et al [90]	2004	RCT	HALS versus OPS	30/30	B, M, P	↓ incision, ↓ analgesia, ↓ blood loss, ↓ bowel time
Targarona et al [88]	2002	RCT	HALS versus LAP	27/27	B, M, P	↓ conversion, ↑ inflammation
HALS Study Group [87]	2000	RCT	HALS versus LAP	22/18	B, I, P	Comparable results
Southern Surgeons' Club [86]	1999	PNS	HALS	24	B, M, P	N/A
Total abdominal colectomy/total proctocolectomy						
Maartense et al [94]	2004	RCT	HALS versus OPS	30/30	B	↑ OR time
Rivadeneira et al [92]	2004	RCT	HALS versus LAP	10/13	B	↓ OR time, ↓ bowel time
Nakajima et al [93]	2004	RCS	HALS versus LAP	12/11	B	↓ OR time, ↓ number of trocars

Abbreviations: B, benign; HALS, hand-assisted laparoscopic surgery; I, incurable malignant; LAP, laparoscopic surgery; M, malignant; OPS, open surgery; P, polyps; PNS, prospective non-randomized study.

* Outcome results are pertaining to HALS, relative to the comparison group; non-statistically significant results are omitted.

Though interesting, these data did not appear to influence the immediate postoperative clinical outcome.

More recently, Chang and coworkers [89] reported the results of a larger cohort study in which they compared 66 patients undergoing hand-assisted segmental resections with 85 undergoing standard laparoscopic colectomy. Both groups were well-matched in terms of demographics and diagnosis. The authors found a trend toward shorter average operative time in the hand-assisted group (189 versus 205 minutes, $P = 0.07$), with a significantly decreased need for conversion to open surgery in this same group (0% versus 13%, $P < 0.01$). No differences were noted in any of the standard postoperative variables. Interestingly, the authors noted that despite the advantageous conversion data and equivalent postoperative results, proportionally more hand-assisted resections were performed by surgeons with limited minimally invasive surgery experience compared with the laparoscopic colectomy group (27% versus 16%, $P < 0.05$), highlighting the potential value of this technology in training laparoscopic surgeons. In another recent study, Kang and colleagues [90] randomized 60 patients to undergo either hand-assisted laparoscopic colectomies or traditional open resections. To the authors' knowledge, this report is the only randomized-controlled trial to date comparing HALS and open surgery for segmental colon resections. Whereas reported operating times were similar between the two groups, the study authors reported significantly less blood loss (193 ± 85 cc versus 343 ± 143 cc, $P < 0.001$), and shorter incision length (7.17 ± 0.38 cm versus 13.73 ± 1.87 cm, $P < 0.001$) with the HALS procedure compared with open resections. They commented that the favorable operative time obtained in the hand-assisted group may have been related to the use of new dissection technologies. Similarly, time to oral intake, time to passage of flatus and stool, use of analgesia, and length of hospital stay were all significantly better in the hand-assisted group compared with the laparotomy group. Finally, pain scores were significantly lower on postoperative days 1, 3, and 14, but were equivalent on day 30 [90]. Overall, the data presented by Chang and colleagues and by Kang and coworkers indicate that hand-assisted laparoscopic techniques may be equivalent to standard laparoscopy for segmental resections of the colon in terms of short-term outcomes. Data from larger randomized-controlled trials will be necessary to confirm this statement. Given that most general surgeons perform only a few colon resections each year [91], it is likely that modern sleeveless handport devices will be helpful in flattening the learning curve associated with laparoscopic colon surgery, and will help in bridging the transition between the purely open and minimally invasive approaches.

Hand-assisted technologies were also recently studied in the context of highly complex colorectal procedures, such as total proctocolectomy with ileal pouch-anal anastomosis or total abdominal colectomy. Given the extent of the colonic and rectal dissections involved in these cases, it is logical to consider these procedures separately from simple segmental resections of

the colon. Rivadeneira and colleagues [92] compared two series of patients who had undergone hand-assisted (n = 10) or standard laparoscopic (n = 13) restorative proctocolectomy for UC or familiar adenomatous polyposis using a prospective database. Interestingly, the study authors found no difference in incision size or length of stay in hospital between the two approaches, but did appreciate a small difference in operative time favoring the hand-assisted group (247 [210–390] versus 300 [240–400] minutes, $P<0.01$). In another retrospective study, Nakajima and coworkers [93] reported similar results, including shorter operative time in hand-assisted total colectomy, but otherwise equivalent intra- and postoperative courses. Although these two studies seem to indicate that total colectomy is easier to perform using hand-assist devices than standard laparoscopy, both suffer from very small sample sizes and retrospective methodologies. As such, a recent randomized controlled trial performed by Maartense and colleagues [94] is particularly interesting. In this study, the authors compared patients undergoing hand-assisted laparoscopic (n = 30) versus open (n = 30) total proctocolectomy with ileal pouch anal anastomosis. They found no difference in postoperative pain, morphine requirements, time to recovery of bowel function, length of stay in hospital, or quality of life between the two groups. The only significant results were related to increased operative time and costs associated with the hand-assisted laparoscopic procedure. It should be noted that the authors used relatively rigid postoperative care protocols, which may have skewed the results in favor of the open approach.

New dissection technologies

Obtaining reliable hemostatic control in mesocolic or mesorectal dissection is not always straightforward, particularly when inflammatory processes such as diverticulitis, or inflammatory bowel disease are present [95]. As such, a number of different methods have been used for hemostatic control, including monopolar and bipolar coagulation, clips, staples, sutures, and ultrasonic dissection. In this section, we review the use and role of two such relatively novel technologies: the high-frequency ultrasonic scalpel and the electrothermal bipolar vessel sealer.

The ultrasonic scalpel was first introduced for laparoscopic use by Amaral in 1994 [96]. Today, three different models of ultrasonically-activated scalpels exist on the market: Harmonic Scalpel/UltraCision (Ethicon Endosurgery, Cincinnati, Ohio), AutoSonix (United States Surgical, Norwalk, Connecticut), and SonoSurg (Olympus Surgical, Orangeburg, New York). These instruments consist of laparoscopic shears that are induced to vibrate at a frequency of 23.5 to 55.5 kHz using a piezoelectric transducer over a 80 to 200 μm arc at the functional tip. This high-frequency vibration is said to achieve hemostasis at low temperatures (50°C–100°C) by denaturing proteins, thus producing a sticky coagulum that effectively seals blood vessels up to 5 mm in diameter [97]. It should be noted that this proposed

mechanism of action was challenged in a recent experimental study by Foschi and colleagues [98]. In contrast to ultrasonic dissection, traditional electrosurgery uses much higher temperatures (150°C–400°C) to rapidly desiccate and char tissues, resulting in eschar formation that seals the bleeding area. Based on these differences, several advantages favoring ultrasonic technology have been proposed, including the ability to coagulate in close proximity to other structures, given the theoretical lack of thermal damage to adjacent tissues, the absence of charring, the absence of smoke, and the ability to use the ultrasonic scalpel for dissection, cutting, grasping, and tissue coagulation, thus saving valuable operative time [97]. Potential limitations of this technology include high costs, the limited availability of reusable shears (both Harmonic Scalpel and AutoSonix are disposable), possible coagulation failure caused by inadequate power application or grip strength, and the creation of a vapor mist that has the potential to contain viable cells [97].

Despite the theoretical benefits of ultrasonic dissection, care must be taken given the data obtained by Emam and Cuschieri in a porcine model [99]. Indeed, they demonstrated histologically that despite the lack of macroscopic damage, ultrasonic dissection of the colon at power level 5 for more than 10 seconds caused partial- to full-thickness injury to the adjacent ureters, in the context of a large zone of significant hyperthermia surrounding the instrument. Nevertheless, the study authors found nonsignificant changes surrounding the dissection when they limited their use of the ultrasonic scalpel to 5 second bursts at a power level of 3. Emam and Cuschieri thus recommend the use of level 4 power in short bursts of 5 seconds or less for routine dissection, and level 3 power in the presence of important surrounding structures [99]. The cost of this technology is another important issue. It has been addressed in two studies of laparoscopic hysterectomy and Nissen fundoplication, comparing the use of ultrasonic shears with endoscopic staplers and clip applicators, respectively [100,101]. In both instances, the study authors reported lower costs associated with ultrasonic dissection, given the need for additional stapler cartridges or clip applicators. Finally, the issue of potentially viable cellular debris within the vapor mist created by ultrasonic dissection should be addressed, because it is directly relevant to the routine use of this technology in colon cancer. In an experimental rat tumor model, Nduka and colleagues [102] demonstrated that despite the release of airborne cellular debris from ultrasonic dissection, no viable cells were present and no subsequent growth occurred in vitro.

Only limited clinical data exists regarding the safety and efficacy of ultrasonic dissection in laparoscopic colon resection. In one such study, Heili and coworkers [103] reviewed 85 patients undergoing laparoscopic-assisted right hemicolectomy or sigmoid resection using either traditional instruments or ultrasonic shears. They reported favorable operative times ($P = 0.1989$) and lengths of stay in hospital ($P = 0.0018$) for the ultrasonic dissection

group. Similarly, a recent prospective series of 34 colorectal resections by Msika and colleagues [104] demonstrated the short-term safety of this instrument, with no reported bleeding complications. Moreover, they also argued in favor of a cost advantage for ultrasonic dissection in this setting, when compared with the use of an average 2.5 clip applicators in laparoscopic colorectal resections. The only randomized controlled trial available to date was published recently, comparing ultrasonic versus monopolar electric dissection in laparoscopic colorectal surgery [105]. In this study, 146 patients were randomized to ultrasonic dissection (n = 74) or monopolar electrosurgery (n = 72), with bipolar cautery used in both groups at the discretion of the operating surgeon. The study authors reported equivalent operative times, except for low anterior resections, for which ultrasonic dissection was significantly shorter (95.4 versus 115.6 minutes, $P = 0.01$), and reported significantly reduced overall intraoperative blood loss (140.79 versus 182.58 mL, $P = 0.032$). All other studied parameters were found to be equivalent between the two study groups, including operative complications, conversion rates, time to recovery of bowel function, stay in hospital, and postoperative complications. Nevertheless, the authors did report a very significant rate of conversion to ultrasonic dissection (20.8% or 15/72 patients) within the standard electrosurgery group. This conversion was based on the operating surgeon's judgment that ultrasonic dissection was essential to the safe completion of the procedure laparoscopically, and was more frequent during right hemicolectomy (26%) and low anterior resection (26%) [105]. Despite concerns raised by the authors of that report regarding the high costs of the technology, ultrasonic dissection appears to be valuable in complex laparoscopic colorectal resections, perhaps more so when issues of learning curves are taken into consideration. Further studies will be required to ascertain the true effectiveness of the ultrasonic scalpel over other hemostatic devices.

The electrothermal bipolar vessel sealer (LigaSure, Valleylab, Boulder, Colorado) is another relatively new hemostatic device in laparoscopic surgery. Its mechanism of action is entirely different from that of the ultrasonic scalpel, relying on high current (4 amps) and low voltage (<200 volts) to denature the collagen and elastin within vessel walls [106]. This reaction, combined with the high compression pressure of the instrument, effectively seals vessels up to 7 mm in diameter by rearranging the collagen and elastin across the collapsed vessel wall. Clinically, this process yields a translucent band of tissue that can then be cut using a second instrument, or using the internal blade of the laparoscopic LigaSure Atlas variant. In theory, this technology is thus particularly well-suited for laparoscopic colon resections, because it allows the operating surgeon to obtain hemostatic control over most if not all large arteries encountered during this procedure. This fact was confirmed in ex vivo experimental protocols using isolated abattoir porcine veins and arteries ranging in diameter from 1.0 to 7.0 mm [107]. In this study, the authors recorded acute burst pressures of 761 ± 221 mmHg for

arteries 3.1 to 5.0 mm in diameter, and of 654 ± 227 mmHg for arteries of 5.1 to 7.0 mm in diameter. Despite three of eight failed seals within the 5.1 to 7.0 mm category, the overall probability of burst strengths being less than 400 mmHg for the electrothermal sealer was only 0.04 (0.00–0.13), compared with 0.95 (0.82–1.00) for the ultrasonic coagulator. In another experimental study by Harold and colleagues [108], the superiority of the electrothermal bipolar vessel sealer over the ultrasonic shears was specifically addressed using small-, medium-, and large-sized arteries harvested from freshly euthanized pigs. Although the recorded burst pressures were statistically comparable for vessels of 2 to 3 mm, the electrothermal bipolar sealer had significantly higher burst pressures for both vessels of 4 to 5 mm (601 versus 205 mmHg, $P < 0.0001$) and 6 to 7 mm diameter (442 versus 174 mmHg, $P < 0.0001$). Finally, the study authors reported no significant difference in histological thermal injury between the two dissection technologies, although the mean reported spread using the ultrasonic shears (2.18 mm) is almost one order of magnitude smaller than that published recently by Emam and Cuschieri [99]. This discrepancy is difficult to explain at this time, but it may be related to differences in methodology between these two studies.

To our knowledge, only five clinical studies have assessed the electrothermal bipolar vessel sealer in laparoscopic colon surgery [106,109–112]. An initial study by Heniford and colleagues comprising 18 cases of laparoscopic colon and small bowel resections among 98 major operations yielded a hemostatic failure rate of only 0.3% for vessels of 2 to 7 mm diameter, demonstrating the safety and effectiveness of this new technology for vascular pedicles of large sizes [106]. Three of the five studies mentioned above were retrospective in nature, and compared small series of restorative proctocolectomies [109], hand-assisted total colectomies [110], and sigmoid and transverse colectomies [111] done using either the electrothermal bipolar sealer or the ultrasonic dissector. In all three series, the electrothermal bipolar sealer was found to be slightly superior to the ultrasonic dissector in terms of decreased mean total operating time [109,110], decreased intraoperative blood loss [110], decreased costs [109], fewer episodes of rebleeding [111], and decreased time to dissect the mesocolon [111]. Finally, Marcello and colleagues [112] reported recently published data from the only prospective randomized clinical trial comparing the electrothermal bipolar sealer (n = 52) to conventional staplers and clips (n = 48) during elective laparoscopic right, left, and total colectomies. In their study, the authors reported a non-statistically significant reduction in mean operative time of 11 minutes in the electrothermal bipolar sealer group ($P = 0.44$), in addition to a difference in vascular pedicle ligation failure rate that was significantly higher in the clips and staples group (3% versus 9.2%, $P = 0.02$). Blood loss associated with device failure was somewhat lower within the clips and staples group, because a single case of major hemorrhage associated with inadequate sealing of the inferior mesenteric vein occurred within the

electrothermal bipolar sealing group. Interestingly, the study authors also reported significantly lower operative costs associated with the use of the LigaSure Atlas device over laparoscopic clips and staples ($317 ± 0 versus $400 ± $112, $P<0.001$) [112]. As expected, this difference was more pronounced for total colectomies, for which six to nine major vascular pedicles must be divided using multiple stapler reloads and clip applicators. It should be kept in mind that purchase prices for such proprietary devices vary enormously across the United States, Canada, and Europe, thus altering the validity of cost-benefit calculations presented above based on practice location. In addition, the calculation would have easily favored the traditional approach had the authors decided to compare the device to laparoscopic clips, instead of clips and staples. That being said, the electrothermal bipolar vessel sealer represents an exciting new tool in laparoscopic colon surgery.

Advances in camera technologies

Improvements in laparoscopic cameras and video imaging systems have paralleled the development of minimally invasive surgery. Recently, important advances in laparoscopic camera technologies have dramatically improved the ease with which surgeons can perform advanced laparoscopic surgery, including colonic resections. One such innovation has been the introduction of charged coupled device (CCD) chip cameras [113], which have essentially replaced traditional tube laparoscopes. Simply put, CCD chips work by acquiring optical or analog images, and converting them into electronic or digital information, which can then be displayed on a monitor for the surgeon to see. The image resolution provided by CCD chips is directly related to a vertical and horizontal grid of sensor elements known as pixels situated on the chip, which provide resolutions of 450 to 600 horizontal lines [114]. Three-chip cameras have also been developed, which function by separating the image signal into red, blue, and green components, thus providing an improved resolution of 700 horizontal lines. These cameras tend to be slightly heavier and to lose their alignment over time due to repeated handling and sterilization, however; hence the potential for deterioration in resolution [114]. More recently, new "chip-on-a-stick" video laparoscopes have been introduced [113,114]. These new designs of laparoscopic cameras involve the placement of a single CCD chip at the tip (patient's side) of the laparoscope, immediately behind the lens. This system allows the immediate processing of the image by the chip, and in doing so, eliminates the bulky fiber-optic apparatus traditionally located within the shaft of the laparoscope. By transmitting the image via cables from the CCD chip at the tip of the laparoscope to a camera now located on the endoscopic cart, this system has several advantages, including improved image quality and resolution, reduced possibility of inadvertent camera damage, less cumbersome video cables, and potentially smaller laparoscope shaft diameter.

The traditional rigid surgical laparoscope is based upon the Hopkins rod-lens system. It is currently available in 0° forward-viewing and 30° forward-oblique-viewing designs [115]. Although the 0° scope provides greater direct illumination on the field of vision, the 30° scope is particularly well-suited for advanced laparoscopic surgery, because it allows the operator to visualize an object from all directions by rotating the shaft of the laparoscope. It should be noted though, that the 30° scope requires somewhat more user experience than its 0° counterpart, but this additional requirement is easily offset by the improved field of vision provided by this laparoscope. Given its clear advantages and similar costs, the 30° scope is used routinely at the authors' center for laparoscopic colon surgery, because it is most valuable for difficult pelvic dissections requiring different points of view. Nevertheless, the need for even greater control and improved visualization over the surgical field has also led to the introduction of flexible-tip laparoscopes [116]. These novel devices provide an observation range of 14 to 120 mm, a vertical motion ability of 100°, and a horizontal motion ability of 60° to 90°, depending on the manufacturer. As such, these laparoscopes allow for a field of view of 80° to 90°, compared with 75° for the 30° scope. In a recent study by Perrone and coworkers [117], two models of flexible-tip laparoscopes (Fujinon EL2-R310 and Olympus LTF-V3) were compared with 30° and 0° models in performing three experimental tasks. Although the study authors did show a significant difference in procedure time, accuracy, and subjective difficulty between the 0° and all three other types of laparoscopes, they did not find a significant improvement when comparing the 30° scope and flexible-tip laparoscopes. Although surprising, these data may be attributable to the simplicity of the in-vitro model used in this study. Indeed, it is likely that the flexible laparoscope would perform much better in the setting of complex colorectal dissections. Based on the current data, however, it appears that the 30° laparoscope provides excellent surgical field visualization at a lesser cost than the novel flexible-tip laparoscopes. Further head-to-head clinical studies will be required to ascertain the true value of these new technologies in colorectal surgery.

Another recent advancement in camera technology is the development of three-dimensional (3D) video imaging systems for minimally invasive surgery [118]. It is well known that the lack of depth perception in laparoscopic surgery has a direct influence on the steep learning curve associated with learning new laparoscopic skills, whether basic ones for the novice surgeon, or advanced ones for the more experienced laparoscopist. Indeed, experimental data have demonstrated that specific tasks such as laparoscopic suturing or knot tying can be performed faster and more accurately using a 3D video imaging system [119]. This system relies upon a stereoendoscope, which acquires the surgical image from two separate side-by-side lenses, yielding two offset images that can be visualized into a single 3D image using simple shutter glasses. Experimental data obtained using early 3D laparoscopes was not very promising, revealing that 3D imaging was both tiring

and awkward to use for the surgeon, and provided no benefit over standard 2D laparoscopy [120]. Nevertheless, more recent data obtained from new second-generation 3D laparoscopes are much more encouraging. Taffinder and colleagues [121] showed that 3D imaging reduced the handicap associated with traditional 2D laparoscopy by as much as 41% to 53% for a variety of experimental tasks, both for novice and experienced laparoscopists. Although not currently widely used, this system may have the potential to reintroduce 3D vision and depth perception to minimally invasive surgery, which would be most useful in colonic resections. Further clinical data will be required before this experimental system can become more widely used in surgical practice.

Summary

Since its first described case in 1991, laparoscopic colon surgery has lagged behind minimally invasive surgical methods for solid intra-abdominal organs in terms of acceptability, dissemination, and ease of learning. In colon cancer, initial concerns over port site metastases and adequacy of oncologic resection have considerably dampened early enthusiasm for this procedure. Only recently, with the publication of several large, randomized controlled trials [14,15,22,23], has the incidence of port site metastases been shown to be equivalent to that of open resection. Laparoscopic surgery for colon cancer has also been demonstrated to be at least equivalent to traditional laparotomy in terms of adequacy of oncologic resection, disease recurrence, and long-term survival. In addition, numerous reports have validated short-term benefits following laparoscopic resection for cancer, including shorter hospital stay, shorter time to recovery of bowel function, and decreased analgesic requirements, as well as other postoperative variables. In benign colonic disease, much less high-quality literature exists supporting the use of laparoscopic methods. Two recent randomized controlled trials have demonstrated some short-term benefits to laparoscopic ileocolic resection for CD [58,59], in addition to evident cosmetic advantages. On the other hand, the current evidence on laparoscopic surgery for UC does not support its routine use among nonexpert surgeons outside of specialized centers. Laparoscopic colonic resection for diverticular disease appears to provide several short-term benefits, although these advantages may not translate to cases of complicated diverticulitis.

Despite the increasing acceptability of minimally invasive methods for the management of benign and malignant colonic pathologies, laparoscopic colon resection remains a prohibitively difficult technique to master. Numerous technological innovations have been introduced onto the market in an effort to decrease the steep learning curve associated with laparoscopic colon surgery. Good evidence exists supporting the use of second-generation, sleeveless, hand-assist devices in this context. Similarly, new hemostatic devices such as the ultrasonic scalpel and the electrothermal bipolar vessel

sealer may be particularly helpful for extensive colonic mobilizations, in which several vascular pedicles must be taken. The precise role of these hemostatic technologies has yet to be established, particularly in comparison with stapling devices and significantly cheaper laparoscopic clips. Finally, recent advances in camera systems are promising to improve the ease with which difficult colonic dissections can be performed.

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