Medtronic

Global value dossier for minimally invasive surgery

Colorectal surgery

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The original document was completed in March 2016, with a literature review conducted up to 2015. During the data check in 2021, all originally included references were cross checked for accuracy and any claims supported only by publications pre-2010 were further examined for accuracy against more recent literature. No exhaustive literature review was performed during the update.

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1.1 Overview of procedure

1.1.1 Colorectal surgery

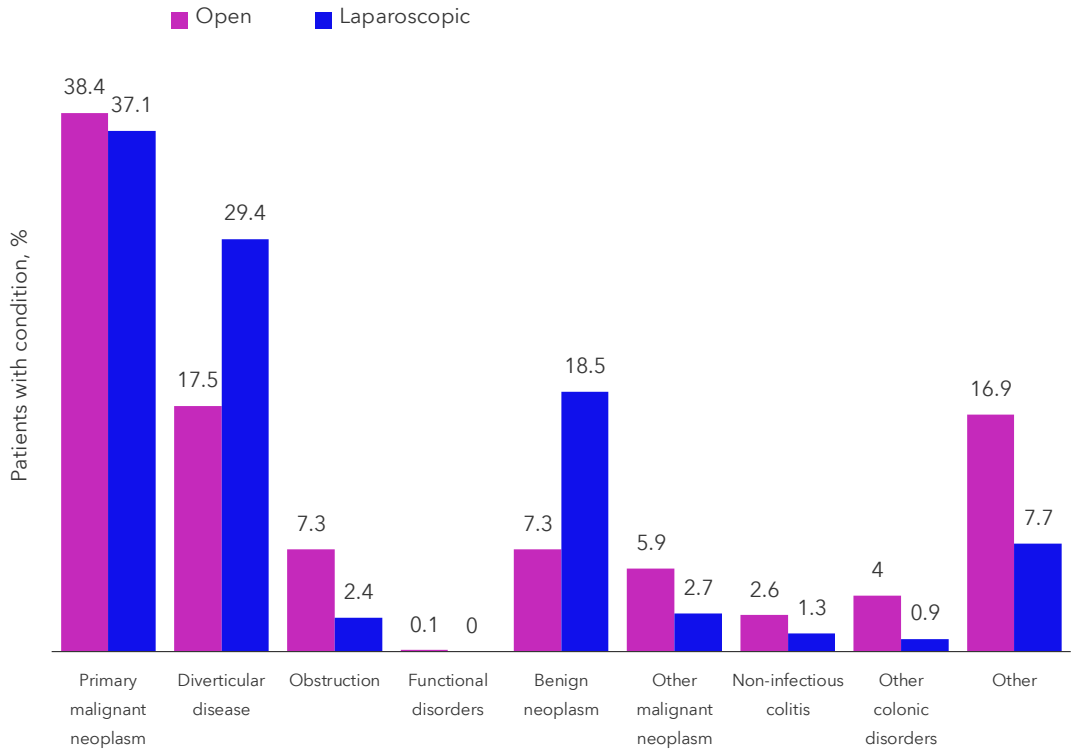
An estimated 149,500 new cases of colorectal cancer are expected for 2021 in the United States, which represents 8% of all new cancer cases in the US, making it the fourth most common cancer.[1] Surgery is the only curative treatment for colorectal cancer and encompasses complete resection of the primary tumor with negative margins in addition to a complete oncologic lymphadenectomy.

1.1.2 Minimally invasive colorectal surgery

Laparoscopic colorectal resection was first performed in 1991.[2,3] Initially, when used for removal of tumors in patients with colorectal cancer there was concern over the high incidence of port-site metastases. This has now largely been negated due to improved technique isolation of diseased tissue prior to extraction and rates of port-site metastases with laparoscopic colectomy are now similar to rates of metastases around the edge of the wound site reported with open colectomy.[4–6] US data show that 37% of laparoscopic colectomies are performed in patients with primary malignant neoplasm, 29% for diverticular disease and 19% for benign neoplasms (Figure 1-1).

Laparoscopic colectomy has several benefits compared with open colectomy (see Section 1.3) and is becoming increasingly widely used across both developed and emerging markets.[7–9] However, as operating time is typically longer with laparoscopic colectomy versus open there is demand in some settings to demonstrate tangible clinical benefit and cost-effectiveness of the use of laparoscopic techniques.[10]

Figure 1-1 Indications for colectomy in US patients 2005–2010



Source: Wilson et al. 2014[10] (n=37,249 patients from the National Surgical Quality Improvement Program database)

1.2 Common colorectal surgical procedures

There are four stages of surgery common to almost all colorectal surgical procedures, these are access to the target site: dissection of target tissue, resection of the target tissue and repair of impacted vasculature, and closure of the access channels (Figure 1-2). During each stage, the surgical instruments required may vary depending on whether access is via the open or laparoscopic route.

Figure 1-2 Stages of colectomy showcasing instruments to assist in each phase

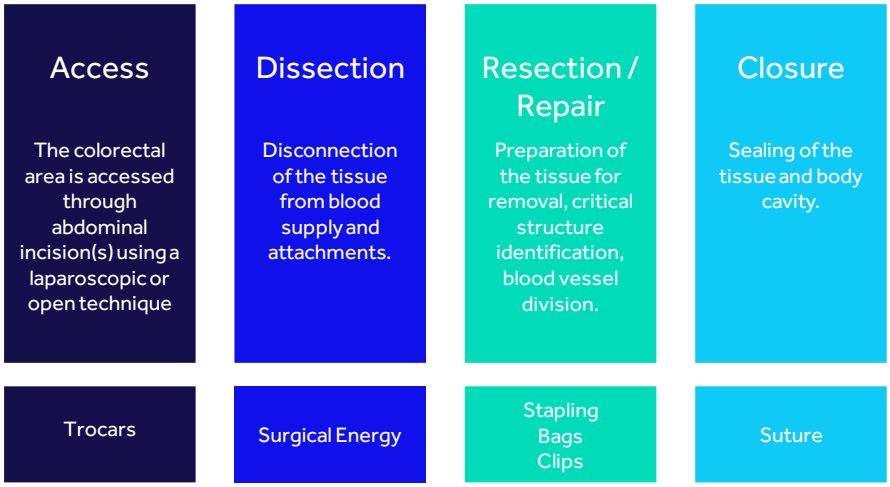
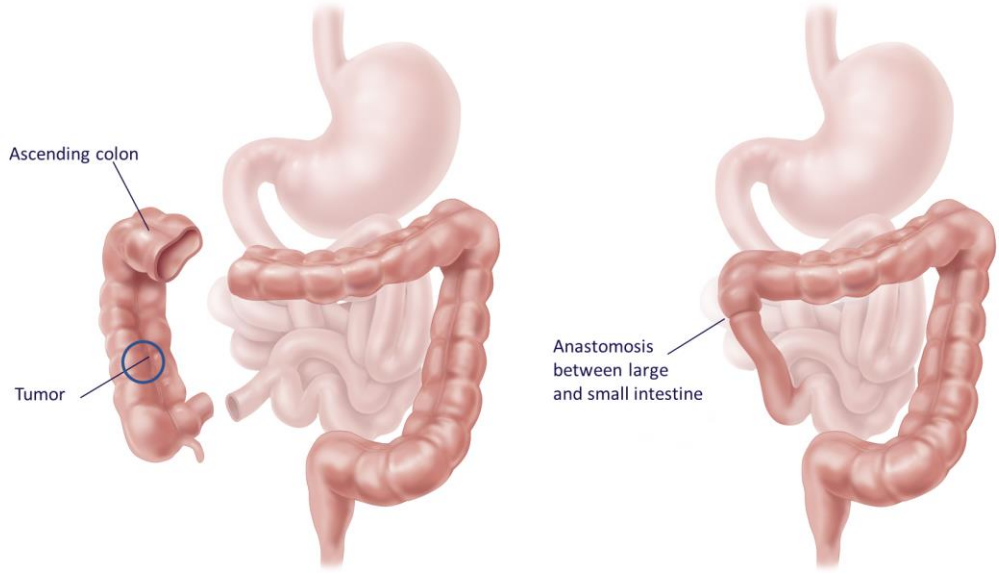


Image modified from a Medtronic internal file.

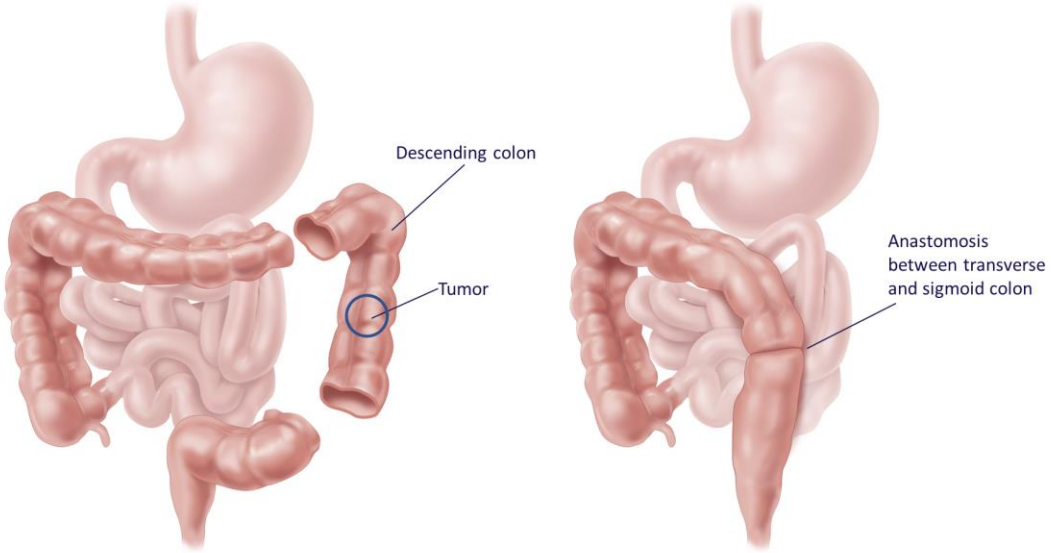
Right hemicolectomy: the removal of the cecum, ascending colon, hepatic flexure, initial third of the transverse colon and part of the terminal ileum (in addition to removal of fat and lymph nodes). Laparoscopic right colectomy involves a total of four surgical incisions and insufflation of the abdomen with carbon dioxide. Prior to any mobilization the surrounded area is examined for the presence of metastases, after which the colon is divided from its posterior and lateral attachments and ileocolic vessels ligated (Figure 1-3). The ascending colon is then transected from the ileum and transverse colon and removed after deflating the abdomen. Finally, an anastomosis is created between the ileum and transverse colon.

Figure 1-3 Right hemicolectomy with ileocolic anastomosis



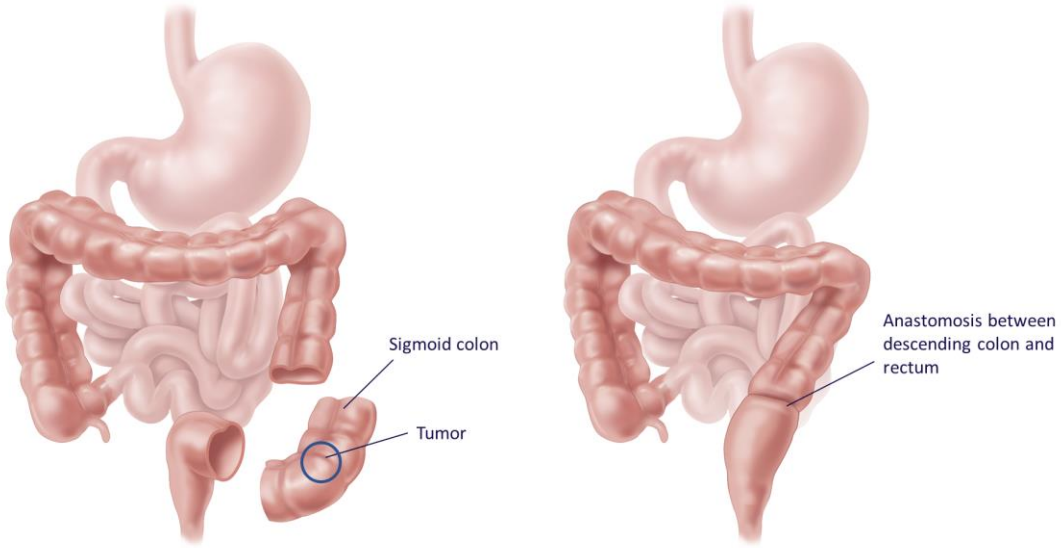
Left hemicolectomy: the removal of the left (descending) colon. The laparoscopic procedures requires approximately five small incisions. The renocolic, splenocolic and pancreaticolic ligaments are first cut to remove the descending colon from its attachments. The mesentery and the major vessels it contains must be ligated and divided. The omentum is divided from the transverse colon, splenic flexure mobilized and the necessary length of diseased bowel removed (Figure 1-4). An anastomosis is then created between the transverse and sigmoid colon.

Figure 1-4 Left hemicolectomy with transverse and sigmoid colon anastomosis



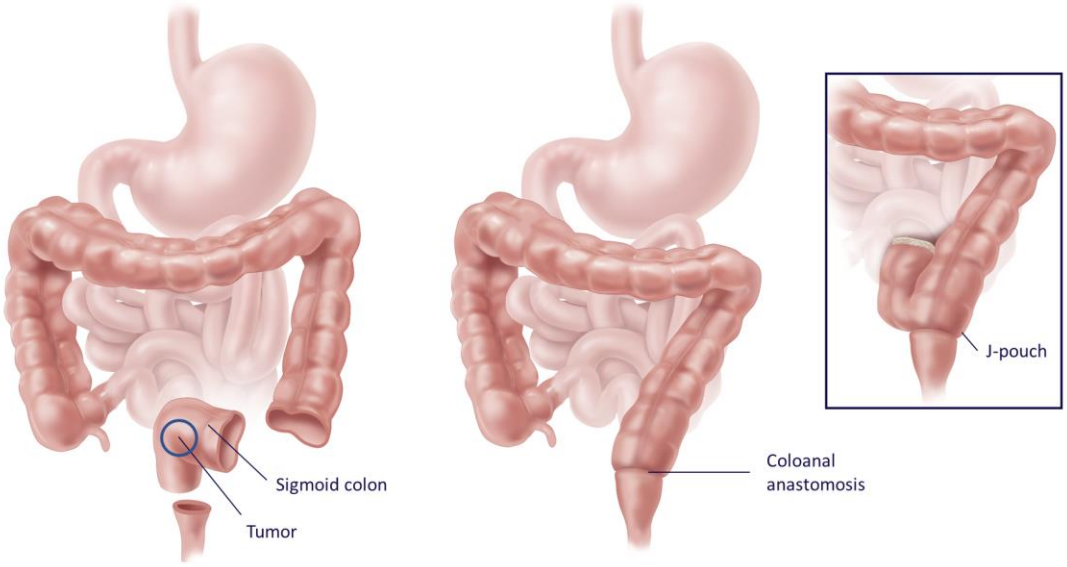
Proctosigmoidectomy, sigmoidectomy and protectomy: the removal of the rectum and sigmoid colon, removal of the sigmoid colon (from the splenic fixture to the rectosigmoid junction) and removal of the rectum, respectively. The laparoscopic procedure involves three to five incisions and the colon transected 5–10 cm on either side of the tumor (or at the rectosigmoid junction); in proctosigmoidectomy the upper section of the rectum is also removed (Figure 1-5). After which, in cases of colorectal carcinoma, the excised tissue can be placed in a specimen bag and removed through the excisions or removed through a wound protector at the wound site to prevent contact of malignant cells with healthy tissue. An anastomosis is then created.

Figure 1-5 Sigmoid colectomy with anastomosis of descending colon and upper rectum



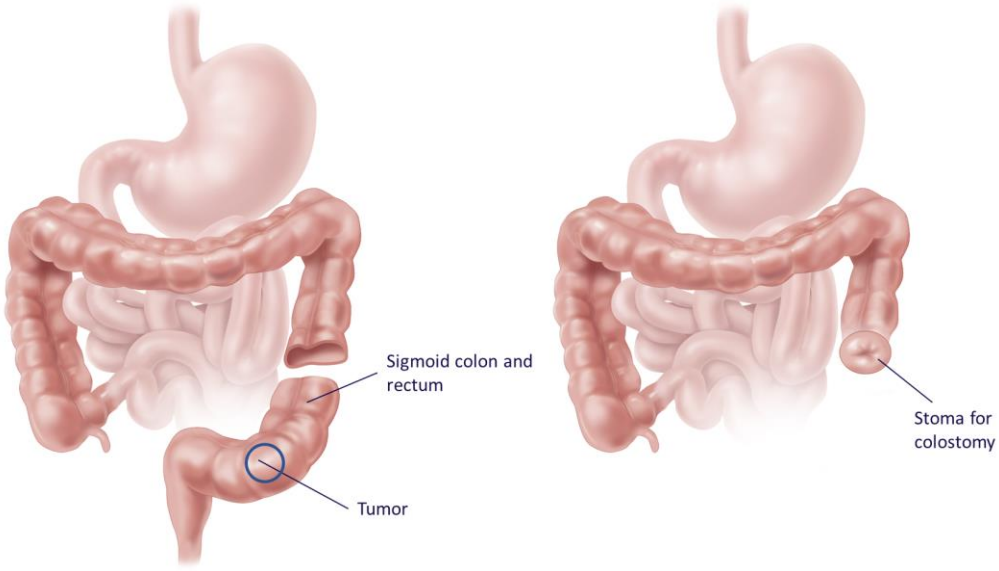
Low anterior resection: the removal of a segment of the rectum (subtype of protectomy), as well as associated lymph nodes in the case of surgery for colorectal cancer (Figure 1-6). The procedure is less extensive than abdominal perineal resection and a colostomy is not required; an anastomosis is created between the remaining part of the colon and rectum.

Figure 1-6 Low anterior resection



Abdominal perineal resection: (also known as the Miles operation) the removal of the anus, rectum and part of the sigmoid colon (in addition to lymph nodes), used in cases of rectal carcinoma in the distal third of the rectum (Figure 1-7). A colostomy is created by pulling the end of the sigmoid colon through the abdominal wall. The creation of a colostomy involves creating an opening (stoma) for the large intestine in the abdomen wall through which stool can exit into an external bag (colostomy bag).

Figure 1-7 Abdominoperineal resection with colostomy



Guidelines on the use of laparoscopic colorectal resection

Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) Guidelines for laparoscopic resection of curable colon and rectal cancer[11]

- We recommend that laparoscopic resection follow standard oncologic principles: proximal ligation of the primary arterial supply to the segment harboring the cancer, appropriate proximal and distal margins, and adequate lymphadenectomy. (++++, strong)
- We recommend that laparoscopic resection for rectal cancer follow standard oncologic principles: Adequate distal margin, ligation at the origin of the arterial supply for the involved rectal segment, and mesorectal excision. (+++O, strong)
- For locally advanced adherent colon and rectal tumors, an en bloc resection is recommended. We suggest an open approach if a laparoscopic en bloc resection cannot be performed adequately. (++OO, weak)
- We recommend that patients with an obstructing right or transverse colon cancer undergo a right or extended right colectomy. The open approach is required if the laparoscopic approach will not result in an oncologically sound resection. (++OO, strong)
- We suggest that for patients with an obstructing left-sided colon cancer, the procedure be individualized according to clinical factors. Colonic stenting may increase the likelihood of completing a one-stage procedure and may decrease the likelihood of an end colostomy. (+++O, weak)
- The use of a wound protector at the extraction site and the irrigation of port sites and extraction site incisions may reduce abdominal wall cancer recurrences. (++OO, strong)
- Before surgeons apply the laparoscopic approach for the resection of curable colon and rectal cancer, they must have adequate knowledge, training, and experience in laparoscopic techniques and oncologic principles. (+++O, strong)

- While robotic surgery for colon and rectal cancer appears feasible and safe, in the absence of long-term oncologic outcome studies, no clear recommendation can be made. (++OO, weak)

United Kingdom National Institute for Health and Care Excellence (NICE) technology appraisal guidance (TA105) on the use of laparoscopic surgery for colorectal cancer[12]

- Laparoscopic (including laparoscopically assisted) resection is recommended as an alternative to open resection for individuals with colorectal cancer in whom both laparoscopic and open surgery are considered suitable.
- Laparoscopic colorectal surgery should be performed only by surgeons who have completed appropriate training in the technique and who perform this procedure often enough to maintain competence.
- The decision about which of the procedures (open or laparoscopic) is undertaken should be made after informed discussion between the patient and the surgeon. In particular, they should consider:
    - The suitability of the lesion for laparoscopic resection
    - The risks and benefits of the two procedures
    - The experience of the surgeon in both procedures

The American Society of Colon and Rectal Surgeons Clinical Practice Guidelines for the laparoscopic treatment of colon cancer[13]

- When expertise is available, a minimally invasive approach to elective colectomy for colon cancer is preferred. Grade of Recommendation: Strong recommendation based on high-quality evidence, 1A.
- Hand-assisted laparoscopic and robotic surgical techniques for right colon cancer result in oncologic outcomes that are equivalent to open or straight laparoscopic techniques. Grade of Recommendation: Strong recommendation based on moderate-quality evidence, 1B.

- For patients with obstructing left-sided colon cancer and curable disease, initial colectomy or initial endoscopic stent decompression and interval colectomy may be performed. Grade of Recommendation: Strong recommendation based on moderate-quality evidence, 1B.
- For patients with obstructing right or transverse colon cancer and curable disease, initial colectomy or initial endoscopic stent decompression and interval colectomy may be performed. Grade of Recommendation: Strong recommendation based on low-quality evidence, 1C.

1.3 Clinical and economic outcomes with laparoscopic versus open colorectal surgery

Key findings

Clinical outcomes

- **Oncologic equivalence/disease-free survival:** Laparoscopic surgery for colorectal cancer is now associated with similar outcomes to open surgery in terms of disease-free survival and port-site metastases[14–19]. Some studies even found laparoscopic surgery to have better survival outcomes regarding disease-free and/or recurrence-free survival than open surgery[20,21].
- **Survival:** There is no significant difference between laparoscopic and open colorectal surgery for colorectal cancer in terms of overall survival rates[14–18,22–24]. Recent studies even reported increased overall survival after laparoscopic surgery[20,21].
- **Surgical Site Infection:** Rates of surgical site infection are consistently lower (often significantly) with laparoscopic colorectal surgery than open colorectal surgery[10,25–28] (Figure 1-8)
- **Length of Stay:** Length of hospital stay is significantly shorter following laparoscopic colorectal surgery than with open colorectal surgery[10,17,19–21,24,26,28–43] (Figure 1-9)
- **Blood loss:** Blood loss during surgery is significantly lower with laparoscopic versus open colorectal surgery[19,21,26,33,38,40,44,45] (Figure 1-10)
- **Blood transfusion:** The proportion of patients requiring blood transfusion is lower with laparoscopic colorectal resection than with open colorectal resection[28,32,39,43,44]
- **Incision size:** Laparoscopic colorectal surgery requires a significantly shorter incision, leading to less scarring, than open colorectal surgery[40,45]
- **Bowel function:** Return of bowel function occurs significantly sooner in patients who have undergone laparoscopic colorectal surgery than in those who have undergone open colorectal surgery[19,26,33,34,38,40]

- **Operating time:** Studies show that the operating time associated with laparoscopic colorectal surgery is consistently and significantly longer than with open surgery[14,19,21,25,32–34,38–41,44,45] (Figure 1-11)

Economic outcomes

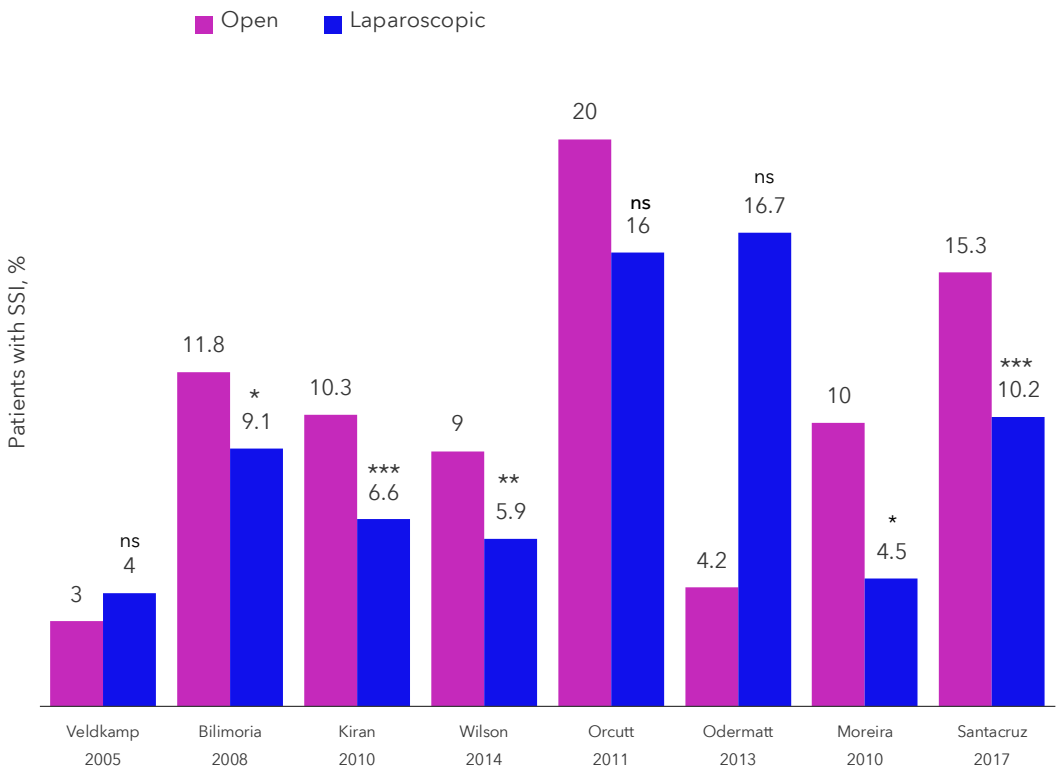
- **Operating time:** Longer operating time is not associated with significantly higher costs[46]
- **Total costs:** Findings from cost studies are inconsistent, in instances where total costs were lower with laparoscopic versus open colorectal surgery the cost savings were primarily driven by lower complication rates
    - **United States:** In US-based studies, total hospital costs for laparoscopic colorectal resection were generally lower than for open colorectal resection[26,37,42,47–50] (Figure 1-12)
    - **Europe:** In the UK, there was no significant difference in total hospital costs for open versus laparoscopic colorectal resection.[51] However, a retrospective study of the whole population of patients undergoing an elective surgery in NHS hospitals found costs of laparoscopy to be significantly less than for open surgery.[52] (Figure 1-13)
    - **Canada:** In Canada, total costs were lower for laparoscopic colectomy than for open colectomy[32,53], in one study this achieved statistical significance[32]
    - **China:** In one study conducted in China total hospital costs were significantly higher with laparoscopic colectomy than open colectomy[40]
    - **Australia:** Findings from Australia were inconsistent; in one study total costs were significantly lower with laparoscopic colectomy than open colectomy[31] and in another study they were non-significantly higher[54]
    - **Brazil:** Total costs for laparoscopic colorectal surgery were found to be significantly lower than for open surgery[43]
- **Savings due to clinical benefits:** Clinical benefits of laparoscopic colectomy, including shorter LoS and lower rates of postoperative

complications translate into economic benefits, which are important from the payer perspective.

Other findings

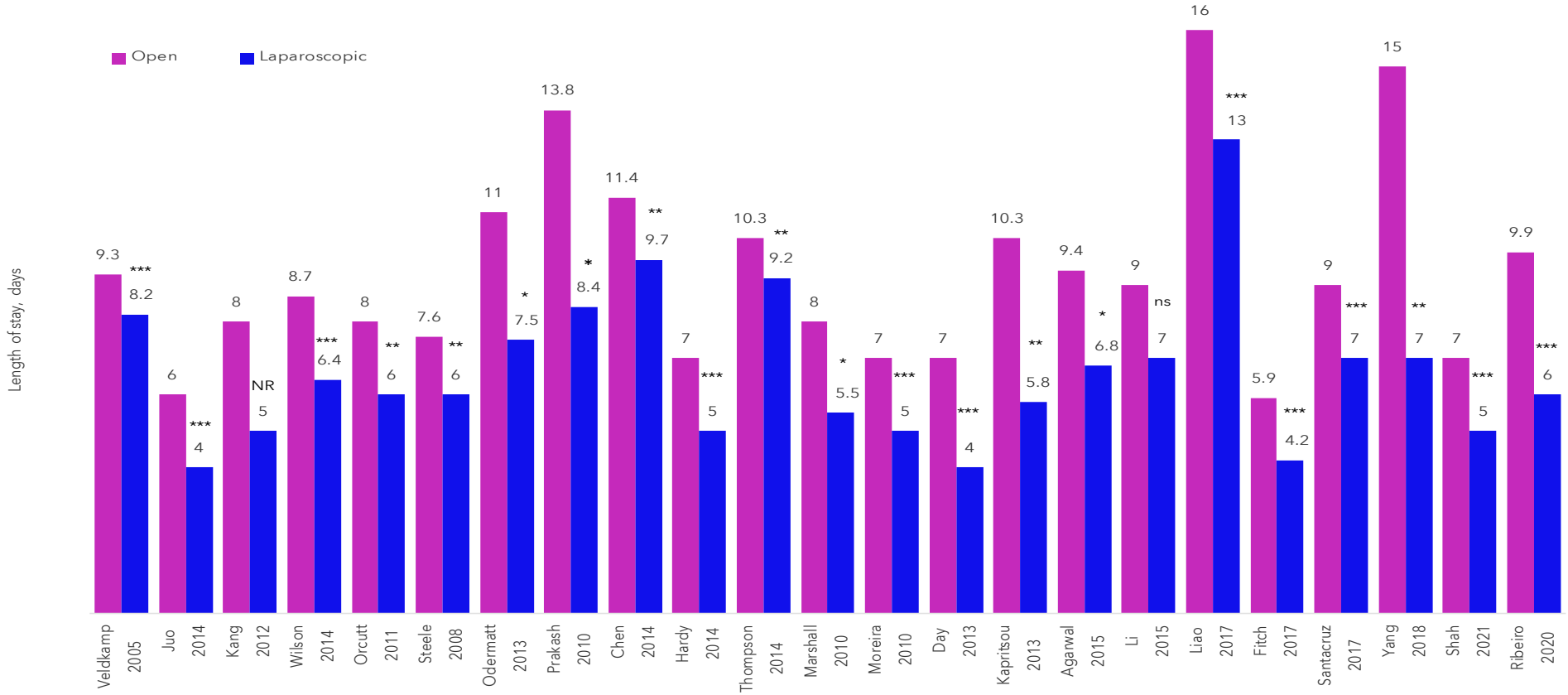
- **Surgeon volume:** Higher surgeon volume is associated with better outcomes and lower costs compared with low volume surgeons.[9]
- **Readmission rates:** Readmission rates are typically lower in patients undergoing laparoscopic colorectal resection than in those undergoing open colorectal resection. The difference was found to be not significant in older studies.[32,33] More recent studies, however, found the difference in readmission rates to be significant.[42,52]
    - Rates of readmission are influenced by several factors including BMI, surgeon volume, operating time and presence of SSI[55,56]; increased BMI is also associated with an increased surgical difficulty[57] and significantly increased risk for SSI.[57,58]
- **Pulmonary complications:** Laparoscopic surgery is associated with lower absolute risk of pulmonary complications versus open surgery.[59]
- **Quality of life:** Evidence from quality of life studies is inconsistent; with a recent systematic review reporting that some studies suggest no significant difference, while others suggest a significant QoL benefit with the laparoscopic approach.[60]
- **Emerging markets:** Clinical outcomes reported in studies of laparoscopic versus open colectomy in emerging markets such as India and Brazil are similar to outcomes reported in Europe and North America.[7,39,43]
- **Trends in cost studies:** In published cost studies the percentage difference between laparoscopic and open colectomy varies widely, but for studies conducted in Western settings there is a trend toward a decline in the cost of laparoscopic colectomy over time.[52,61]

Figure 1-8 Reported rates of SSI with laparoscopic versus open colorectal surgery



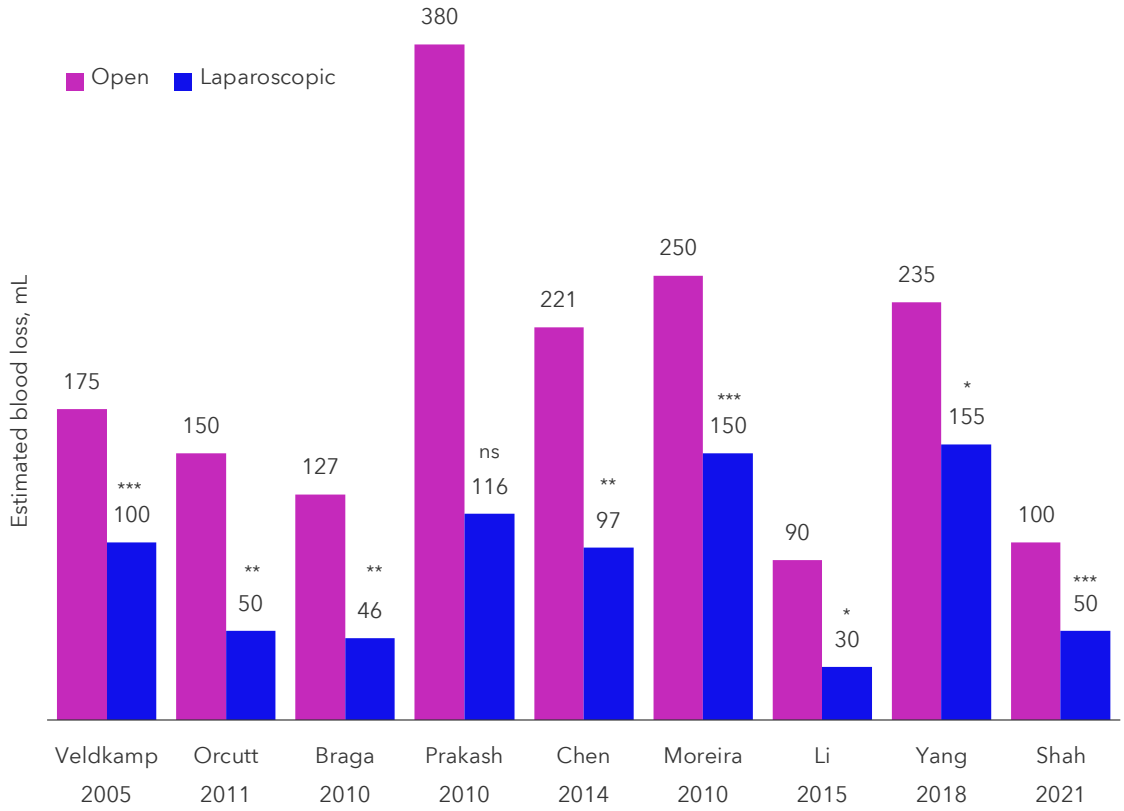
**p<0.05; **p<0.01; ***p<0.001; NR, not reported; ns, not significant; SSI surgical site infection*

Figure 1-9 Length of stay with laparoscopic versus open colorectal surgery



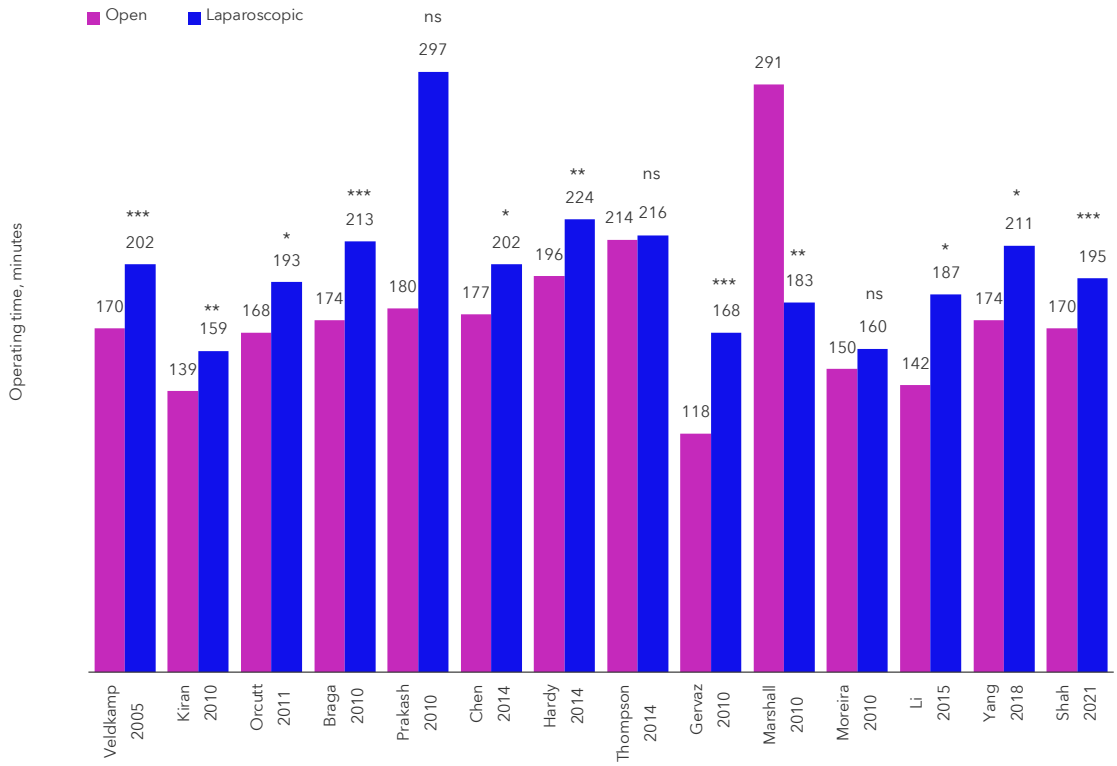
**p<0.05; **p<0.01; ***p<0.001; NR, not reported; ns, not significant*

Figure 1-10 Blood loss with laparoscopic versus open colorectal surgery



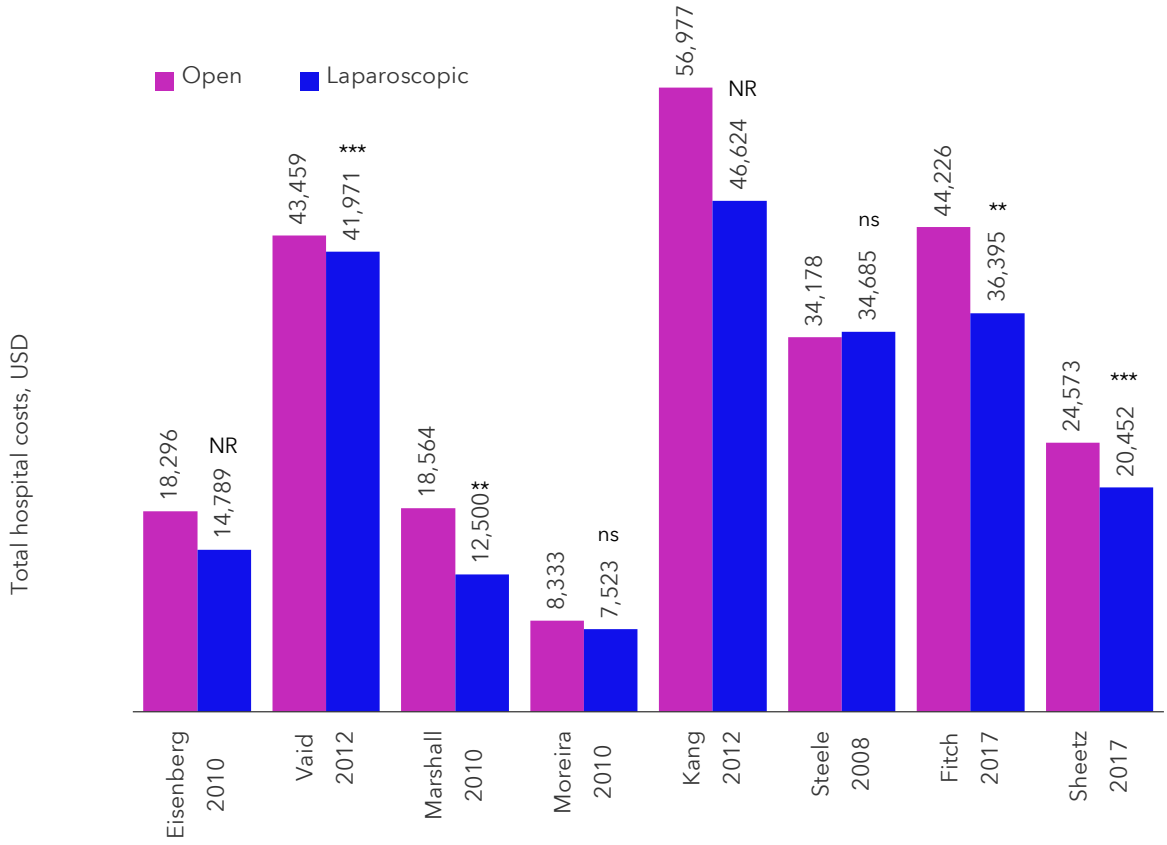
**p<0.05; **p<0.01; ***p<0.001; NR, not reported; ns, not significant*

Figure 1-11 Operating time with laparoscopic versus open colorectal surgery



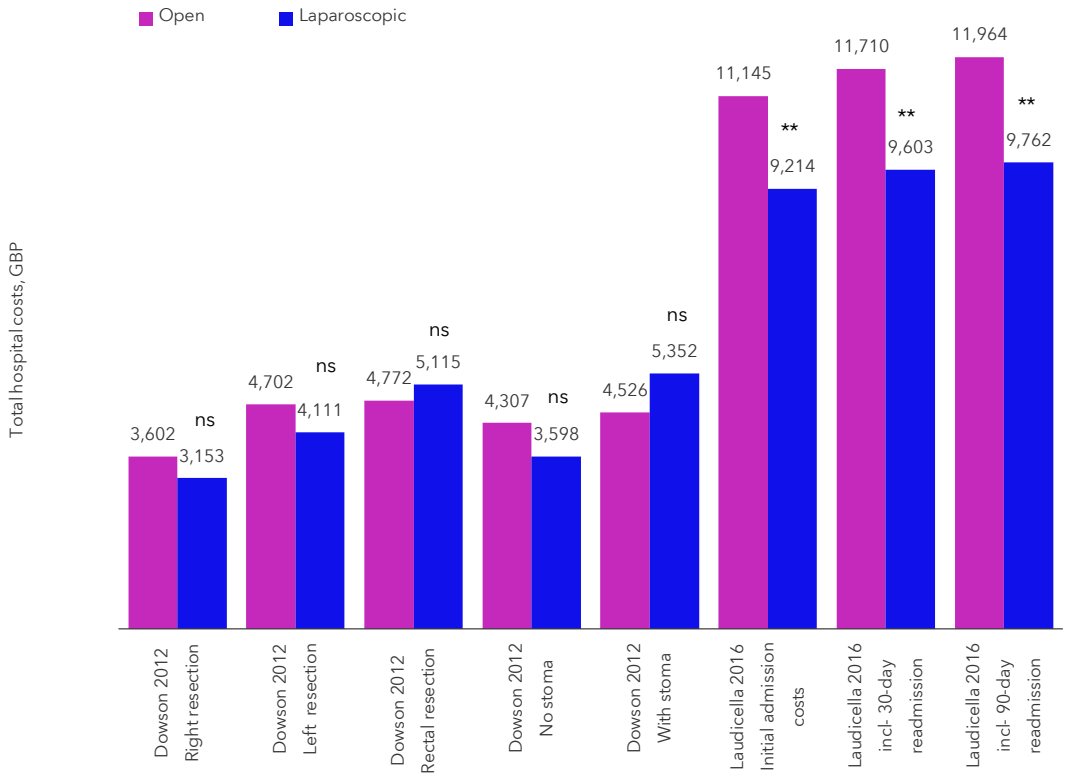
**p<0.05; **p<0.01; ***p<0.001; NR, not reported; ns, not significant*

Figure 1-12 Total hospital costs for laparoscopic versus open colorectal surgery in US-based studies



**p<0.05; **p<0.01; ***p<0.001; NR, not reported; ns, not significant*

Figure 1-13 Total hospital costs for laparoscopic versus open colorectal surgery in the UK



**p<0.05; **p<0.01; ***p<0.001; NR, not reported; ns, not significant*

1.1.1. Clinical and economic evidence tables

A summary of clinical evidence on laparoscopic versus open colorectal surgery from published meta-analyses and published studies is shown in Table 1-1 and Table 1-2, respectively. A summary of economic evidence from published cost studies is shown in Table 1-3.

In the following tables outcomes where p<0.05 are underlined.

Table 1-1 Summary of meta-analyses comparing laparoscopic versus open colorectal surgery

Authors	Details	Procedures	Outcome	Effect (95% CI)	P value
Wang *et al*. 2014[18]	15 RCTs, n=6,557 patients	Open versus laparoscopic surgery for colorectal cancer	**Peri-operative**		
			Blood loss, mL (WMD)	−91.06 (−179.66, −2.46)[a]	0.044
			Operating time, minutes (WMD)	49.34 (29.57, 69.12)[a]	0.000
			Length of incision, cm (WMD)	−9.23 (−13.77, −4.68)[a]	0.000
			Postoperative		
			Time to first bowel movement, days (WMD)	−0.95 (−1.18, −0.73)[a]	0.000
			Fluid intake (WMD)	−0.70 (−1.11, −0.29)[a]	0.042
			Complication rate (OR)	0.86 (0.77, 0.97)	0.067
			Blood transfusion (OR)	0.46 (0.32, 0.65)	0.026
			30-day mortality (OR)	0.58 (0.38, 0.88)	0.996
			Anastomotic leak (OR)	0.99 (0.72, 1.34)	0.543
			Length of hospital stay, days (WMD)	-2.64 (-4.41, -0.87)	0.000
			Post-discharge		
			3-year overall survival (OR)	1.03 (0.97, 1.10)	0.856
			3-year disease-free survival (OR)	1.03 (0.95, 1.10)	0.014
			3-year local recurrence (OR)	1.30 (0.82, 2.07)	0.356
			5-year overall survival (OR)	1.00 (0.95, 1.05)	0.595
			5-year disease-free survival (OR)	0.97 (0.90, 1.04)	0.649
			5-year local recurrence (OR)	1.09 (0.76, 1.57)	0.119

Ma *et al.* 2011[62]	15 RCTs, n=4,207 patients	Open versus laparoscopic resection for colorectal cancer	**Post-discharge**		
			Overall recurrence (OR)	0.92 (0.77, 1.11)	0.34
			Local recurrence (OR)	0.81 (0.59, 1.12)	0.20
			Distant metastases (OR)	1.01 (0.78, 1.30)	0.95
			Wound-site recurrence	1.97 (0.77, 5.02)	0.16
			Cancer-related mortality at max follow up (OR)	0.82 (0.66, 1.02)	0.07
			Overall mortality at max follow up (OR)	0.87 (0.73, 1.03)	0.11
			Overall complications (OR)	0.71 (0.58, 0.87)	0.001
Ohtani *et al.* 2011[14]	12 RCTs, n=4,458 patients	Open versus laparoscopic surgery for colorectal cancer	**Peri-operative**		
			Operating time, minutes (WMD)	39.32 (30.72, 47.91)[a]	<0.001
			Estimated blood loss, mL (WMD)	−133.05 (−201.30, −64.81)[a]	<0.001
			Postoperative		
			Number of transfused patients (OR)	0.45 (0.19, 1.05)	0.06
			LoS, days (WMD)	−2.80 (−4.78, −0.81)[a]	0.006
			Incision length, cm (WMD)	−10.97 (−14.37, −7.57)[a]	<0.001
			Time to oral intake, days (WMD)	−1.08 (−1.36, −0.80)[a]	<0.001
			Overall complication (OR)	0.83 (0.66, 1.05)	0.12
			Anastomotic leakage (OR)	1.07 (0.74, 1.54)	0.73
			Peri-operative mortality (OR)	0.69 (0.36, 1.31)	0.25

			Post-discharge		
			Overall recurrence (OR)	0.98 (0.84, 1.14)	0.81
			Local recurrence (OR)	0.86 (0.62, 1.19)	0.36
			Distant metastasis (OR)	1.02 (0.84, 1.25)	0.81
			Wound-site recurrence (OR)	2.87 (1.08, 7.68)	0.04
			Cancer-related mortality (OR)	0.83 (0.65, 1.07)	0.14
			Overall mortality (OR)	0.93 (0.79, 1.08)	0.33
Kuhry *et al*. 2008[22]	12 RCTs, n=3,346 patients	Open versus laparoscopic surgery for non-metastasized colorectal cancer	**Postoperative**		
			Recurrence in operation area, colorectal (OR)	0.81 (0.54, 1.22)	0.31
			Port-site recurrence, colorectal (OR)	1.97 (0.77, 5.02)	0.16
			Distant metastases, colorectal (OR)	1.01 (0.76, 1.34)	0.93
			Cancer-related mortality at maximum follow up, colorectal (OR)	0.84 (0.67, 1.06)	0.15
			Overall mortality at maximum follow up, colorectal (OR)	0.84 (0.70, 1.00)	0.050
Di *et al*. 2013[15]	5 RCTs, n=2,695 patients	Open versus laparoscopic surgery for colon cancer	**Post-discharge**		
			Total recurrence (RR)	0.94 [0.81, 1.10][b]	0.47
			Total mortality (RR)	0.94 [0.82, 1.09][b]	0.43
			5-year tumor-free survival (RR)	1.00 [0.94, 1.06][b]	0.87
			5-year survival rate (RR)	1.02 [0.97, 1.07][b]	0.54

Ding *et al.* 2013[63]	12 studies (RCTs and non-randomized), n=1,362 patients	Open versus hand-assisted laparoscopic surgery for colorectal disease	**Peri-operative**		
			Operating time, minutes (WMD)	3.51 (−16.47, 23.50)[a]	0.73
			Blood loss, mL (WMD)	−108.20 (−141.52, −74.87)[a]	<0.00001
			Postoperative		
			Time to first flatus, days (WMD)	−0.94 (−1.22, −0.65)[a]	<0.00001
			LoS, days (WMD)	−3.22 (−3.88, −2.57)[a]	<0.00001
			Urinary tract infection (OR)	0.58 (0.15, 2.20)	0.43
			Pneumonia (OR)	0.46 (0.16, 1.35)	0.16
			Anastomotic leak (OR)	0.95 (0.40, 2.27)	0.91
			Wound infection (OR)	0.45 (0.23, 0.87)	0.02
			Ileus (OR)	0.35 (0.16, 0.74)	0.006
			Mortality (OR)	0.68 (0.19, 2.36)	0.54
Athanasiou *et al.* 2017[41]	11 case control trials, n=1,415 patients	Open versus laparoscopic resection of transverse colon cancer	**Peri-operative**		
			Operating time, min (WMD)	45.0 (29.5, 60.5)	<0.00001
			Postoperative		
			Anastomotic leaks (OR)	0.72 (0.33, 1.53)	0.39
			Surgical site infection (OR)	1.15 (0.50, 2.64)	0.74
			Time to oral intake, days (WMD)	-1.68 (-1.84, -1.53)	<0.00001
			LoS, days (WMD)	-2.94 (-4.27, -1.62)	0.001
			Post-discharge		
			Mortality (OR)	1.36 (0.22, 8.44)	0.74
			Overall survival (HR)	0.83 (0.56, 1.22)	0.34
			Disease-free survival (HR)	0.82 (0.60, 1.11)	0.20
			Local recurrence (OR)	1.13 (0.42, 3.07)	0.81

Wu *et al.* 2017[64]	28 studies (RCT and non-randomized), n=140,640 patients	Open versus laparoscopic surgery for treatment of diverticulitis	**Postoperative**		
			Overall mortality (OR)	0.40 (0.25, 0.63)	<0.001
			Overall morbidity (OR)	0.65 (0.51, 0.82)	<0.001
			LoS, days (pooled mean difference)	-4.05 (-4.64, -3.47)	<0.001
			Ileus (OR)	0.80 (0.76, 0.84)	<0.001
			Anastomotic leak (OR)	0.69 (0.62, 0.75)	<0.001
			Surgical site infection (OR)	0.53 (0.49, 0.57)	<0.001
Tong *et al.* 2017[65]	9 studies (RCT and non-randomized), n=4,747 patients	Open versus laparoscopic colorectal cancer surgery	**Peri-operative**		
			Operating time, minutes (WMD)	0.46 (-55.56, 56.60)	0.99
			Blood loss, mL (WMD)	-64.66 (-87.31, -42.01)	<0.00001
			Postoperative		
			Time to first flatus, days (WMD)	-1.22 (-1.53, -0.91)	<0.00001
			Postoperative complications (OR)	0.62 (0.52, 0.72)	<0.00001
			LoS, days (WMD)	-2.38 (-3.30, -1.46)	<0.00001
Rausa *et al.* 2019[66]	48 studies (RCT and controlled clinical trials), n=5,652 patients	Total laparoscopic versus open right hemicolectomy [a]	**Peri-operative**		
			Operating time (RR)	20.0 (-29.0, 70.0)	NR
			Blood loss (RR)	41.0 (11.0, 72.0)	NR
			Postoperative		
			Overall complications (RR)	1.9 (1.3, 2.7)	NR
			Anastomotic leak (RR)	1.3 (0.7, 2.6)	NR
			Surgical site infection (RR)	2.1 (1.2, 3.6)	NR
			Reoperation (RR)	3.3 (1.3, 8.0)	NR
			30-day mortality (RR)	1.5 (0.7, 3.2)	NR

			60-day readmission (RR)	1.2 (0.4, 3.8)	NR
			LoS (RR)	3.8 (0.5, 7.0)	NR
Baloyiannis *et al.* 2020 [67]	21 studies (prospective and retrospective trials), n=2,498 patients	Open versus laparoscopic transverse colon cancer colectomy	**Peri-operative**		
			Intraoperative complications (OR)	2.45 (0.59, 10.19)	0.22
			Operative time, min (WMD)	42.47 (28.81, 56.14)	<0.00001
			Blood loss, mL (WMD)	-86.84 (-108.29, -65.39)	<0.00001
			Postoperative		
			Overall postoperative complications (OR)	0.64 (0.51, 0.82)	0.0003
			Ileus (OR)	0.83 (0.49, 1.40)	0.49
			Anastomotic leak (OR)	0.64 (0.37, 1.11)	0.11
			Surgical site infection (OR)	0.62 (0.39, 0.98)	0.04
			Reoperation (OR)	0.59 (0.26, 1.32)	0.2
			Time to first flatus, days (WMD)	-0.94 (-1.30, -0.57)	<0.00001
			Time to oral intake, days (WMD)	-1.25 (-1.87, -0.64)	<0.0001
			LoS, days (WMD)	-2.39 (-3.23, -1.56)	<0.00001
			Post-discharge		
			Mortality (OR)	0.35 (0.12, 1.01)	0.05
			Recurrence (OR)	0.65 (0.43, 0.97)	0.04
			Overall survival (HR)	0.83 (0.68, 1.02)	0.08
			Disease-free survival (HR)	0.81 (0.65, 1.02)	0.07

a Meta-analysis also included comparison versus robot-assisted and laparoscopic-assisted right hemicolectomy; only the findings of total laparoscopic right hemicolectomy are presented here. Laparoscopic-assisted right hemicolectomy was only compared to robotic-assisted right hemicolectomy, therefore the findings regarding laparoscopic-assisted right hemicolectomy ware not reported here. The comparison is inverted, so that RR values above 1.00 favor

laparoscopic surgery and values below 1.00 favor open surgery.

WMD = Weighted mean difference (95% CI); negative values favor laparoscopic surgery, positive values favor open surgery

RR = Relative Risk (95% CI); HR = Hazard Ratio (95% CI); OR = Odds Ratio (95% CI); for HRs, ORs and RRs, values below 1.00 normally favor laparoscopic surgery, values above 1.00 normally favor open surgery with the exception of Rausa et al. 201966 where the comparison is inverted.

Table 1-2 Summary of key clinical studies comparing laparoscopic versus open colorectal surgery

Study	Setting	Study details	Procedure (year performed)	Summary of clinical findings Endpoint	Open	Laparoscopic	P value
Veldkamp *et al.* 2005[38]	Multinational	COLOR RCT n=621 open, n=627 laparoscopic	Elective open versus laparoscopic colectomy for colon cancer[g] (1997–2003)	**Peri-operative**			
				Median time in theater, minutes	170	202	<0.0001
				Median blood loss, mL	175	100	<0.0001
				Postoperative			
				Mean fluid intake <1L, days	3.8	2.9	<0.0001
				Mean time to first bowel movement, days	4.6	3.6	<0.0001
				Mean LoS, days	9.3	8.2	<0.0001
				All complications	20%	21%	0.88
				Wound infection	3%	4%	0.57
				Anastomotic failure	2%	3%	0.39
				Bowel obstruction >3 days	3%	2%	0.45
				Re-intervention	5%	7%	0.13
				Death	2%	1%	0.45
Jayne *et al.* 2010[23]	United Kingdom	MRC CLASSICC RCT 5-year follow up n=268 open; n=526 laparoscopic	Open versus laparoscopic colectomy for colorectal cancer (1996–2002)	**Post-discharge (5 years)**			
				5 year overall survival	58.1%	57.9%	0.848
				5-year disease-free survival	58.6%	55.3%	0.483
				5 year local recurrence	8.7%	10.8%	0.594
				5 year distant recurrence	20.6%	21.0%	0.820

Fleshman *et al.* 2007[16]	United States and Canada	5 year follow up of the COST RCT, n=428 open; n=435 laparoscopic	Open versus laparoscopic colectomy for colon cancer[d] (1994–2001)	**Post-discharge (5 years)**			
				5 year overall survival	74.6%	76.4%	0.93
				5 year disease-free survival	68.4%	69.2%	0.94
				5 year local recurrence rate	2.6%	2.3%	0.79
				5 year overall recurrence rate	21.8%	19.4%	0.25
Juo *et al.* 2014[29]	United States	US Nationwide Inpatient sample n=116,261 open; n=115,694 laparoscopic; propensity matched	Elective open versus laparoscopic colectomy[a] (2008–2010)	**Postoperative**			
				In-hospital mortality	2.0%	0.4%	<0.001
				Complication rate	33.2%	19.8%	<0.001
				Ostomy rate	13.0%	3.5%	<0.001
				Median LoS, days	6	4	<0.001
				Discharge disposition:			
				Routine	68.4%	86.1%	<0.001
				Transfer to other healthcare facility	12.1%	4.6%	<0.001
Kang *et al.* 2012[49]	United States	Retrospective analysis using the National Inpatient Sample, n=71,200 open, n=43,165 laparoscopic and n=7,545 converted	Elective open versus laparoscopic colorectal resection for colon cancer, rectal cancer or diverticulitis (2009)	**Postoperative**			
				In-hospital mortality	1.17%	0.49%	NR
				Mean LoS (days)	8	5	NR
				Wound complication	5.8%	2.6%	NR
				Anastomotic leak	13.5%	9.4%	NR
				Pneumonia	2.7%	1.3%	NR
				Ileus or bowel obstruction	18.7%	14.1%	NR
				Urinary retention	2.7%	1.9%	NR
				Respiratory failure	2.5%	1.0%	NR

				Acute renal failure	7.1%	3.9%	NR
				Cardiac complications	2.3%	1.6%	NR
Wilson *et al.* 2014[10]	United States	Retrospective study using National Surgical Quality Improvement Program data, n=21,606 open; n=15,643 laparoscopic	Open versus laparoscopic partial colectomy[h] (2005–2010)	**Postoperative**			
				LoS (days)	8.7	6.4	<0.0001
				Overall complications	29.1%	21.2%	<0.0001
				Superficial SSI	9.0%	5.9%	0.003
				Deep SSI	5.8%	5.4%	0.959
				Deep Vein Thrombosis	1.2%	0.3%	0.001
				Urinary tract infection	3.9%	3.7%	0.122
Steele *et al.* 2008[30]	United States	Retrospective analysis of the Nationwide Inpatient Sample, n=95,627 open, n=3,296 laparoscopic	Elective open versus laparoscopic resection for colon cancer (2003–2004)	**Postoperative**			
				In-hospital complication	22%	18%	<0.001
				In-hospital mortality	1.4%	0.6%	<0.001
				Mean LoS, days	7.6	6.0	0.006
Kiran *et al.* 2010[25]	United States	Retrospective analysis of the National Surgical Quality Improvement Program	Open versus laparoscopic colorectal surgery[e] (2006–2007)	**Peri-operative**			
				Mean operating time, minutes	139	159	0.001
				Operating time >180 minutes	30.8%	39.1%	0.001
				Postoperative			
				Superficial infection	10.3%	6.6%	0.001
				Deep infection	2.4%	1.0%	0.001

		database; n=7,565 open; n=3,414 laparoscopic		Organ space infection	4.3%	2.4%	0.001
				Wound dehiscence	2.7%	0.85%	0.001
Bilimoria *et al.* 2008[27]	United States	Retrospective analysis of the American College of Surgeons - National Surgical Quality Improvement Program data; 121 hospitals n=2,222 open, n=837 laparoscopic	Elective open versus laparoscopic colectomy for cancer (2005–2006)	**Postoperative**			
				Any adverse event	21.7%	14.6%	<0.0001
				SSI	11.8%	9.1%	0.033
				Wound disruption/dehiscence	1.5%	0.5%	0.025
				Pneumonia	3.4%	1.8%	0.022
				Pulmonary embolism	0.8%	0.5%	0.47
				Unplanned intubation	2.5%	1.6%	0.13
				Renal failure	2.0%	1.3%	0.23
				Urinary tract infection	3.2%	1.9%	0.066
				Bleeding requiring transfusion	0.5%	0.7%	0.60
				Deep venous thrombosis	1.3%	0.6%	0.12
				Sepsis	6.5%	4.7%	0.060
				Return to OR	5.8%	5.5%	0.79
				Postoperative LoS >6 days	49.7%	26.3%	<0.0001
				Mortality	1.8%	1.4%	0.53
Thompson *et al.* 2014[31]	Australia	Retrospective analysis, n=647 open, n=744 laparoscopic	Elective open versus laparoscopic resection for colorectal cancer[k] (2009–2011)	**Peri-operative**			
				Mean (95% CI) operating time, minutes	214 (204–224)	216 (209–224)	0.687
				Postoperative			
				Mean (95% CI) anesthesia duration, minutes	261 (251–272)	260 (252–269)	0.937

				Mean (95% CI) LoS, days	10.3 (9.7–11.0)	9.2 (8.7–9.7)	0.008
				Mean (95% CI) ICU admission, hours	14.7 (10.8–18.7)	7.4 (4.8–10.0)	0.002
Causey *et al*. 2012[68]	United States	Retrospective database analysis of the American College of Surgeons - National Surgical Quality Improvement Program data, n=735 open; n=342 laparoscopic	Open versus laparoscopic colectomy for ulcerative colitis (2005–2008)	**Postoperative**			
				Superficial incisional SSI			
				Partial colectomy	10.6%	8.25%	0.599
				Total abdominal colectomy	6.25%	11.6%	0.151
				End ileostomy	5.71%	14.1%	0.186
				Pouch	7.43%	12.4%	0.11
				Deep incisional SSI			
				Partial colectomy	4.25%	1.83%	0.312
				Total abdominal colectomy	0.89%	0.00%	0.3
				End ileostomy	2.85%	2.02%	0.774
				Pouch	0.00%	2.34%	0.06
				Organ/space SSI			
				Partial colectomy	6.38%	9.17%	0.538
				Total abdominal colectomy	2.67%	8.33%	0.061
				End ileostomy	14.2%	2.02%	0.005
				Pouch	5.4%	5.03%	0.867
				Wound disruption			
				Partial colectomy	4.25%	1.37%	0.188
				Total abdominal colectomy	0.89%	2.5%	0.347
				End ileostomy	0%	6.06%	0.136
				Pouch	1.35%	1.34%	0.994

				Mortality			
				Partial colectomy	0%	1.37%	0.419
				Total abdominal colectomy	0.89%	6.66%	0.023
				End ileostomy	0%	2.02%	0.397
				Complication			
				Partial colectomy	27.6%	28.4%	0.914
				Total abdominal colectomy	18.7%	41.6%	<0.001
				End ileostomy	34.2%	34.3%	0.995
				Pouch	18.2%	29.8%	0.008
Moreira *et al*. 2010[26]	United States	Retrospective analysis of a prospectively maintained database, n=231 open and n=231 matched laparoscopic patients with ASA class 3 or 4	Open versus laparoscopic colectomy[l] in patients with ASA classification 3 or 4 (2002–2007)	**Peri-operative**			
				Median (range) estimated blood loss, mL	250 (20–2000)	150 (20–1500)	<0.001
				Median (range) operating time, minutes	150 (60–400)	160 (40–500)	0.09
				Postoperative			
				Median (range) time to first flatus, days	4 (1–35)	3 (1–13)	<0.001
				Median (range) time to first bowel movement, days	5 (1–35)	3 (1–13)	<0.001
				Median (range) LoS, days	7 (3–97)	5 (2–67)	<0.001
				30-day mortality	2.5%	1%	0.3
				Postoperative complication	28%	19%	0.02
				Anastomotic leak	4%	5%	0.6
				Wound infection	10%	4.5%	0.02

Braga *et al.* 2010[44]	Italy	RCT n=134 open, n=134 laparoscopic	Open versus laparoscopic left colonic resection (2000–2004)	**Peri-operative**			
				Mean (SD) operating time, minutes	174 (77)	213 (57)	<0.001
				Mean (SD) operative blood loss, mL	127 (265)	46 (130)	0.002
				Transfused patients	14.9%	8.2%	0.136
				Conversion to open	–	5.2%	–
				Postoperative			
				30-day morbidity	20.1%	11.9%	0.094
				Reoperation	6.7%	5.2%	0.881
Day *et al.* 2013[24]	United Kingdom	Retrospective single center data, n=208 open; n=457 laparoscopic	Elective resection for colorectal cancer[m] (2003–2010)	**Postoperative**			
				Median (range) LoS, days	7 (2–43)	4 (1–59)	<0.0005
				Post-discharge (5 years)			
				5 year overall survival	72.5%	75.8%	0.12
Vallribera *et al.* 2014[69]	Spain	Retrospective single center chart review, n=268 open, n=277 laparoscopic	Open versus laparoscopic colectomy for colonic adenocarcinoma (2005–2009)	**Postoperative**			
				All complications	37.3%	21.6%	0.001
				Medical complications	16.4%	10.5%	0.033
				Wound complications	4.8%	4.7%	0.924
				Surgical complications	23.5%	15.5%	0.034
				Mortality	6.7%	3.2%	0.034

White *et al.* 2014[70]	United Kingdom	Retrospective analysis of n=207 consecutive patients, n=131 open, n=76 laparoscopic	Open versus laparoscopic restorative portectomy and protocolectomy (2006–2011)	**Postoperative**			
				30-day readmission	12.2%	17%	NR
				30-day reoperation	7.6%	13%	NR
				Ileostomy closure at 6 months	63%	66%	0.772
				Ileostomy closure at 1 year	86.6%	93%	0.173
				Pouch problems	13.2%	11%	0.198
				Pouch failure	11.3%	3%	0.172
				Anastomotic leakage	9.2%	11%	NR
				Median (IQR) LoS, days	6 (4-8)	8 (7-12)	<0.001
Hardy *et al.* 2014[32]	Canada	Retrospective cohort analysis, n=168 open, n=223 laparoscopic	Elective open versus laparoscopic colon surgery for all indications[j] (2004–2009)	**Peri-operative**			
				Median (IQR) operating time, minutes	196 (152–251)	224 (185–259)	0.001
				Median (IQR) incision to closure time, minutes	133 (95–187)	170 (133–200)	0.001
				Postoperative			
				Median (IQR) LoS, days	7.0 (6.0–11.0)	5.0 (4.0–7.0)	0.000
				In-hospital complication	22.5%	21.6%	0.900
				Admission to ICU	6.0%	5.8%	0.966
				Received blood transfusion	9.7%	5.4%	0.116
				Reoperation	6.5%	5.8%	0.833
				30-day readmission	12.5%	7.6%	0.122

Orcutt *et al.* 2011[33]	United States	Retrospective database analysis of prospectively collected data, n=243 open, n=75 hand-assisted laparoscopic and n=35 laparoscopic-assisted	Open versus MIS (laparoscopic-assisted [LA] and hand-assisted laparoscopic [HAL]) for colorectal cancer (2002–2010)	**Peri-operative**			
				Median blood loss, mL	150	50	<0.01
				Median surgical time, minutes	168	193 (LA=229; HAL =179)	0.02
				Postoperative			
				Complication rate	49%	36%	0.03
				Wound infection rate	20%	16%	0.38
				Anastomotic leak	5%	2%	0.24
				Median days to return of flatus	4	3	<0.01
				Median days to return of BM	5	4	<0.01
				Median LoS, days	8	6	<0.01
				Median length of ICU stay, days	1	0	<0.01
				90-day readmission rate	22%	13%	0.08
Gervaz *et al.* 2010[34]	Switzerland	RCT, n=54 open, n=59 laparoscopic	Elective open versus laparoscopic sigmoidectomy for diverticulitis (2005-2009)	**Peri-operative**			
				Mean (SD) duration of surgery, minutes	118 (28)	168 (37)	<0.001
				Postoperative			
				Mean (SD) maximal pain, VAS	4.5 (1.9)	3.9 (1.8)	0.055
				Mean (SD) duration of ileus (flatus), hours	53.6 (18)	35.9 (14.2)	<0.001
				Mean (SD) duration of ileus (bowel movement), hours	106.6 (24)	81.4 (31)	<0.001
				Mean (SD) LoS, days	7.9 (2.6)	7.7 (9.7)	<0.001

Agarwal *et al*. 2015[17]	United States	Retrospective, single center case-matched review, n=123 open; n=41 laparoscopic	Open versus laparoscopic colectomy (extended right, extended left and total abdominal) for stage I–III adenocarcinoma of the transverse colon (1996–2009)	**Postoperative**			
				Mean (SD) LoS, days	9.4 (6.3)	6.8 (2.9)	0.02
				Complication rate	29%	24%	0.68
				Mild	50%	44%	NR
				Moderate	16%	22%	NR
				Severe	34%	34%	NR
				Post-discharge (5 years)			
				5 year survival	59%	61%	0.39
				Stage I	75%	55%	0.80
				Stage II	61%	83%	0.19
				Stage III	35%	58%	0.82
				5 year DFS	82%	88%	0.23
Chen *et al*. 2014[40]	China	Retrospective non-randomized analysis, n=80 open, n=80 laparoscopic-assisted	Open versus laparoscopic surgery for colorectal cancer[i] (2009–2013)	**Peri-operative**			
				Conversion to open	–	1.3%	–
				Mean (SD) surgical time, minutes	177 (7)	202 (7)	0.015
				Mean (SD) blood loss, mL	221 (38)	97 (10)	0.002
				Mean (SD) incision length, cm	19.9 (0.62)	5.0 (0.18)	<0.001
				Postoperative			
				Mean (SD) time to first flatus, days	3.80 (0.17)	2.34 (0.12)	<0.001
				Mean (SD) time to first BM, days	4.87 (0.18)	3.43 (0.28)	0.009
				Mean (SD) time to resume liquid food, days	4.34 (0.19)	3.66 (0.15)	0.015

				Mean (SD) time to walk independently, days	2.22 (0.17)	1.63 (0.11)	0.006
				Mean (SD) LoS, days	11.36 (0.67)	9.7 (0.59)	0.007
Prakash *et al*. 2010[39]	India	Retrospective analysis n=62 open and n=62 matched laparoscopic patients	Open versus laparoscopic colorectal resection for cancer in the rectosigmoid region (2006–2008 for laparoscopic; 2003–2005 for open)	**Peri-operative**			
				Conversion to open surgery	–	6.4%	–
				Mean (SD) operation time, minutes	180 (58.3)	296.7 (57.5)	ns
				Mean (SD) blood loss, mL	380 (108)	116 (108)	0.23
				Blood transfusion	38.7%	6.4%	<0.001
				Postoperative			
				Mean (SD) length of ICU stay, hours	79 (37.1)	24.2 (11.8)	<0.05
				Mean (SD) LoS, days	13.8 (5.3)	8.4 (1.04)	<0.05
Odermatt *et al*. 2013[35]	United Kingdom	Retrospective analysis of a prospective database, patients propensity matched, n=181 open, n=36 laparoscopic	Open versus laparoscopic emergency resection[f] for colon cancer (2006–2011)	**Postoperative**			
				30-day mortality	12.5%	8.3%	0.747
				Wound infection	4.2%	16.7%	0.057
				Complication needing re-intervention	8.3%	13.9%	0.668
				Median LoS, days	11.0	7.5	0.019
				Readmission	6.9%	8.3%	1.00
				Post-discharge (3 years)			
				3 year overall survival	43.2%	51.1%	0.239
				3 year recurrence-free survival	36.6%	34.9%	0.528

Kapritsou *et al*. 2013[36]	Greece	Retrospective study, n= 40 open, n=48 laparoscopic	Open versus laparoscopic colectomy for colorectal cancer (2009–2011)	**Postoperative**			
				Mean (SD) LoS, days	10.28 (8.59)	5.79 (1.61)	0.001
				Complications	42.9%	2.4%	0.000
Marshall *et al*. 2010[37]	United States	Single center retrospective database analysis, n=17 open, n=33 laparoscopic	Open versus laparoscopic surgery for colon cancer (2008-2009)	**Peri-operative**			
				Median operation time, minutes	291	183	0.008
				Median LoS, days	8	5.5	<0.05
				Median ICU stay, days	1.5	<1	<0.02
Li *et al*. 2015[45]	China	Retrospective single center study of n=25 open and n=10 laparoscopic matched patients	Open versus hand-assisted laparoscopic right hemicolectomy for obstructive right-sided colon cancer (2013)	**Peri-operative**			
				Mean (SD) length of incision, cm	16 (2.3)	5.8 (0.7)	<0.05
				Mean (SD) operating time, minutes	142 (20.8)	186.5 (18.4)	<0.05
				Mean (SD) blood loss, mL	90 (29.4)	30 (15.2)	<0.05
				Postoperative			
				Mean (SD) time to flatus, days	5 (1.8)	5 (1.2)	NS
				Mean (SD) LoS, days	9 (3.6)	7 (2.5)	NS

Liao *et al.* 2017[20]	Taiwan	Retrospective study of nationwide population-based cohort with n=5,658 open and n=1,738 laparoscopic	Open versus laparoscopic colectomy for colon cancer (2009-2011)	**Postoperative**			
				Mean (SD) LoS, days	15.6 (10.4)	12.7 (9.2)	<0.0001
				Post-discharge			
				Mean (SD) overall survival, days	685.9 (146.5)	704.7 (104.3)	0.0005
				Mean (SD) recurrence-free survival, days	649.8 (189.3)	667.6 (168.4)	0.0051
				Mean (SD) disease-free survival, days	564.7 (270.2)	588.9 (252.3)	0.0065
Fitch *et al.* 2017[42]	USA	Retrospective analysis of healthcare claims database with n=558 open and n=741 laparoscopic	Open versus laparoscopic colectomy for colon cancer (2013)	**Postoperative**			
				ICU stay	3.4%	2.2%	0.0615
				Mean (SD) LoS, days	5.94 (4.32)	4.25 (2.67)	<0.001
				Readmissions	10.93%	6.61%	0.0165
				Total complications	47.0%	26.9%	<0.001
				Colorectal-specific complications	24.6%	11.1%	<0.001
Santacruz *et al.* 2017[28]	Spain	Prospective multi-center study with n=1,655 open and n=1,313 laparoscopic	Open versus laparoscopic colectomy for colon cancer (2011-2012)°	**Peri-operative**			
				Blood transfusion (%)	339 (20.5)	160 (12.2)	0.001
				Peri-operative complications (%)	60 (3.6)	51 (3.9)	0.392
				Postoperative			
				Surgical site infection (%)	254 (15.3)	134 (10.2)	<0.0001
				Postoperative complications (%)	500 (30.2)	303 (23.1)	<0.0001
				Anastomotic leak (%)	138 (8.3)	111 (8.5)	0.53
				Mortality (%)	54 (3.3)	24 (1.8)	0.015
				Median (IQR) LoS, days	9 (7-13)	7 (5-9)	<0.0001

Yang *et al.* 2018[19]	China	Single center retrospective study, n=111 open and n=101 laparoscopic	Open versus laparoscopic surgery for colorectal cancer (2006-2015)	**Peri-operative**			
				Mean (SD) operative time	173.5 (72.7)	210.8 (88.9)	0.028
				Mean (SD) blood loss)	235.1 (120.5)	155.0 (75.9)	0.033
				Intraoperative complications	8	3	0.117
				Postoperative			
				30-day total (%) complications	35 (31.8)	12 (12.9)	0.006
				30-day morbidity	1	0	0.667
				Median (range) time to flatus, days	4 (3-15)	2 (1-9)	0.037
				Median (range) time to diet, days	7 (5-27)	3 (2-18)	0.003
				Median (range) time to ambulation, days	5 (3-9)	2 (1-5)	0.027
				Median (range) LoS, days	15 (7-31)	7 (5-21)	0.004
				Post-discharge			
				5-year overall survival	46.5%	60.5%	0.060
				5-year disease-free survival	39.8%	57.3%	0.053
				Recurrence during follow up	22.7%	21.8%	0.711
Shah *et al.* 2021[21]	Pakistan	Single center retrospective analysis of prospectively maintained database, n=89	Open versus laparoscopic surgical resection of right colon adenocarcinoma (2010-2018)	**Peri-operative**			
				Median (IQR) operative time	170 (130-204)	195 (168-241)	<0.001
				Median (IQL) blood loss	100 (60-120)	50 (30-90)	<0.001
				Postoperative			
				Median (IQR) LoS, days	7 (6.0-9.5)	5 (5.0-6.5)	<0.001
				90-day mortality (%)	11 (12.4)	2 (1.4)	0.001

		open and n=141 laparoscopic		Complications (%)	15 (16.9)	14 (9.9)	0.123
				Anastomotic leak (%)	1 (1.1)	2 (1.4)	>0.999
				Post-discharge (5 years)			
				5-year overall survival	75.7%	88.9%	0.033
				5-year disease-free survival	66.0	88.7	0.002
Laudicella *et al.* 2016[52]	England	Retrospective cost study of hospital administrative database with propensity score matching, n=55,358 patients in total[p]	Open versus laparoscopic colectomy for colon cancer (2006-2013)	**Postoperative**			
				Mean LoS, days	11.0	8.5	<0.01
				30-day in-hospital mortality	2.0%	1.2%	<0.01
				Post-discharge			
				30-day unplanned readmission	4.8%	4.2%	<0.01
				90-day unplanned readmission	6.9%	5.9%	<0.01
Chiu *et al.* 2019[71]	USA	Retrospective analysis of the Nationwide Inpatient Sample, n=348,645 open and n=174,748 laparoscopic	Laparoscopic versus open surgery for colon cancer (2008-2014)[q]	**Postoperative**			
				Mortality, OR (95% CI)	Ref	2.975 (2.605, 3.398)	NR
				Wound complications, OR (95% CI)	Ref	1.021 (1.009, 1.033)	NR
				General medical complications (95% CI)	Ref	1.767 (1.670, 1.869)	NR
				General surgical complications, OR (95% CI)	Ref	1.405 (1.351, 1.461)	NR
				LoS, OR (95% CI)	Ref	2.805 (2.712, 2.900)	NR

Ribeiro *et al.* 2020[43]	Brazil	Retrospective database analysis, n=164 open and n=116 laparoscopic	Elective laparoscopic versus open colorectal surgery (2012-2013)	**Postoperative**			
				Mean (SD) LoS, days	9.86 (16.27)	6.02 (3.86)	<0.001
				Blood transfusion	20.1%	9.5%	0.019
				ICU admission	56.1%	37.1%	0.002
				Mortality	3.0%	0.9%	0.406
				Use of antibiotics	47.0%	43.1%	0.54
				Anastomotic leak	5.5%	4.3%	0.784
				Readmission	10.4%	10.3%	1.000

[a]Excluded rectal resection and patients with distant metastases; study also included comparison versus robot-assisted colectomy; only the findings of open versus laparoscopic colectomy are presented here

[b]Excluding previous colonic resection, multiple previous surgeries, severe co-morbid conditions, coagulopathy and metastatic disease

[c]Including anterior resection, high anterior resection, right hemicolectomy, left colonic resection, APER, subtotal colectomy, Hartmann's, right hemicolectomy and anterior resection, and panproctocolectomy

[d]Excluded patients with advanced or systemic cancer

[e]Includes partial colectomy, ileocolic resection, low pelvic anastomosis, Hartmann's procedure, total abdominal colectomy, colectomy/coloprotostomy, TPC/EI

[f]Includes right colectomy, left colectomy, subtotal colectomy and sigmoid colectomy

[g]Includes right hemicolectomy, left hemicolectomy, sigmoid resection and other

[h]Excluded patients undergoing total abdominal colectomy or a procedure involving the rectum

[i]Includes right hemicolectomy, left hemicolectomy, sigmoid colectomy, low anterior resection, abdominoperineal resection and total colectomy

[j]Includes right hemicolectomy, extended right hemicolectomy, ileocecal resection, transverse colectomy, left colectomy, sigmoid colectomy, subtotal colectomy, Hartmann's

[k]Includes right hemicolectomy, transcolectomy, extended right hemicolectomy/total colectomy, left hemicolectomy, sigmoidectomy, high anterior resection, abdominoperineal resection, anterior resection of the rectum, ultralow anterior resection

[l]including right colectomy/ileocecectomy, left colectomy/sigmoidectomy, anterior resection, total abdominal colectomy, abdominoperineal resection, and ileo-pouch anal anastomosis

[m]Including anterior resection (TME), high anterior resection, right hemicolectomy, left colonic resection, APER, subtotal colectomy, Hartmann's, right hemicolectomy and anterior resection, panprotocolectomy

[n] In addition to colectomy, this study also compared the open and minimally invasive approach to bariatric, cholecystectomy, hysterectomy, inguinal hernia, thoracic, and ventral hernia procedures

[o] Includes right colectomy, extended right colectomy, transverse colon resection, left colectomy, sigmoidectomy, subtotal colectomy and total colectomy

[p] Neither the absolute number nor the overall percentage of patients with laparoscopic and open approaches were stated in the study.

[q] Also includes data regarding robotic approach, only the findings regarding laparoscopic versus open surgery are reported here

ASA, American Society of Anaesthesiology; BM, bowel movement; DFS, disease-free survival; HAL; hand-assisted laparoscopic; LA, laparoscopic-assisted; LoS, length of stay; NR, not reported; NS, not significant; OS, overall survival; RCT, randomized controlled trial; SSI, surgical site infection

OR = Odds Ratio (95% CI); for ORs, values below 1.00 normally favor laparoscopic surgery, values above 1.00 normally favor open surgery with the exception of Chiu *et al*. 2019[71] where the comparison is inverted.

Table 1-3 Summary of key studies comparing economic outcomes of laparoscopic versus open colorectal surgery

Study	Setting	Study details	Procedures	Currency (Cost year)	Cost Outcome	Open	Laparoscopic	P value
Hardy *et al*. 2014[32]	Canada	Retrospective cohort analysis, n=168 open, n=223 laparoscopic	Elective open versus laparoscopic colon surgery for all indications (2004–2009)	CAD (2010)	Median (IQR) OR cost	3,456 (2,456–5,089)	4,171 (3,332–5,491)	0.009
					Median (IQR) PACU cost	505 (0–767)	438 (269–602)	0.022
					Median (IQR) ward cost	5,592 (3,972–8,478)	3,224 (2,141–5,391)	0.001
					Median (IQR) total hospital cost	12,721 (9,621–18,790)	9,600 (7,666–13,518)	0.001
Thompson *et al*. 2014[31]	Australia	Retrospective analysis, n=647 open, n=744 laparoscopic	Elective open versus laparoscopic resection for colorectal cancer[a](2009–2011)	EUR (2012)	Mean (95% CI) total cost	22,442 (21,125, 23,719)	20,396 (19,451, 21,286)	0.010
					Mean (95% CI) anesthesia cost	2,155 (2,028, 2,273)	2,424 (2,323, 2,525)	0.001
					Mean (95% CI) imaging cost	134 (108, 161)	168 (130, 208)	0.174
					Mean (95% CI) pathology cost	818 (768, 867)	789 (748, 830)	0.389
					Mean (95% CI) pharmacy cost	229 (164, 295)	154 (122, 187)	0.058

					Mean (95% CI) theater cost	5,584 (5,386, 5,783)	5,628 (5,445, 5,810)	0.757
Alkhamesi *et al.* 2011[53]	Canada	Retrospective analysis, n=503 open, n=233 laparoscopic	Elective open versus laparoscopic segmental colectomies (right and left-sided colectomies) (2005–2010)	CAD (year not stated)	**Right colectomy**			
					Bed cost	6,632.8	4,556.1	NR
					OR cost	3,811.9	5,541.9	NR
					Total cost	10,444.7	10,097.9	NR
					Left colectomy			
					Bed cost	5,949.1	3,297.2	NR
					OR cost	5,197.5	7,770.5	NR
					Total cost	11,146.6	11,076.7	NR
Norwood *et al.* 2011[54]	Australia	Analysis of RCT data, n=44 open, n=41 laparoscopic	Open versus laparoscopic surgery for colon cancer (1998–2005)	AUD (year not stated)	Median (range) total cost	9,948 (5,395–90,398)	10,111 (6,505–44,405)	0.65
Eisenberg *et al.* 2010[47]	United States	Retrospective analysis, n=162 open, n=76 laparoscopic	Elective open versus laparoscopic colon resection (2004–2006)	USD (year not stated)	Total cost with complication	18,296	14,789	NR
					Total cost with no complication	17,686	14,518	0.0003

Vaid *et al*. 2012[48]	United States	Retrospective cost study using the National Inpatient Sample, n=58,802 open, n=5,147 laparoscopic	Elective open versus laparoscopic colectomy for cancer (right, left or sigmoid) (2008)	USD (2008)	Median total cost Median total cost, complicated Median total cost, not complicated	43,459 62,221 39,152	41,971 58,388 39,017	<0.001 0.407 0.532
Marshall *et al*. 2010[37]	United States	Single center retrospective database analysis, n=17 open, n=33 laparoscopic	Open versus laparoscopic surgery for colon cancer (2008-2009)	USD (year not stated)	Median overall inpatient cost Median surgical cost Median nursing cost Median laboratory cost Median radiology cost Median cost, other	18,564 8,709 10,095 1,703 504 2,509	12,500 5,842 5,328 805 0 1,459	<0.01 <0.05 <0.05 ns <0.05 <0.05
Dowson *et al*. 2012[51]	United Kingdom	Prospective cost study in consecutive patients, n=70 open,	Elective open versus laparoscopic colorectal surgery (2006–2007)	GBP (2006/7)	Mean (SD) hospital costs (all) Mean (SD) total costs (all) Mean (SD) operative cost right resection	3468 (3805) 4,383 (2,953) 3,602 (1,070)	1807 (1801) 3,875 (2,008) 3,153 (1,246)	0.001 0.308 0.350

		n=131 laparoscopic			Mean (SD) operative cost left resection	4,702 (4,091)	4,111 (2,187)	0.509
					Mean (SD) operative cost rectal resection	4,772 (2,431)	5,115 (2,433)	0.768
					Mean (SD) total cost no stoma	4,307 (3,303)	3,598 (1,821)	0.218
					Mean (SD) total cost with stoma	4,526 (2,321)	5,352 (2,366)	0.413
Moreira *et al.* 2010[26]	United States	Retrospective analysis of a prospectively maintained database, n=231 open and n=231 matched laparoscopic patients with ASA class 3 or 4	Open versus laparoscopic colectomy in patients with ASA classification 3 or 4 (2002–2007)	USD (year not stated)	Mean anesthesia cost	1,328	1,229	0.3
					Mean pharmacy cost	886	725	<0.001
					Mean medicine therapy cost	643	423	<0.001
					Mean nursing floors cost	2,445	1,687	<0.001
					Mean ICU cost	360	286	0.2
					Mean radiology cost	222	180	0.08
					Mean OR cost	1,725	2,672	<0.001
					Mean other costs	1,870	1,338	<0.01
					Mean total direct cost	8,333	7,523	0.05
Crawshaw *et al.* 2015[72]	United States	Retrospective analysis of a national claims	Elective open versus laparoscopic	USD (year not stated)	Mean (SD) net payment to hospital	25,470 (19,957)	19,140 (13,523)	<0.001
					Mean (SD) net payment to physician	2,141 (2,160)	2,182 (1,630)	0.49

		database, n=2,265 open; n=1,895 laparoscopic	colectomy (2010)		Mean (SD) payment to hospital	26,919 (21,928)	19,970 (13,515)	<0.001
					Mean (SD) payment to physician	2,340 (2,243)	2,355 (1,715)	0.80
					Mean (SD) total net payment	29,753 (21,421)	23,064 (14,558)	<0.001
					Mean (SD) total payment	31,601 (23,586)	24,196 (14,507)	<0.001
Kapritsou *et al.* 2013[36]	Greece	Retrospective study, n= 40 open, n=48 laparoscopic	Open versus laparoscopic colectomy for colorectal cancer (2009–2011)	USD (year not stated)	Mean surgical cost	3,617	5,750	0.000
Jensen *et al.* 2012[73]	United States	Cost-effectiveness analysis using decision analytic model	Open versus laparoscopic surgery for colon and rectal cancer	USD (2010)	Total cost	Not stated	4,283 cheaper with laparoscopic	NR

Kang *et al*. 2012[49]	United States	Retrospective analysis using the National Inpatient Sample, n=71,200 open, n=43,165 laparoscopic and n=7,545 converted	Elective open versus laparoscopic colorectal resection for colon cancer, rectal cancer or diverticulitis (2009)	USD (year not stated)	Mean hospital cost	56,977	46,624	NR
Chen *et al*. 2014[40]	China	Retrospective non-randomized analysis, n=80 open, n=80 laparoscopic-assisted	Open versus laparoscopic surgery for colorectal cancer (2009–2013)	RMB (year not stated)	Mean (SD) surgery expenditure, thousands	3.9 (1.1)	8.1 (3.1)	0.003
					Mean (SD) post-surgery costs, thousands	10.8 (6.5)	9.6 (3.7)	0.372
					Mean (SD) total hospitalization costs, thousands	26.9 (7.5)	48.3 (10.7)	<0.001

Steele *et al.* 2008[30]	United States	Retrospective database analysis using the Nationwide Inpatient Sample, n=95,627 open, n=3,296 laparoscopic	Elective open versus laparoscopic resection for colon cancer (2003–2004)	USD (year not stated)	Total hospital charges	34,178	34,685	0.187
Mar *et al.* 2018[74]	Spain	Retrospective analysis of prospective multi-center observational study, n=628 open and n=963 laparoscopic	Open versus laparoscopic colorectal cancer surgery (2010-2012)	EUR (year not stated)	Mean (SD) hospitalization costs	15,468 (9,429)	12,824 (6,538)	NR
					Mean (SD) complications costs			
					30 days	950 (2,885)	420 (1,594)	NR
					1 year	1,505 (3,509)	1,040 (3,346)	NR
					2 years	1,693 (3,925)	1,246 (2,977)	NR
					Mean (SD) costs	23,023 (12,089)	18,822 (8,939)	NR

Liao *et al.* 2017[20]	Taiwan	Retrospective study of nationwide population-based cohort with n=5,658 open and n=1,738 laparoscopic	Open versus laparoscopic colectomy for colon cancer (2009-2011)	USD (year not stated)	Mean (SD) hospital costs	4,735 (3,922)	4,386 (3,124)	0.0011
					Mean (SD) costs during 1st year after discharge			
					outpatient	3,303 (3,994)	3,206 (3,537)	0.8186
					inpatient	3,350 (5,837)	3,536 (6,732)	0.3521
					Mean (SD) costs during 2nd year after discharge			
					outpatient	2,472 (4,013)	2,400 (3,504)	0.1155
					inpatient	1,592 (5,070)	1,599 (5,041)	0.7586
Fitch *et al.* 2017[42]	United States	Retrospective analysis of healthcare claims database with n=558 open and n=741 laparoscopic	Open versus laparoscopic colectomy for colon cancer (2013)	USD (2013)	Mean cost of anchor hospitalization	37,105	31,552	<0.001
					Mean facility costs	31,631	26,221	<0.001
					Mean 30-day post-surgery healthcare utilization costs	7,121	4,842	0.0047
					Mean professional costs	5,474	5,331	0.4934
					Mean total costs	44,226	36,395	<0.001
					Mean readmission costs per case	3,151	1,676	0.0309

Laudicella *et al.* 2016[52]	England	Retrospective cost study of hospital administrative database with propensity score matching, n=55,358 patients in total[b]	Open versus laparoscopic colectomy for colon cancer (2006-2013)	GBP (2012)	Cost of initial admission	11,145	9,214	<0.01
					Including 30-day readmission	11,710	9,603	<0.01
					Including 90-day readmission	11,964	9,762	<0.01
Sheetz *et al.* 2017[50]	USA	Retrospective population-based study of Medicare claims database, n=295,271 open and n=133,528 laproscopic	Open versus laparoscopic colectomy (2010-2012)	USD (year not stated)	**Multiple linear regression**			
					Total episode payments	26,062	17,161	<0.01
					Index hospitalization payments	18,502	13,016	<0.01
					Physician payments	2,798	2,019	<0.01
					Readmission payments	10,429	9,284	<0.01
					Post-acute care payments	3,029	1,204	<0.01

					Instrumental variable analysis[c]			
					Total episode payments	24,573	20,452	<0.01
					Index hospitalization payments	17,570	15,077	0.38
					Physician payments	2,694	2,249	<0.01
					Readmission payments	10,292	9,791	<0.01
					Post-acute care payments	2,737	1,850	<0.01
Ribeiro *et al.* 2020[43]	Brazil	Retrospective database analysis, n=164 open and n=116 laparoscopic	Elective laparoscopic versus open colorectal surgery (2012-2013)	BRL (year not stated)	Mean (SD) costs of index admission	41,652 (95,127)	32,915 (16,314)	0.024
					Mean (SD) costs of readmissions	2,808 (13,679)	2,508 (7,511)	0.650
					Mean (SD) total costs	44,461 (95,789)	35,424 (18,350)	0.026

[a]*Includes right hemicolectomy, transcolectomy, extended right hemicolectomy/total colectomy, left hemicolectomy, sigmoidectomy, high anterior resection, abdominoperineal resection, anterior resection of the rectum, ultralow anterior resection*

[b] *Neither the absolute number nor the overall percentage of patients with laparoscopic and open approaches was stated in the study.*

[c] *The instrumental variable analysis addresses selection bias that was not accounted for in the conventional multivariable analysis. In this study, regional use of the laparoscopic approach was used as the instrumental variable.*

ICU; intensive care unit; IQR, inter-quartile range; OR, operating room; PACU, post-anesthesia care unit; SD, standard deviation

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