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ORIGINAL SCIENTIFIC REPORT

The Impact of Operative Approach on Postoperative Complications Following Colectomy for Colon Caner

Benedetto Mungo[1] · Christina M. Papageorge[2] · Miloslawa Stem[1] · Daniela Molena[1,3] · Anne O. Lidor[1,2]

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Abstract

Background Colectomy is one of the most common major abdominal procedures performed in the USA. A better understanding of risk factors and the effect of operative approach on adverse postoperative outcomes may significantly improve quality of care.

Methods Adult patients with a primary diagnosis of colon cancer undergoing colectomy were selected from the National Surgical Quality Improvement Program 2013–2015 targeted colectomy database. Patients were stratified into five groups based on specific operative approach. Univariate and multivariate analyses were used to compare the five groups and identify risk factors for 30-day anastomotic leak, readmission, and mortality.

Results In total, 25,097 patients were included in the study, with a 3.32% anastomotic leak rate, 1.20% mortality rate, and 9.57% readmission rate. After adjusting for other factors, open surgery and conversion to open significantly increased the odds for leak, mortality, and readmission compared to laparoscopy. Additionally, smoking and chemotherapy increased the risk for leak and readmission, while total resection was associated with increased mortality and leak.

Conclusions Operative approach and several other potentially modifiable perioperative factors have a significant impact on risk for adverse postoperative outcomes following colectomy. To improve quality of care for these patients, efforts should be made to identify and minimize the influence of such risk factors.

Introduction

Colectomy is not only the mainstay of treatment for most colon cancers, but also constitutes an invaluable therapeutic option in the management of several non-neoplastic diseases, making it one of the most commonly performed abdominal operations in the USA. The last two decades have witnessed widespread adoption of minimally invasive techniques for many surgical procedures. Randomized trials have justified this trend, providing evidence for several benefits of minimally invasive surgery over the traditional open approach. Specifically, in patients undergoing colectomy, significant advantages in terms of shorter hospital length of stay (LOS), less pain, and earlier recovery of bowel function have been extensively reported [1, 2]. Nevertheless, laparoscopy remains underutilized for colectomy, showing a remarkably lower adoption rate over time than that observed for other procedures, such as cholecystectomy and Nissen fundoplication [3]. Furthermore, in recent years, newer techniques such as robotic

✉ Anne O. Lidor
lidor@surgery.wisc.edu

[1] Department of Surgery, Johns Hopkins University School of Medicine, Baltimore, MD, USA

[2] Department of Surgery, University of Wisconsin School of Medicine and Public Health, 600 Highland Ave K4/752, Madison, WI 53792-7375, USA

[3] Department of Surgery, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

surgery have entered the landscape of colorectal surgery, and there are data suggesting that this approach might deliver even additional benefits over conventional laparoscopy [4].

With the recent development of the targeted colectomy participant use file (PUF), the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database is a powerful tool to study current trends and outcomes surrounding colectomy. In addition to the robust preoperative data available for risk stratification, this database now uniquely contains details of the specific operative approach utilized as well as the ability to identify unplanned conversion from a minimally invasive to an open approach. This database provides adequate sample size to generate the statistical power to detect differences in less common complications between various operative approaches. Furthermore, a specific outcome measure for anastomotic leak was recently introduced, providing the opportunity to study this complication on a national scale using a standardized definition for the first time.

Therefore, the primary purpose of this study was to compare postoperative outcomes between various operative approaches for colectomy in patients with colon cancer. Secondarily, we aimed to identify other patient- and disease-related risk factors for mortality, anastomotic leak, and readmission following colon resection.

Materials and methods

Data source

This study is a retrospective analysis of the ACS-NSQIP-targeted colectomy database. Although this database was first introduced in 2011, detailed information regarding operative approach was not reported until 2013, and therefore this analysis was restricted to 2013–2015. The PUF contains 22 colectomy-specific variables collected from 154 participating sites [5]. Patients' demographics, preoperative comorbidities, intraoperative variables, and 30-day postoperative morbidity and mortality outcomes were obtained by merging the aforementioned colectomy PUF with the main ACS-NSQIP database using the unique case identification variable.

Briefly, both the procedure-targeted and main ACS-NSQIP PUFs are validated databases that contain data regarding surgical patient comorbidities and 30-day outcomes. The data are abstracted from clinical records, rather than from administrative sources, by trained surgical clinical reviewers. Additional details of ACS-NSQIP are described elsewhere [6, 7]. This study was approved by the Institutional Review Board of the Johns Hopkins School of Medicine.

Study population

This study included patients with a primary diagnosis of colon cancer aged 18 years or older who underwent colectomy with or without proximal diverting ostomy (Current Procedural Terminology (CPT) codes of 44204, 44140, 44207, 44145, 44150, 44210, 44147, 44143, 44146, 44206, or 44208, 44205, or 44160) between January 1, 2013 and December 31, 2015. Patients undergoing emergency surgery were excluded. We restricted our cohort to colon cancer patients in order to achieve a more homogenous population. For the purpose of this study, five categories of operative approach were defined for comparison as detailed in Table 1. Patients who underwent single-incision laparoscopic surgery (SILS) and other less commonly performed procedures were excluded. Further exclusion criteria included diagnosis of disseminated cancer.

An additional small proportion of patients were excluded specifically from the readmission analysis alone. Readmission is defined by NSQIP as at least one readmission (to the same or other hospital), for any reason, within 30 days of surgery. Therefore, patients who remain in the hospital longer during their initial hospitalization have fewer days of follow-up time, introducing an immortal time bias. To address this concern, patients with LOS greater than 16 days (2.92% of the overall population) were excluded in order to allow a minimum of 2-week post-discharge follow-up. Additionally, patients not at risk of readmission due to predischarge in-hospital mortality

Table 1 Definitions for operative approach categories

Group	Description
LAP	Laparoscopic procedures, excluding those with hand or open assist, in which conversion did not occur
OPEN	Planned open procedures only
CONVERSION	All cases in which unplanned conversion from a minimally invasive to open approach occurred, including cases started via a laparoscopic, robotic, hybrid, hand-assisted, or open-assisted technique
HAND-ASSISTED	Any minimally invasive technique with hand or open assist (including laparoscopic, robotic, hybrid, or other with hand or open assist) in which conversion to open did not occur
ROBOTIC	Robotic cases, excluding those with hand- or open-assist, in which conversion did not occur

and discharge to a separate acute care hospital were excluded from the readmission analysis as well.

Demographic and clinical characteristics

Demographic and clinical characteristics considered to be potentially associated with anastomotic leak, mortality, and hospital readmission were assessed. Demographic characteristics included age, gender, and race. Clinical characteristics included American Society of Anesthesiologists (ASA) classification of physical condition, functional status, body mass index (BMI), and preoperative comorbidities. Current smoking is defined as smoking within 1 year before surgery; weight loss is defined as >10% weight loss within 6 months prior to surgery; chemotherapy identifies patients receiving treatment within 90 days prior to surgery. Age and BMI were categorized as follows: <50, 50–59, 60–69, 70–79 and ≥80 years old, and <18.5 kg/m^2 (underweight), 18.5–24.9 kg/m^2 (normal), 25–29.9 kg/m^2 (overweight), and ≥30 (obese), respectively. Other variables included in analysis were type of resection (partial vs. total), and proximal diversion.

Outcomes

Intraoperative and postoperative outcomes were compared between the five operative approaches. The three primary outcomes were anastomotic leak, mortality, and hospital readmission within 30-days of surgery. Secondary outcomes included LOS (days from operation to discharge), operative time, non-home discharge destination (transfer to rehabilitation facility, separate acute care, or skilled care), prolonged postoperative ileus, and individual complications reported in the NSQIP database. Additional secondary composite endpoints were based on groupings of similar complications. These included wound complications (any of superficial surgical site infection (SSI), deep incisional SSI, or wound dehiscence); cardiac complications (cardiac arrest requiring cardiopulmonary resuscitation and myocardial infarction); renal complications (postoperative acute renal failure or progressive renal insufficiency); and thrombotic complications (deep vein thrombosis/thrombophlebitis and pulmonary embolism). Serious morbidity was defined as occurrence of one of the following complications: cardiac complication, sepsis/shock, unplanned intubation, on ventilator for more than 48 h, organ space SSI, or reoperation.

Statistical analysis

Baseline patient demographics and comorbidities were compared using Pearson's Chi-square tests for categorical variables and analysis of variance (ANOVA) for continuous variables. Initial exploratory data analyses were performed using univariate logistic regression to compare the odds of anastomotic leak, mortality, and readmission across the five operative approach groups. Odds ratios (OR) and 95% confidence intervals (CI) are reported. Multivariable logistic regression analyses were then performed to compare outcomes between operative approaches while controlling for baseline differences between the groups. Initially, each multivariable model included all covariates with associations in the exploratory analysis at the $p < 0.25$ significance level, as recommended by Hosmer and Lemeshow [8]. These models were then refined based on the clinical importance of covariates and their impact on the overall model, as determined by likelihood ratio tests. The final models were evaluated using the Hosmer–Lemeshow goodness-of-fit test [8]. Statistical significance was defined as $p < 0.05$ for all statistical tests. All statistical analysis was conducted using Stata/MP version 14 (StataCorp LP, College Station, TX, USA).

Results

Study population

A total of 25,097 patients underwent partial or total colectomy and met inclusion criteria for the study. The mean [SD] age and BMI of the overall study population were 66.2 [13.5] years and 28.5 [6.6], respectively. Laparoscopy, open, and hand assisted procedures were the most common (30.51, 26.74, and 30.51%, respectively). Significant differences between the five operative approaches were observed with regards to patient demographics and clinical characteristics. Not surprisingly, older patients with higher ASA classification and multiple comorbidities more frequently underwent an open procedure (Table 2). Open surgery was the most commonly utilized operative approach for total colectomy (43.79% of total resections). Patients requiring conversion to open were more likely to be obese (43.06%) compared to those completed via the planned minimally invasive approach.

Outcomes

Unadjusted analysis

The overall rates for anastomotic leak, mortality, and readmission were 3.32% ($n = 834$), 1.20% ($n = 300$), and 9.57% ($n = 2286$), respectively. Anastomotic leak and readmission rates were highest in the open and conversion to open groups (4.37 and 4.49, 12.11 and 12.14%, respectively) and lowest in the lap group (2.30, 7.57%, respectively) (Table 3). Mortality rate was highest in the

Table 2 Characteristics of study population stratified by operative approach, NSQIP 2013–2015

Characteristic (%)	Lap 7657 (30.51)	Open 6712 (26.74)	Conversion 2006 (7.99%)	Hand assisted 7657 (30.51%)	Robotic 1065 (4.24%)	*p*
Type of resection						**<0.001**
Partial	7551 (98.62)	6451 (96.11)	1946 (97.01)	7497 (97.61)	1056 (99.15)	
Total	106 (1.38)	261 (3.89)	60 (2.99)	160 (2.09)	9 (0.85)	
Proximal diversion	361 (4.71)	933 (13.90)	211 (10.52)	479 (6.26)	107 (10.05)	**<0.001**
Age group (years)						**<0.001**
<50	819 (10.70)	643 (9.58)	189 (9.42)	863 (11.27)	164 (15.40)	
50–59	1582 (20.66)	1171 (17.45)	421 (20.99)	1708 (22.31)	280 (26.29)	
60–69	1976 (25.81)	1681 (24.04)	556 (27.72)	2006 (26.20)	308 (28.92)	
70–79	1943 (25.38)	1669 (24.87)	485 (24.18)	1821 (23.78)	211 (19.81)	
≥80	1337 (17.46)	1548 (23.06)	355 (17.70)	1259 (16.44)	102 (9.58)	
Male	3713 (48.49)	3405 (50.73)	1119 (55.78)	3983 (52.02)	589 (55.31)	**<0.001**
Race						**<0.001**
White	5182 (67.68)	4815 (71.74)	1409 (70.24)	5861 (76.54)	831 (78.03)	
Black	840 (10.97)	703 (10.47)	248 (12.36)	671 (8.76)	93 (8.73)	
Other	431 (5.63)	211 (3.14)	87 (4.34)	454 (5.93)	48 (4.51)	
Not reported/unknown	1204 (15.72)	983 (14.65)	262 (13.06)	671 (8.76)	93 (8.73)	
ASA classification						**<0.001**
I–II	3488 (45.66)	2116 (31.59)	723 (36.06)	3419 (44.72)	477 (44.79)	
III	3764 (49.27)	3979 (59.41)	1158 (57.76)	3890 (50.88)	562 (52.77)	
IV–V	387 (5.07)	603 (9.00)	124 (6.18)	336 (4.40)	26 (2.44)	
Partially/totally dependent	172 (2.26)	290 (4.33)	52 (2.61)	148 (1.94)	13 (1.23)	**<0.001**
BMI group						**<0.001**
Underweight (<18.5)	159 (2.09)	208 (3.13)	35 (1.76)	138 (1.81)	13 (1.22)	
Normal (18.5–24.9)	2312 (30.37)	2131 (32.04)	457 (22.99)	2166 (28.41)	285 (26.79)	
Overweight (25–29.9)	2641 (34.69)	2139 (32.16)	640 (32.19)	2675 (35.08)	374 (35.15)	
Obese (≥30)	2502 (32.86)	2174 (32.68)	856 (43.06)	2646 (34.70)	392 (36.84)	
Diabetes	1383 (18.06)	1378 (20.53)	437 (21.78)	1383 (18.06)	182 (17.09)	**<0.001**
Current smoker	933 (12.18)	963 (14.35)	288 (14.36)	919 (12.00)	142 (13.33)	**<0.001**
Dyspnea	570 (7.44)	707 (10.53)	205 (10.22)	625 (8.16)	54 (5.07)	**<0.001**
History of COPD	376 (4.91)	445 (6.63)	125 (6.23)	384 (5.02)	38 (3.57)	**<0.001**
History of CHF	91 (1.19)	135 (2.01)	18 (0.90)	88 (1.15)	4 (0.38)	**<0.001**
Hypertension	4028 (52.61)	3723 (55.47)	1189 (59.27)	4068 (53.13)	533 (50.05)	**<0.001**
Weight loss	250 (3.26)	495 (7.37)	87 (4.34)	309 (4.04)	31 (2.91)	**<0.001**
Steroid use	212 (2.77)	265 (3.95)	67 (3.34)	220 (2.87)	24 (2.25)	**<0.001**
Renal disease	53 (0.69)	77 (1.15)	13 (0.65)	47 (0.61)	5 (0.47)	**0.002**
Chemotherapy	384 (5.09)	664 (9.74)	158 (8.01)	652 (8.65)	227 (21.42)	**<0.001**

ASA: I–II (No/Mild Disturb), III (Severe Disturb), IV–V (Life Threat/Moribund). ASA classification not reported for 45 patients, partial/total dependency for 103 patients, and BMI for 154 patients

Bold indicates statistical significance

LAP laparoscopic, *ASA* American Society of Anesthesiology, *BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *CHF* congestive heart failure

open group (2.21%) and lowest in the robotic group (0.19%). Aside from operative approach, factors associated with increased risk of anastomotic leak included, male gender, chemotherapy and smoking (Table 4). Higher mortality was associated with older age and multiple comorbidities and factors associated with readmission

Table 3 Unadjusted rates of postoperative outcomes stratified by operative approach, NSQIP 2013–2015

Outcome (%)	Lap 7657 (30.51)	Open 6712 (26.74)	Conversion 2006 (7.99)	Hand assisted 7657 (30.51)	Robotic 1065 (4.24)	*p*
Anastomotic leak	176 (2.30)	293 (4.37)	90 (4.49)	243 (3.17)	32 (3.00)	**<0.001**
Mortality	55 (0.72)	148 (2.21)	32 (1.60)	63 (0.82)	2 (0.19)	**<0.001**
Readmission	563 (7.57)	743 (12.11)	226 (12.14)	662 (8.94)	92 (8.80)	**<0.001**
LOS, days, mean ± SD	5.0 ± 4.9	8.0 ± 7.5	7.3 ± 7.4	5.4 ± 4.6	4.7 ± 3.6	**<0.001**
Operation time, min, mean ± SD	172.0 ± 83.4	165.0 ± 98.3	217.9 ± 105.8	185.6 ± 91.4	235.9 ± 103.3	**<0.001**
Transfer[a]	462 (6.04)	1094 (16.33)	223 (11.14)	536 (7.00)	49 (4.61)	**<0.001**
Prolonged ileus	671 (8.77)	1408 (21.03)	443 (22.12)	858 (11.21)	101 (9.49)	**<0.001**
Overall morbidity[b]	1226 (16.01)	2154 (32.09)	677 (33.75)	1460 (19.07)	167 (15.68)	**<0.001**
Wound infection	266 (3.47)	564 (8.40)	190 (9.47)	336 (4.39)	29 (2.72)	**<0.001**
Pneumonia	104 (1.36)	221 (3.29)	62 (3.09)	94 (1.23)	17 (1.60)	**<0.001**
UTI	100 (1.31)	208 (3.10)	70 (3.49)	151 (1.97)	19 (1.78)	**<0.001**
VTE	77 (1.01)	173 (2.58)	51 (2.54)	95 (1.24)	12 (1.13)	**<0.001**
Cardiac complication	57 (0.74)	117 (1.74)	38 (1.89)	77 (1.01)	7 (0.66)	**<0.001**
Shock/sepsis	174 (2.27)	389 (5.80)	112 (5.58)	220 (2.87)	22 (2.07)	**<0.001**
Unplanned intubation	95 (1.24)	158 (2.35)	43 (2.14)	87 (1.14)	7 (0.66)	**<0.001**
Bleeding transfusion	487 (6.36)	1023 (15.24)	318 (15.85)	543 (7.09)	47 (4.41)	**<0.001**
Renal complication	52 (0.68)	120 (1.79)	36 (1.79)	82 (1.07)	12 (1.13)	**<0.001**
On ventilator > 48 h	60 (0.78)	130 (1.94)	31 (1.55)	65 (0.85)	7 (0.66)	**<0.001**
Organ space SSI	182 (2.38)	329 (4.90)	107 (5.33)	259 (3.38)	42 (3.94)	**<0.001**
Reoperation	252 (3.29)	359 (5.35)	113 (5.63)	311 (4.06)	38 (3.57)	**<0.001**
Serious morbidity[c]	469 (6.13)	849 (12.65)	262 (13.06)	580 (7.57)	73 (6.85)	**<0.001**

LAP laparoscopic, *LOS* length of stay, *UTI* urinary tract infection, *VTE* venous thrombosis, *SSI* surgical site infection

[a] Transfer is discharge to rehab, separate acute care, or skilled care (not home)

[b] Overall morbidity: Wound infection, pneumonia, urinary tract infection, VTE, cardiac complication, shock/sepsis, unplanned intubation, bleeding transfusion, renal complication, on ventilator >48 h, organ space surgical site infection, and reoperation

[c] Serious morbidity: cardiac complication, shock/sepsis, unplanned intubation, on ventilator >48 h, organ space surgical site infection, and reoperation

Transfer and prolonged ileus not reported for 26 and 30 patients, respectively

Different denominators for readmission due to additional exclusions: lap $n = 7436$, open $n = 6133$, conversion to open $n = 1861$, hand assisted $n = 7401$, robotic $n = 1046$

Bold indicates statistical significance

Table 4 Unadjusted rates and odds ratios of anastomotic leak, mortality, and readmission, NSQIP 2013–2015

Characteristic (%)	Anastomotic Leak 834/25097 (3.32%)		Mortality 300/25097 (1.20%)		Readmission 2286/23,877 (9.57%)	
	Rate, %	OR (95% CI)	Rate, %	OR (95% CI)	Rate, %	OR (95% CI)
Surgical approach						
Laparoscopic	2.30	Reference	0.7	Reference	7.57	Reference
Open	4.37	**1.94 (1.60–2.35)**	2.21	**3.12 (2.28–4.25)**	12.11	**1.68 (1.50–1.89)**
Conversion to open	4.49	**2.00 (1.54–2.59)**	1.60	**2.24 (1.45–3.47)**	12.14	**1.69 (1.43–2.00)**
Hand assisted	3.17	**1.39 (1.14–1.70)**	0.82	1.15 (0.80–1.65)	8.94	**1.20 (1.07–1.35)**
Robotic	3.00	1.32 (0.90–1.93)	0.19	0.26 (0.63–1.07)	8.80	1.18 (0.93–1.48)
Type of resection						
Partial	3.24	Reference	1.16	Reference	9.44	Reference
Total	6.54	**2.09 (1.50–2.91)**	2.85	**2.51 (1.53–4.13)**	15.47	**1.76 (1.38–2.23)**
Proximal diversion	4.69	**1.49 (1.20–1.85)**	2.06	**1.86 (1.34–2.58)**	15.72	**1.88 (1.64–2.14)**
Age group (years)						
<50	3.66	Reference	0.07	–	8.82	Reference
50–59	3.95	1.08 (0.85–1.38)	0.41	Reference (<60)	8.28	0.93 (0.79–1.10)
60–69	3.13	0.85 (0.66–1.09	0.64	**2.20 (1.32–3.66)**	9.39	1.07 (0.91–1.26)
70–79	3.28	0.89 (0.70–1.14)	1.39	**4.78 (3.01–7.59)**	10.13	1.17 (0.99–1.37)
≥80	2.76	**0.75 (0.57–0.98)**	3.26	**11.45 (7.37–17.79)**	11.08	**1.29 (1.09–1.52)**
Male	3.96	**1.51 (1.31–1.74)**	1.26	1.11 (0.89–1.40)	10.15	**1.14 (1.05–1.25)**
Race						
White	3.23	Reference	1.28	Reference	9.63	Reference
Black	2.66	0.82 (0.63–1.06)	1.10	0.85 (0.58–1.27)	10.25	1.07 (0.93–1.23)
Other	2.68	0.82 (0.58–1.18)	0.57	**0.44 (0.21–0.94)**	8.42	0.86 (0.70–1.07)
Not reported/unknown	4.61	**1.45 (1.20–1.74)**	1.03	0.80 (0.55–1.15)	9.17	0.95 (0.83–1.08)
ASA classification						
I–II	2.66	Reference	0.37	Reference	7.09	Reference
III	3.78	**1.44 (1.24–1.67)**	1.48	**4.01 (2.83–5.69)**	10.91	**1.60 (1.46–1.76)**
IV–V	3.66	**1.39 (1.03–1.87)**	4.40	**12.34 (8.24–18.50)**	15.84	**2.47 (2.08–2.92)**
Partially/totally dependent	2.81	0.84 (0.53–1.33)	6.22	**6.24 (4.46–8.72)**	15.44	**1.75 (1.39–2.21)**
BMI group						
Normal (18.5–24.9)	3.98	Reference	3.07	Reference	10.15	Reference
Underweight (<18.5)	3.12	1.29 (0.82–2.01)	1.52	**2.05 (1.22–3.44)**	9.00	1.14 (0.85–1.54)
Overweight (25–29.9)	3.44	1.11 (0.93–1.32)	0.93	**0.61 (0.46–0.81)**	9.29	1.04 (0.93–1.16)
Obese (≥30)	3.35	1.08 (0.90–1.29)	1.05	**0.69 (0.52–0.91)**	10.31	**1.16 (1.04–1.30)**
Diabetes	3.44	1.05 (0.88–1.25)	1.66	**1.53 (1.18–2.00)**	11.32	**1.26 (1.14–1.40)**
Current smoker	4.87	**1.60 (1.34–1.91)**	1.02	0.83 (0.58–1.19)	10.96	**1.19 (1.05–1.35)**
Dyspnea	3.66	1.11 (0.88–1.41)	3.24	**3.30 (2.52–4.33)**	12.57	**1.40 (1.22–1.61)**
History of COPD	3.29	0.99 (0.73–1.34)	3.44	**3.30 (2.41–4.53)**	13.24	**1.47 (1.24–1.75)**
History of CHF	3.57	1.08 (0.60–1.93)	7.44	**7.16 (4.68–10.94)**	19.71	**2.35 (1.74–3.18)**
Hypertension	3.47	1.11 (0.96–1.27)	1.57	**2.07 (1.61–2.66)**	10.97	**1.42 (1.30–1.55)**
Weight loss	5.97	**1.93 (1.50–2.48)**	2.05	**1.79 (1.18–2.73)**	12.45	**1.36 (1.13–1.64)**
Steroid use	3.93	1.20 (0.83–1.73)	2.16	**1.87 (1.14–3.07)**	0.84	1.92 (0.84–4.40)
Renal disease	5.13	1.58 (0.83–3.00)	2.05	1.74 (0.64–4.72)	23.67	**2.96 (2.07–4.23)**
Chemotherapy	6.34	**2.17 (1.79–2.63)**	0.39	**0.30 (0.15–0.61)**	15.40	**1.83 (1.60–2.08)**

ASA: I–II (No/Mild Disturb), III (Severe Disturb), IV–V (Life Threat/Moribund). ASA classification not reported for 12 patients, partial/total dependency for 48 patients, BMI for 88 patients, and colon cancer, acute diverticulitis, and Crohn's disease for 9 patients

OR odds ratio, *CI* confidence interval, *ASA* American Society of Anesthesiology, *BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *CHF* congestive heart failure

Bold indicates statistical significance

included proximal diversion, age ≥80, ASA class, chemotherapy and renal disease.

Adjusted analysis

Even when controlling for underlying differences between the five groups, patients undergoing open, conversion to open, and hand assisted procedures had worse outcomes compared to laparoscopy (Table 5). Specifically, patients who underwent an open or conversion to open procedures were nearly twice as likely to suffer from anastomotic leak, and over twice more likely to die. Open and conversion to open procedures also had about 1.5-fold increase in readmission. In addition, although the hand-assisted approach had increased odds of leak (OR 1.30, 95% CI 1.06–1.59, $p = 0.010$) and readmission (OR 1.17, 95% CI 1.03–1.31, $p = 0.012$), those odds were substantially lower than the odds of leak in the open (OR 1.72, 95% CI 1.42–2.10, $p < 0.001$) and conversion to open (OR 1.81, 95% CI 1.39–2.36, $p < 0.001$) approaches and readmission in the open (OR 1.44, 95% CI 1.28–1.62, $p < 0.001$) and conversion to open (OR 1.52, 95% CI 1.28–1.80, $p < 0.001$) approaches. Smoking carried increased odds of both anastomotic leak (OR 1.37; 95% CI 1.13–1.64, $p < 0.001$) and readmission (OR 1.19, 95% CI 1.04–1.36, $p = 0.009$). Additional independent predictors of both mortality and readmission included ASA class, partially/totally dependent status, and history of CHF, while chemotherapy was associated with both anastomotic leak and readmission. Finally, proximal diversion was associated with significantly increased odds of readmission (OR 1.51, 95% CI 1.29–1.78, $p < 0.001$).

Discussion

In this study, we have identified several factors, including both patient characteristics and chosen operative approach that increase the risk for anastomotic leak, mortality, and readmission after colon resection.

Anastomotic leak is one of the most feared complications of colectomy, having a direct influence on other important outcome measures such as need for reoperation and mortality [9]. Prior to the development of the NSQIP-targeted colectomy PUF, the ability to reliably measure the risk of anastomotic leak using large multi-institutional datasets has been limited. The absence of a standardized outcome variable has previously required investigators to rely on surrogate measures such as “organ space SSI,” which grossly underestimates true leak rates [10]. In the present study, we were able to identify several risk factors for anastomotic leak. We found that sicker patients, with higher ASA classification, had higher risk for leak.

Other independent predictors for anastomotic leak identified in this study included male gender and smoking. Higher risk of leak in male patients has been reported previously and is generally attributed to increased difficulty operating in the narrower male pelvis [11]. Smoking has also been identified as an important risk factor for leak in prior studies. Sørensen et al. proposed an underlying etiology of anastomotic malperfusion secondary to nicotine-induced vasoconstriction and microthromboses due to increased platelet aggregation [12]. The influence of smoking behavior on anastomotic integrity is a factor worth stressing, as it not only increases the risk of leak, but also represents one of the few truly modifiable variables.

Both open surgery and conversion to open were associated with significantly worse outcomes by all measures. The effect of conversion on postoperative outcomes is likely related in part to the reason for conversion itself. For example, factors such as unusual anatomy, occurrence of unexpected intraoperative complications, or staging errors may both dictate the decision to convert and also lead to a suboptimal postoperative course, thereby confounding the relationship between conversion and outcomes. This represents a controversial topic in the literature, with some authors reporting higher morbidity and mortality in converted patients, while others describe outcomes comparable to laparoscopy [13–15]. The NSQIP-targeted colectomy database makes a particularly meaningful contribution to the literature on this topic, benefiting from a very large, high-quality sample and detailed information regarding operative approach.

Patients undergoing open colectomy were older and had more comorbid conditions at baseline compared to those undergoing minimally invasive approaches, and it is therefore unsurprising that unadjusted analysis revealed worse outcomes in this group. Nonetheless, these differences remained significant in the adjusted analysis, suggesting that there are true benefits to minimally invasive colon resection. These findings are in contrast to two highly cited previous randomized, multi-center studies comparing laparoscopic versus open surgery for colon cancer. In both the COST [16] and COLOR [17] trials, overall complications, readmissions, and mortality were equivalent in both the open and laparoscopic group. However, in both studies, approximately 20% of patients with either an open or a converted to open approach were analyzed in the laparoscopic group given the intention to treat analysis. A recent analysis of the Nationwide Inpatient Sample (NIS) database described higher mortality and complication rates for patients undergoing open colectomy, even after applying propensity matching [18]. Furthermore, open colectomy is economically disadvantageous, leading to significantly higher healthcare costs and utilization in the short- and long-term [19]. In light of this evidence, one must wonder

Table 5 Logistic regression analyses of factors associated with leak, mortality, and readmission, NSQIP 2013–2015

Factor	Anastomotic Leak 834/25,097 (3.32%) OR (95% CI)	*p*	Mortality 300/25,097 (1.20%) OR (95% CI)	*p*	Readmission 2286/23,877 (9.57%) OR (95% CI)	*p*
Surgical approach						
Laparoscopic	Reference		Reference		Reference	
Open	1.72 (1.42–2.10)	**<0.001**	2.36 (1.70–3.27)	**<0.001**	1.44 (1.28–1.62)	**<0.001**
Conversion to open	1.81 (1.39–2.36)	**<0.001**	2.21 (1.41–3.48)	**0.001**	1.52 (1.28–1.80)	**<0.001**
Hand assisted	1.30 (1.06–1.59)	**0.010**	1.20 (0.83–1.75)	0.339	1.17 (1.03–1.31)	**0.012**
Robotic	1.07 (0.72–1.58)	0.728	0.38 (0.09–1.58)	0.185	1.05 (0.83–1.33)	0.677
Type of resection						
Partial	Reference		Reference		Reference	
Total	1.83 (1.18–2.83)	**0.007**	2.18 (1.12–4.21)	**0.021**	1.19 (0.90–1.59)	0.225
Proximal diversion	0.91 (0.69–1.20)	0.514	1.21 (0.79–1.87)	0.386	1.51 (1.29–1.78)	**<0.001**
Age group (years)						
<50	Reference		–		Reference	
50–59	1.05 (0.82–1.35)	0.694	Reference (<60)		0.89 (0.75–1.06)	0.185
60–69	0.84 (0.65–1.07)	0.162	1.81 (1.07–3.07)	**0.026**	0.96 (0.81–1.14)	0.645
70–79	0.90 (0.69–1.16)	0.405	3.08 (1.88–5.05)	**<0.001**	1.04 (0.87–1.24)	0.641
≥80	0.76 (0.57–1.01)	0.060	5.77 (3.54–9.40)	**<0.001**	1.10 (0.91–1.33)	0.320
Male	1.44 (1.20–1.64)	**<0.001**			1.09 (1.00–1.19)	0.060
ASA classification						
I–II	Reference		Reference		Reference	
III	1.40 (1.20-1.64)	**<0.001**	2.04 (1.40–2.96)	**<0.001**	1.37 (1.23–1.52)	**<0.001**
IV–V	1.39 (1.02–1.90)	**0.040**	3.25 (2.05–5.14)	**<0.001**	1.78 (1.47–2.16)	**<0.001**
BMI group						
Underweight (<18.5)			Reference		Reference	
Normal (18.5–24.9)			1.74 (1.02–2.98)	**0.043**	1.02 (0.75–1.38)	0.909
Overweight (25–29.9)			0.71 (0.52–0.96)	**0.025**	1.06 (0.94–1.19)	0.327
Obese (≥30)			0.81 (0.59–1.10)	0.174	1.12 (1.00–1.26)	0.054
Partially/totally dependent			2.45 (1.71–3.50)	**<0.001**	1.36 (1.07–1.73)	**0.013**
Diabetes			1.18 (0.89–1.56)	0.259	1.02 (0.91–1.14)	0.729
Current smoker	1.37 (1.13–1.64)	**<0.001**			1.19 (1.04–1.36)	**0.009**
Dyspnea			1.51 (1.11—2.06)	**0.008**	1.08 (0.93–1.26)	0.315
History of COPD			1.49 (1.05–2.11)	**0.027**	1.08 (0.89–1.30)	0.441
History of CHF			2.20 (1.38–3.53)	**0.001**	1.67 (1.21–2.29)	**0.002**
Hypertension			1.06 (0.80–1.39)	0.696	1.22 (1.10–1.35)	**<0.001**
Weight loss	1.69 (1.30–2.18)	**<0.001**	1.06 (0.68–1.66)	0.796	1.19 (0.98–1.44)	0.080
Steroid use			1.22 (0.73–2.05)	0.446		
Renal disease					2.07 (1.42–3.02)	**<0.001**
Chemotherapy	1.97 (1.60–2.41)	**<0.001**	0.57 (0.28–1.17)	0.128	1.85 (1.60–2.13)	**<0.001**

ASA: I–II (No/Mild Disturb), III (Severe Disturb), IV–V (Life Threat/Moribund)

Bold indicates statistical significance

OR odds ratio, *CI* confidence interval, *ASA* American Society of Anesthesiology, *BMI* body mass index, *COPD* chronic obstructive pulmonary disease, *CHF* congestive heart failure

why minimally invasive colon resection has not achieved the same reach as other abdominal operations, such as laparoscopic cholecystectomy. Although some possible reasons for the empiric selection of an open approach, such as prior history of complex abdominal surgery or intraabdominal infection, are not traceable through NSQIP, such explanations likely do not fully account for why over one-third of patients continue to undergo open surgery. Barriers to wider adoption must be identified and addressed in order to deliver the highest quality of care to all patients.

Robotic approach did not differ significantly from laparoscopic colectomy in terms of mortality, readmission rates, and risk of anastomotic leak. Hand-assisted techniques, which accounted for nearly 30% of all cases, may serve as an important bridge to a totally minimally invasive approach and, importantly, appear to offer some of the benefits granted by pure minimally invasive techniques. Cima and colleagues [20] found hand-assisted colectomy to have comparable 30-day outcomes to laparoscopy. These findings were associated with the added benefit of shortened operative times, resulting in meaningful economical savings. Unfortunately, they did not investigate the effect of the hand-assisted approach on anastomotic leak or readmission, nor have any other published studies to date. As robotic surgery is also significantly more costly than laparoscopy [18], the equivalence in outcomes becomes an important factor in assessing value. While features of the surgical robot (magnified tridimensional visualization, excellent range of motion, tremor filtration) have the theoretical potential to improve outcomes over other techniques, this potential has gone largely unrealized in practice [4, 21].

The last main outcome we evaluated was readmission, which represents an increasingly important quality indicator for surgery and has been estimated to cost about $300 million annually for colorectal surgery alone in the USA [22]. Several of the risk factors we identified for readmission, such as proximal diversion and open surgery, have been previously reported [23, 24] and are to some extent at the discretion of the operating surgeon. Most of the independent predictors of readmission, however, such as renal disease, recent chemotherapy and history of CHF, are poorly modifiable patient characteristics. This is an important finding in the era of pay-for-performance and financial penalties tied to hospital readmission.

While the novel NSQIP-targeted colectomy database has many strengths which have been leveraged for this study, there are also inherent limitations. For example, we were unable to assess functional and oncologic outcomes, both of which are clearly important when comparing surgical techniques. In addition, NSQIP is limited to 30-day outcomes and therefore fails to detect deaths and readmissions occurring after that time period. While we made every attempt to control for differences between groups, there are certainly remaining unmeasured differences, such as previous surgical history and patient preferences, which may play an important role when comparing operative techniques. Specifically, our analysis assumes that all patients were candidates for any of the potential operative approaches, which is almost certainly untrue. Ideally, we would have been able to exclude patients who underwent an open procedure because it was the only available option. Given this inherent limitation of a retrospective database study, we undertook a comprehensive multivariate analysis to adjust for confounding baseline differences between the five groups. Finally, hospital participation in NSQIP is voluntary and self-funded, so it is unknown whether the data reported by this small subset of hospitals, usually high volume centers, can accurately be extrapolated to all hospitals. Despite these limitations, we believe that the use of a surgically oriented database and the large sample size in this study have allowed us to evaluate the comparative effectiveness of various operative approaches to colectomy.

We found that minimally invasive techniques are associated with improved short-term outcomes following colectomy. While there is clearly significant selection bias in terms of operative approach, our adjusted analysis suggests that there are likely real differences in outcomes between patients undergoing minimally invasive and open procedures. We have also identified several potentially modifiable perioperative factors that are associated with increased risk of anastomotic leak, mortality, and readmission. These results are important for risk stratification, patient counseling, and quality improvement efforts in this patient population.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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