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Laparoscopic versus robotic colectomy: a national surgical quality improvement project analysis

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Abstract

Introduction Robotic colorectal surgery is being increasingly adopted. Our objective was to compare early postoperative outcomes between robotic and laparoscopic colectomy in a nationally representative sample.

Methods The American College of Surgeons National Surgical Quality Improvement Project Colectomy Targeted Dataset from 2012 to 2014 was used for this study. Adult patients undergoing elective colectomy with an anastomosis were included. Patients were stratified based on location of colorectal resection (low anterior resection (LAR), left-sided resection, or right-sided resection). Bivariate data analysis was performed, and logistic regression modeling was conducted to calculate risk-adjusted 30-day outcomes.

Results There were a total of 25,998 laparoscopic colectomies (30 % LAR's, 45 % left-sided, and 25 % right-sided) and 1484 robotic colectomies (54 % LAR's, 28 % left-sided, and 18 % right-sided). The risk-adjusted overall morbidity, serious morbidity, and mortality were similar between laparoscopic and robotic approaches in all anastomotic groups. Patients undergoing robotic LAR had a lower conversion rate (OR 0.47, 95 % CI 1.20–1.76) and postoperative sepsis rate (OR 0.49, 95 % CI 0.29–0.85) but a higher rate of diverting ostomies (OR 1.45, 95 % CI 1.20–1.76). Robotic right-sided colectomies had significantly lower conversion rates (OR 0.58, 95 % CI 0.34–0.96). Robotic colectomy in all groups was associated with a longer operative time (by 40 min) and a decreased length of stay (by 0.5 days).

Conclusions In a nationally representative sample comparing laparoscopic and robotic colectomies, the overall morbidity, serious morbidity, and mortality between groups are similar while length of stay was shorter by 0.5 days in the robotic colectomy group. Robotic LAR was associated with lower conversion rates and lower septic complications. However, robotic LAR is also associated with a significantly higher rate of diverting ostomy. The reason for this relationship is unclear. Surgeon factors, patient factors, and technical factors should be considered in future studies.

Keywords Colorectal surgery · Robotic surgery · ACS-NSQIP · Laparoscopic surgery

The role of the robotic platform in elective colorectal surgery is a contentious debate. Like any extensively debated topic, studies on the literature surrounding robotic-assisted colectomy have found that there is bias in the language used in reporting results and that over 80 % of studies include reporting that could distort the interpretation of results and mislead readers [1]. Further analyses have found that regional competition may influence a hospital's decision to acquire a surgical robot, suggesting that the robot may be as much a marketing tool as an improved surgical technique [2].

There have been several meta-analyses of small retrospective series studying the role of the robotic platform in

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colorectal surgery. These reveal that robotic colectomy is associated with lower rates of conversion and decreased time to return of bowel function with no differences in perioperative morbidity [3–11]. At the same time though, robotic colectomy is associated with increased costs [7, 10–12]. In rectal cancer, robotic-assisted surgery in the confines of the pelvis might provide a technical advantage. However, oncologic outcomes following robotic colectomy have shown no benefit in circumferential resection margin positivity or number of lymph nodes resected [5, 8, 10, 13].

In the single published randomized clinical trial, there was no difference in outcomes in 70 patients randomized to robot-assisted versus laparoscopic right colectomy aside from increased hospital costs in patients undergoing robotic colectomy [14]. While preliminary results from a large, well-designed prospective randomized control trial [the robotic vs. laparoscopic resection for rectal cancer (ROLARR)] investigating the role of the robotic platform in the pelvis has been presented at the American Society of Colon and Rectal Surgeons in June 2015 and updated in May 2016, the peer reviewed publication is still pending. Preliminary data demonstrated no significant difference in outcomes between patients treated with robotic colectomy or laparoscopic colectomy. The presentation of these results has been greeted with a great deal of controversy with proponents and detractors of the robotic platform voicing their concerns [15, 16].

The American College of Surgeons National Surgical Quality Improvement Project (ACS-NSQIP) could provide insight into advantages and disadvantages of the use of the robotic platform in real-world setting [17]. The ACS-NSQIP colectomy-specific database provides detailed and specific information on techniques and outcomes associated with colectomy. There are three manuscripts that have used the same ACS-NSQIP dataset between 2012 and 2013, which have reported differing results on conversion rates and postoperative length of stay [18–20]. Including data from 2014 should allow a more granular investigation into the role of the robotic platform to address the discrepancies in previous reports. Based on the current literature, we hypothesize there will be a decreased conversion rate to open among robotic colectomy with no significant difference in perioperative morbidity.

Materials and methods

This is a retrospective study that analyzes the ACS-NSQIP colectomy targeted dataset from 2012 to 2014. This study was deemed exempt by the institutional review board at the Indiana University School of Medicine.

Patient selection

All patients undergoing elective laparoscopic or robotic colorectal procedures with anastomosis were included in this analysis. Specifically, patients were selected based on CPT codes including 44140, 44145, 44146, 44160, 44204, 44205, 44207, and 44208. Patients were stratified based on the location of the colon or rectal resection as undergoing a low anterior resection (LAR) if the CPT included 44145, 44146, 44207, or 44208; a left-sided resection if the CPT included 44140 or 44204; or a right-sided resection if the CPT included 44160 or 44205. There was significant interaction between location of resection, robotic versus laparoscopic colectomy, and several postoperative outcomes, so the data for these groups are presented separately.

Patients were grouped as undergoing a laparoscopic versus robotic colectomy based on the data in the colectomy targeted dataset. The procedure was categorized as laparoscopic if the procedure was coded as laparoscopic, laparoscopic hand-assisted, laparoscopic with open assist, laparoscopic with unplanned conversion to open, single-incision laparoscopic surgery (SILS), SILS with open assist, or SILS with unplanned conversion to open. The procedure was categorized as robotic if the procedure was coded as robotic, robotic with open assist, or robotic with unplanned conversion to open.

Patients were coded as receiving a proximal diverting ostomy if the primary CPT was 44146 or 44208 or if any of the secondary CPT codes included 44310, 44316, 44320, 44187, or 44188.

Only patients undergoing elective colectomy were included, as emergent cases are more likely to be performed laparoscopically than robotically. Cases were thus excluded if they were coded as emergent or not elective, if the patient had an American Society of Anesthesiologists (ASA) class of 5, acute diverticulitis, a preoperative wound infection, ventilation requirement, or sepsis, if the operation did not occur on hospital day zero, or if there were missing data for indication. Figure 1 details the inclusion and exclusion criteria.

Preoperative variables

Preoperative variables were defined from reported ACS-NSQIP variables. Patient characteristics include age, gender, body mass index (BMI) (grouped based on NIH recommendations) [21], and race/ethnicity. Comorbid conditions were dichotomized and included preoperative diabetes, smoking status, dyspnea, functional status before surgery (independent vs. partially dependent or totally dependent), chronic obstructive pulmonary disease (COPD), ascites, history of congestive heart failure

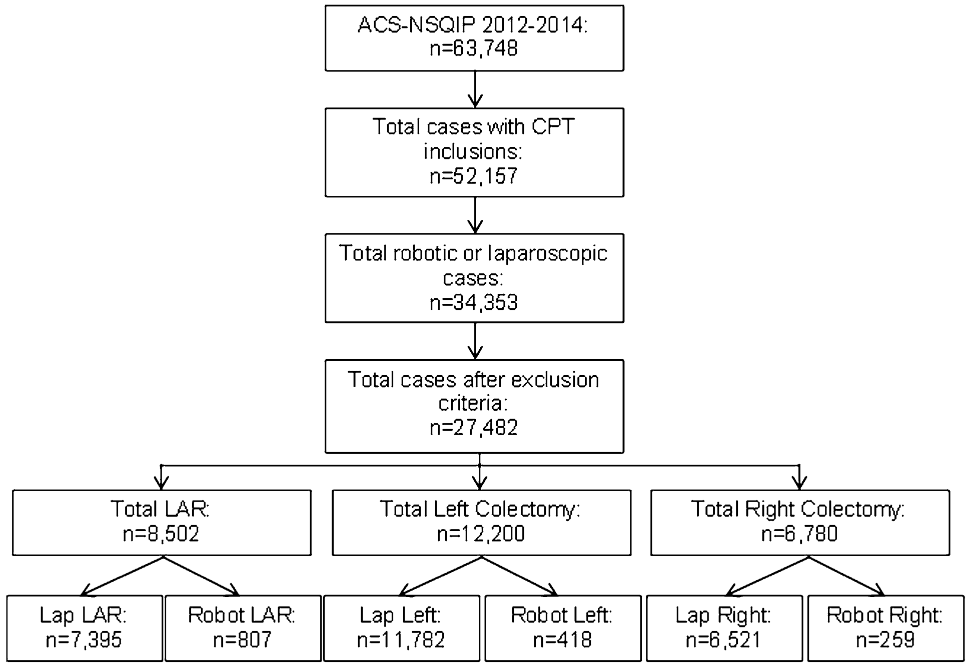

Fig. 1 Flow diagram outlining inclusion and inclusion criteria. *ACS-NSQIP* American college of surgeons colectomy targeted national surgical quality improvement project targeted colectomy file; *CPT* current procedural terminology; *LAR* low anterior resection; *Lap* laparoscopic; *Robot* robotic

(CHF), hypertension, renal failure, disseminated cancer, preoperative chemotherapy use, steroid use, weight loss (>10 % loss of body weight in the last 6 months), bleeding disease, and ASA class. We also included patients' bowel preparation information as this has been found to be significantly associated with postoperative outcomes [22, 23].

Outcomes

Thirty-day outcomes were analyzed with multivariable analyses. These included mortality, overall morbidity, and serious morbidity. Serious morbidity was defined as having at least one of the following: anastomotic leak, organ space surgical site infection (SSI), wound dehiscence, postoperative sepsis, prolonged ventilator requirement, kidney injury, bleeding requiring ≥4 transfusions, stroke, cardiac arrest, myocardial infarction, or pulmonary embolism. The rate of diverting ostomy was also evaluated as well as the unplanned conversion to open rate.

Individual complications were evaluated including infectious and wound complications (superficial SSI, deep space SSI's, organ space SSI's, wound dehiscence, urinary tract infections (UTI), and sepsis); respiratory compromise (pneumonia, unplanned intubation, or prolonged ventilator requirement); any venous thromboembolisms (VTE); kidney injury (progressive renal insufficiency or acute renal failure); bleeding requiring ≥4 transfusions; stroke; cardiac complications (myocardial infarction or cardiac arrest); and readmission rates.

Statistical analysis

Bivariate analysis was conducted using Chi-squared or Fisher's exact tests for categorical outcomes as appropriate and Kruskal–Wallis tests for continuous outcomes given lack of normality. Multivariable logistic regression models were then built to evaluate the outcomes and included patient and preoperative values that were different between the laparoscopic and robotic colectomy groups at a p value of 0.1. Patients with missing data for any of the covariates were excluded from the logistic regression models. A stepwise selection criterion was used with an entry and exit criterion of a p value <0.05. After running selection models with all covariates, the models were re-run with only the covariates selected in the prior stepwise selection process in order to minimize the number of observations excluded from analysis secondary to missing values. All statistical analyses were performed using SAS 9.4 (SAS Institute Inc, Cary, NC).

Results

A total of 27,482 patients undergoing elective colorectal resection were included for analysis, of which 25,998 were laparoscopic and 1484 were robotic. There were 8502 LAR's with 7395 laparoscopic LAR's and 807 robotic LAR's. There were 12,200 left colectomies with 11,782 laparoscopic left colectomies and 418 robotic left colectomies. There were 6780 right colectomies, with 6521

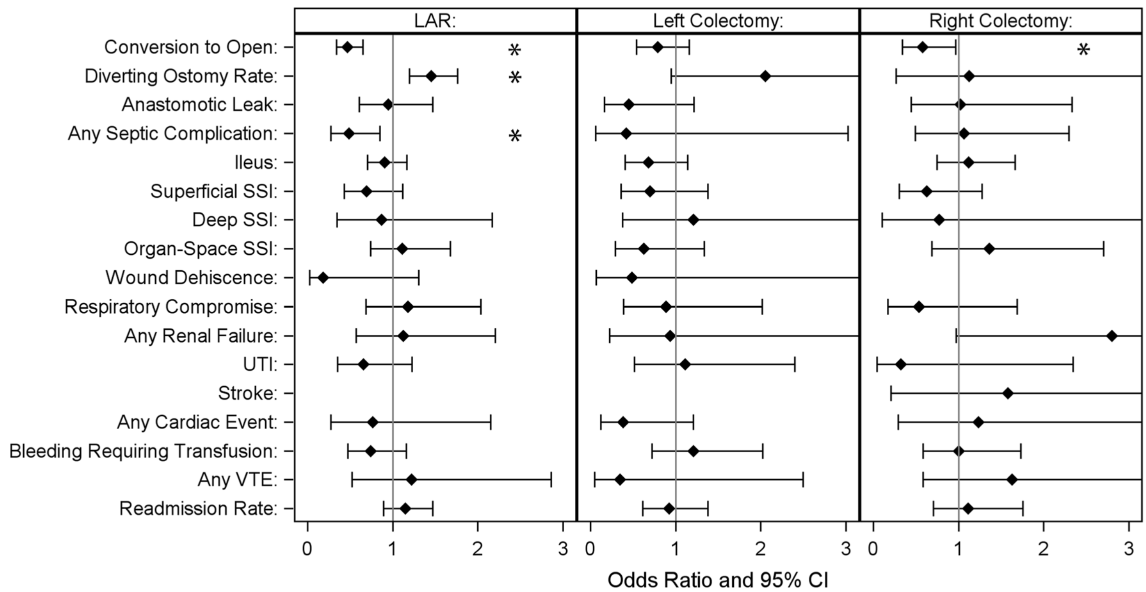

Fig. 2 Forest plot of individual adjusted morbidity information. Laparoscopy serves as reference group. *Indicates p value <0.05. *LAR* low anterior resection; *SSI* surgical site infection; *UTI* urinary tract infection; *VTE* venous thromboembolism. If no odds ratio is listed (for example for stroke in LAR), the accurate confidence limit was unable to be determined given lack of convergence as no events occurred in the robotic group

laparoscopic right colectomies and 259 robotic right colectomies.

Low anterior resection

In evaluating patients undergoing low anterior resections, there were several significant baseline differences between the groups (Tables 1, 2). Indications for robotic LAR were predominantly for cancer (47.5 % in lap vs. 58.4 % in robot) and less commonly for diverticular disease (41.1 % in lap vs. 32.8 % in robot). Patients were more likely to undergo proximal diversion in the robotic group (18.7 % in lap vs. 31.1 % in robot) (p value <0.001). The higher rate of proximal diversion in the robotic group was also found in patients with colorectal cancer who underwent preoperative chemotherapy (71.9 % in lap vs. 80.7 % in robot, p value = 0.02) and those who did not undergo preoperative chemotherapy (19.5 % in lap vs. 30.0 % in robot, p value <0.001). Patients in the robotic group also tended to be younger, have lower rates of preoperative dyspnea, higher rates of preoperative chemotherapy, and were more likely to have a preoperative leukocytosis.

In evaluating unadjusted outcomes, there was no statistically significant difference in the rate of mortality (0.3 % in lap vs. 0.3 % in robot), overall morbidity (21.8 % in lap vs. 20.5 % in robot), or serious morbidity (10.8 % in lap vs. 10.5 % in robot) (p value >0.05 for all). There was a significantly higher unplanned conversion to open (12.8 % in lap vs. 6.8 % in robot, p value <0.001), sepsis rate (3.1 % in lap vs. 1.6 % in robot, p value = 0.02), and wound dehiscence rate in the laparoscopic group (0.7 % in lap vs. 0.1 % in robot, p value = 0.05) (Fig. 2). The median operative time was 45 min longer in the robotic group (195 ± 112 min in lap vs. 240 ± 134 in robot, p value <0.001). The mean length of stay was significantly shorter in the robotic group, but the median value was identical between groups (4 days (interquartile range (IQR) = 3–6) in lap versus 4 days (IQR = 3–5) in robot, p value <0.001).

In evaluating adjusted outcomes, there was no significant difference in mortality, overall morbidity, or serious morbidity between the groups. Robotic colectomy was associated with significantly lower conversion rates (OR 0.47, 95 % CI 0.34–0.65) and rates of postoperative sepsis (OR 0.49, 95 % CI 0.28–0.85). However, robotic colectomy was associated with an increased rate of diverting ostomies (OR 1.45, 95 % CI 1.20–1.76). A multivariable logistic regression analysis was performed to investigate which factors were predictive of proximal diversion among patients undergoing LAR (Table 5). Robotic procedure, colon cancer and inflammatory bowel disease as indications, preoperative chemotherapy, class III–IV wounds, and ASA class over 2 were predictors of proximal diversion (Table 5).

Left-sided and right-sided colonic resection

There were significant baseline differences between robotic-assisted versus laparoscopic left- and right-sided colectomies as demonstrated in Tables 1, 2. These differences were controlled in our multivariable models.

Table 1 Baseline characteristics of patients undergoing robotic and laparoscopic colectomy

	LAR			Left colectomy			Right colectomy		
	Lap	Robot	*p*	Lap	Robot	*p*	Lap	Robot	*p*
Gender (%F)	50.1	51.1	0.60	51.8	55.7	0.11	46.6	51.4	0.13
Age (%)									
<55 yo	34.8	39.4		28.3	34.0		29.9	22.4	
55–64 yo	29.5	28.8		25.5	28.5		22.1	23.2	
65–74 yo	23.3	20.3		26.9	24.9		26.8	30.1	
≥75 yo	12.4	11.5	0.05	19.3	12.7	<0.01	21.3	24.3	0.07
BMI (%)									
Underweight	1.3	1.4		1.8	0.7		2.4	3.1	
Normal	26.4	27.7		27.6	23.0		31.7	26.7	
Overweight	35.8	32.9		34.6	38.4		32.9	34.1	
Obese	36.5	38.1	0.43	36.1	37.9	0.06	33.0	36.1	0.35
Race (%)									
White	89.4	88.4		84.9	83.0		86.2	86.0	
Black	6.7	7.4		9.9	14.5		10.9	11.6	
Other	3.9	4.2	0.71	5.2	2.5	<0.01	2.9	2.4	0.84
Diabetes (%)	12.3	11.9	0.72	15.1	15.1	0.99	14.0	18.9	0.02
Smokers (%)	16.1	15.0	0.40	15.1	15.3	0.92	14.9	13.9	0.65
Dyspnea (at rest or with activity) (%)	4.9	2.5	<0.01	5.8	5.0	0.53	6.8	7.0	0.91
Not independent (%)	0.6	0.5	1	0.9	0.5	0.59	1.2	1.9	0.23
COPD (%)	3.1	2.2	0.19	4.2	2.9	0.19	4.3	5.0	0.54
Pre-op ascites (%)	0.1	0.0	1	0.2	0.2	0.48	0.1	0.4	0.23
CHF (%)	0.2	0.0	0.40	0.4	0.2	1	0.3	0.4	0.56
Hypertension (%)	45.1	43.5	0.38	49.7	50.0	0.90	47.8	55.6	0.01
Renal failure (%)	0.1	0.1	0.33	0.1	0.0	1	0.1	0.4	0.14
Preoperative dialysis (%)	0.3	0.3	1	0.5	0.2	1	0.3	0.0	1
Disseminated cancer (%)	3.9	4.1	0.70	2.8	1.2	0.05	3.2	1.5	0.14
Pre-op steroid use (%)	3.5	3.5	0.98	4.4	3.1	0.22	12.9	7.7	0.01
Pre-op weight loss (%)	2.7	2.6	0.82	2.4	1.7	0.36	3.0	3.1	0.93
Bleeding disease (%)	1.5	1.4	0.81	2.0	1.2	0.24	2.0	3.9	0.03
Pre-op chemo (%)	10.6	22.2	<0.01	1.6	1.4	0.86	1.5	1.6	0.80
Pre-op transfusion (%)	0.2	0	0.62	0.3	0.0	0.63	0.4	0.0	0.62
Wound classification (%)									
1	0.5	0.9		1.0	0.5		0.8	1.5	
2	82.4	84.0		89.1	87.3		89.8	93.1	
3	12.0	11.4		7.4	8.4		7.0	3.1	
4	5.1	3.7	0.20	2.5	3.8	0.22	2.4	2.3	0.06
ASA (% 3 or 4)	39.7	42.4	0.14	42.9	42.6	0.91	45.0	49.0	0.20

LAR low anterior resection; *Lap* laparoscopic; *F* female; *BMI* body mass index; *COPD* chronic obstructive pulmonary disease; *Pre-op* preoperative; *CHF* congestive heart failure; *chemo* chemotherapy; *Yo* years old; *Lap* laparoscopy; *Robot* robotic; *p p* value

In evaluating the crude outcomes, there was no significant difference in mortality, overall morbidity, or serious morbidity in robotic-assisted versus laparoscopic left- or right-sided colectomies (p value >0.05 for all) (Table 3). For left-sided colectomies, there were no crude differences in any of the specific morbidities (Table 3). For right-sided colectomies, robotic colectomy was associated with a lower unplanned conversion rate to open (10.5 % in lap vs. 6.2 % in robot, p value = 0.03) but a higher rate of postoperative renal failure (0.5 % in lap vs. 1.5 % in robot, p value = 0.04) (Table 3). The median operative time was 50 min longer in robotic left colectomies and

Table 2 Operative characteristics of patients undergoing robotic and laparoscopic colectomy

	LAR			Left colectomy			Right colectomy		
	Lap	Robot	*p*	Lap	Robot	*p*	Lap	Robot	*p*
Ostomy rate (%)	18.7	31.1	<0.01	0.8	1.7	0.09	1.0	0.8	1
Indication (%)									
Benign	10.3	8.6		25.5	23.7		32.9	42.5	
Cancer	47.5	58.4		46.0	35.9		49.8	44.8	
Diverticular disease	41.1	32.8		25.2	39.7		1.2	1.9	
IBD	1.1	0.3	<0.01	3.2	0.7	<0.01	16.1	10.8	<0.01
Bowel prep (%)									
None	20.5	18.8		23.1	18.2		33.6	36.7	
MBP only	44.2	38.4		37.0	44.8		31.4	32.6	
OABP only	3.0	2.9		3.4	4.1		5.2	6.3	
MBP + OABP	32.3	39.9	0.02	36.5	32.9	0.02	29.9	24.4	0.35

LAR low anterior resection; *Lap* laparoscopic; *IBD* inflammatory bowel disease; *MBP* mechanical bowel preparation; *OABP* oral antibiotic bowel preparation

Table 3 Unadjusted outcomes of laparoscopic and robotic colectomy stratified by colectomy site

	LAR			Left colectomy			Right colectomy		
	Lap	Robot	*p*	Lap	Robot	*p*	Lap	Robot	*p*
Mortality (%)	0.3	0.3	1	0.5	0.2	0.49	0.4	1.2	0.12
Overall morbidity (%)	21.8	20.5	0.36	19.0	15.6	0.08	22.1	22.0	0.99
Serious morbidity (%)	10.8	10.5	0.81	9.0	7.2	0.19	10.4	11.2	0.66
Convert to open (%)	12.8	6.8	<0.01	8.8	7.2	0.25	10.5	6.2	0.03
Anastomotic leak (%)	3.6	3.9	0.75	2.4	1.7	0.32	2.2	2.3	0.90
Post-op sepsis (%)	3.1	1.6	0.02	2.4	1.4	0.20	2.6	2.7	0.94
Ileus (%)	9.2	9.8	0.55	7.8	6.0	0.18	9.6	10.8	0.53
Superficial SSI (%)	4.4	3.0	0.05	4.2	4.8	0.73	4.9	3.1	0.19
Deep SSI (%)	0.7	0.6	0.76	0.6	0.7	0.74	0.5	0.4	1
Organ SSI (%)	3.9	4.7	0.23	2.6	1.7	0.26	2.7	3.5	0.47
Wound dehisc (%)	0.7	0.1	0.05	0.6	0.5	1	0.3	0.0	1
Respiratory compromise (%)	1.7	1.9	0.66	1.8	1.4	0.60	2.0	1.2	0.49
Renal failure (%)	0.9	1.2	0.27	0.5	0.5	1	0.5	1.5	0.04
UTI (%)	2.4	1.6	0.14	1.5	1.7	0.72	1.2	0.4	0.37
Cardiac event (%)	0.6	0.5	1	0.7	0.2	0.53	0.5	0.8	0.39
Bleeding requiring transfusion (%)	4.4	3.1	0.07	4.1	3.8	0.79	5.6	5.8	0.89
Any VTE (%)	0.6	0.7	0.65	0.7	0.2	0.53	0.9	1.5	0.31
Readmission (%)	8.8	10.5	0.09	6.8	6.2	0.63	7.5	8.1	0.73
Operative time (min, median ± IQR)	195 ± 112	240 ± 134	<0.01	153 ± 87	202.5 ± 106	<0.01	133 ± 73	173 ± 91	<0.01
Length of stay (days, median ± IQR)	4 ± 3	4 ± 2	<0.01	4 ± 2	4 ± 2	<0.01	4 ± 3	3 ± 2	<0.01

LAR low anterior resection; *Lap* laparoscopic; *SSI* surgical site infection; *Dehisc* Dehiscence; *UTI* urinary tract infection; *VTE* venous thromboembolism; *IQR* interquartile range; *Post-op* postoperative

40 min longer in robotic right colectomies (Table 3). There was no significant difference in the robotic operative time pooling all sites of colectomy between 2013 and 2014 (2013:211 min (IQR = 152–282); 2014:218 min (IQR = 165–285); p value = 0.23). The mean length of stay was again shorter in the robotic group for both sites of colectomy although the median length of stay was identical in the left-sided colectomy group (left-sided colectomy: 4 days (IQR = 3–5) in lap vs. 4 days (IQR = 3–5) in robot, p value <0.001). For right-sided colectomy, the

median length of stay was 1 day shorter in the robotic group [4 days (IQR = 3–6) in lap vs. 3 days (IQR = 3–5) in robot, p value <0.001].

In evaluating the adjusted outcomes in the left-sided colectomy group, there were no significant differences. In the right-sided colectomy group, robotic colectomy was associated with a significantly decreased conversion rate (OR 0.58, 95 % CI 0.34–0.96), but no other significant differences (Table 4).

Discussion

This study represents a sizable analysis with validated and specific colectomy data on the impact of robotic-assisted and laparoscopic colectomy on postoperative outcomes. Including data from the 2014 ACS-NSQIP dataset augmented the number of robotic colectomies by threefold as compared to the current literature, which increased statistical power for a more granular analysis [18–20].

In evaluating outcomes, there were no significant changes in mortality, overall morbidity, serious morbidity, anastomotic leak rate, or ileus between the laparoscopic and robotic groups. There was a significantly lower conversion rate in robotic LAR's and right-sided colectomies compared with laparoscopy (OR 0.47, 95 % CI 0.34–0.65 and OR 0.58, 95 % CI 0.34–0.96, respectively). This decreased conversion rate among LAR's is in concordance with prior studies [5, 10]. The conversion rate among robotic right-sided colectomy comes as a surprise. Right-sided colectomy has been associated with a shorter learning curve, lower rate of conversion, and morbidity when compared with left-sided colectomy in the current literature [24–27]. However, in our study, the laparoscopic right colectomy conversion rate was higher than the laparoscopic left colectomy conversion rate (10.5 vs. 8.8 %, respectively). Thus, there may be unmeasured variables driving the higher rate of conversion in laparoscopic right-sided colectomies. In particular, surgeon-level variation in conversion rates, possibly due to learning curve differences among surgeons or other surgeon-level factors, could be a contributor to the observed variability. However, it is not possible to investigate potential surgeon-level differences using ACS-NSQIP research dataset. The increased sample size of this study allowed for studying colectomy by site which helped uncover an overall decreased conversion rate. Prior studies have used different categorizations for colectomy site, which may explain the discrepancy among these studies in regards to conversion rates and highlights the importance of appropriate and consistent stratification [18–20].

In evaluating all colectomy sites, there was one adjusted postoperative event that was significantly different. Robotic LAR was associated with a lower rate of postoperative sepsis compared with laparoscopic LAR (OR 0.49, 95 CI 0.28–0.85). The reason for this association is not clear as there was no difference in adjusted rates of other infectious complications such as anastomotic leak, SSI's, pneumonia, or UTI.

The rate of diverting ostomy, as noted, was significantly higher in the robotic LAR group after adjusting for differences between groups (OR 1.45, 95 % CI 1.2–1.8). The reasons underlying this trend are unclear. There was a higher rate of cancer diagnoses and lower rate of diverticulitis in the robotic group, and our study demonstrated cancer was a risk factor for ostomy creation when compared to diverticulitis (Table 5). In a separate analysis performed only in patients with cancer who received preoperative chemotherapy and those who did not, there remained a significantly increased rate of proximal diversion in the robotic LAR group. Furthermore, in a multivariable logistic regression model including both indication for operation and preoperative chemotherapy, robotic LAR persisted as an independent risk factor for proximal diversion (Table 5). The notion that surgeons who perform robotic colectomy tend to be more cautious and thus perform diverting ostomies at a higher rate could explain this finding. However, technical factors that may lead to higher rates of positive intraoperative air leak tests resulting in higher rates of diverting ostomy creation must be considered. The rate of ostomy formation in robotic colectomy is not well described in the literature, and those in print report conflicting data on the rate of proximal diversion with heterogeneous patient populations [12, 28–31]. In addition, modern database studies have specifically excluded patients with proximal diversion or have neglected this

Table 4 Adjusted outcomes of robotic versus laparoscopic colectomy stratified by colectomy site

	LAR OR (95 % CI)	Left colectomy OR (95 % CI)	Right colectomy OR (95 % CI)
Mortality	1.24 (0.54–2.85)	1.08 (0.25–4.67)	0.59 (0.08–4.31)
Overall morbidity	0.88 (0.76–1.01)	0.82 (0.67–1.01)	0.72 (0.52–1.01)
Serious morbidity	0.93 (0.77–1.13)	0.92 (0.69–1.21)	0.68 (0.43–1.09)

Laparoscopy serves as reference for all odds ratios

LAR low anterior resection; *OR* odds ratio

Table 5 Predictors of diverting ostomy use based on site of colectomy

Colectomy site	Effect	Odds ratio (95 % CI)
LAR	Procedure type (lap is reference)	1.5 (1.2–1.8)
	Indication	
	Benign, not diverticulitis versus colon cancer	0.5 (0.4–0.6)
	Chronic diverticular disease versus colon cancer	0.2 (0.2–0.2)
	IBD versus colon cancer	1.4 (0.9–2.3)
	Pre-op chemotherapy (no chemo is reference)	10.3 (8.7–12.2)
	Wound class	
	Clean/contaminated versus clean	0.5 (0.2–1.0)
	Contaminated versus clean	0.7 (0.3–1.5)
	Dirty/infected versus clean	1.8 (0.8–4.0)
	ASA class (ASA class of 1–2 serves is reference)	1.3 (1.2–1.5)
Left-sided	Indication	
	Benign, not diverticulitis versus colon cancer	0.3 (0.1–0.7)
	Chronic diverticular disease versus colon cancer	1.5 (1.0–2.5)
	IBD versus colon cancer	7.1 (4.1–12.4)
	Pre-op chemotherapy (no chemo is reference)	9.9 (5.3–18.6)
Right-sided	Pre-op steroid use (no steroid is reference)	14.5 (8.6–24.3)

Lap laparoscopy; *IBD* inflammatory bowel disease; *pre-op* preoperative; *ASA* American society of anesthesiology; *chemo* chemotherapy

critical variable in multivariable regression analyses [18–20]. Future prospective studies should examine this relationship and include proximal diversion in risk adjustment models.

In all groups, robotic colectomy had a 45 min longer operative time, with unchanged operative time among robotic colectomy between 2013 and 2014. Given the lack of surgeon-specific data, it is difficult to speculate on the failure to shorten length of operative time over the study time period was a result of surgeons early in the learning curve or a limitation attributed to a technology-specific plateau.

Robotic colectomy was associated with significantly shorter lengths of stay in all groups. The median length of stay, which is the most accurate measure given the skewness of the data, was identical in the LAR and left-sided colectomy groups, but one day less in robotic right colectomies compared with laparoscopic right colectomies. ACS-NSQIP does not allow for analysis of the hourly length of stay, and differences in length of stay would be more accurately studied with data to this level of precision. Additionally, underlying differences in postoperative management and utilization of enhanced recovery pathways may have an effect on this outcome, but were variables that were not collected by ACS-NSQIP during the study time period reported here.

There are several limitations of our study. It is a retrospective database review subject to inherent biases. Selection bias in particular is potentially problematic in this type of review. We attempted to mitigate confounders and selection bias as much as possible by investigating differences between groups and including these differences in a multivariable logistic regression analysis. However, it is still likely that there are unmeasured confounders. In patients undergoing LAR, for example, there may be unrecorded surgeon-specific differences in indications for robotic LAR (lower tumors, difficult anatomy) that were not recorded. Further, surgeons early in their learning curve have been shown to prefer to perform robotic colectomy in more straightforward cases, which carries a bias that cannot be controlled for with ACS-NSQIP [32].

Overall, robotic and laparoscopic elective colorectal resections are associated with similar mortality, overall morbidity, and serious morbidity. Robotic low anterior resection and robotic right colectomy are associated with lower conversion rates compared with laparoscopy. Robotic LAR is associated with lower rates of postoperative sepsis, but significantly higher rates of diverting ostomy formation for unclear reasons. This could negate any potential advantage of robotic colectomy in these patients. Robotic colectomy is associated with a 45 min increased length of operative time, yet a statistically significant decreased length of stay by 0.5 days. Future studies should investigate the rate of ostomy creation with robotic proctectomy, potential improvements in operative time as technical skills evolve, and oncologic-specific outcomes comparing the different methods of colorectal resection.

Compliance with ethical standards

Disclosures Dolejs, Waters, Ceppa, and Zarzaur have no conflicts of interests or financial ties to disclose.

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