International Journal of Colorectal Disease (2019) 34:1385–1392
https://doi.org/10.1007/s00384-019-03334-x

ORIGINAL ARTICLE

Robotic versus laparoscopic elective colectomy for left side diverticulitis: a propensity score–matched analysis of the NSQIP database

Mohammed H. Al-Temimi[1,2] · Bindupriya Chandrasekaran[2] · Johan Agapian[3] · Walter R. Peters Jr[1] · Katrina O. Wells[1]

Accepted: 12 June 2019 / Published online: 23 June 2019

Abstract

Purpose Robotic surgery might have an advantage over conventional laparoscopy for colonic diverticulitis. We intend to compare both approaches in the elective management of left side diverticulitis.

Methods The National Surgical Quality Improvement Program (NSQIP) database (2012–2014) was surveyed for patients undergoing elective left/sigmoid colectomy for diverticulitis. Patient demographics, co-morbidities, disease complexity, and intraoperative details were matched on propensity scores derived from logistic regression model.

Results We identified 441 robotic and 6584 laparoscopic cases. Mean age was 56.8 years. Mean BMI was 29.5, and 46.5% of patients were males. Low preoperative albumin (< 3.5 mg/dl, 11.1% vs. 6.8%, $p = 0.003$), splenectomy (0.45% vs. 0.05%, $p = 0.002$), and enterotomy repair (1.1% vs. 0.4%, $p = 0.029$) were higher in the robotic group than the laparoscopic group. Hand assistance (35.8% vs. 42.9%, $p = 0.003$), splenic flexure takedown (41.5% vs. 49.2%, $p = 0.002$), and ureteric stent placement (18.6% vs. 23.5%, $p = 0.017$) were less common in the robotic group than the laparoscopic group. Case-matched analysis showed that robotic surgery was associated with shorter hospital stay (3.89 ± 2.18 days vs. 4.75 ± 3.25 days, $p < 0.001$), lower conversion rate (7.5% vs. 14.3%, $p = 0.001$), and longer operative time (219.2 ± 95.6 min vs. 188.8 ± 82.3 min, $p < 0.001$) than laparoscopic surgery. Robotic approach was associated with lower overall morbidity in multivariate analysis (OR = 0.72, 95% CI = 0.55–0.96), but not in case-matched analysis (14.4% vs. 19.2%, $p = 0.058$).

Conclusions Robotic surgery is associated with shorter hospital stay and lower conversion rate and may offer lower overall morbidity than laparoscopy after elective left side colectomy for diverticulitis. Controlled prospective studies are needed to confirm these findings.

Keywords Diverticulitis · Concomitant procedures · Robotic surgery · Laparoscopic surgery · Colectomy · Fistula

Introduction

Surgery for colonic diverticulitis can be challenging due to recurrent inflammation and often complicated nature of the cases requiring surgery (fistula, abscess, and stricture). Those patients often have adhesions, bulky mesentery, and loss of tissue planes. As such, colectomy for diverticulitis can be more difficult than colectomy for cancer [1]. Some studies suggest higher conversion rate with laparoscopy for diverticulitis in comparison with other diseases [1–4].

The robotic platform has many technical advantages over conventional laparoscopy (improved visualization, articulating instruments, and stable camera platform) and can be helpful for dissection in complex cases such as complicated diverticulitis [5–8]. Earlier studies comparing robotic colectomy for diverticulitis to laparoscopic approach were limited to small

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00384-019-03334-x) contains supplementary material, which is available to authorized users.

✉ Mohammed H. Al-Temimi
mohammed.altemimi@bswhealth.org

1 Department of Surgery, Division of Colorectal Surgery, Baylor University Medical Center, 3409 Worth St# 640, Dallas, TX 75246, USA

2 Department of Surgery, Kaiser Permanente Fontana Medical Center, 9961 Sierra Ave., Fontana, CA 92335, USA

3 Department of Surgery, Riverside University Health system, 26520 Cactus Ave,, Moreno Valley, CA 92555, USA

size, single-institution case series [6–8]. More recently, large case-matched studies comparing robotic with laparoscopic colectomy using national databases were performed [9–13]. Those studies showed that the robotic approach was associated with lower conversion rate [9, 10] and shorter hospital stay [9–12] with longer operative time [10, 12, 13] and no morbidity or mortality benefits [9–13]. None of those studies *specifically* compared robotic with laparoscopic colectomy for diverticulitis [9–13] or accounted for the case complexity characterized by disease severity and concomitant procedures performed at the time of colectomy. Disease severity and concomitant procedures could be potential confounders of the association between the index procedure and operative time or postoperative complications [14].

The purpose of this study is to compare elective robotic and laparoscopic left-sided/sigmoid colectomy performed for diverticulitis using case-matched analysis that accounts for surgical complexity.

Materials and methods

We used the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) Targeted Colectomy Database that was available to our institution (2012–2014) to identify patients undergoing colectomy for diverticulitis as defined by the International Classification of Disease Ninth Edition (ICD-9) diagnosis codes (562.11, 562.13). Patients who had emergent surgery, open colectomy, preoperative sepsis, right side colectomy, or total colectomy were excluded. The final cohort included patients undergoing elective laparoscopic or robotic left side colectomy with current procedural terminology (CPT) codes (44140, 44141, 44143, 44144, 44145, 44146, 44147, 44204, 44206, 44207, and 44208) for diverticulitis. Concomitant procedures were identified from any additional CPT codes that were reported in conjunction with the primary index procedure.

Age, gender, race, body mass index (BMI), functional status, the American Society of Anesthesiologists (ASA) class, smoking, steroid use, bleeding disorders, cardiac disease (congestive heart failure or history of coronary artery disease), renal disease (renal failure or being on dialysis), pulmonary disease (dyspnea or chronic obstructive pulmonary disease), weight loss, preoperative laboratory values, and intraoperative details (ostomy creation, hand-assisted technique, robotic vs. laparoscopic approach, surgical wound class, presence of colonic fistula, and concomitant procedures) were reported. Primary study outcomes were 30-day mortality, overall morbidity, and major morbidity. Secondary outcomes included operative time, hospital length of stay, conversion to open, readmission rate, and unplanned return to the OR. Major morbidity was defined as (organ/space infection, wound dehiscence requiring return to OR, postoperative intubation, pulmonary embolism, acute renal failure or dialysis, stroke, cardiac arrest, myocardial infarction, bleeding, sepsis, septic shock, leak, concomitant splenectomy, or ureteric repair). Any morbidity was defined as major morbidities (listed above) plus unplanned return to operating room, superficial wound infection, deep wound infection, pneumonia, failure to wean off the ventilator > 48 h, deep vein thrombosis, urinary tract infection, or ileus). Hospital stay was defined as prolonged if a patient stayed more than 5 days, which is the cutoff for 75th percentile of hospital stay in the cohort. Readmission was reported only if it was related to the operation.

Chi-squared test and Fisher's exact test were used to compare categorical variables, while Student *t* test or Wilcoxon rank sum test were used to compare continuous variables.

Propensity scores derived from multivariate logistic regression model for performing robotic vs. laparoscopic surgery were used to match the two groups (1:1) using the nearest neighbor method without replacement. Preoperative characteristics and lab values as well as intraoperative details were used in the propensity score logistic regression model. It was decided a priori that splenectomy and ureteric repair or reconstruction were not included in the matching process, because those procedures are likely performed for intraoperative inadvertent events. In the matched cohort, bivariate analysis was used to compare the primary and secondary outcomes between the two approaches.

For the entire non-matched cohort, supplemental multivariate logistic regression analysis was performed to test the effect of surgical approach (robotic versus laparoscopic) on mortality, major morbidity, and overall morbidity. Multivariate linear regression analysis was used to test the effect of surgical approach on hospital length of stay and operative time. The results of this supplemental analysis were provided as online tables.

All statistical analyses were performed using Stata, version 11 (College Station, TX, USA). Statistical significance was judged at $p < 0.05$.

Results

We identified 441 robotic and 6776 laparoscopic cases that met our inclusion criteria. Patient demographics and preoperative characteristics were comparable between the two groups. Mean patient age was 57 years for both groups, and mean BMI was 29. The robotic cohort was more likely to have albumin < 3.5 g/dl (11.1% vs. 6.9%; $p = 0.003$), but it is important to note that 40% of patients had missing albumin levels (Table 1).

Stoma creation was performed in less than 4% of the cases and that was similar between the two groups ($p = 0.870$). Hand assistance (42.98% vs. 35.83%, $p = 0.003$) and

Table 1 Comparison of baseline characteristics of the cohort before propensity score matching

	Laparoscopic ($N = 6584$)	Percentage	Robotic ($N = 441$)	Percentage	p value
Preoperative characteristics					
Age (years), mean ± SD	56.88 ± 11.94		56.83 ± 11.58		0.934
Gender (male)	3071	46.64	195	44.22	0.323
Race (white)	5776	87.73	382	86.62	0.494
ASA ≥ 3	1967	29.88	146	33.11	0.152
Functional status (dependent)	15	0.23	0	0	0.62
BMI (kg/m^2), mean ± SD	29.52 ± 6.19		29.30 ± 6.08		0.463
Smoking (yes)	1271	19.3	73	16.55	0.155
Preoperative weight loss	124	1.88	7	1.59	0.656
Steroid use	427	6.31	14	5.38	0.545
Preoperative infection	76	1.15	4	0.91	0.636
Dyspnea	279	4.24	15	3.4	0.396
Preoperative pulmonary disease	176	2.67	7	1.59	0.166
Preoperative cardiac disease	8	0.12	0	0	0.464
Hypertension	2822	42.86	197	44.67	0.457
Preoperative renal dysfunction	20	0.3	2	0.45	0.586
Bleeding disorder	80	1.22	6	1.36	0.788
Preoperative transfusion	9	0.14	0	0	0.437
Diabetes	582	8.84	43	9.75	0.515
Preoperative laboratory values					
Albumin					0.003
≥ 3.5	3403	51.69	226	51.25	
< 3.5	451	6.85	49	11.11	
Missing	2730	41.46	166	37.64	
Creatinine					0.203
1.5	5826	88.49	357	80.95	
> 1.5	94	1.43	9	2.04	
Missing	664	10.09	75	17.01	
White cell count					0.312
4000–11,000	5646	82.99	349	79.14	
< 4000	141	2.14	13	2.95	
> 11,000	482	7.32	26	5.9	
Missing	497	7.55	53	12.02	
HCT					0.137
≥ 35	5696	86.51	354	80.27	
< 35	470	7.14	38	8.62	
Missing	418	6.35	49	11.11	

concomitant procedures (38.1% vs. 30.2%, $p = 0.001$) other than splenic flexure takedown were more commonly performed in the laparoscopic group (Table 2).

The rate of diverticular fistulas was similar between the two groups (laparoscopic 1.69% vs. robotic 1.59%). Splenic flexure takedown (49.26% vs. 41.5%, $p = 0.002$) and ureteric stent placement (23.57% vs. 18.59%, $p = 0.017$) were also more common in the laparoscopic group; however, performing splenectomy (0.45% vs 0.05% $p < 0.002$) and small bowel repair (1.13% versus 0.41%, $p = 0.029$) were more common in the robotic group. Other procedures such as lysis of adhesions, cholecystectomy, hernia repair, small bowel resection, and gastrectomy were more often performed in the laparoscopic group, but the difference was not statistically significant (Table 2).

Out of 441 patients undergoing robotic procedures, 439 were matched (1:1) to patients undergoing laparoscopic resection on preoperative characteristics, laboratory values (Table 3), and concomitant intraoperative procedures (Table 4).

Table 2 Comparison of intraoperative details for the cohort before propensity score matching

	Laparoscopic ($N = 6584$)	Percentage	Robotic ($N = 441$)	Percentage	p value
Procedure					0.653
Partial colectomy with ostomy	236	3.58	14	3.17	
Partial colectomy without ostomy	6348	96.41	427	96.82	
Wound class					0.88
Clean contaminated	4709	71.52	320	72.56	
Contaminated	1194	18.13	76	17.23	
Dirty	681	10.34	45	10.2	
Hand assisted	2830	42.98	158	35.83	0.003
Concomitant procedures (yes)	2511	38.1	133	30.2	0.001
Fistula takedown	111	1.69	7	1.59	0.876
Splenic flexure takedown	3243	49.26	183	41.5	0.002
Lysis of adhesions	574	8.72	32	7.26	0.29
Ureteral stent	1552	23.57	82	18.59	0.017
OB-GYN procedures	188	2.86	8	1.81	0.199
Cholecystectomy	48	0.73	1	0.23	0.22
Hernia repair	161	2.45	8	1.81	0.402
Liver biopsy	17	0.26	0	0	0.285
Nephrectomy	2	0.03	0	0	0.714
Paraesophageal hernia repair	2	0.03	0	0	0.714
Vascular procedures	1	0.02	0	0	0.796
Thyroidectomy	1	0.02	0	0	0.796
Gastrectomy	1	0.02	0	0	0.796
Bladder repair/partial resection	51	0.77	3	0.68	0.826
Splenectomy	3	0.05	2	0.45	0.002
Enterotomy repair	27	0.41	5	1.13	0.029
Small bowel resection	122	1.85	5	1.13	0.272
Ureteric reconstruction	41	0.62	2	0.45	0.659

In the case-matched cohort, the robotic approach was associated with lower conversion rate to open (7.5% vs. 14.3%, $p = 0.001$) as well as shorter hospital stay (3.89 days vs. 4.75 days, $p < 0.001$) and longer operative time (219.26 ± 95.66 min vs. 188.87 ± 82.28 min, $p < 0.001$). There was a suggestive association with lower overall morbidity (14.4% vs. 19.2%, $p = 0.058$), but it did not reach statistical significance. Major morbidity, mortality, individual complications, return to the OR, and readmissions were similar between the two groups (Table 5).

In multivariate analysis of the entire cohort before propensity score matching, robotic colectomy was associated with better overall morbidity (OR = 0.72, 95% CI = 0.55–0.96) and suggestive association with better major morbidity (OR = 0.69, 95% CI = 0.46–1.04). Robotic colectomy was also associated with an average 33-min increase in operative time and 0.75-day shorter hospital stay in comparison with the laparoscopic approach (Supplemental Table 1).

Discussion

We report that elective robotic colectomy for diverticulitis is associated with lower morbidity than laparoscopic colectomy in multivariate analysis, but not in a case-matched cohort that accounts for disease complexity and intraoperative details. To our knowledge, this is the first study from the NSQIP database to compare robotic with laparoscopic colectomy for diverticulitis while adjusting for disease complexity and intraoperative details. Only few studies specifically investigated the use of the robot for diverticulitis [6–8]. In addition, most studies from national databases grouped this patient population with other diseases across all types of colectomy [9–13, 15]. Many prior studies failed to show differences in morbidity and mortality between robotic and laparoscopic colon resection [6–17]; however, very few of those studies stratified their analysis by the disease process and type of resection [10, 15–17], and the outcome of robotic procedures for diverticulitis is largely unknown. Dolejs et al. stratified their case-matched analysis by type of colon resection, but not the

Table 3 Comparison of baseline characteristics of the propensity score–matched cohort

	Laparoscopic ($N = 439$)	Percentage	Robotic ($N = 439$)	Percentage	p value
Preoperative characteristics					
Age (years), mean ± SD	56.97 ± 11.78		56.79 ± 11.57		0.815
Gender (male)	197	44.87	195	44.42	0.892
Race (white)	396	90.21	380	86.56	0.092
ASA ≥ 3	138	31.44	146	33.26	0.564
Functional status (dependent)	0	0	0	0	1
BMI (kg/m^2), mean ± SD	29.50 ± 6.03		29.30 ± 6.04		0.623
Smoking (yes)	68	15.49	73	16.63	0.646
Preoperative weight loss	10	2.28	6	1.37	0.313
Steroid use	16	3.64	14	3.19	0.71
Preoperative infection	6	1.37	4	0.91	0.525
Dyspnea	13	2.96	15	3.42	0.701
Preoperative pulmonary disease	8	1.82	7	1.59	0.795
Preoperative cardiac disease	0	0	0	0	1
Hypertension	189	43.05	196	44.65	0.634
Preoperative renal dysfunction	0	0	2	0.46	0.157
Bleeding disorder	4	0.91	6	1.37	0.525
Preoperative transfusion	0	0	0	0	1
Diabetes	46	10.48	43	9.79	0.737
Preoperative laboratory values					
Albumin					0.454
≥ 3.5	235	53.53	226	51.48	
< 3.5	38	8.66	49	11.16	
Missing	166	37.81	164	37.36	
Creatinine					0.114
1.5	392	98.25	357	97.54	
> 1.5	4	1	9	2.47	
White cell count					0.115
4000–11,000	352	87.13	348	90.16	
< 4000	10	2.48	13	3.37	
> 11,000	42	10.4	25	6.48	
HCT					0.103
≥ 35	382	93.63	353	90.51	
< 35	26	6.37	37	9.49	

disease process and found that robotic low anterior resection was associated with less septic complications (3.1 vs. 1.6%) without differences in overall mortality or morbidity [10]. Similarly, Al-Mazrou et al. found robotic colectomy for various diagnoses to be associated with lower septic complications (4% vs. 2.6%) [11].

Similar to these studies, we report that the robotic approach is not associated with significantly lower overall morbidity rate in case-matched cohort of patients undergoing colectomy for diverticulitis. However in our unmatched cohort, robotic colectomy was associated with better overall morbidity. Conversion rate [18] and performing concomitant procedures [14] are independent predictors of morbidity and could have contributed to the difference in morbidity rates on multivariate analysis for the non-matched cohort. It is likely that the effect of these details did not persist after matching due to their low frequency of occurrence and larger sample size is needed to validate these findings if difference in overall morbidity exists.

Robotic surgery was associated with longer operative time in our study, which is consistent with earlier randomized controlled studies [19] and retrospective comparative analysis [10, 12, 13, 15, 16, 20]. Longer operative time can be attributed to the learning curve of new technique [21], the need for extra time to dock and undock the robot [21] as well as performing concomitant procedures or more complex cases [14]. Performing concomitant procedures is associated with

Table 4 Comparison of intraoperative details for the propensity score–matched cohort

Procedure					0.691
Partial colectomy with ostomy	12	2.73	14	3.19	
Partial colectomy without ostomy	427	97.27	425	96.82	
Wound class					0.708
Clean contaminated	328	74.72	318	72.44	
Contaminated	72	16.4	76	17.31	
Dirty	39	8.88	45	10.25	
Hand assisted	158	35.99	158	35.99	1
Concomitant procedures (yes)	136	31.0	133	30.3	0.826
Fistula of the colon/rectum with other organs	9	2.05	7	1.59	0.614
Splenic flexure takedown	187	42.6	183	41.69	0.785
Lysis of adhesions	29	6.61	32	7.29	0.69
Ureteral stent	79	18	82	18.68	0.794
OB-GYN procedures	4	0.91	8	1.82	0.245
Cholecystectomy	2	0.46	1	0.23	0.563
Hernia repair	10	2.28	8	1.82	0.634
Liver biopsy	0	0	0	0	1
Nephrectomy	0	0	0	0	1
Paraesophageal hernia repair	0	0	0	0	1
Vascular procedures	0	0	0	0	1
Thyroidectomy	0	0	0	0	1
Small bowel resection	3	0.68	5	1.14	0.477
Gastrectomy	0	0	0	0	1
Bladder repair/partial resection	6	1.37	3	0.68	0.315
Enterotomy repair	1	0.23	5	1.14	0.101

longer operative time; therefore, it is necessary to adjust for disease-related concomitant procedures when comparing operative time of different interventions. The differences in operative time persist in our study even when case complexity and intraoperative details (ostomy creation, presence of fistula, and type of concomitant procedures) are accounted for. These findings suggest that the learning curve and docking/undocking time are perhaps better explanations of the longer operative time associated with robotic cases [21]. Another potential explanation for longer operative time for robotic cases is that using the robot may encourage surgeons to persist despite the complexity of the dissection resulting in lower conversion rate but at a longer time. Details about the operator case volume and experience as well as breakdown of robot-specific times (console time, docking time, and total operative time) are not available in the NSQIP database, so it is not feasible to clearly define whether those factors are contributing to longer operative time in this study.

Shorter hospital stay and lower conversion rate were associated with robotic procedures in our study, which is consistent with other reports [9–12, 16]. These positive outcomes after using the robot are encouraging and might offset the time and cost associated with robotic procedures [22].

In the unmatched cohort, robotic surgery was associated with higher rate of splenectomy and lower rate of splenic flexure takedown than laparoscopic surgery. In the case-matched cohort, splenectomy was still more common in the robotic group, but that did not reach statistical significance. Splenectomy in the context of colectomy for diverticulitis is most likely related to traction injuries. The loss of haptic feedback and the learning curve associated with using the robot might explain concomitant splenectomy in the robotic group. Furthermore, mobilizing the splenic flexure at time of robotic sigmoidectomy using the earlier models of the robot (Da Vinci Si) can sometimes be challenging, because the robot arm position at time of sigmoidectomy could limit the reach from the left lower quadrant and the pelvis to the left upper quadrant. Splenic flexure mobilization under such circumstances might be a daunting task that is avoided unless absolutely necessary, which may explain the lower rate of splenic flexure mobilization in the robotic group. In the same context, enterotomy repair was also more common in the robotic group. It is not clear whether those are iatrogenic enterotomies or they are related to the disease process (such as the presence of coloenteric fistula); however, these findings are consistent with a prior national study

Table 5 Postoperative outcomes in the propensity score–matched cohort

	Laparoscopic (N = 439)	Percentage	Robotic (N = 439)	Percentage	p value
Mortality	1	0.23	1	0.23	1
All morbidity	84	19.13	63	14.35	0.058
Major morbidity	33	7.52	27	6.15	0.422
Intraoperative transfusion	0	0	0	0	1
Operative time (min), mean ± SD	188.87 ± 82.28		219.26 ± 95.66		< 0.001
Total length of hospital stay (days)	4.75 ± 3.25		3.89 ± 2.18		< 0.001
Prolonged hospital length of stay (> 75 percentile)	106	24.15	46	10.48	< 0.001
Superficial wound infection	24	5.47	14	3.19	0.097
Deep wound infection	3	0.68	3	0.68	1
Organ space infection	11	2.51	12	2.73	0.833
wound dehiscence	2	0.46	1	0.23	0.563
Pneumonia	1	0.23	3	0.68	0.316
Unplanned intubation	0	0	1	0.23	0.317
Pulmonary embolism	1	0.23	1	0.23	1
Failure to wean off the vent	1	0.23	2	0.46	0.563
Renal failure	0	0	2	0.46	0.157
UTI	7	1.59	9	2.05	0.614
Stroke	0	0	0	0	1
Cardiac arrest	0	0	0	0	1
Myocardial infarction	1	0.23	1	0.23	1
Bleeding	13	2.96	7	1.59	0.175
DVT	2	0.46	0	0	0.157
Sepsis	7	1.59	5	1.14	0.561
Septic shock	2	0.46	2	0.46	1
Return to OR	18	4.1	15	3.42	0.594
Leak	11	2.51	9	2.05	0.655
Ileus	31	7.08	26	5.92	0.488
Conversion to open	63	14.35	33	7.52	0.001
Readmission					0.615
No	405	92.26	409	93.17	
Related to the procedure	32	7.29	26	5.92	
Not related to the procedure	1	0.23	2	0.46	
Unknown	1	0.23	2	0.46	
Intraoperative ureteric reconstruction	1	0.23	2	0.46	0.563
Splenectomy	0	0	2	0.46	0.157

[17]. In a study of the National Inpatient Sample database, Yeo et al. found that robotic procedures were associated with higher rate of iatrogenic complications (such as intraoperative bleeding events or bowel puncture). While this is an important finding in both studies, they are rare events that did not translate into an observed increase in overall morbidity or mortality.

Both ureteric stent placement and ureteric reconstruction were less common in the robotic group, but the latter was not significant. Ureteric stent placement could be related to surgeon preference or the complexity of diverticular disease. Also, better visualization of vital structures at time of dissection and lack of tactile feedback in robotic procedures may limit the usefulness of stents and are therefore less often utilized.

This study is limited by the retrospective nature of the study design; however, the NSQIP database is a robust clinical data that is validated in prior studies [23]. Second, rational for concomitant procedures is not captured, and it is not clear whether they are related to intraoperative inadvertent events or planned combined procedures. As such procedures that are likely related to inadvertent event at time of surgery for diverticulitis (ureteric reconstruction and splenectomy) were included as complications. Enterotomy repair and small bowel resection could be related to inadvertent event or the disease process (coloenteric fistula), so sensitivity analysis was performed to include them as complications and as concomitant procedures without any significant change in the outcomes demonstrated between groups.

In conclusion, robotic surgery for left side diverticulitis is associated with shorter hospital stay and lower conversion rate to open than conventional laparoscopy at the expense of longer operative time. There was a trend of lower overall morbidity with the robotic approach that did not reach statistical significance after controlling for operative complexity and performance of concomitant procedures. Controlled prospective studies are needed to confirm these findings.

Compliance with ethical standards

Conflict of interest Drs. Al-Temimi, Chandrasekaran, Agapian, and Wells have no conflict of interest or financial ties to disclose. Dr. Peters receives personal fees as a consultant for Ethicon outside the work presented here.

References

1. Bordeianou L, Rattner D (2010) Is laparoscopic sigmoid colectomy for diverticulitis the new gold standard? Gastro 4:2213–2216
2. Laurent SR, Detroz B, Detry O, Degauque C, Honor'e P, Meurisse M (2005) Laparoscopic sigmoidectomy for fistulized diverticulitis. Dis Colon Rectum 48:148–152
3. Joo JS, Agachan F, Wexner SD (1997) Laparoscopic surgery for lower gastrointestinal fistulas. Surg Endosc 11:116–118
4. Schwandner O, Farke S, Fischer F, Eckmann C, Schiedeck TH, Bruch HP (2004) Laparoscopic colectomy for recurrent and complicated diverticulitis: a prospective study of 396 patients. Langenbeck's Arch Surg 389:97–103
5. Baek SJ, Kim CH, Cho MS, Bae SU, Hur H, Min BS, Baik SH, Lee KY, Kim NK (2015) Robotic surgery for rectal cancer can overcome difficulties associated with pelvic anatomy. Surg Endosc 296:1419–1424
6. Elliott PA, McLemore EC, Abbas MA, Abbas MA (2015) Robotic versus laparoscopic resection for sigmoid diverticulitis with fistula. J Robot Surg 9:137–142
7. Maciel V, Lujan HJ, Plasencia G, Zeichen M, Mata W, Jorge I, Lee D, Viamonte M 3rd, Hartmann RF (2014) Diverticular disease complicated with colovesical fistula: laparoscopic versus robotic management. Int Surg 99:203–210
8. Ragupathi M, Ramos-Valadez DI, Patel CB, Haas EM (2011) Robotic-assisted laparoscopic surgery for recurrent diverticulitis: experience in consecutive cases and a review of the literature. Surg Endosc 25:199–206
9. Kulaylat AS, Mirkin KA, Puleo FJ, Hollenbeak CS, Messaris E (2018) Robotic versus standard laparoscopic elective colectomy: where are the benefits? J Surg Res 224:72–78
10. Dolejs SC, Waters JA, Ceppa EP, Zarzaur BL (2017) Laparoscopic versus robotic colectomy: a national surgical quality improvement project analysis. Surg Endosc 31:2387–2396
11. Al-Mazrou AM, Chiuzan C, Kiran RP (2017) The robotic approach significantly reduces length of stay after colectomy: a propensity score matched analysis. Int J Color Dis 32:1415–1421
12. Benlice C, Aytac E, Costedio M, Kessler H, Abbas MA, Remzi FH, Gorgun E (2016) Robotic, laparoscopic, and open colectomy: a case-matched comparison from the ACS-NSQIP. Int J Med Robot 13:2016. https://doi.org/10.1002/rcs.1783
13. Ezekian B, Sun Z, Adam MA, Kim J, Turner MC, Gilmore BF, Ong CT, Mantyh CR, Migaly J (2016) Robotic-assisted versus laparoscopic colectomy results in increased operative time without improved perioperative outcomes. J Gastrointest Surg 20:1503–1510
14. Simmons KD, Hoffman RL, Kuo LE, Bartlett EK, Holena DN, Kelz RR (2015) Is a colectomy always just a colectomy? Additional procedures as a proxy for operative complexity. J Am Coll Surg 221:862–870
15. Miller PE, Dao H, Paluvoi N, Baily M, Margolin D, Shah N, Vargas HD (2016) Comparison of 30-day postoperative outcomes after laparoscopic vs robotic colectomy. J Am Coll Surg 223:369–373
16. Bhama AR, Obias V, Welch KB, Vandewarker JF, Cleary RK (2016) A comparison of laparoscopic and robotic colorectal surgery outcomes using the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database. Surg Endosc 30:1576–1584
17. Yeo HL, Isaacs AJ, Abelson JS, Milsom JW, Sedrakyan A (2016) Comparison of open, laparoscopic, and robotic colectomies using a large national database: outcomes and trends related to surgery center volume. Dis Colon Rectum 59:535–542
18. Lee YF, Albright J, Akram W, Wu J, Ferraro J, Cleary RK (2018) Unplanned robotic-assisted conversion-to-open colorectal surgery is associated with adverse outcomes. J Gastrointest Surg 22:1059–1067
19. Jayne D, Pigazzi A, Marshall H, Croft J, Corrigan N, Copeland J, Quirke P, West N, Rautio T, Thomassen N, Tilney H, Gudgeon M, Bianchi PP, Edlin R, Hulme C, Brown J (2017) Effect of robotic-assisted vs conventional laparoscopic surgery on risk of conversion to open laparotomy among patients undergoing resection for rectal cancer: the ROLARR randomized clinical trial. JAMA 318:1569–1580
20. Zhang X, Wei Z, Bie M, Peng X, Chen C (2016) Robot-assisted versus laparoscopic-assisted surgery for colorectal cancer: a meta-analysis. Surg Endosc 30:5601–5614
21. Barrie J, Jayne DG, Wright J, Murray CJ, Collinson FJ, Pavitt SH (2014) Attaining surgical competency and its implications in surgical clinical trial design: a systemic review of the learning curve in laparoscopic and robot-assisted laparoscopic colorectal cancer surgery. Ann Surg Oncol 21:829–840
22. Rashidi L, Neighorn C, Bastawrous A (2017) Outcome comparisons between high-volume robotic and laparoscopic surgeons in a large healthcare system. Am J Surg 213:901–905
23. Shiloach M, Frencher SK Jr, Steeger JE, Rowell KS, Bartzokis K, Tomeh MG, Richards KE, Ko CY, Hall BL (2010) Toward robust information: data quality and inter-rater reliability in the American College of Surgeons National Surgical Quality Improvement Program. J Am Coll Surg 210:6–16