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ORIGINAL ARTICLE

Trends of complications and innovative techniques' utilization for colectomies in the United States

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Abstract

Despite an increasing trend towards utilization of minimally invasive approaches (MIS), results regarding their safety profile are contradictory. All patients who underwent elective colectomy for any underlying disease with an identifiable operative approach available from the targeted colectomy files of the ACS-NSQIP PUFs 2013 to 2018 were included. The trend of utilization and complication rates of the different operative approaches (open, laparoscopic, robotic) were assessed during the inclusion period. Furthermore, overall, surgical, and medical complications were compared between the three approaches. The study cohort included 78,987 patients. Of them, 12,335 (15.6%) patients underwent open, 57,874 (73.3%) laparoscopic, and 8,778 (11.1%) robotic surgery. There was an increasing trend towards the utilization of robotic surgery (2.5% increase per year) at the expense of the other approaches. With the increasing trend toward the utilization of the robotic approach, a decreasing trend in overall and surgical complications and length of stay was observed. After adjusting for the baseline confounders, robotic surgery was associated with shorter length of stay, lower rate of overall (OR 0.397; $p<0.05$ compared to open and OR: 0.763; $p<0.05$ compared to laparoscopy) and surgical complications (OR: 0.464; $p<0.05$ compared to open and OR: 0.734; $p<0.05$ compared to laparoscopy). This study revealed an increasing trend toward the utilization of MIS for elective colectomy in the US. Robotic surgery was associated with a decreasing trend in overall and surgical morbidity and length of stay.

Keywords Robotic · Laparoscopic · Open · Colectomy · Surgical complications · Trend analysis

Introduction

Robotic surgery is a minimally invasive technique that is still emerging into mainstay surgical practice [1–3]. The acceptance of a novel surgical technique, such as robotics, premises extensive assessment of safety profiles, along with surgical, functional, and long-term outcomes including quality of life [1, 4–6]. This assessment will be critical to the greater adoption of robotic surgery [1]. Prior work has evaluated the safety of innovative approaches such as robotics and laparoscopy. These institutional series have shown promising results regarding both short and long term outcomes [7, 8]. Despite these individual efforts, little has been published on a national level regarding robotic surgery utilization and complication rates in the field of colon and rectal surgery.

Colectomy is a common operative procedure performed for both malignant and benign etiologies by general surgeons and colon and rectal surgeons throughout the nation [1, 9]. National quality registries, such as the American College of Surgeons National Quality Improvement Program (ACS-NSQIP), provide critical data for evaluating the utilization of the operative techniques for elective colectomies [10]. Thus, the aim of this study was to assess national trends of utilization, complications, and length of stay for open, laparoscopic, and robotic elective colectomy using the ACS-NSQIP database.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s13304-020-00862-y) contains supplementary material, which is available to authorized users.

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Materials and methods

Data source and study population

We used data from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) which is a nationally validated, risk-adjusted, and outcome-based program to measure and improve the quality of surgical care [10]. Trained data abstractors from the participant sites use standardized sampling methods and definitions to collect patient-specific and disease-related pre-, intra- and postoperative variables. Patients are identified for inclusion in the final dataset based on a random sample with approximately 20% of all cases retained [11].

After merging ACS-NSQIP Participant User Files (PUFs) with their corresponding *Targeted Colectomies'* files, patients who underwent colectomy for any reason between 2013 to 2018 were identified using Current Procedure Terminology (CPT) codes 44140, 44141, 44143, 44144, 44145, 44146, 44147, 44150, 44151, 44155, 44156, 44157, 44158, 44160, 44188, 44204, 44205, 44206, 44207, 44208, 44210, 44211, 44212, 44340, 44345, 44346, 44605, 44626, 45110, 45111, 45112, 45113, 45114, 45116, 45119, 45120, 45121, 45123, 45126, 45136, 45150, 45160, 45395, and 45397. Patients with no operative approach available were excluded using the "COL_APPROACH" variable accessed from the targeted colectomy files. Only patients who had elective, non-urgent colectomy were included in the present study. Patients who had a concurrent operation under the responsibility of another primary surgeon were excluded.

Using the International Classification of Disease Medical Codes (ICD-9-CM and ICD-10-CM), the patients were categorized into three groups: colon cancer (ICD-9-CM; 153.x; and ICD-10-CM; C18.x), inflammatory bowel disease (IBD) (ulcerative colitis; ICD-9-CM: 556.x, and ICD-10-CM: K51.x; Crohn's disease: ICD-9-CM: 555.x, and ICD-10-CM: K50.x), and other benign diseases including diverticular disease (ICD-9-CM: 562.x and ICD-10-CM: K57.x) and benign neoplasms (ICD-9-CM: 211.3 and ICD-10-CM: D12.x and K63.5).

Preoperative baseline characteristics, intraoperative, and postoperative information were compared between the three surgical approaches. The trend of the utilization, specific preoperative risk factors (age > 80 years, Body Mass Index (BMI) > 30 kg/m^2, and American Society of Anesthesiologists (ASA) class ≥ 3), disease category, postoperative complications, and length of stay (LOS) were assessed according to the consecutive years. Postoperative short term (30-day) complications were categorized into overall complication, surgical complication, or medical complication. Postoperative surgical complications included: anastomotic leak, unplanned reoperation, ileus, superficial incisional surgical site infection (SSI), deep SSI, organ space infection, wound disruption, sepsis, septic shock, need for blood transfusion, or death within 30 days after surgery, in line with standardized ACS NSQIP definitions. Post-operative medical complications included: pneumonia, unplanned intubation, pulmonary embolism, deep venous thrombosis, need of mechanical ventilation for more than 48 h, progressive renal insufficiency, urinary tract infection, stroke, myocardial infarction, or cardiac arrest requiring cardiopulmonary resuscitation (CPR).

Statistical analysis

Data were summarized using frequencies and percentages for categorical variables and median (interquartile range) for continuous variables. Raw proportions (unadjusted) were used to plot the trend graphs. Trend analysis was assessed using linear regression for continuous variables and the Cochran-Armitage test for categorical variables. Fold change for each approach over time was evaluated by dividing the proportional use (or complication rate) of the approach in 2018 by the proportional use of the approach in 2013. The annual increase or decrease in the proportional use or the complication rate was assessed using linear regression. The coefficient for the consecutive study years, modeled as a continuous variable, was reported as the annual trend. To study the differences between the three surgical approaches, we used the Chi-squared test for categorical variables and the Kruskal–Wallis test for continuous variables. Variables that had an alpha level of less than 0.1 in the univariate analysis were further examined using multivariable binary logistic regression. Ordinal logistic regression was used to assess the impact of the operative approach on the increasing length of stay (LOS), categorized as 0–2 days, 3–4 days, 5–6 days, and > 6 days, after adjusting for the baseline confounders. The model was fitted using LOS categories as the dependent variable. The proportional odds ratio with its 95% confidence intervals were reported. Furthermore, a multinominal regression analysis was used to assess the impact of operative approach on the LOS using the lowest LOS category (0–2 days) as a reference. The baseline confounders included in the regression models included; race, age > 80 years old, ASA ≥ 3, COPD, BMI > 30Kg/m^2, ascites, CHF, HTN, currently on dialysis, bleeding disorder, smoking status, functional status, disseminated cancer, chronic steroid use, > 10 loss of weight before the operation, need a blood transfusion before the operation, systemic sepsis, and operation time. For all the analyses conducted in this study, a p-value < 0.05 was considered statistically significant and all tests were two-sided. Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS, Version 25; SPSS, Inc., Armonk, NY, USA).

Results

In total 78,987 patients were included. Of them, 12,335 (15.6%) patients had open surgery, 57,874 (73.3%) had laparoscopic surgery, and 8778 (11.1%) had robotic surgery. The most common indication for surgery was colon cancer (47.5% of operations), followed by benign diseases (diverticular disease or benign neoplasms, 44.85%), and followed by IBD (7.6%). Among all three disease categories, laparoscopy was the most commonly utilized approach (71.1% for colon cancer, 74.2% for IBD, and 74.8% for other benign diseases) (Table 1).

General trends of utilization

As shown in Fig. 1, the national utilization of the robotic approach for elective non-urgent colectomies has increased from 3.9% in 2013 to 16% in 2018 (4.1 fold change; slope,

Table 1 Patients' baseline characteristics

	Open $N=12{,}335$	Laparoscopic $N=57{,}874$	Robotic $N=8778$	Total $N=78{,}987$	*p* value
Male	597 (48.4%)	28,117 (48.6%)	4331 (49.3%)	38,419 (48.6%)	0.357
Race					< 0.0001
White	896 (72.7%)	42,517 (73.5%)	7264 (82.8%)	58,745 (74.4%)	
African/American	1191 (9.7%)	5080 (8.8%)	833 (9.5%)	7104 (9.0%)	
Asian	298 (2.4%)	1839 (3.2%)	240 (2.7%)	2377 (3.0%)	
Others	44 (0.4%)	374 (0.7)	27 (0.3%)	445 (0.5%)	
Unknown	1838(14.9%)	8064 (13.9%)	414 (4.7%)	10,316 (13.1%)	
Age > 80 years	1747 (14.2%)	5231 (9.0%)	555 (6.3%)	7533 (9.5%)	< 0.0001
BMI > 30 kg/m^2	4360 (35.5%)	21,357(37.1%)	3662 (41.8%)	29,379 (37.4%)	< 0.0001
ASA ≥ 3	7748 (62.8%)	28,112 (48.6%)	4296 (48.9%)	40,156 (50.8%)	< 0.0001
DM	2277 (18.5%)	9116 (15.8%)	1451 (16.5%)	12,844 (16.3%)	< 0.0001
COPD	794 (6.4%)	2428 (4.2%)	352 (4.0%)	3574 (4.5%)	< 0.0001
Ascites	48 (0.4%)	76 (0.1%)	7 (0.1%)	131 (0.2%)	< 0.0001
CHF	149 (1.2%)	313 (0.5%)	39 (0.4%)	501 (0.6%)	< 0.0001
HTN requiring medication	6478 (52.5%)	27,892 (48.2%)	4431 (50.5%)	38,801(49.1%)	< 0.0001
Hemodialysis	90 (0.7%)	271 (0.5%)	34 (0.4%)	395 (0.5%)	< 0.0001
Bleeding disorder	390 (3.2%)	1140(2.0%)	171 (1.9%)	1701 (2.2%)	< 0.0001
Number of comorbidities					< 0.0001
No comorbidities	5094 (41.3%)	27,173 (47.0%)	3932 (44.8%)	36,199 (45.8%)	
One	4678 (37.9%)	21,280 (36.8%)	3355 (38.2%)	29,313 (37.1%)	
Two	2187 (17.7%)	8390 (14.5%)	1352 (15.4%)	11,929 (15.1%)	
Three	331 (2.7%)	951 (1.6%)	131 (1.5%)	1413 (1.8%)	
Four	44 (0.4%)	77 (0.1%)	7 (0.1%)	128 (0.2%)	
Five	1	3	1 (0.0%)	5 (0.0%)	
Post-operative diagnosis					< 0.0001
Colon cancer	7014 (56.9%)	26,896 (46.5%)	3617 (41.2%)	37,527 (47.5%)	
IBD	1319 (10.7%)	4474 (7.7%)	239 (2.7%)	6032 (7.6%)	
Others*	4002 (32.4%)	26,504 (45.8%)	4922 (56.1%)	35,428 (44.9%)	
Functional status: independent	12,004(97.3%)	56,990 (98.5%)	8627 (98.3%)	77,621 (98.3%)	< 0.0001
Disseminated cancer	979 (7.9%)	1640 (2.8%)	188 (2.1%)	2807 (3.6%)	< 0.0001
Chronic steroid use	1330 (10.8%)	4598 (7.9%)	408 (4.6%)	6336 (8.0%)	< 0.0001
> 10% loss of body weight in last 6 months	612 (5.0%)	1603 (2.8%)	165 (1.9%)	2380 (3.0%)	< 0.0001
Transfusion of ≥ 1 pRBCs in 72 h before surgery	169 (1.4%)	296 (0.5%)	22 (0.3%)	487 (0.6%)	< 0.0001
Operation time; median (IQR); minutes	134 (96–189)	151 (114–201)	194 (152–247)		< 0.0001

BMI body mass index, *ASA* American Society of Anesthesiologists, *DM* diabetes mellitus, *COPD* chronic obstructive pulmonary disease, *CHF* congestive heart failure, *HTN* hypertension, *IBD* inflammatory bowel disease, *pRBCs* packed red blood cells, *IQR* interquartile range

*Others: including diverticular diseases or benign conditions of the colon

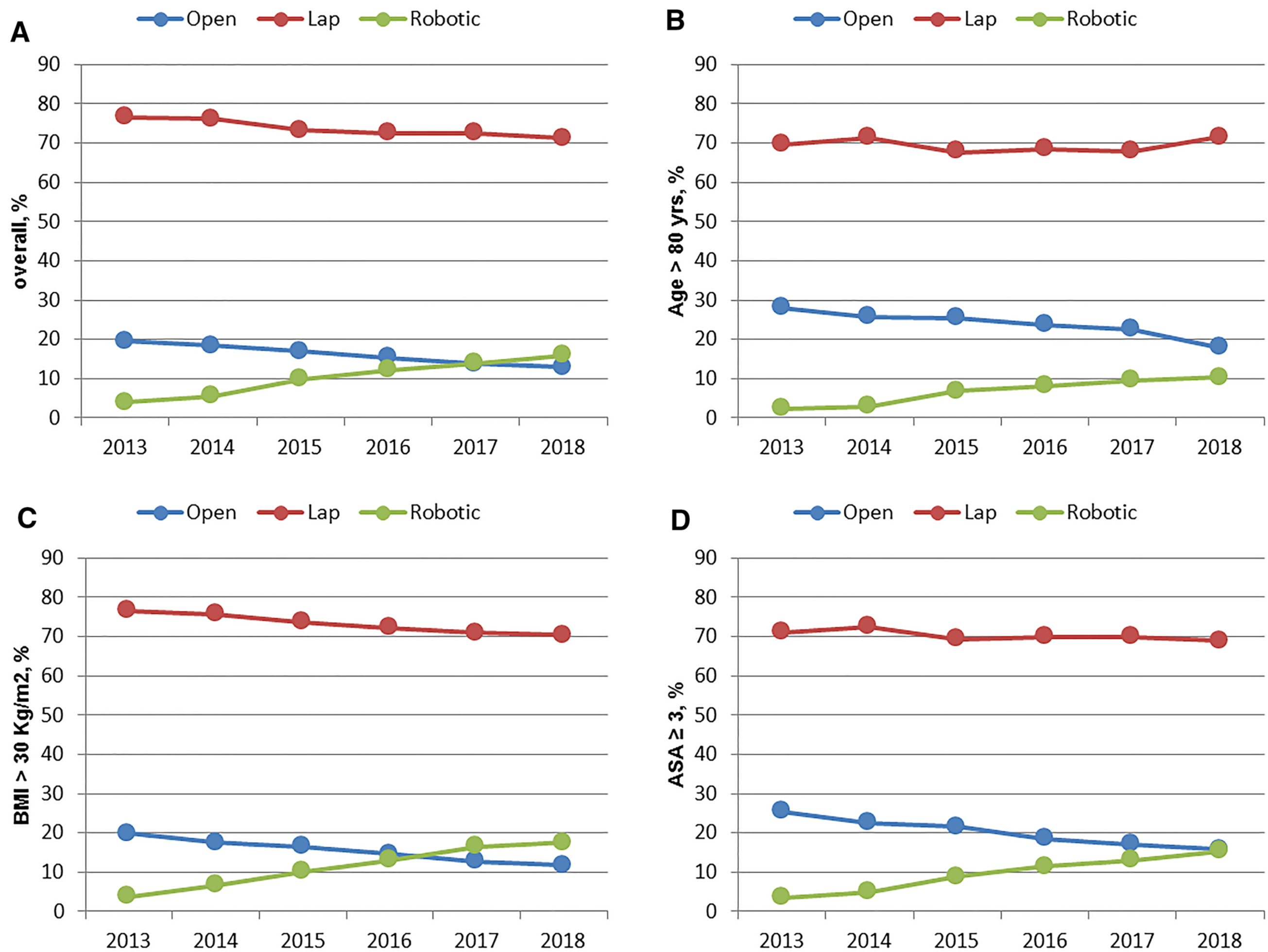

Fig. 1 Trend utilization according to operative approach. **a** Overall trend: robotic approach for elective non-urgent colectomies has increased from 3.9% in 2013 to 16% in 2018 (4.1 fold change; slope, 2.5% per year; 95% CI 2.3–2.6%) at the expense of a decrease in the utilization of open (19.5% in 2013 to 12.9% in 2018; 0.67 fold change; slope, − 1.4% per year; 95% CI − 1.6% to − 1.2%) and laparoscopic (76.6% in 2013 to 71.2% in 2018; 0.9 fold change; slope − 1.1% per year, 95% CI − 1.2 to − 0.9) approaches; (p-value < 0.0001). **b** Age > 80-years-old: the utilization of the robotic approach increased from 2.4% in 2013 to 10.4% in 2018 (4.3 fold change, slope 1.7% per year, 95% CI 1.4–2.1%) at the expense of the open approach which decreased from 27.9% in 2013 to 18% in 2018 (0.65 fold change, slope − 1.8% per year, 95% CI − 2.4% to − 1.3%). **c** BMI > 30Kg/m^2: robotic approach utilization has increased among patients with obesity (BMI > 30 kg/m^2) (3.7% in 2013 to 17.7% in 2018; 4.78 fold change, slope 2.9 per year, 95% CI 2.6–3.1%) on the expense of open (19.8% in 2013 to 11.9% in 2018, 0.6 fold change, slope − 1.6% per year; 95% CI − 1.8% to − 1.3%) and laparoscopic (76.5% in 2013 to 70.4% in 2018, 0.9 fold change, slope − 1.3%, 95% CI − 1.6 to − 1) approaches. **d** ASA ≥ 3: robotic approach utilization has increased over time for patients with a higher American Society of Anesthesiology class (ASA) ≥ 3 (3.5% in 2013 to 15.3% in 2018, 4.37 fold change, slope 2.4% per year; 95% CI 2.2–2.6%) on the expense of both open (25.4% in 2013 to 15.9% in 2018, 0.63 fold change, slope − 1.9% per year, 95% CI − 2.1% to − 1.6%) and laparoscopic (71.1% in 2013 to 68.9% in 2018, 0.969 fold change, slope − 0.5% per year, 95% CI − 0.8% to − 0.2%) approaches

2.5% per year; 95% CI 2.3–2.6%) at the expense of open (19.5% in 2013 to 12.9% in 2018; 0.67 fold change; slope, − 1.4% per year; 95% CI − 1.6% to − 1.2%) and laparoscopic (76.6% in 2013 to 71.2% in 2018; 0.9 fold change; slope − 1.1% per year, 95% CI − 1.2 to − 0.9) approaches; (p-value < 0.0001). A similar trend was observed for the subgroup analysis according to disease category (Supplementary Fig. 1).

Subgroup analysis of high-risk patients

Among older patients (> 80 years), the utilization of the robotic approach increased at the expense of the open approach. Furthermore, robotic utilization has increased among patients with obesity (BMI > 30 kg/m^2) and ASA class ≥ 3 at the expense of both open and laparoscopic approaches (Fig. 1).

Trends of postoperative morbidity

Overall complications

Open surgery was associated with a higher overall complication rate (34.4%) compared to laparoscopic (19.7%) and robotic (16.8%) approaches (p-value < 0.0001). After adjusting for baseline confounders, robotic surgery was associated with a lower overall complication rate compared to both open (OR: 0.397; 95% CI [0.370–0.426]) and laparoscopic (OR 0.763; 95% CI [0.717–0.812]) surgery. Furthermore, the laparoscopic approach was associated with a lower overall complication rate compared to the open approach (OR 0.521; 95% CI [0.499–0.545]) (Tables 2 and 3).

Table 2 Postoperative complications

	Open *N* = 12,335	Laparoscopic *N* = 57,874	Robotic *N* = 8778	Total *N* = 78,987	*p* value
Overall complications	4247 (34.4%)	11,421 (19.7%)	1479 (16.8%)	17,147(21.7%)	< 0.0001
Surgical complications	3860 (31.4%)	10,148 (17.6%)	1273 (14.6%)	15,281 (19.4%)	< 0.0001
Medical complications	1020 (8.3%)	2578 (4.5%)	378 (4.3%)	3976 (5.0%)	< 0.0001
Unplanned conversion to open	NA	5382 (9.3%)	448 (5.1%)	5830 (7.4%)	< 0.0001
SSI					
Superficial SSI	663 (5.4%)	1651 (2.9%)	191 (2.2%)	2505 (3.2%)	< 0.0001
Deep SSI	136 (1.1%)	223 (0.4%)	31 (0.4%)	390 (0.5%)	< 0.0001
Organ/space SSI	607 (4.9%)	1668 (2.9%)	250 (2.8%)	2525 (3.2%)	< 0.0001
Any SSI	1342 (10.9%)	3420 (5.9%)	448 (5.1%)	5210 (6.6%)	< 0.0001
Wound disruption	123 (1.0%)	231 (0.4%)	22 (0.3%)	376 (0.5%)	< 0.0001
Systemic sepsis					
Sepsis	401 (3.3%)	1030 (1.8%)	130 (1.5%)	1561 (2.0%)	< 0.0001
Septic shock	195 (1.6%)	391 (0.7%)	51 (0.6%)	637 (0.8%)	< 0.0001
Other surgical complications					
Need for blood transfusion	1135 (9.2%)	2707 (4.7%)	319 (3.6%)	4161 (5.3%)	< 0.0001
Ileus	2066 (16.8%)	5066 (8.8%)	625 (7.1%)	7757 (9.8%)	< 0.0001
Unplanned reoperation	566 (4.6%)	1863 (3.2%)	333 (3.8%)	2762 (3.5%)	< 0.0001
Leak	428 (3.5%)	1406 (2.4%)	195 (2.2%)	2029 (2.6%)	< 0.0001
Respiratory complications					
Pneumonia	276 (2.2%)	624 (1.1%)	67 (0.8%)	967 (1.2%)	< 0.0001
Unplanned intubation	222 (1.8%)	444 (0.8%)	53 (0.6%)	719 (0.9%)	< 0.0001
On ventilator for > 48h	155 (1.3%)	306 (0.5%)	45 (0.5%)	506 (0.6%)	< 0.0001
VTE					
PE	84 (0.7%)	211 (0.4%)	32 (0.4%)	327 (0.4%)	< 0.0001
DVT	164 (1.3%)	451 (0.8%)	68 (0.8%)	683 (0.9%)	< 0.0001
Renal complications					
Progressive renal insufficiency	99 (0.8%)	184 (0.3%)	47 (0.5%)	330 (0.4%)	< 0.0001
UTI	254 (2.1%)	735 (1.3%)	112 (1.3%)	1101 (1.4%)	< 0.0001
Stroke	35 (0.3%)	90 (0.2%)	18 (0.2%)	143 (0.2%)	0.01
Cardiovascular complications					
Cardiac arrest requiring CPR	67 (0.5%)	149 (0.3%)	26 (0.3%)	242 (0.3%)	< 0.0001
MI	110 (0.9%)	273 (0.5%)	30 (0.3%)	413 (0.5%)	< 0.0001
LOS: days					< 0.0001
0–2	507 (4.1%)	11,076 (19.2%)	2650 (30.2%)	14,233 (18.0%)	
3–4	3747 (30.4%)	28,161 (48.7%)	4129 (47.1%)	36,037 (45.7%)	
5–6	3753 (30.5%)	10,367 (17.9%)	1138 (13.0%)	15,258 (19.3%)	
> 6	4302 (35.0%)	8206 (14.2%)	853 (9.7%)	13,361 (16.9%)	
30 day mortality	170 (1.4%)	299 (0.5%)	39 (0.4%)	508 (0.6%)	< 0.0001

SSI surgical site infection, *VTE* vascular thromboembolism, *PE* pulmonary embolism, *DVT* deep venous thrombosis, *UTI* urinary tract infection, *CPR* cardiopulmonary resuscitation, *MI* myocardial infarction, *LOS* length of stay

Table 3 Multivariable regression analysis adjusting for the baseline confounders

	Laparoscopic versus open		Robotic versus open		Robotic versus laparoscopic	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Overall complications	0.521 (0.499–0.545)	< 0.0001	0.397 (0.370–0.426)	< 0.0001	0.763 (0.717–0.812)	< 0.0001
Surgical complications	0.543 (0.519–0.568)	< 0.0001	0.464 (0.431–0.499)	< 0.0001	0.734 (0.687–0.784)	< 0.0001
Medical complications	0.516 (0.493–0.540)	< 0.0001	0.377 (0.350–0.406)	< 0.0001	0.926 (0.825–1.038)	0.187
Unplanned conversion to open	NA		NA		0.551 (0.498 -0.610)	< 0.0001
SSI						
Superficial SSI	0.544 (0.495–0.598)	< 0.0001	0.432 (0.366–0.510)	< 0.0001	0.693 (0.594–0.809)	< 0.0001
Deep SSI	0.369 (0.296–0.459)	< 0.0001	0.321 (0.215–0.480)	< 0.0001	0.822 (0.560–1.207)	0.318
Organ/space SSI	0.615 (0.558–0.679)	< 0.0001	0.563 (0.482–0.658)	< 0.0001	0.903 (0.786–1.038)	0.150
Any SSI	0.533 (0.498–0.571)	< 0.0001	0.420 (0.374–0.470)	< 0.0001	0.775 (0.698–0.860)	< 0.0001
Wound disruption	0.481 (0.382–0.604)	< 0.0001	0.280 (0.176–0.446)	< 0.0001	0.551 (0.353–0.860)	0.009
Systemic sepsis						
Sepsis	0.640 (0.566–0.724)	< 0.0001	0.486 (0.395–0.597)	< 0.0001	0.753 (0.624–0.909)	0.003
Septic shock	0.512 (0.428–0.611)	< 0.0001	0.418 (0.304–0.574)	< 0.0001	0.812 (0.602–1.096)	0.173
Other surgical complications						
Need for blood transfusion	0.618 (0.573–0.667)	< 0.0001	0.527 (0.462–0.6)	< 0.0001	0.858 (0.760–0.968)	0.013
Ileus	0.547 (0.517–0.579)	< 0.0001	0.461 (0.418–0.507)	< 0.0001	0.846 (0.775–0.923)	< 0.0001
Unplanned reoperation	0.768 (0.696–0.848)	< 0.0001	0.864 (0.748–0.997)	0.045	1.103 (0.976–1.246)	0.117
Leak	0.735 (0.657–0.823)	< 0.0001	0.637 (0.534–0.761)	< 0.0001	0.853 (0.730–0.997)	0.046
Respiratory complications						
Pneumonia	0.613 (0.528–0.711)	< 0.0001	0.434 (0.329–0.573)	< 0.0001	0.699 (0.539–0.907)	0.007
Unplanned intubation	0.544 (0.460–0.644)	< 0.0001	0.411 (0.301–0.561)	< 0.0001	0.771 (0.574–1.034)	0.082
On ventilator for > 48hrs	0.529 (0.432–0.647)	< 0.0001	0.483 (0.342–0.681)	< 0.0001	0.941 (0.681–1.300)	0.714
VTE						
PE	0.581 (0.448–0.754)	< 0.0001	0.523 (0.344 –0.796)	0.002	0.853 (0.583–1.247)	0.411
DVT	0.658 (0.546–0.791)	< 0.0001	0.596 (0.445–0.799)	0.001	0.889 (0.684–1.156)	0.380
Renal complications						
Progressive renal insufficiency	0.478 (0.372–0.615)	< 0.0001	0.699 (0.487–1.004)	0.053	1.464 (1.051–2.040)	0.024
UTI	0.701 (0.604–0.814)	< 0.0001	0.721 (0.571–0.909)	0.006	1.031 (0.839–1.267)	0.772
Stroke	0.725 (0.485–1.082)	0.115	0.987 (0.545–1.788)	0.966	1.394 (0.823–2.360)	0.217
Cardiovascular complications						
Cardiac arrest requiring CPR	0.608 (0.451–0.820)	0.001	0.736 (0.459–1.182)	0.205	1.232 (0.800–1.899)	0.343
MI	0.649 (0.517–0.817)	< 0.0001	0.483 (0.318–0.733)	0.001	0.712 (0.483–1.049)	0.086
LOS, days						
0–2	Reference		Reference		Reference	
3–4	0.321 (0.291–0.353)	< 0.0001	0.162 (0.146–0.181)	< 0.0001	0.503 (0.475–0.532)	< 0.0001
5–6	0.115(0.104–0.127)	< 0.0001	0.038 (0.034—0.043)	< 0.0001	0.326 (0.301–0.353)	< 0.0001
> 6	0.08 (0.073–0.089)	< 0.0001	0.022 (0.020–0.025)	< 0.0001	0.278 (0.254–0.304)	< 0.0001
30 day mortality	0.541 (0.444–0.660)	< 0.0001	0.521 (0.362–0.750)	< 0.0001	0.956 (0.675–1.352)	0.798

SSI surgical site infection, *VTE* vascular thromboembolism, *PE* pulmonary embolism, *DVT* deep venous thrombosis, *UTI* urinary tract infection, *CPR* cardiopulmonary resuscitation, *MI* myocardial infarction, *LOS* length of stay

Over the six study years, the overall complication rate decreased significantly among all three operative approaches (Fig. 2).

Surgical complications

Open surgeries had a higher overall surgical complication rate (31.4%) compared to laparoscopic (17.6%) and robotic (14.6%) approaches (p-value < 0.0001). After adjusting for

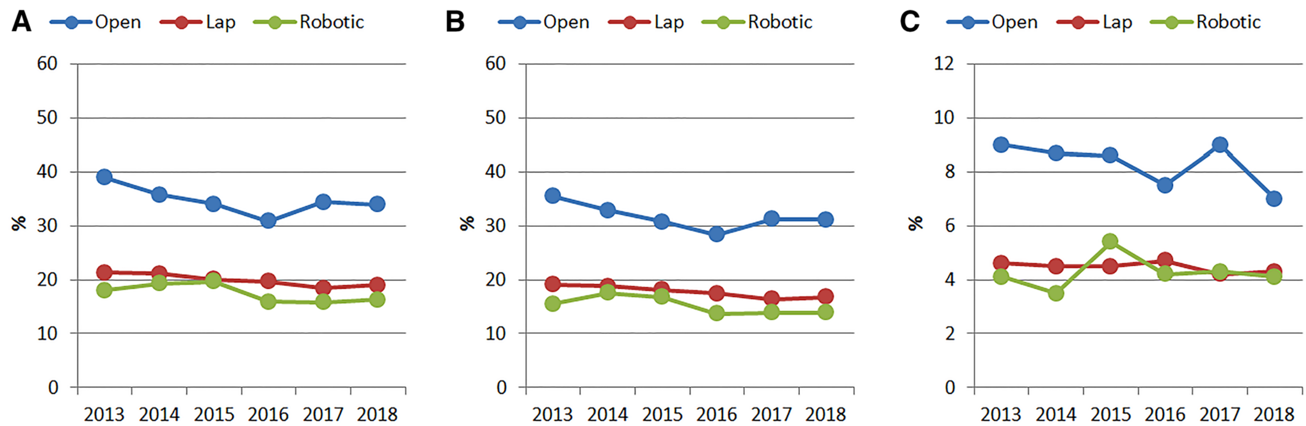

Fig. 2 Trends of postoperative complications according to operative approach. **a** Overall complications: the overall complication rate decreased over time for the three operative approaches; open (38.9% in 2013 to 33.9% in 2018, 0.87 fold change, slope − 0.9% per year, 95% CI [− 1.4% to − 0.4%] *p*-value 0.001), laparoscopic (21.3% in 2013 to 19% in 2018, 0.89 fold change, slope − 0.6% per year, 95% CI [− 0.8% to − 0.4%] *p*-value < 0.0001), and robotic (18% in 2013 to 16.3% in 2018, 0.9 fold change, slope − 0.7% per year, 95% CI [− 1.3% to − 0.2%], *p* value 0.012). **b** Surgical complications: the surgical complication rate decreased over time for the three operative approaches; open (35.5% in 2013 to 31.1% in 2018, 0.88 fold change, slope − 0.8% per year, 95% CI [− 1.3% to − 0.3%], *p*-value = 0.002), laparoscopic (19.1% in 2013 to 16.8% in 2018, 0.88 fold change, slope − 0.5% per year, 95% CI [− 0.7% to − 0.4%], *p*-value < 0.0001), and robotic (15.5% in 2013 to 13.9% in 2018, 0.9 fold change, slope − 0.7% per year, 95% CI [− 1.2% to − 0.2], *p* value = 0.008) **c** Medical complications: the medical complication rate decreased over time for the open approach (9% in 2013 to 7% in 2018, 0.8 fold change, slope − 0.3% per year, 95% CI [− 0.6 to − 0.0001], *p* value = 0.041) but not for the laparoscopic (4.6% in 2013 to 4.3% in 2018, 0.9 fold change, slope − 0.1% per year, 95% CI [− 0.2 to − 0.0004], *p* value = 0.239) and robotic (4.1% in 2013 to 4.1% in 2018, onefold change, slope − 0.1, 95% CI [− 0.4 to 0.002], *p* value = 0.585) approaches

baseline confounders, robotic surgery was associated with a lower overall surgical complication rate compared to open (OR: 0.464; 95% CI [0.431–0.499]) and laparoscopic (OR 0.734; 95% CI [0.687–0.784]) approaches. Furthermore, the laparoscopic approach was associated with a lower overall surgical complication rate comparing to the open approach (OR 0.543; 95% CI [0.519–0.568]), as detailed in (Tables 2 and 3).

Over the inclusion period, the overall surgical complication rate decreased significantly among the three operative approaches (Fig. 2).

Medical complications

Open surgeries had a higher overall medical complication rate (8.3%) compared to laparoscopic (4.5%) and robotic (4.3%) approaches (*p*-value < 0.0001). After adjusting for baseline confounders, robotic surgery was associated with a lower overall medical complication rate compared to open (OR: 0.377; 95% CI [0.350–0.406]) but not laparoscopic (OR 0.926; 95% CI [0.825–1.038]) approaches. Furthermore, the laparoscopic approach was associated with a lower risk of overall medical complication rate comparing to the open approach (OR 0.516; 95% CI [0.493–0.540]), as detailed in (Tables 2 and 3).

Over the inclusion period, the overall medical complication rate decreased significantly among open surgeries but not among robotic and laparoscopic surgeries (Fig. 2).

Trend analysis of length of stay (LOS)

Robotic surgery resulted in a shorter length of stay than open and laparoscopic surgeries (as summarized in Table 2) even after adjusting for baseline confounders as the ordinal regression showed the odds ratio for increasing LOS were − 2.067; 95% CI [− 2.121 to − 2.012] for robotic versus open, − 1.315; 95% CI [− 1.353 to − 1.277] for laparoscopic versus open, and -0.753; 95% CI [− 0.797 to − 0.709] for robotic versus laparoscopic. Results for the multinominal regression are presented in Table 3.

Most of the patients who had robotic surgery were discharged by the third or fourth postoperative days (47.1%) or within the first two days (30.2%). The proportion of patients who discharged within the first two days after robotic surgery increased over time (16% in 2013 to 38.2% in 2018; 2.3 fold change, slope 5% per year, 95% CI 4.3–5.7%) (Fig. 3).

A similar trend was noted for laparoscopic surgery (Fig. 3). Trends for the open approach are described in detail in Fig. 3.

Detailed tables of trends and complications are provided in supplementary Tables 1–7.

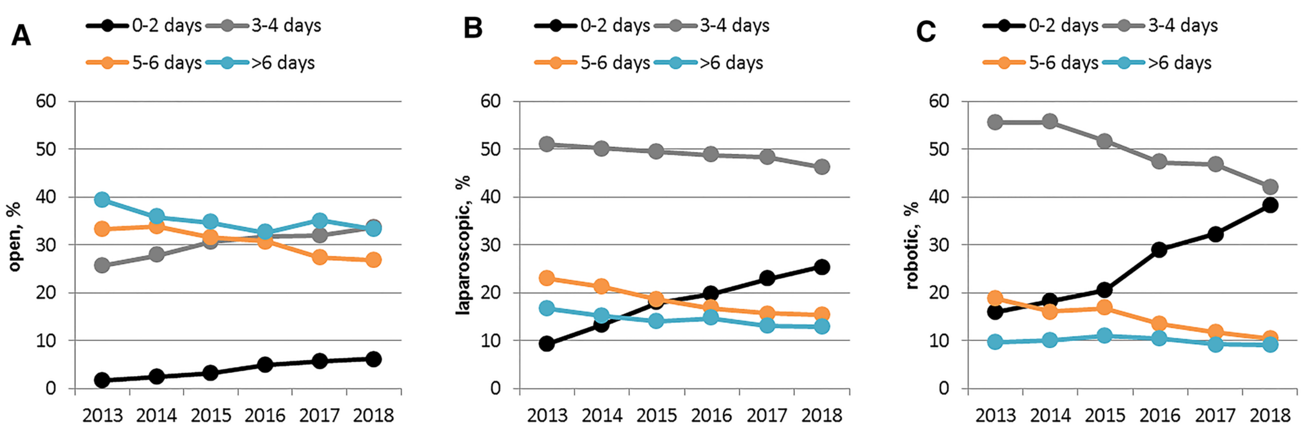

Fig. 3 Trends of length of stay according to operative approach. 0–2 days: trend in increasing the proportion of patients discharged in the first two days across all approaches, **a** Open: (1.6% in 2013 to 6.2% in 2018, 3.9 fold change, slope 1% per year, 95% CI [0.8–1.2%], *p*-value < 0.0001), **b** Laparoscopic: (9.3% in 2013 to 25.4% in 2018, 2.7 fold change, slope 3.1% per year, 95% CI [2.9–3.3%], *p*-value < 0.0001), **c** Robotic: (16% in 2013 to 38.2% in 2018, 2.3 fold change, slope 5% per year, 95% CI [4.3–5.7%], *p*-value < 0.0001). 3–4 days: increasing trend for the **a** open approach (25.7% in 2013 to 33.7% in 2018, 1.3 fold change, slope 1.5% per year, 95% CI [1% to 2%], p value < 0.0001). Decreasing trend for the **b** laparoscopic (51% in 2013 to 46.3% in 2018, 0.9 fold change, slope − 0.9% per year, 95% CI [− 1.1% to − 0.6%] *p*-value < 0.0001) and **c** robotic (55.5% in 2013 to 42.2% in 2018, 0.76 fold change, slope − 2.9% per year, 95% CI [− 3.6% to − 2.2%], *p* value < 0.0001) approach. 5–6 days: a decreasing trend for all the operative approaches, **a** Open: 33.3% in 2013 to 26.9% in 2018, 0.8 fold change, slope − 1.5% per year, 95% CI [− 2% to − 1%], *p*-value < 0.0001, **b** laparoscopic: 23% in 2013 to 15.4% in 2018, 0.67 fold change, slope − 1.5% per year, 95% CI [− 1.7% to − 1.4%], *p*-value < 0.0001, and **c** robotic: 18.9% in 2013 to 10.5% in 2018, 0.56 fold change, slope − 1.7% per year, 95% CI [− 2.2% to − 1.2], p-value < 0.0001. > 6 days: a decreasing trend for all the operative approaches, **a** Open: 39.4% in 2013 to 33.2% in 2018, 0.8 fold change, slope − 1% per year, 95% CI [− 1.5% to − 0.5%], *p*-value < 0.0001, **b** laparoscopic: 16.7% in 2013 to 12.9% in 2018, 0.77 fold change, slope − 0.7% per year, 95% CI [− 0.9% to − 0.5%], *p*-value < 0.0001, and **c** robotic: 9.6% in 2013 to 9.1% in 2018, 0.95 fold change, slope − 0.4% per year, 95% CI [− 0.8% to 0.001], *p*-value = 0.097

Discussion

This study utilized an audited validated database (ACS-NSQIP) to evaluate national trends in the use of operative approaches for elective colectomy. While laparoscopy remained the most commonly utilized modality over the study period, an increasing trend towards the adoption of robotics at the expense of both open and laparoscopic surgery was observed. This increasing trend persisted across all disease categories and even in high-risk patients. In parallel to the increasing implementation of the robotic platform, there was a decreasing trend over time in overall complications, surgical complications, and LOS. Complication rates were lowest after robotic surgery after adjusting for baseline confounders.

The proven shift towards the robotic platform during the study period could not be precisely delineated regarding the interplay between the three groups. The main shift appeared to be from open to MIS, while within the MIS section, there was a shift from laparoscopy to robotic approach over the last few years of the study period. Alternatively, the robotic platform may have allowed surgeons who perform open surgery to offer MIS with its benefits to their patients. Taken together, whether the shift occurred from open to robotic directly OR through all 3 platforms could not be definitely elucidated.

A recent study from a nationally representative sample of Medicare beneficiaries in the U.S. reported a similar increasing trend towards the adoption of the robotic platform for elective colectomy between 2010 and 2016 [1]. Interestingly, the proportion of patients who underwent open colectomy was higher than what has been found in our study, which raises the question of a potential selection bias favoring open surgery in higher-risk Medicare patients. This former study used a robust risk-adjustment method (instrumental variable analysis) to account for unmeasured confounders and found that the robotic platform was associated with a lower risk of postoperative complications compared to open surgery in high volume but not low to average volume centers [1]. However, there was no statistically significant benefit of the robotic approach over the laparoscopic approach even in high volume centers [1]. Although in our study we have found a similar potential benefit of the robotic platform over both open and laparoscopic approaches, case-volume per-center could not be adjusted for as this information is not provided in ACS-NSQIP.

Data from recent randomized controlled trials showed ambiguous results regarding the potential benefit of robotic surgery. While safety profiles between laparoscopic and robotic approaches for colectomy appeared to be similar, a clear benefit of the robotic approach could not be demonstrated by the landmark ROLARR trial [12]. Nevertheless, our findings are aligned with data of recent systematic reviews revealing reduced anastomotic complications, conversion rate, and length of stay with robotic surgery compared to the laparoscopic approach [13–15]. Moreover, in cases with more challenging anatomy than colectomy such as rectal cancer cases, robotic surgery could provide benefits beyond the laparoscopic approach when implemented in a high-volume practice [8, 16–18].

The decreasing complication rate over time in patients who underwent open surgery might reflect the widespread implementation of enhanced recovery protocols and improved surgical and perioperative care in general, potentially also reflecting better conditioning of patients through prehabilitation programs [19, 20]. The combination of evidence-based perioperative care and well-structured training programs for minimally invasive surgeries bears an important potential to improve surgical outcomes further [19–24].

Limitations

The results of this study have to be interpreted with caution considering limitations related to ACS-NSQIP including a high risk of selection bias regarding patients and operative approach given a wide heterogeneity of practice and experience of contributing surgeons. This was accounted for through risk-stratification and -adjustment. The studied sample represents only 20% of the total number of patients in the U.S. and the targeted file does not capture all patients for each year. Furthermore, ACS-NSQIP provides data on short term (30-day) morbidity only, whereas long term outcomes were not available. Lastly, a sensitivity analysis according to the volume of robotic cases per hospital could not be performed as this information is not provided.

Conclusion

The adoption of robotic surgery is increasing in the U.S. for elective colectomy and is associated with a decrease of postoperative complications and length of stay. Robotic surgery appears to be independently associated with a lower rate of short-term morbidity and surgical conversion compared to both open and laparoscopic approaches.

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Compliance with ethical standard

Conflict of interest None.

Ethical approval Institutional Review Board approval was not required for this study.

Informed consent Informed consent was not applicable.

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