Trends and consequences of surgical conversion in the United States

Mohamed A. Abd El Aziz¹ · Fabian Grass¹ · Kevin T. Behm¹ · Anne-Lise D'Angelo¹ · Kellie L. Mathis¹ · Eric J. Dozois¹ · David W. Larson¹

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Abstract

Background The aim of this study was to identify national utilization trends of robotic surgery for elective colectomy, conversion rates over time, and the specific impact of conversion on postoperative morbidity. Conversion to open represents a hard endpoint for minimally invasive surgery (MIS) and is associated with worse outcomes when compared to MIS or even traditional open procedures.

Methods All adult patients who underwent either laparoscopic or robotic elective colectomy from 2013 to 2018 as reported in the American College of Surgeons Quality Improvement Program (ACS-NSQIP) database were included. National trends of both robotic utilization and conversion rates were analyzed, overall and according to underlying disease (benign disease, inflammatory bowel disease (IBD), cancer), or the presence of obesity (body mass index (BMI) ≥ 30 kg/m²). Demographic and surgical risk factors for surgical conversion to open were identified through multivariable regression analysis. Further assessed were overall and specific postoperative 30-day complications, which were risk adjusted and compared between converted patients and the remaining cohort.

Results Of 66,652 included procedures, 5353 (8.0%) were converted to open. Conversion rates were 8.5% for laparoscopic and 4.9% for robotic surgery ($p < 0.0001$). A decline in conversion rates over the 6-year inclusion period was observed overall and for patients with obesity. This trend paralleled an increased utilization of the robotic platform. Several surrogates for advanced disease stages for cancer, diverticulitis, and IBD and prolonged surgical duration were identified as independent risk factors for unplanned conversion, while robotic approach was an independent protective factor (OR 0.44, $p < 0.0001$). Patients who had unplanned conversion were more likely to experience postoperative complications (OR 2.36; 95% CI [2.21–2.51]), length of hospital stay ≥ 6 days (OR 2.86; 95% CI [2.67–3.05], and 30-day mortality (OR 2.28; 95% CI [1.72–3.02]).

Conclusion This nationwide study identified a decreasing trend in conversion rates over the 6-year inclusion period, both overall and in patients with obesity, paralleling increased utilization of the robotic platform. Unplanned conversion to open was associated with a higher risk of postoperative complications.

Keywords Minimally invasive surgery · Unplanned conversion · Robotic surgery · Laparoscopic surgery

Minimally invasive approaches have been widely implemented due to the proven short- and long-term benefits including both functional and surgical recovery without compromising oncological outcomes [1–3]. While laparoscopy has been established as the standard approach for

elective colectomy in well-resourced countries, the robotic platform continues to gain popularity due to technical advantages of improved dexterity, navigation, and visualization [4].

Recent studies comparing short-term outcomes of both approaches have provided contradictory results. The landmark ROLARR trial failed to demonstrate significant benefits of robotic surgery regarding short-term outcomes as well as unplanned conversion to open [5]. However, it was criticized for being underpowered and for a high variety of experience among participating surgeons [6]. On the other hand, a growing number of large institutional reports

Mohamed A. Abd El Aziz and Fabian Grass Shared first authorship.

✉ David W. Larson
Larson.David2@mayo.edu

¹ Division of Colon and Rectal Surgery, Department of Surgery, Mayo Clinic, 200 first St. Southwest, Rochester, MN 55905, USA

described favorable outcomes associated with robotic colorectal surgery, particularly in obese patients [7–10].

Conversion to open represents a hard endpoint for minimally invasive surgery (MIS) and reflects the ability to manage more challenging intraoperative conditions or disease presentations. Furthermore, previous authors have shown that unplanned conversion is associated with worse outcomes when compared to MIS or even traditional open procedures [11, 12]. National quality improvement databases are limited for in-depth analysis of sensitive outcomes such as surgical conversion given the lack of specific details related to surgical technique or intraoperative disease presentations, the heterogeneity of participating centers, and the focus on postoperative outcomes. However, national datasets are useful tools to study utilization trends and event rates over time.

The aims of this study were to analyze national trends of surgical conversion during elective colectomy alongside MIS utilization, to identify risk factors for surgical conversion, and to assess the impact of surgical conversion on postoperative short-term morbidity.

Material and methods

Patients and data registry

This retrospective analysis included all patients who underwent either laparoscopic or robotic elective colectomy for any underlying disorder in the “*Targeted Colectomy*” file of the American College of Surgeons National Quality Improvement Program (ACS-NSQIP) during the period of January 2013 to December 2018.

The ACS-NSQIP has been established for quality assessment purposes to improve surgical outcomes. Trained data abstractors use standardized data extraction sheets including variables for patient demographics and disease-specific pre- and perioperative information. Patients are included in the final dataset on a random sample with approximately 20% of total cases included.

After merging the Participant User Files (PUFs) with their corresponding “*Targeted Colectomy*” files, patients who had colectomy were identified using the 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 who had open surgery or concurrent operation under the responsibility of another primary surgeon were excluded.

Using the International Classification of Diseases (ICD) medical codes, patients who had a postoperative diagnosis of colon cancer (ICD-9-CM codes: 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), or other benign diseases [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)] were included.

Outcomes

The primary endpoint was unplanned surgical conversion to an open approach. Baseline demographic, anthropometric, and perioperative characteristics were compared between patients who had unplanned conversion vs. patients without conversion. Since reasons for conversion are not provided by ACS-NSQIP, characteristics of converted patients were compared between the laparoscopic and robotic groups. Conversion rates were also compared according to body mass index (BMI) ≥ 30 kg/m² considering the three different disease categories cancer, IBD, and other benign diseases.

In a second step, independent risk factors for conversion to open were identified through multivariable binary logistic regression analysis. Furthermore, postoperative outcomes including length of stay (LOS, prolonged defined as ≥ 6 days according to median LOS of the entire cohort) and 30-day mortality were compared between converted and non-converted patients after adjusting for pre-operative risk factors.

Trends

The utilization trend of robotic colectomy over the study period was assessed overall, according to underlying pathology (colon cancer vs. benign indications), according to high-risk procedures (using American Society of Anesthesiologists (ASA) score ≥ 3) and according to BMI ≥ 30 kg/m². Further, conversion rates were assessed over time comparing the laparoscopic and robotic approach overall and according to the subgroup of patients with BMI ≥ 30 kg/m².

Statistical analysis

Descriptive statistics were summarized using frequencies and percentages for categorical variables, and median (interquartile range) for continuous variables. Trend analysis was assessed using the linear regression, the year of the operation was considered as a continuous variable (covariate), and the percentage change per year was obtained based on the unstandardized B coefficients with their 95% confidence intervals. To assess the differences between the two groups (unplanned conversion vs. no conversion), the χ^2 test was used for categorical variables and independent samples

Mann–Whitney *U* test for continuous variables. To investigate independent risk factors for conversion, any risk factor with a *p* value of less than 0.1 in the univariate analysis was further assessed using multivariable logistic regression. A *p* value of <0.05 was considered statistically significant.

The analysis was performed using the Statistical Package for Social Sciences (SPSS, Version 25; SPSS, Inc., Armonk, NY, USA).

Results

A total of 66,652 patients underwent minimally invasive colectomy over the study period. Of these, 5353 (8.0%) procedures were converted to open. Conversion rate was 8.5% (4926/52,948) for laparoscopic and 4.9% (427/8351) for robotic surgery (*p* < 0.0001). For patients with BMI ≥ 30 kg/m², conversion rates were 10.3% (2200/19,157) in the laparoscopic and 6% (220/3442) in the robotic group (*p* < 0.0001). Rates according to indication in obese patients were 11.3% for laparoscopic vs. 5.7% for robotic (*p* < 0.0001) for cancer, 11.6% for laparoscopic vs. 5.4% for robotic (*p* = 0.149) for IBD, and 9.3% for laparoscopic vs. 6.2% for robotic (*p* < 0.0001) for other benign diseases.

Patients in the unplanned conversion group were older, predominantly male, had a higher BMI, suffered from more comorbidities such as diabetes mellitus (DM), cardiac, renal, and respiratory disorders, and ASA class ≥ 3 , as detailed in Table 1. Furthermore, they were more likely to have disseminated cancer, functional dependence, and malnutrition ($\geq 10\%$ loss of body weight/6 months). Total surgical duration of converted procedures was longer.

Characteristics of converted patients

Converted patients undergoing robotic surgery were more likely to have a BMI ≥ 30 kg/m². Furthermore, total surgical duration was longer in the converted robotic group. Underlying diseases were different with fewer cancer and IBD patients and more benign diseases in the converted robotic compared to the converted laparoscopic group (Table 2).

Risk factors for conversion

Age ≥ 80 years, male sex, BMI ≥ 30 kg/m², smoking, presence of dyspnea, ascites, functional dependency, disseminated cancer, open wound and/or wound infection, chronic steroid use, loss of $\geq 10\%$ of body weight within 6 months, systemic sepsis, ASA ≥ 3 , and prolonged operation time were independent risk factors for unplanned conversion. While the disease category itself was not predictive, robotic approach was an independent protective factor (OR 0.44, *p* < 0.0001, Table 1).

Trend analysis

Overall utilization of the robotic platform increased over time. A similar robotic trend was noted in colon cancer, benign disease, patients with ASA class ≥ 3 , and patients with BMI ≥ 30 kg/m² (Fig. 1).

A decreasing trend in unplanned conversion rate was observed overall and included cancer, benign indications, and the subgroup BMI ≥ 30 kg/m², as detailed in Fig. 2. This trend was mainly driven by a significant decrease between 2013 and 2014, with more consistent percentages thereafter.

Impact of unplanned conversion on postoperative outcomes

Patients who had unplanned conversion were more likely to experience overall, surgical, medical, and specific complications, prolonged length of hospital stay (≥ 6 days), and 30-day mortality, before and after adjusting for baseline confounders (Table 3).

Discussion

This nationwide large-scale study revealed a 2.3-fold increased conversion rate of laparoscopic compared to robotic procedures after adjustment for baseline risk factors. The study further observed a decrease of conversion rates over the 6-year inclusion period, in concert to increased utilization of the robotic platform for elective colectomy across the U.S., both overall and in high-risk (ASA ≥ 3) or patients with obesity (BMI ≥ 30 kg/m²). Conversion was further associated with a variety of demographic, disease-specific, and constitutional risk factors as surrogates for severe disease presentation and worse postoperative outcomes.

The overall colectomy-associated conversion rate of 8.0% compares well to former ACS-NSQIP analyses. Al-Temimi et al. revealed a slightly higher rate of 10.9% in a propensity score-matched cohort of patients undergoing elective colectomy for left-sided diverticulitis [13]. Dolejs et al. found a rate of 10.5% for laparoscopic and 6.2% for robotic right colectomy in an analysis from 2012 to 2014 [14]. Our study, which represents the most recent update, revealed lower rates of 8.5% for laparoscopy and 4.9% for robotic cases. Furthermore, a decreasing trend for conversion over the study period was observed for both malignant and benign indications, with a more pronounced decrease in the robotic group. Interestingly, robotic conversion rates were consistently lower compared to the laparoscopic group over the study years, despite increased penetration of the robotic approach in high-risk and obese patients. This may reflect both benefits of the platform including improved exposure and visualization through 360-degree navigation

Table 1 Baseline risk factors between patients who had unplanned conversion to open versus patients who did not have unplanned conversion

	Surgical conversion			Univariable analysis <i>p</i> value	Multivariable analysis	
	No = 61,299	Yes = 5353	Total = 66,652		Odds ratio	<i>p</i> value
Age ≥ 80 years	5239 (8.5%)	547 (10.2%)	5786 (8.7%)	< 0.0001	1.271 (1.148–1.408)	< 0.0001
Male	29,613 (48.3%)	2835 (53.0%)	32,448 (48.7%)	< 0.0001	1.113 (1.051–1.179)	< 0.0001
Race				< 0.0001		
White	45,874 (74.8%)	3907 (73.0%)	49,781 (74.7%)		Reference	
African American	5347 (8.7%)	566 (10.6%)	5913 (8.9%)		1.080 (0.982–1.189)	0.114
Asian	1961 (3.2%)	118 (2.2%)	2079 (3.1%)		0.720 (0.593–0.874)	0.001
Others	374 (0.6%)	27 (0.5%)	401 (0.6%)		0.732 (0.492–1.089)	0.123
Unknown	7743 (12.6%)	735 (13.7%)	8478 (12.7%)		0.973 (0.893–1.060)	0.525
BMI ≥ 30 kg/m ²	22,599 (37.0%)	2420 (45.4%)	25,019 (37.7%)	< 0.0001	1.282 (1.207–1.362)	< 0.0001
DM	9472 (15.5%)	1095 (20.5%)	10,567 (15.9%)	< 0.0001	1.277 (0.892–1.829)	0.181
Current smoker	8702 (14.2%)	914 (17.1%)	9616 (14.4%)	< 0.0001	1.253 (1.159–1.354)	< 0.0001
COPD	2480 (4.0%)	300 (5.6%)	2780 (4.2%)	< 0.0001	1.270 (0.878–1.839)	0.205
Dyspnea				< 0.0001		
No	57,718 (94.2%)	4909 (91.7%)	62,627 (94.0%)		Reference	
At rest	126 (0.2%)	25 (0.5%)	151 (0.2%)		1.789 (1.144–2.796)	0.011
At moderate exertion	3455 (5.6%)	419 (7.8%)	3874 (5.8%)		1.188 (1.061–1.331)	0.003
Ascites	59 (0.1%)	24 (0.4%)	83 (0.1%)	< 0.0001	3.722 (2.025–6.842)	< 0.0001
CHF	317 (0.5%)	35 (0.7%)	352 (0.5%)	0.186	NA	
HTN	29,394 (48.0%)	2929 (54.7%)	32,323 (48.5%)	< 0.0001	1.198 (0.828–1.734)	0.337
Currently on dialysis	270 (0.4%)	35 (0.7%)	305 (0.5%)	0.027	1.257 (0.757–2.087)	0.376
Bleeding disorder	1172 (1.9%)	139 (2.6%)	1311 (2.0%)	0.001	1.291 (0.881–1.892)	0.191
Number of comorbidities				< 0.0001		
Zero	28,998 (47.3%)	2107 (39.4%)	31,105 (46.7%)		Reference	
1	22,550 (36.8%)	2085 (39.0%)	24,635 (37.0%)		0.977 (0.674–1.415)	0.910
2	8717 (14.2%)	1025 (19.1%)	9742 (14.6%)		0.886 (0.434–1.807)	0.739
≥ 3	1034 (1.7%)	136 (2.5%)	1170 (1.8%)		0.656 (0.227–1.897)	0.436
Functional health status				< 0.0001		
Independent	60,380 (98.5%)	5237 (97.8%)	65,617 (98.4%)		Reference	
Dependent	611 (1.0%)	92 (1.7%)	703 (1.1%)		1.325 (1.049–1.672)	0.018
Unknown	308 (0.5%)	24 (0.4%)	332 (0.5%)		1.048 (0.680–1.613)	0.833
Disseminated cancer	1575 (2.6%)	253 (4.7%)	1828 (2.7%)	< 0.0001	1.593 (1.380–1.838)	< 0.0001
Open wound/ wound infection	292 (0.5%)	50 (0.9%)	342 (0.5%)	< 0.0001	1.496 (1.095–2.043)	0.011
Chronic steroid use	4526 (7.4%)	480 (9.0%)	5006 (7.5%)	< 0.0001	1.156 (1.020–1.310)	0.023
Loss of body weight ≥ 10%/ 6 months	1547 (2.5%)	221 (4.1%)	1768 (2.7%)	< 0.0001	1.527 (1.315–1.773)	< 0.0001
Transfusion of ≥ 1 pRBC 72 h before the operation	279 (0.5%)	39 (0.7%)	318 (0.5%)	0.005	1.230 (0.864–1.751)	0.252
Systemic sepsis	381 (0.6%)	65 (1.2%)	446 (0.7%)	< 0.0001	1.660 (1.260–2.186)	< 0.0001
ASA class ≥ 3	29,382 (47.9%)	3026 (56.5%)	32,408 (48.6%)	< 0.0001	1.121 (1.052–1.196)	< 0.0001
Underlying disease				< 0.0001		
Other benign ^a	29,104 (47.5%)	2322 (43.4%)	31,426 (47.1%)		Reference	
Colon cancer	27,911 (45.5%)	2602 (48.6%)	30,513 (45.8%)		1.040 (0.976–1.109)	0.226
IBD	4284 (7.0%)	429 (8.0%)	4713 (7.1%)		1.099 (0.959–1.259)	0.176
Operative approach				< 0.0001		
Laparoscopic	52,948 (86.4%)	4926 (92.0%)	57,874 (86.8%)		Reference	
Robotic	8351 (13.6%)	427 (8.0%)	8778 (13.2%)		0.440 (0.396–0.488)	< 0.0001
Operation time, min	155 (116–205)	186 (141–242.5)	157 (117–208)	< 0.0001	1.005 (1.005–1.005)	< 0.0001

BMI body mass index, DM diabetes mellitus, COPD chronic obstructive pulmonary disease, CHF congestive heart failure, HTN hypertension requiring medications, pRBC packed red blood cells, ASA American Society of Anesthesiologists, IBD inflammatory bowel disease

^aOther benign: Diverticular disease or benign neoplasms

Bold value indicates statistical significance

Table 2 Characteristics of patients who had unplanned conversion based on the operative approach

	Lap <i>N</i> = 4926	Robotic <i>N</i> = 427	Total <i>N</i> = 5353	<i>p</i> value
Male	2607 (52.9%)	228 (53.4%)	2835 (53.0%)	0.851
Age $\geq$ 80 years	505 (10.3%)	42 (9.8%)	547 (10.2%)	0.786
BMI $\geq$ 30 kg/m ²	2200 (44.9%)	220 (51.6%)	2420 (45.4%)	0.007
Underlying disease				< 0.0001
Colon cancer	2429 (49.3%)	173 (40.5%)	2602 (48.6%)	
IBD	415 (8.4%)	14 (3.3%)	429 (8.0%)	
Others ^a	2082 (42.3%)	240 (56.2%)	2322 (43.4%)	
ASA $\geq$ 3	2795 (56.7%)	231 (54.1%)	3026 (56.5%)	0.291
COPD	275 (5.6%)	25 (5.9%)	300 (5.6%)	0.815
Bleeding disorder	124 (2.5%)	15 (3.5%)	139 (2.6%)	0.215
Operation time	183 (139–304)	220 (168–284)		< 0.0001

Lap laparoscopic, *BMI* body mass index, *IBD* inflammatory bowel disease, *ASA* American Society of anesthesiologists, *COPD* chronic obstructive pulmonary disease

^aOthers includes diverticular disorders and benign neoplasms

Bold value indicates statistical significance

Fig. 1 Trend utilization of the robotic approach. *BMI* body mass index, *ASA* American Society of anesthesiologists. Benign diseases include inflammatory bowel diseases, diverticular disorders, and benign neoplasms. *All cases* utilization of the robotic approach increased from 4.9 in 2013 to 18.3% in 2018 (slope 2.7% per year; 95% CI [2.6% to 2.9%]). *Colon cancer* utilization of the robotic approach increased from 3.5 in 2013 to 16% in 2018 (slope 2.5%

per year; 95% CI [2.3% to 2.7%]). *Benign diseases* utilization of the robotic approach increased from 5.8 in 2013 to 20.5% in 2018 (slope 3% per year; 95% CI [2.7% to 3.2%]). *ASA $\geq$ 3* utilization of the robotic approach increased from 4.7 in 2013 to 18.1% in 2018 (slope 2.7% per year; 95% CI [2.5% to 2.9%]). *BMI $\geq$ 30 kg/m²* utilization of the robotic approach increased from 4.6 in 2013 to 20.1% in 2018 (slope 3.1% per year; 95% CI [2.9% to 3.4%])

and improved skills due to the growing experience of individual surgeons. However, the ACS-NSQIP data pool did not allow associating these findings to individual case volume of institutions to support the latter assumption. Hence, large reports from individual high-volume centers remain important to further elucidate potential benefits and the impact of growing experience with the robotic platform [15]. Interestingly, the decreasing trend of conversion in robotics was

mainly driven by the decrease from 2013 to 2014 (Fig. 2). Potential explanations include both a learning-curve effect related to robotic surgery reflecting more widespread implementation in lower-volume centers and increased utilization in high-risk patients in more recent years. However, while the present study revealed increased penetration of the robotic platform in high-risk patients, robotic case mix was not affected, which may also explain the more steady

Fig. 2 Trend of the unplanned conversion rate. *Lap* laparoscopic. **A** All cases for robotic cases, the conversion rate decreased from 7.3 in 2013 to 4.8 in 2018 (slope -0.3% per year; 95% CI $[-0.6\%$ to 0%]), for lap cases, the conversion rate decreased from 9.9 in 2013 to 7.7 in 2018 (slope -0.3% per year; 95% CI $[-0.5\%$ to -0.2%]). **B** Patients with BMI ≥ 30 kg/m² for robotic cases, the conversion rate decreased from 12.2 in 2013 to 5.5 in 2018 (slope -0.6% per year; 95% CI $[-1.1\%$ to 0%]), for lap cases, the conversion rate decreased from 11.9 in 2013 to 9.1 in 2018 (slope -0.5% per year; 95%

$[-0.7\%$ to -0.2%]). **C** Colon cancer for robotic cases, the conversion rate decreased from 8.9 in 2013 to 4.4 in 2018 (slope -0.4% per year; 95% CI $[-0.9\%$ to 0.1%]), for lap cases, the conversion rate decreased from 10.7 in 2013 to 7.6 in 2018 (slope -0.6% per year; 95% CI $[-0.8\%$ to -0.4%]). **D** Benign diseases for robotic cases, the conversion rate decreased from 6.6 in 2013 to 5.1 in 2018 (slope -0.2% per year; 95% CI $[-0.6\%$ to 0.2%]), for lap cases, the conversion rate decreased from 9.4 in 2013 to 7.9 in 2018 (slope -0.1% per year; 95% CI $[-0.3\%$ to 0%]).

conversion rates in the robotic group in recent study years. The lack of specific details in ACS-NSQIP has limited our ability to further investigate this observation.

The comparison of baseline characteristics of converted patients was an attempt to identify potential risk profiles according to approach, given the lack of information regarding reasons for conversion in ACS-NSQIP. Overall, the comparison showed similar characteristics in both groups (laparoscopic vs. robotic) despite differences in underlying disease categories and surgical duration. However, conversion had a major impact on postoperative outcomes, as demonstrated by increased overall, surgical, medical, and specific complications in the converted group (Table 3). This has been previously observed with outcomes after conversion resembling traditional open surgery, with an even higher risk of wound infection [11, 16].

A variety of independent risk factors for conversion were identified. At first glance, they seem nonspecific and unrelated to surgical technique or disease presentation at the time

of surgery. However, this risk factor analysis has to be interpreted within the known limitations of the available NSQIP data items, yielding scarce intraoperative details on disease or technique. For example, well-known risk factors such as previous surgery (adhesions) are missing. Those identified demographic and pre-operative risk factors instead represent surrogates for disease severity rather than straightforward intuitive risk factors. Malnutrition, chronic steroid use, and systemic sepsis as surrogates of severe disease presentation in the IBD population have been formerly associated with increased conversion rates [17, 18]. Chronic or infected wounds, sepsis, and prolonged surgery may be associated with complicated diverticular disease. Finally, ascites and disseminated cancer are markers of (locally) advanced disease and may highlight technical barriers to successful completion of a MIS approach [19]. On the other hand, dyspnea and smoking status as surrogates of impaired functional lung capacity may reflect the challenges to maintain capnoperitoneum when respiratory status is impaired [20]. In line with

Table 3 Postoperative complications

	Unplanned conversion to open			Unadjusted <i>p</i> value	Adjusted odds ratio ^a
	No = 61,299	Yes = 5353	Total = 66,652		
Any complication	10,896 (17.8%)	2004 (37.4%)	12,900 (19.4%)	< 0.0001	2.360 (2.219–2.511)
Any surgical complication	9571 (15.7%)	1850 (34.7%)	11,421 (17.2%)	< 0.0001	2.423 (2.275–2.581)
Any SSI	3178 (5.2%)	690 (12.9%)	3868 (5.8%)	< 0.0001	2.328 (2.128–2.548)
Superficial SSI	1472 (2.4%)	370 (6.9%)	1842 (2.8%)	< 0.0001	2.622 (2.323–2.960)
Deep SSI	186 (0.3%)	68 (1.3%)	254 (0.4%)	< 0.0001	3.331 (2.495–4.447)
Organ/space infection	1634 (2.7%)	284 (5.3%)	1918 (2.9%)	< 0.0001	1.775 (1.554–2.027)
Wound disruption	189 (0.3%)	64 (1.2%)	253 (0.4%)	< 0.0001	2.915 (2.172–3.912)
Systemic sepsis					
Sepsis	958 (1.6%)	202 (3.8%)	1160 (1.7%)	< 0.0001	2.029 (1.730–2.381)
Septic shock	358 (0.6%)	84 (1.6%)	442 (0.7%)	< 0.0001	2.150 (1.681–2.750)
Need for blood transfusion	2522 (4.1%)	504 (9.4%)	3026 (4.5%)	< 0.0001	2.106 (1.894–2.341)
Ileus	4708 (7.7%)	983 (18.4%)	5691 (8.5%)	< 0.0001	2.242 (2.073–3.424)
Unplanned reoperation	1931 (3.2%)	265 (5.0%)	2196 (3.3%)	< 0.0001	1.401 (1.224–1.602)
Leak	1399 (2.3%)	202 (3.8%)	1601 (2.4%)	< 0.0001	1.440 (1.234 – 1.680)
30-day mortality	266 (0.4%)	72 (1.3%)	338 (0.5%)	< 0.0001	2.281 (1.724–3.019)
Any medical complication	2495 (4.1%)	461 (8.6%)	2956 (4.4%)	< 0.0001	1.839 (1.651–2.049)
Respiratory complications					
Pneumonia	569 (0.9%)	122 (2.3%)	691 (1.0%)	< 0.0001	1.969 (1.604–2.417)
Unplanned intubation	409 (0.7%)	88 (1.6%)	497 (0.7%)	< 0.0001	1.961 (1.538–2.500)
Need for mechanical ventilation > 48 h	287 (0.5%)	64 (1.2%)	351 (0.5%)	< 0.0001	1.918 (1.444–2.547)
Vascular thromboembolism					
PE	196 (0.3%)	47 (0.9%)	243 (0.4%)	< 0.0001	2.225 (1.605–3.086)
DVT	442 (0.7%)	77 (1.4%)	519 (0.8%)	< 0.0001	1.691 (1.318–2.168)
Progressive RF	179 (0.3%)	52 (1.0%)	231 (0.3%)	< 0.0001	2.559 (1.855 – 3.530)
UTI	740 (1.2%)	107 (2.0%)	847 (1.3%)	< 0.0001	1.505 (1.220–1.857)
MACE					
Stroke	94 (0.2%)	14 (0.3%)	108 (0.2%)	0.059	1.393 (0.770–2.521)
Cardiac arrest required CPR	142 (0.2%)	33 (0.6%)	175 (0.3%)	< 0.0001	2.132 (1.433–3.171)
MI	253 (0.4%)	50 (0.9%)	303 (0.5%)	< 0.0001	1.856 (1.356–2.539)
LOS, ≥ 6 days	7323 (12.0%)	1736 (32.5%)	9059 (13.6%)	< 0.0001	2.857 (2.674–3.053)

SSI surgical site infection, PE pulmonary embolism, DVT deep venous thrombosis, RF renal failure, UTI urinary tract infection, MACE major adverse cardiovascular events, CPR cardiopulmonary resuscitation, MI myocardial infarction, LOS length of stay

^a“No unplanned conversion” was used as a reference

Adjusted for: age ≥ 80, sex, race, BMI ≥ 30 kg/m², diabetes mellitus, chronic obstructive pulmonary disease, dyspnea, ascites, congestive heart failure, hypertension requiring medication, currently on dialysis, bleeding disorders, number of comorbidities, functional health status prior to surgery, systemic sepsis, disseminated cancer, open wound/wound infection, steroid use for chronic condition, > 10% loss bodyweight in last 6 months, transfusion ≥ 1 units in 72 h before surgery, ASA ≥ 3, underlying disease, operative approach, total operation time

Bold value indicates statistical significance

this observation, the significant association of comorbidities (ASA score, functional dependence) and advanced age may primarily reflect the general physiologic tolerance of MIS surgery in frail patients.

Obesity has been repeatedly identified as a risk factor for postoperative complications in general and surgical conversion in particular, independently of the underlying disease [21, 22]. The present analysis confirmed the significant impact of obesity on surgical conversion, yielding

consistently higher rates in patients with cancer, IBD, and other benign diseases. The increasing utilization of the robotic platform, especially in obese patients, may highlight the technical advantages of robotics in patients with severe visceral obesity and often limited working space [23, 24]. These proposed advantages are further supported by the down-trending robotic conversion rates, which were also observed in the subgroup of obese patients.

This study has limitations related to the lack of conversion-specific technical and surgical ACS-NSQIP data, coding of procedures, and indications. Hence, the primary focus of this study was trend analysis and clinical consequences of surgical conversion rather than the analysis of specific risk factors. Reasons for conversion were not recorded, impeding further in-depth analysis. However, studying specific reasons and risk factors for conversion is probably more meaningful in single-institutional studies given different individual thresholds to conversion, leading to bias if data are pooled. Second, ACS-NSQIP does not provide data on setting, size, or case volume of included centers; the robotic data may mainly derive from large-volume facilities with high MIS experience. Third, worse outcomes after conversion are multifactorial, and straightforward cause-effect patterns related to conversion solely are not suggested. Fourth, ACS-NSQIP does not distinguish between pre-emptive and reactive conversion. Thresholds for conversion are individual and surgeon dependent. Especially early pre-emptive conversion due to adhesions may lead to an overestimation to laparoscopic conversion rates given the comparative simplicity of laparoscopic exploration compared to the more complex docking process of the robotic platform. Fifth, the study focused on colonic resections. Arguably, analysis of conversion rates related to rectal resections would be of interest to further study potential benefits of the robotic platform in the narrow pelvis. However, this was not possible due to low numbers of robotic rectal resections reported in the targeted files and a lack of available comparative data in early study years.

In conclusion, this large-scale study identified a decreasing trend in conversion rates over the 6-year inclusion period, both overall and in patients with obesity, paralleling increased utilization of the robotic platform. Given the potential negative impact of conversion on patient outcomes, individual institutions should consider review of their own conversion data as this may represent an opportunity for quality improvement. Significantly lower conversion rates associated with the robotic platform call for further exploration of these findings.

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References

1. Zhao JH, Sun JX, Huang XZ, Gao P, Chen XW, Song YX et al (2016) Meta-analysis of the laparoscopic versus open colorectal surgery within fast track surgery. *Int J Colorectal Dis* 31(3):613–622
2. Goh BK (2007) Impact of laparoscopic resection for colorectal cancer on operative outcomes and survival. *Ann Surg* 246(2):338–339
3. Bonjer HJ, Deijen CL, Abis GA, Cuesta MA, van der Pas MH, de Lange-de Klerk ES et al (2015) A randomized trial of laparoscopic versus open surgery for rectal cancer. *N Engl J Med* 372(14):1324–1332
4. Simillis C, Lal N, Thoukididou SN, Kontovounisios C, Smith JJ, Hompes R et al (2019) Open versus laparoscopic versus robotic versus transanal mesorectal excision for rectal cancer: a systematic review and network meta-analysis. *Ann Surg* 270(1):59–68
5. Jayne D, Pigazzi A, Marshall H, Croft J, Corrigan N, Copeland J et al (2019) Robotic-assisted surgery compared with laparoscopic resection surgery for rectal cancer: the ROLARR RCT. *Effic Mech Eval*. <https://doi.org/10.3310/eme06100>
6. Corrigan N, Marshall H, Croft J, Copeland J, Jayne D, Brown J (2018) Exploring and adjusting for potential learning effects in ROLARR: a randomised controlled trial comparing robotic-assisted vs. standard laparoscopic surgery for rectal cancer resection. *Trials* 19(1):339
7. Crippa J, Grass F, Achilli P, Mathis KL, Kelley SR, Merchea A et al (2020) Risk factors for conversion in laparoscopic and robotic rectal cancer surgery. *Br J Surg* 107(5):560–566
8. Crippa J, Grass F, Dozois EJ, Mathis KL, Merchea A, Colibaseanu DT et al (2020) Robotic surgery for rectal cancer provides advantageous outcomes over laparoscopic approach: results from a large retrospective cohort. *Ann Surg*. <https://doi.org/10.1097/sla.0000000000003805>
9. Panteleimonitis S, Pickering O, Abbas H, Harper M, Kandala N, Figueiredo N et al (2018) Robotic rectal cancer surgery in obese patients may lead to better short-term outcomes when compared to laparoscopy: a comparative propensity scored match study. *Int J Colorectal Dis* 33(8):1079–1086
10. Duchalais E, Machairas N, Kelley SR, Landmann RG, Merchea A, Colibaseanu DT et al (2018) Does obesity impact postoperative outcomes following robotic-assisted surgery for rectal cancer? *Surg Endosc* 32(12):4886–4892
11. Lee YF, Albright J, Akram WM, Wu J, Ferraro J, Cleary RK (2018) Unplanned robotic-assisted conversion-to-open colorectal surgery is associated with adverse outcomes. *J Gastrointest Surg* 22(6):1059–1067
12. Bastawrous AL, Landmann RG, Liu Y, Liu E, Cleary RK (2020) Incidence, associated risk factors, and impact of conversion to laparotomy in elective minimally invasive sigmoidectomy for diverticular disease. *Surg Endosc* 34(2):598–609
13. Al-Temimi MH, Chandrasekaran B, Agapian J, Peters WR Jr, Wells KO (2019) Robotic versus laparoscopic elective colectomy for left side diverticulitis: a propensity score-matched analysis of the NSQIP database. *Int J Colorectal Dis* 34(8):1385–1392
14. Dolejs SC, Waters JA, Ceppa EP, Zarzaur BL (2017) Laparoscopic versus robotic colectomy: a national surgical quality improvement project analysis. *Surg Endosc* 31(6):2387–2396
15. Spinoglio G, Bianchi PP, Marano A, Priora F, Lenti LM, Ravazoni F et al (2018) Robotic versus laparoscopic right colectomy with complete mesocolic excision for the treatment of colon cancer: perioperative outcomes and 5-year survival in a consecutive series of 202 patients. *Ann Surg Oncol* 25(12):3580–3586
16. Giglio MC, Celentano V, Tarquini R, Luglio G, De Palma GD, Bucci L (2015) Conversion during laparoscopic colorectal resections: a complication or a drawback? A systematic review and meta-analysis of short-term outcomes. *Int J Colorectal Dis* 30(11):1445–1455
17. Mino JS, Gandhi NS, Stocchi LL, Baker ME, Liu X, Remzi FH et al (2015) Preoperative risk factors and radiographic findings predictive of laparoscopic conversion to open procedures in Crohn's disease. *J Gastrointest Surg* 19(6):1007–1014

18. Schmidt CM, Talamini MA, Kaufman HS, Lilliemoe KD, Learn P, Bayless T (2001) Laparoscopic surgery for Crohn's disease: reasons for conversion. *Ann Surg* 233(6):733–739
19. Li J, Guo H, Guan XD, Cai CN, Yang LK, Li YC et al (2015) The impact of laparoscopic converted to open colectomy on short-term and oncologic outcomes for colon cancer. *J Gastrointest Surg* 19(2):335–343
20. Sujatha-Bhaskar S, Alizadeh RF, Inaba CS, Koh CY, Jafari MD, Mills SD et al (2018) Respiratory complications after colonic procedures in chronic obstructive pulmonary disease: does laparoscopy offer a benefit? *Surg Endosc* 32(3):1280–1285
21. McKenna NP, Habermann EB, Zielinski MD, Lightner AL, Mathis KL (2019) Body mass index: implications on disease severity and postoperative complications in patients with Crohn's disease undergoing abdominal surgery. *Surgery* 166(4):703–708
22. He Y, Wang J, Bian H, Deng X, Wang Z (2017) BMI as a predictor for perioperative outcome of laparoscopic colorectal surgery: a pooled analysis of comparative studies. *Dis Colon Rectum* 60(4):433–445
23. Abd El Aziz MA, Grass F, Behm KT, Shawki S, D'Angelo AL, Mathis KL et al (2020) Trends of complications and innovative techniques' utilization for colectomies in the United States. *Updates Surg*. <https://doi.org/10.1007/s13304-020-00862-y>
24. Abd El Aziz MA, Grass F, Perry W, Behm KT, Shawki SF, Larson DW et al (2020) Colectomy for patients with super obesity: current practice and surgical morbidity in the United States. *Surg Obesity Relat Dis* 16:1764

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