Surgical Endoscopy (2020) 34:598–609
https://doi.org/10.1007/s00464-019-06804-z

Incidence, associated risk factors, and impact of conversion to laparotomy in elective minimally invasive sigmoidectomy for diverticular disease

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Received: 5 August 2018 / Accepted: 29 April 2019 / Published online: 6 May 2019
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Abstract

Background Benefits of minimally invasive surgical approaches to diverticular disease are limited by conversion to open surgery. A comprehensive analysis that includes risk factors for conversion may improve patient outcomes.

Methods The US Premier Healthcare Database was used to identify patients undergoing primary elective sigmoidectomy for diverticular disease between 2013 and September 2015. Propensity-score matching was used to compare conversion rates for laparoscopic and robotic-assisted sigmoidectomy. Patient, clinical, hospital, and surgeon characteristics associated with conversion were analyzed using multivariable logistic regression, providing odds ratios for comparative risks. Clinical and economic impacts were assessed comparing surgical outcomes in minimally invasive converted, completed, and open cases.

Results The study population included 13,240 sigmoidectomy patients (8076 laparoscopic, 1301 robotic-assisted, 3863 open). Analysis of propensity-score-matched patients showed higher conversion rates in laparoscopic (13.6%) versus robotic-assisted (8.3%) surgeries ($p < 0.001$). Greater risk of conversion was associated with patients who were Black compared with Caucasian, were Medicaid-insured versus Commercially insured, had a Charlson Comorbidity Index ≥ 2 versus 0, were obese, had concomitant colon resection, had peritoneal abscess or fistula, or had lysis of adhesions. Significantly lower risk of conversion was associated with robotic-assisted sigmoidectomy (versus laparoscopic, OR 0.58), hand-assisted surgery, higher surgeon volume, and surgeons who were colorectal specialties. Converted cases had longer operating room time, length of stay, and more postoperative complications compared with minimally invasive completed and open cases. Readmission and blood transfusion rates were higher in converted compared with minimally invasive completed cases, and similar to open surgeries. Differences in inflation-adjusted total ($4971), direct ($2760), and overhead ($2212) costs were significantly higher for converted compared with minimally invasive completed cases.

Conclusions Conversion from minimally invasive to open sigmoidectomy for diverticular disease results in additional morbidity and healthcare costs. Consideration of modifiable risk factors for conversion may attenuate adverse associated outcomes.

Keywords Diverticulitis · Sigmoidectomy · Robotic-assisted surgery · Laparoscopic surgery · Colon resection · Conversion

Sigmoid diverticular disease is common in aging Western populations. In the US, the prevalence is about 50% in those 60 years or older and 70% in those 80 years or more [1]. It is commonly asymptomatic, but if inflammation (diverticulitis) or bleeding develops, patients often seek medical treatment. Elective surgery for sigmoid diverticulitis is a common procedure for those who fail medical management with antibiotics [2].

The benefits of minimally invasive surgery (MIS) for treatment of diverticular and other colorectal diseases have been well documented. Studies show that minimally invasive colorectal surgery results in lower mortality, morbidity, and transfusion rates; fewer surgical-site infections

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00464-019-06804-z) contains supplementary material, which is available to authorized users.

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and related complications; less postoperative pain; shorter hospital length of stay (LOS); and quicker return to normal diet and gastrointestinal recovery compared with open procedures [3–8]. The use of MIS sigmoidectomy has grown substantially and has replaced open sigmoidectomy (OS) as the standard elective surgical option for recurrent and complicated diverticulitis [9–12].

AQRates of conversion to open sigmoidectomy (OS) for elective laparoscopic sigmoidectomy (LS) are reported in up to 13.1%, and the converted patients are at increased risk for complications [11, 13–16]. Conversion to OS is an appropriate decision when there is lack of operative progress or for complications such as bleeding or bowel injury. While conversion should not be considered a failure, it does result in downstream implications for the patient and the health system. Conversion in colorectal surgery is associated with more expense than with either open or laparoscopic surgery, and is associated with the loss of MIS benefits such as decreased pain, quicker recovery, and shorter LOS [17].

There has been limited research describing risk factors for conversion during LS and robotic-assisted sigmoidectomy (RS) [18]. A better understanding of risk factors for conversion may help guide patient management and choice of operative approach in the treatment of diverticular disease.

This large, national database study was designed to describe risk factors for conversion for conventional laparoscopic and robotic-assisted approaches in the treatment of diverticular disease. To assess the clinical and economic impacts of conversion, outcomes were compared among three patient groups: converted, completed MIS as planned, and completed OS as planned.

Materials and methods

Data

This study has received institutional review board exemption status. The Premier Healthcare Database (PHD) was used to identify patients with diverticular disease [19]. More than 700 acute care hospitals throughout the United States contribute discharge records to PHD, which contained detailed information on disease diagnosis and billed services, allowing accurate estimates of costs. PHD is a de-identified, HIPAA-compliant database which has been validated and used in a number of outcome studies [20, 21].

Study sample and surgical procedures

Patients were eligible if they were 18 years and older and had undergone a sigmoidectomy as the primary elective procedure for diverticulitis or diverticulosis disease (International Classification of Diseases, Ninth Revision [ICD-9] codes 562.10, 562.11, 562.12, 562.13) between January 1, 2013 and September 30, 2015 prior to the implementation of ICD-10 coding. Patients with a known colon malignancy (see Supplement Appendix 1) were excluded as well as those having nonelective procedures. The database definition of elective is based on the Centers for Medicare and Medicaid Services (CMS) UB-04 admission type and is described as 'the patient's condition permitted adequate time to schedule the availability of suitable accommodations.' Cases were stratified into three groups based on the type of sigmoidectomy procedure performed: OS (ICD-9 45.76), LS (ICD-9 17.36), or RS (ICD-9 code 17.42 or 17.44). In addition, the database was searched to identify charges for robotic equipment or instrumentation. Such use of text string search methodology has been previously validated for the identification of robotic-assisted procedures [22, 23]. Converted cases in the LS or RS group were identified using ICD-9 code V64.41.

Patient demographics and clinical characteristics

Patient demographics and clinical characteristics were classified as pre- or intraoperative given their different relationships for risk of conversion. Available patient sociodemographic data elements of interest included age, race (Caucasian, black, or other), gender (female, male), and insurance status (commercial/private, Medicare, Medicaid, or other). Patient comorbid conditions were assessed using the Charlson Comorbidity Index (CCI) [24, 25]. Additional preoperative patient characteristics included obesity (body mass index ≥ 30), and smoking status defined by current or previous use of tobacco (ICD-9 codes 305.1 or V15.82).

Patients who required a blood transfusion were captured using ICD-9 codes 99.00–99.09 (see Supplement Appendix 2). Concomitant procedures including other colorectal surgeries and hernia repairs were also identified (see Supplement Appendix 3). Additional clinical characteristics obtained were the presence of peritoneal abscess or fistula (ICD-9 567.2x, 567.89, 567.9, 569.81) and the presence of adhesions (54.51, 54.59). Unexpected colon malignancy was defined as sigmoidectomy performed for diverticular disease when any malignancy in the colon was detected during the surgery (see Supplement Appendix 1). To identify patients who had hand-assisted laparoscopic sigmoidectomy, the database was searched to identify charges for billing text relating to hand assist ('%HAND%ASSIST%,' '%GEL%PORT%,' '%MINI%LAP%,' '%HALS%') [22, 23].

Hospital and surgeon characteristics

Hospitals were characterized based on location (urban or nonurban), region (Midwest, Northeast, West, South), number of beds (0–99, 100–199, 200–299, 300–399, 400–499,

≥ 500) and teaching status (teaching or nonteaching). Surgeon characteristics included surgeon specialty General Surgeon, Colorectal Surgeon, other) and surgeon volume [19]. Surgeon volume was calculated individually for each patient and estimated as the number of colon and rectal resections performed by the surgeon during the 12 months before the index procedure in the hospital [22]. Volume-based calculations were performed independently for LS or RS, respectively. For purposes of analysis, surgeon volume was divided into quartiles: 0–3 procedures were considered low volume, 4–9 low–medium volume, 10–20 medium–high volume, and > 20 high volume [26].

Analysis: The objectives of this study were to evaluate (1) the rate of conversion from MIS to OS, (2) the risk factors for conversion, and (3) the clinical and economic impacts for conversion for both LS and RS performed for diverticular diseases.

This study was based on three hypotheses:

(1) The laparoscopic approach to sigmoidectomy has a higher rate of conversion than the robotic approach.
(2) There are many risk factors for conversion, and the laparoscopic approach is a strong independent risk factor for conversion.
(3) MIS conversion is associated with worse outcomes and higher cost.

Part I: analysis of conversion rates in LS and RS groups

To analyze the conversion rates and minimize selection bias, a PSM analysis was performed for patients who underwent LS or RS. The propensity score is the probability that a patient will receive a given treatment based on the distribution of factors associated with the treatment [27–29]. In this study, a propensity score was generated from logistic regression models that included patient demographics (age, race, gender, payor, comorbidity, obesity, tobacco use, year of admission), clinical characteristics (concomitant procedures, peritoneal abscess, adhesion, unexpected colon malignancy, use of hand-assistance), surgeon and hospital characteristics (surgeon volume, surgeon specialty, hospital teaching status, location, bed size, region). Matching was done 1-to-1 with a propensity score difference (caliper) no greater than 0.01. A series of sensitivity analyses were performed around matching ratios with varying calipers to determine the best approach.

Part II: analysis of risk factors for conversion

The analysis of potential risk factors associated with conversion to OS was done using a logistic regression model on all MIS patients. Patient pre- and intraoperative factors were first considered in univariate and then in multivariable logistic regression to examine the influence of specific factors on the likelihood of conversion to OS. The predicted rates of conversion among robotic-assisted and conventional laparoscopic patients were calculated using the final multivariable logistic regression model providing risks adjusted for all covariates.

Part III: analysis of impact of conversion

Variables related to the clinical and economic impacts of conversion included postoperative 30-day complication rate, ileus, surgical-site infection, and readmission related to complications, as well as operation room time (wheels in to wheels out), length of stay, and perioperative 30-day total, direct, and overhead costs. Anastomotic leak was not reliably defined in this database and was therefore not included. Differences in 30-day outcomes were compared between patients who underwent sigmoidectomy by MIS versus those who had been converted to OS, and between patients who were planned and completed as OS versus those who had been converted to OS.

Statistical tests

One-way ANOVA *t* test for means and the Mann–Whitney–Wilcoxon test for nonnormal distributions were used for patient population comparisons between LS and RS. Descriptive analysis of categorical patient population characteristics was conducted using the χ^2 test or Fisher exact test in the case of small sample sizes. Comparison of unadjusted and PSM-adjusted conversion rates was also conducted using the χ^2 test. In multivariable logistic regression, Huber–White Robust standard errors were calculated for each of the parameter estimates. Statistical significance tests were performed for all parameters in the multivariable regression. For categorical variables with more than two levels, a Wald test was performed to ascertain whether pairwise differences from the referent level were statistically different from zero.

All data analysis was performed using R 3.3.1(The R Foundation, https://www.r-project.org/).

Results

Patient population

There were 25,967 patients in the PHD with a diagnosis of diverticulitis or diverticulosis without colon cancer who underwent primary sigmoidectomy during the 33-month time period examined in this study (Fig. 1). Of these, 13,240 (51.0%) had an elective OS or MIS with records providing

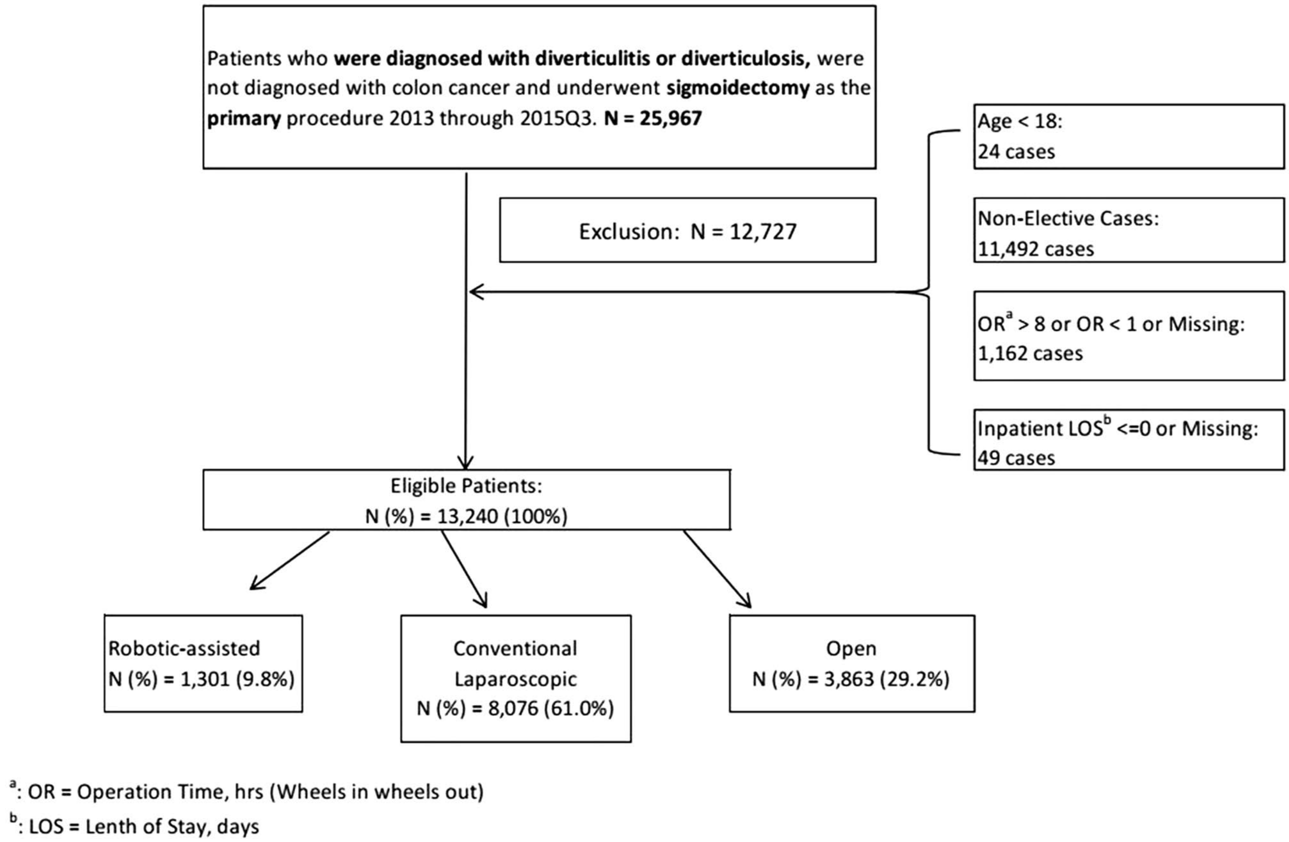

Fig. 1 Flow chart of patient eligibility from the premier healthcare database

adequate data on the variables of interest. The majority of the procedures (70.8%) were done using MIS (8076 LS, 1301 RS) and the remainder (3863 or 29.2%) with OS. Patients with procedures that were done on an emergency or unknown basis, patients with zero or unknown LOS or operating room time, and those with operating room time greater than eight hours were excluded from data analysis.

Comparison of patients who underwent LS versus RS

Laparoscopic and robotic-assisted groups showed no significant differences in demographic and preoperative characteristics prior to PSM (Table 1). Examination of patient intraoperative characteristics showed that LS was more likely to include a concomitant hernia repair ($p = 0.03$) and use of hand assistance ($p < 0.001$) than RS (Table 1). There were small but statistically significant differences in surgeon volume between the two approaches ($p = 0.02$) (Table 1). Surgeons who performed LS compared to RS surgeons were more likely to be general surgeons and those who performed RS were more likely to be colorectal specialists ($p < 0.001$) (Table 1). Robotic compared to laparoscopic procedures were more likely done in an urban hospital ($p < 0.001$) with a greater number beds ($p < 0.001$), in the Northeast and Western regions of the country ($p < 0.001$) and at the later time period of study ($p < 0.001$) (Table 1).

These differences between laparoscopic and robotic-assisted patient groups were no longer statistically significant after PSM (Table 1).

Conversion rates and risk factors

Rate of conversion to OS was significantly higher in patients who underwent LS compared to those with RS procedures (Table 2). These differences were similar in the unadjusted (13.1% versus 8.0%) and the PSM (13.6% versus 8.3%) analysis (both $p < 0.001$).

Unadjusted univariate logistic regression analyses of risk factors for conversion in MIS are presented in Table 3. Characteristics that were significantly associated with greater risk of conversion were patients aged 65 years or more, Black race, insurance other than commercial, Charlson Comorbidity Index of one or more, obesity, previous or current tobacco use, use of LS, intraoperative factors including concomitant colonic resection, concomitant hernia repair, the presence of peritoneal abscess or fistula, and adhesions as well as procedure performed by a general surgeon

Table 1 Comparison of patient, surgeon and provider characteristics by surgical approach

	Conventional laparoscopic	Robotic-assisted	p value	PS[a] Matched laparoscopic	PS[a] Matched robotic-assisted	p value
	$n=8076$ (86.1%)	$n=1301$ (13.9%)		$n=1236$	$n=1236$	
Patient demographic and preoperative characteristics						
Age, years			0.43			0.94
18–34	302 (3.7%)	52 (4.0%)		51 (4.1%)	51 (4.1%)	
35–44	1053 (13.0%)	164 (12.6%)		167 (13.5%)	157 (12.7%)	
45–64	4429 (54.8%)	741 (57.0%)		691 (55.9%)	702 (56.8%)	
65+	2292 (28.4%)	344 (26.4%)		327 (26.5%)	326 (26.4%)	
Race			0.87			0.19
Black	403 (5.0%)	66 (5.1%)		55 (4.4%)	66 (5.3%)	
Caucasian	6690 (82.8%)	1067 (82.2%)		1039 (84.1%)	1005 (81.3%)	
Other	982 (12.2%)	165 (12.7%)		142 (11.5%)	165 (13.3%)	
Gender			1.00			0.69
Male	4430 (54.9%)	713 (54.8%)		546 (44.2%)	557 (45.1%)	
Female	3646 (45.1%)	588 (45.2%)		690 (55.8%)	679 (54.9%)	
Payor			0.12			0.75
Commercial	4718 (58.4%)	803 (61.7%)		782 (63.3%)	756 (61.2%)	
Medicare	2485 (30.8%)	368 (28.3%)		334 (27.0%)	353 (28.6%)	
Medicaid	407 (5.0%)	66 (5.1%)		60 (4.9%)	65 (5.3%)	
Other	465 (5.8%)	64 (4.9%)		60 (4.9%)	62 (5.0%)	
Charlson Comorbidity Index			0.06			0.53
0	6318 (78.2%)	1046 (80.4%)		1008 (81.6%)	986 (79.8%)	
1	1265 (15.7%)	186 (14.3%)		165 (13.3%)	181 (14.6%)	
≥ 2	493 (6.1%)	69 (5.3%)		63 (5.1%)	69 (5.6%)	
Obesity			0.73			0.96
Yes	1399 (17.3%)	231 (17.8%)		225 (18.2%)	223 (18.0%)	
Tobacco current or previous use			0.38			0.23
Yes	2492 (30.9%)	385 (29.6%)		404 (32.7%)	375 (30.3%)	
Patient intraoperative characteristics						
Concomitant procedure other colon resection			0.12			0.34
Yes	115 (1.4%)	11 (0.8%)		17 (1.4%)	11 (0.9%)	
Concomitant procedure hernia			0.03			0.81
Yes	324 (4.0%)	35 (2.7%)		38 (3.1%)	35 (2.8%)	
Presence of peritoneal abscess or fistula			0.53			0.43
Yes	351 (4.3%)	51 (3.9%)		59 (4.8%)	50 (4.0%)	
Presence of adhesions			0.48			0.74
Yes	1237 (15.3%)	189 (14.5%)		195 (15.8%)	188 (15.2%)	
Unexpected colon malignancy			0.19			1.00
Yes	17 (0.2%)	0 (0.0%)		0 (0.0%)	0 (0.0%)	
Hand assist			< 0.001			0.83
Yes	1706 (21.1%)	114 (8.8%)		110 (8.9%)	114 (9.2%)	
Surgeon and provider characteristics						
Surgeon volume			0.02			0.77
Low	2304 (28.5%)	382 (29.4%)		346 (28.0%)	366 (29.6%)	
Low–medium	1957 (24.2%)	310 (23.8%)		319 (25.8%)	305 (24.7%)	
Medium–high	1847 (22.9%)	253 (19.4%)		244 (19.7%)	249 (20.1%)	
High	1968 (24.4%)	356 (27.4%)		327 (26.5%)	316 (25.6%)	
Surgeon specialty			< 0.001			0.66
General	5982 (74.1%)	768 (59.0%)		790 (63.9%)	768 (62.1%)	

Table 1 (continued)

	Conventional laparoscopic	Robotic-assisted	*p* value	PS[a] Matched laparoscopic	PS[a] Matched robotic-assisted	*p* value
	n = 8076 (86.1%)	*n* = 1301 (13.9%)		*n* = 1236	*n* = 1236	
Colorectal	1457 (18.0%)	465 (35.7%)		381 (30.8%)	400 (32.4%)	
Other	637 (7.9%)	68 (5.2%)		65 (5.3%)	68 (5.5%)	
Hospital teaching status			0.14			0.51
Teaching hospital	3007 (37.2%)	513 (39.4%)		485 (39.2%)	502 (40.6%)	
Nonteaching	5069 (62.8%)	788 (60.6%)		751 (60.8%)	734 (59.4%)	
Hospital urban or not			< 0.001			0.58
Urban	7220 (89.4%)	1212 (93.2%)		1155 (93.4%)	1147 (92.8%)	
Nonurban	856 (10.6%)	89 (6.8%)		81 (6.6%)	89 (7.2%)	
Hospital number of beds			< 0.001			0.67
000–099	470 (5.8%)	30 (2.3%)		23 (1.9%)	30 (2.4%)	
100–199	1292 (16.0%)	141 (10.8%)		138 (11.2%)	140 (11.3%)	
200–299	1292 (16.0%)	235 (18.1%)		224 (18.1%)	229 (18.5%)	
300–399	1399 (17.3%)	231 (17.8%)		224 (18.1%)	230 (18.6%)	
400–499	1004 (12.4%)	231 (17.8%)		207 (16.7%)	179 (14.5%)	
500+	2619 (32.4%)	433 (33.3%)		420 (34.0%)	428 (34.6%)	
Hospital census region			< 0.001			0.11
Midwest	1616 (20.0%)	178 (13.7%)		161 (13.0%)	177 (14.3%)	
Northeast	1707 (21.1%)	303 (23.3%)		310 (25.1%)	297 (24.0%)	
South	3698 (45.8%)	598 (46.0%)		551 (44.6%)	587 (47.5%)	
West	1055 (13.1%)	222 (17.1%)		214 (17.3%)	175 (14.2%)	
Year			< 0.001			0.19
2013	3245 (40.2%)	374 (28.8%)		364 (29.4%)	374 (30.3%)	
2014	3003 (37.2%)	518 (39.8%)		533 (43.1%)	491 (39.7%)	
2015	1828 (22.6%)	409 (31.4%)		339 (27.4%)	371 (30.0%)	

PS propensity score

[a]All covariates listed in the table were included in 1:1 propensity-score matching with caliper 0.01

Table 2 Unadjusted and propensity-score-matched conversion rates of minimally invasive sigmoidectomy to open

	Conventional laparoscopic	Robotic-assisted	*p* value	PS Matched laparoscopic	PS matched robotic	*p* value
	n = 8076 (86.1%)	*n* = 1301 (13.9%)		*n* = 1236	*n* = 1236	
Conversion						
Yes	1059 (13.1%)	104 (8.0%)	< 0.001	168 (13.6%)	103 (8.3%)	< 0.001

All covariates listed below were included in 1:1 propensity-score matching with caliper 0.01: age, gender, race, Charlson Comorbidity Index, payor, tobacco current or previous use, obesity, the presence of peritoneal abscess or fistula, concomitant procedure hernia, concomitant procedure other than colon resection, the presence of adhesions, unexpected colon malignancy, surgeon volume, surgeon specialty, hospital number of beds, hospital teaching status, hospital census region, hospital urban, use of hand assistance, year

PS propensity score

(compared with a colorectal surgeon), and a hospital that was a teaching hospital and a nonurban center. Use of RS, use of hand assistance, medium–high to high-volume surgical experience (compared with low-volume experience), and a Colorectal Surgeon (versus a General Surgeon) were associated with lower conversion risk.

Multivariable logistic regression was then used to examine the covariate-adjusted likelihood of conversion from MIS to OS (Table 3). The adjusted odds ratio presents the independent risk for each characteristic relative to the referent, adjusted for the effects of other covariates in the model. Black patients had a 48% higher risk of conversion than

Table 3 Risk factors for conversion of minimally invasive to open sigmoidectomy

	Completed MIS $n=8214$ (87.6%)	Converted $n=1163$ (12.4%)	Unadjusted OR (95% CI)	p value[a]	Adjusted OR (95% CI)	p value[b]
Age, years						
18–34	318 (89.8%)	36 (10.2%)	Referent		Referent	
35–44	1099 (90.3%)	118 (9.7%)	0.95 (0.65–1.42)	0.79	0.98 (0.66–1.49)	0.92
45–64	4572 (88.4%)	598 (11.6%)	1.16 (0.82–1.67)	0.43	1.28 (0.90–1.89)	0.19
65+	2225 (84.4%)	411 (15.6%)	1.63 (1.15–2.38)	0.01	1.51 (0.99–2.35)	0.06
Race						
Caucasian	6840 (88.2%)	917 (11.8%)	Referent		Referent	
Black	378 (80.6%)	91 (19.4%)	1.80 (1.41–2.27)	< 0.001	1.48 (1.14–1.91)	0.003
Others	992 (86.5%)	155 (13.5%)	1.16 (0.96–1.39)	0.11	1.13 (0.93–1.38)	0.20
Gender						
Male	4476 (87.0%)	667 (13.0%)	Referent		Referent	
Female	3738 (88.3%)	496 (11.7%)	0.89 (0.79–1.01)	0.07	0.94 (0.82–1.08)	0.38
Payor						
Commercial	4959 (89.8%)	562 (10.2%)	Referent		Referent	
Medicare	2411 (84.5%)	442 (15.5%)	1.62 (1.41–1.85)	< 0.001	1.19 (0.95–1.5)	0.14
Medicaid	389 (82.2%)	84 (17.8%)	1.91 (1.47–2.44)	< 0.001	1.57 (1.20–2.05)	< 0.001
Other	455 (85.8%)	75 (14.2%)	1.45 (1.11–1.87)	0.005	1.37 (1.03–1.79)	0.03
Charlson Comorbidity Index						
0	6527 (88.6%)	837 (11.4%)	Referent		Referent	
1	1223 (84.3%)	228 (15.7%)	1.45 (1.24–1.70)	< 0.001	1.22 (0.95–1.55)	0.12
≥ 2	464 (82.6%)	98 (17.4%)	1.65 (1.30–2.06)	< 0.001	1.28 (1.08–1.51)	0.005
Obesity						
No	6842 (88.3%)	905 (11.7%)	Referent		Referent	
Yes	1372 (84.2%)	258 (15.8%)	1.42 (1.22–1.65)	< 0.001	1.38 (1.17–1.62)	< 0.001
Tobacco current or previous use						
No	5743 (88.4%)	757 (11.6%)	Referent		Referent	
Yes	2471 (85.9%)	406 (14.1%)	1.25 (1.09–1.42)	< 0.001	1.12 (0.97–1.28)	0.12
Surgical technique						
Conventional laparoscopic	7017 (86.9%)	1059 (13.1%)	Referent		Referent	
Robotic-assisted	1197 (92.0%)	104 (8.0%)	0.58 (0.46–0.71)	< 0.001	0.58 (0.46–0.72)	< 0.001
Concomitant procedure other colon resection						
No	8132 (87.9%)	1119 (12.1%)	Referent		Referent	
Yes	82 (65.1%)	44 (34.9%)	3.90 (2.67–5.62)	< 0.001	3.13 (2.10–4.62)	< 0.001
Concomitant procedure hernia						
No	7912 (87.7%)	1106 (12.3%)	Referent		Referent	
Yes	302 (84.1%)	57 (15.9%)	1.35 (1.00–1.79)	0.04	1.16 (0.85–1.56)	0.35
Presence of peritoneal abscess or fistula						
No	7911 (88.1%)	1064 (11.9%)	Referent		Referent	
Yes	303 (75.4%)	99 (24.6%)	2.43 (1.91–3.06)	< 0.001	2.14 (1.65–2.74)	< 0.001
Presence of adhesions						
No	7157 (90.0%)	794 (10.0%)	Referent		Referent	
Yes	1057 (74.1%)	369 (25.9%)	3.15 (2.74–3.62)	< 0.001	2.79 (2.41–3.23)	< 0.001
Unexpected colon malignancy						
No	8202 (87.6%)	1158 (12.4%)	Referent		Referent	
Yes	12 (70.6%)	5 (29.4%)	2.95 (0.94–7.97)	0.04	2.09 (0.63–6.06)	0.19
Hand assist						
No	6577 (87.0%)	980 (13.0%)	Referent		Referent	
Yes	1637 (89.9%)	183 (10.1%)	0.75 (0.63–0.88)	< 0.001	0.67 (0.55–0.79)	< 0.001

Table 3 (continued)

	Completed MIS $n=8214$ (87.6%)	Converted $n=1163$ (12.4%)	Unadjusted OR (95% CI)	p value[a]	Adjusted OR (95% CI)	p value[b]
Surgeon volume						
Low	2277 (84.8%)	409 (15.2%)	Referent		Referent	
Low–medium	1948 (85.9%)	319 (14.1%)	0.91 (0.78–1.07)	0.25	0.90 (0.76–1.06)	0.20
Medium–high	1848 (88.0%)	252 (12.0%)	0.76 (0.64–0.90)	0.001	0.75 (0.62–0.90)	0.002
High	2141 (92.1%)	183 (7.9%)	0.48 (0.40–0.57)	< 0.001	0.51 (0.41–0.63)	< 0.001
Surgeon specialty						
General	5816 (86.2%)	934 (13.8%)	Referent		Referent	
Colorectal	1775 (92.4%)	147 (7.6%)	0.52 (0.43–0.62)	< 0.001	0.66 (0.54–0.80)	< 0.001
Other	623 (88.4%)	82 (11.6%)	0.82 (0.64–1.04)	0.10	0.70 (0.54–0.89)	0.005
Hospital teaching status						
Nonteaching hospital	5170 (88.3%)	687 (11.7%)	Referent		Referent	
Teaching hospital	3044 (86.5%)	476 (13.5%)	1.18 (1.04–1.33)	0.01	1.30 (1.11–1.53)	0.001
Hospital urban or not						
Urban	7421 (88.0%)	1011 (12.0%)	Referent		Referent	
Nonurban	793 (83.9%)	152 (16.1%)	1.41 (1.17–1.69)	< 0.001	1.33 (1.08–1.63)	0.01
Hospital number of beds						
000–099	434 (86.8%)	66 (13.2%)	Referent		Referent	
100–199	1278 (89.2%)	155 (10.8%)	0.80 (0.59–1.09)	0.15	0.88 (0.64–1.22)	0.43
200–299	1324 (86.7%)	203 (13.3%)	1.01 (0.75–1.37)	0.96	1.12 (0.82–1.54)	0.49
300–399	1431 (87.8%)	199 (12.2%)	0.91 (0.68–1.24)	0.56	1.13 (0.82–1.57)	0.45
400–499	1067 (86.4%)	168 (13.6%)	1.04 (0.77–1.41)	0.82	1.26 (0.90–1.78)	0.18
500+	2680 (87.8%)	372 (12.2%)	0.91 (0.69–1.22)	0.52	1.09 (0.80–1.51)	0.60
Hospital census region						
Midwest	1559 (86.9%)	235 (13.1%)	Referent		Referent	
Northeast	1780 (88.6%)	230 (11.4%)	0.86 (0.71–1.04)	0.12	0.89 (0.72–1.11)	0.31
South	3757 (87.5%)	539 (12.5%)	0.95 (0.81–1.12)	0.56	1.06 (0.89–1.27)	0.51
West	1118 (87.5%)	159 (12.5%)	0.94 (0.76–1.17)	0.60	0.98 (0.78–1.24)	0.88
Year						
2013	3155 (87.2%)	464 (12.8%)	Referent		Referent	
2014	3102 (88.1%)	419 (11.9%)	0.92 (0.80–1.06)	0.24	1.06 (0.91–1.24)	0.46
2015	1957 (87.5%)	280 (12.5%)	0.97 (0.83–1.14)	0.73	1.12 (0.94–1.33)	0.21

Unadjusted OR odds ratio from univariate logistic regression

Adjusted OR odds ratio from multivariable logistic regression

CI confidence interval

[a]p value for the unadjusted OR from the univariate logistic regression

[b]p value for the adjusted OR from the multivariable logistic regression

Caucasians ($p=0.003$). Those who had Medicaid (57%, $p<0.001$) or Other (37%, $p=0.03$) insurance had greater likelihood of conversion compared with patients who were commercially insured. A CCI of 2 or more (versus 0) conferred a 28% ($p=0.005$) higher risk of conversion, and obesity by itself was associated with 38% ($p<0.001$) greater odds. Although not statistically significant, patients aged 65 years or more had a 51% greater likelihood of conversion than the younger age group (18–34 years) ($p=0.06$).

RS was independently associated with a significantly lower probability of conversion (OR 0.58, 95% CI 0.46–0.72, $p<0.001$) compared with LS (Table 3). Intraoperative procedures and findings associated with higher risk of conversion included other colon resection (OR 3.13, 95% CI 2.10–4.62), the presence of peritoneal abscess or fistula (OR 2.14, 95% CI 1.65–2.74), and the presence of adhesions (OR 2.79, 95% CI 2.41–3.23) (all p values < 0.001). Hand assistance with surgery conveyed lower risk (OR 0.67, 95% CI 0.55–0.79).

Patients whose surgeons had medium–high and high-volume experience were also at significantly less risk (75% and 51% less, respectively) of being converted than patients of surgeons with low-volume experience. Conversion was also less likely when the operating surgeon was a Colorectal ($p < 0.001$) compared with a General Surgeon. Teaching (versus nonteaching) hospital providers conferred 30% greater risk ($p = 0.001$) and nonurban (versus urban) providers 33% higher odds of conversion ($p = 0.03$).

The predicted risks of conversion to OS for LS compared with RS, after adjustment for all risk covariates, were 13.1% and 8.0%, respectively ($p < .001$).

Impact of conversion

Thirty-day postoperative outcomes are shown in Table 4. Complication rates were significantly higher for MIS converted (40%) than for MIS completed (20.3%, $p < 0.001$) and OS (31.6%, $p < 0.001$). Ileus and surgical-site infections were also significantly higher for MIS converted than for MIS completed and OS. Blood transfusion and readmissions were significantly higher for MIS converted than for MIS completed operations and not significantly different compared with OS.

Examination of perioperative outcomes showed that operating room time was 27 min longer and inpatient length of stay was 2.4 days longer in converted patients than in patients whose surgeries were completed using MIS ($p < 0.001$) (Table 4). The differences in inflation-adjusted total ($4971), direct ($2760), and overhead ($2212) costs for conversions versus surgeries completed by MIS were highly significant as well ($p < 0.001$). Comparisons of these outcomes between converted patients and patients who had OS indicated statistically longer operating room time ($p < 0.001$) and greater overhead costs ($p = 0.01$) with conversion. Total costs in the converted group were also higher than OS by $1708, but this difference did not reach statistical significance ($p = 0.07$).

Discussion

This study used a large administrative and clinical database to gain real-world-setting insights into rates of conversion for surgery for diverticulitis, risk factors for conversion, and how rates compare among surgeons, specialty, and hospitals for benign but challenging sigmoid diverticular disease. We also investigated and demonstrated the downstream negative implications of conversion. As MIS options continue to evolve, conversion rates and understanding the impact of conversion require updated monitoring so that surgeons have data that help guide surgical choices. LS is a challenging operation, especially when complicated by adhesions, obesity, peritoneal abscess and fistula, and other risk factors for conversion [30]. Based on these data, surgeons may choose the LS option more selectively in patients with fewer conversion risk factors.

This study revealed that risk for MIS conversion is significantly higher for patients who are Black, have Medicaid insurance, have multiple comorbidities, are obese, have concomitant colon resections, or have abscesses, fistulas, or adhesions. Risk for MIS conversion is significantly less with the robotic-assisted approach, with greater surgeon

Table 4 Perioperative and 30-day postoperative outcomes in completed minimally invasive, converted, and open sigmoidectomy

	Intension to treat MIS $n = 9377$	Completed MIS $n = 8214$ (87.2%)	Converted $n = 1163$ (12.8%)	p value[a]	Planned open $n = 3863$	p value[b]
Any postoperative complication	2132 (22.7%)	1667 (20.3%)	465 (40.0%)	< 0.001	1222 (31.6%)	< 0.001
Ileus	878 (9.4%)	676 (8.2%)	202 (17.4%)	< 0.001	466 (12.1%)	< 0.001
Surgical-site infection	491 (5.2%)	361 (4.4%)	130 (11.2%)	< 0.001	325 (8.4%)	0.005
Postoperative blood transfusion	293 (3.1%)	203 (2.5%)	90 (7.7%)	< 0.001	291 (7.5%)	0.87
Postoperative readmission related to complication	514 (5.9%)	424 (5.2%)	90 (7.8%)	< 0.001	255 (6.7%)	0.18
	Mean (SD)	Mean (SD)	Mean (SD)		Mean (SD)	
Operation room time, mins	217 (74)	213 (72)	240 (78)	< 0.001	189 (73)	< 0.001
Inpatient length of stay, days	5.8 (3.2)	5.5 (2.8)	7.9 (4.8)	< 0.001	7.9 (5.6)	0.82
Total cost, US dollars[c]	16,941 (11,190)	16,325 (10,201)	21,296 (15,915)	< 0.001	19,588 (31,337)	0.07
Direct cost	8873 (6804)	8530 (6170)	11,290 (9886)	< 0.001	10,422 (23,759)	0.22
Overhead cost	8069 (6345)	7794 (5754)	10,006 (9306)	< 0.001	9166 (10,203)	0.01

MIS minimally invasive surgery

[a] p value comparison between completed MIS and converted groups

[b] p value comparison between converted and planned open groups

[c] All cost data reported using inflation adjusted relative to 2015 US dollars

volume, and for colorectal specialists. Converted cases are characterized by longer operating times and hospital LOS, more postoperative complications, readmissions, and blood transfusions, and higher costs than cases completed successfully via MIS.

MIS conversion rates and conversion risk factors

The significantly higher conversion rate for LS (13.6%) compared with RS (8.3%) in our study was not unexpected. Although there is a paucity of data on conversion rates specific to sigmoidectomy, this finding of lower rates for the robotic-assisted approach compared with the laparoscopic option is consistent with data from other studies evaluating conversion rates for colorectal procedures [17, 31, 32].

Our study adds to the value of conversion–risk assessment for MIS sigmoidectomy. Patients requiring "complex" sigmoidectomy for diverticular disease are at higher risk for conversion and may benefit from a different operative plan when the laparoscopic approach is too challenging. These "complex" operations include those characterized by adhesions, diverticular disease with peritoneal abscess or fistula, and those having concomitant colon resection. Although the reason for conversion may be more difficult to determine, other groups that may benefit from the robotic-assisted approach include Medicaid-insured patients with multiple comorbidities (CCI ≥ 2). Other studies have also determined that age, comorbidity, obesity, and case complexity are associated with the increased conversion risk for sigmoidectomy [18, 33–37] and other colorectal procedures [13, 30, 38–43]. Teaching hospitals and rural regions were also significant risk factors for conversion in our study. Another study confirmed our finding of a higher rate of conversion for laparoscopic colorectal surgeries at teaching hospitals [13]. Although the difference in conversion rates between teaching and non-teaching hospitals in our study is statistically significant, the absolute difference is small (13.5% vs 11.7%) and may not have real-world significance. The difference between conversion rates at urban and nonurban hospitals is also small (3.9%). The reason for the small difference is difficult to determine and is likely multifactorial.

The robotic-assisted surgical approach, the hand-assisted approach, and high surgeon volumes were protective factors against conversion in our study. Others have confirmed these findings with one study showing lower conversion rates for hand-assisted approach than for conventional laparoscopic elective sigmoidectomy for diverticulitis [44]. Several studies have demonstrated that higher surgeon volume decreases the risk for conversion for laparoscopic sigmoidectomy [18, 33] and other colorectal procedures [32, 39].

The impact of conversion

The benefits of MIS and the negative impact of MIS conversion in elective sigmoidectomy for diverticular disease were clearly demonstrated in our study. Outcomes that are favorable for MIS completed compared with MIS converted groups include hospital LOS, blood transfusions, 30-day postoperative complications, and readmission rates. Other studies have confirmed many of these differences between MIS completed and MIS converted patient populations in our study, while some reveal MIS converted outcomes comparable to conventional open laparotomy [14, 18, 33, 34, 41, 42]. A meta-analysis comparing outcomes of MIS converted versus open colorectal resections showed no significant difference in hospital LOS and 30-day morbidity, but there were higher rates of surgical-site infections in MIS converted patients [42, 43].

MIS converted cases were associated with significantly higher inflation-adjusted total, direct, and indirect costs than MIS completed cases, and higher (although not statistically significant) total costs than traditional open procedures in our study. Other studies have shown MIS converted hospital charges or risk-adjusted payments that were higher compared with MIS completed but lower than that with open colorectal resections [13, 17]. These findings reflect the higher cost and expense of utilization healthcare resources for MIS converted and open procedures.

The strength of this study is that it is a large, real-world database analysis composed of diverse patients, surgeons, and hospitals. There are limitations inherent to any analysis of retrospective data. Data reliability depends on accurate abstraction of disease- and procedure-related outcomes by ICD and CPT codes. The same possible coding errors were applicable to each study group so it is unlikely that there would be systematic bias in the comparative analysis of results. It was not possible to control for all patient, surgeon, and hospital covariates. Surgeon decision-making for operative approach may introduce selection bias. Variation in surgeon techniques may potentially impact the results of this study. Conversions early in the case due to adhesions or obesity are associated with better outcomes than conversions later in the procedure associated with lack of progress, bleeding, or visceral injury [42]. Operative timing of conversion was not available in this database. A randomized trial conducted by surgeons of equal laparoscopic and robotic colorectal skill sets would be the ideal study design, but is not likely to occur. PSM methodology to control bias may currently be the most practical approach to assessing differences in surgical approaches [44, 45]. Finally, we chose to combine LS and RS into a single MIS group in the analysis and showed a difference in conversion rate, but the two platforms may share similar risk factors.

This study demonstrates that MIS is the preferred option for sigmoidectomy for diverticular disease when available and that conversion risk assessment is an opportunity to improve outcomes in this patient population. It is not practical in the current healthcare environment to provide access to high-volume laparoscopic surgeons in specialty centers to all patients with complicated diverticulitis. RS may be a consideration for patients who have multiple conversion risk factors. This study suggests that conversion risk factors should be considered when providing patients informed consent and when choosing surgical approach options. Self-assessed surgeon skill set and hospital resources will impact the conversations leading to these decisions. Furthermore, these results may influence needs assessments by hospitals, postgraduate surgeons, and residency programs for training opportunities.

Conclusion

Conversion from minimally invasive to open sigmoidectomy for diverticular disease results in additional morbidity and healthcare costs. Consideration of modifiable risk factors for conversion may attenuate adverse associated outcomes. Evolving MIS technologies and MIS training techniques may potentially improve MIS proficiency and decrease conversion rates.

Acknowledgements The authors wish to express their gratitude to Helen B. Hubert, PhD, consulting epidemiologist, for her assistance with manuscript preparation.

Compliance with ethical standards

Disclosures Dr. Amir Bastawrous has received honoraria for courses, lectures, and proctoring from Intuitive Surgical, Inc. Dr. Robert Cleary has received honoraria for courses and lectures from Intuitive Surgical, Inc. Dr. Ron Landmann has received honoraria for teaching from Intuitive Surgical, Inc. Yuki Liu is a Health Economist and Data Scientist at Intuitive Surgical, Inc. Emelline Liu is the Director of Global Health Economics and Outcomes Research at Intuitive Surgical, Inc.

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