Comparison of Open, Laparoscopic, and Robotic Colectomies Using a Large National Database: Outcomes and Trends Related to Surgery Center Volume

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BACKGROUND: Previous studies have shown that high-volume centers and laparoscopic techniques improve outcomes of colectomy. These evidence-based measures have been slow to be accepted, and current trends are unknown. In addition, the current rates and outcomes of robotic surgery are unknown.

OBJECTIVE: The purpose of this study was to examine current national trends in the use of minimally invasive surgery and to evaluate hospital volume trends over time.

DESIGN: This was a retrospective study.

SETTINGS: This study was conducted in a tertiary referral hospital.

PATIENTS: Using the National Inpatient Sample, we evaluated trends in patients undergoing elective open, laparoscopic, and robotic colectomies from 2009 to 2012. Patient and institutional characteristics were evaluated and outcomes compared between groups using multivariate hierarchical-logistic regression and nonparametric tests. The National Inpatient Sample includes patient and hospital demographics, admission and treating diagnoses, inpatient procedures, in-hospital mortality, length of hospital stay, hospital charges, and discharge status.

MAIN OUTCOME MEASURES: In-hospital mortality and postoperative complications of surgery were measured.

RESULTS: A total of 509,029 patients underwent elective colectomy from 2009 to 2012. Of those 266,263 (52.3%) were open, 235,080 (46.2%) laparoscopic, and 7686 (1.5%) robotic colectomies. The majority of minimal access surgery is still being performed at high-volume compared with low-volume centers (37.5% vs 28.0% and 44.0% vs 23.0%; $p < 0.001$). A total of 36% of colectomies were for cancer. The number of robotic colectomies has quadrupled from 702 in 2009 to 3390 (1.1%) in 2012. After adjustment, the rate of iatrogenic complications was higher for robotic surgery (OR = 1.73 (95% CI, 1.20–2.47)), and the median cost of robotic surgery was higher, at $15,649 (interquartile range, $11,840–$20,183) vs $12,071 (interquartile range, $9338–$16,203; $p < 0.001$ for laparoscopic).

LIMITATIONS: This study may be limited by selection bias by surgeons regarding the choice of patient management. In addition, there are limitations in the measures of disease severity and, because the database relies on billing codes, there may be inaccuracies such as underreporting.

CONCLUSIONS: Our results show that the majority of colectomies in the United States are still performed open, although rates of laparoscopy continue to increase. There is a trend toward increased volume of laparoscopic procedures at specialty centers. The role of robotics is still being defined, in light of higher cost, lack of clinical benefit, and increased iatrogenic complications, albeit comparable overall complications, as compared with laparoscopic colectomy.

KEY WORDS: Colectomy; Colorectal cancer; Laparoscopy; Robotic; Volume outcome.

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Over the past 20 years, volume and techniques of colectomy surgery have been evaluated using national data.[1–4] National cohort studies from the early 2000s showed that patients undergoing colectomy fared better when they received their care at high-volume centers.[5,6] These findings prompted recommendations for increasing specialization and referrals to high-volume institutions and surgeons.[6–9] This policy intervention has been advocated in a form of regionalization of care by several high-impact policy groups.[9,10] However, whether there has been a shift toward regionalization on a national level is unknown.

Simultaneously, the use of minimal access surgeries such as laparoscopic colectomy has been growing and replacing the old standard of open surgery for both benign and malignant colon resections.[11–13] When compared with open surgery, laparoscopic technology has been shown to be associated with shorter length of stay, decreased hospital costs, and reduced mortality.[14] However, data regarding its adoption and diffusion on a national level have been limited, partially because of a lack of appropriate billing codes.[15] Adding to the complexity is the recent and growing interest in the use of robotics in colectomy.[16,17] Although there is some limited supportive evidence, robot use in colectomy is controversial because of higher costs and the paucity of data regarding outcomes on a national level.[18–20]

Understanding current patterns with regard to these 2 trends in colorectal surgery requires comprehensive evaluation and comparison using large national databases. Accordingly, we sought to examine a national cohort of patients undergoing colectomy in the context of adoption of minimally invasive surgery (MIS), such as laparoscopic and robotic methods compared with traditional open methods, and interaction with changes in surgery volume over the past 3 years. A secondary goal of this study was to compare the outcomes after robotics and laparoscopy in the early years of robotic adoption.

PATIENTS AND METHODS

Data Source

The Agency for Healthcare Research and Quality has maintained the Nationwide Inpatient Sample (NIS) database since 1988, which has recently been renamed the National Inpatient Sample in 2012. The NIS contains data on more than 8 million hospital stays from approximately 1000 community hospitals. It is the largest all-payer inpatient database in the United States and represents a stratified 20% sample of inpatient admissions to acute care hospitals nationwide. Data contained within the NIS include patient and hospital demographics, admission and treating diagnoses, inpatient procedures, in-hospital mortality, length of hospital stay, hospital charges, and discharge status. The NIS data set has numerous internal quality measures and is validated by the Healthcare Cost and Utilization Project by comparison with other similar databases, the National Discharge Survey and the Medicare Provider Analysis and Review.[21] This study was approved by the institutional review board at Weill Cornell Medical College (protocol No. 1209013064) and conforms to the data use agreement for the NIS from the Healthcare Cost and Utilization Project.

Patient Population

The study population consists of patients listed in the NIS database who underwent elective colectomy as the principal procedure from 2009 to 2012. All of the patients undergoing open (*International Classification of Diseases, Ninth Revision, Clinical Modification* procedure codes: 45.72, 45.73, 45.75, and 45.76) or laparoscopic (17.32, 17.33, 17.35, and 17.36) left or right colectomies were included. If a patient was marked as undergoing both a laparoscopic and open procedure, the patient was classified as laparoscopic for an intent-to-treat analysis, even if the patient actually underwent conversion to open. Patients undergoing a proctectomy (*International Classification of Diseases, Ninth Revision, Clinical Modification* codes 48.5, 48.51, 48.52, 48.53, 48.62, and 48.63) during the same hospitalization were excluded. Robotic assistance and additional laparoscopic procedures were identified by the presence of codes 17.42, 17.49, and 17.39. We chose these recent years because coding methods before 2009 may have underrepresented the number of minimally invasive procedures; new coding for MIS and robotic colectomy are now widely used.[22]

Variables

We categorized patients based on age, sex, race (white vs nonwhite), and procedure status (emergent vs nonemergent). Patient diagnosis and relevant comorbidities were identified from the patient's *International Classification of Diseases, Ninth Revision, Clinical Modification* diagnosis codes during the index hospitalization using previously validated algorithms (Table 1).[23] Variation attributed to hospital location, teaching status, region, and annual colectomy volume (all procedures) were also considered. There is no current convention or standard for determining high- and low-volume facilities for colectomy, so we included volume as a continuous variable for analysis and also investigated by tertiles of patients for ease of presentation, as was done in the past.[24] The categories presented are low volume (1–92 colectomies per year), midvolume (93–174 colectomies per year), and high volume (175 or more colectomies per year). Through 2011, the NIS sample included 100% of discharges from a 20% sample of hospitals within each sampling strata. In 2012, the sampling strategy changed to a 20% sample of discharges across hospitals. Therefore, facility volume used before 2012 is exact, whereas in 2012 it is a weighted estimate.

TABLE 1. Demographics, comorbidities, and hospital characteristics

Characteristic	Robotic (n = 7686)	Laparoscopic (n = 235,080)	Open (n = 266,263)	p
Procedure, n (%)				<0.0001
Right colectomy	2755 (35.8)	117,005 (49.8)	123,009 (46.2)	
Left colectomy	4931 (64.2)	118,075 (50.2)	143,254 (53.8)	
Year, n (%)				<0.0001
2009	702 (9.1)	54,985 (23.4)	69,348 (26.0)	
2010	1170 (15.2)	55,606 (23.7)	68,711 (25.8)	
2011	2424 (31.5)	65,539 (27.9)	68,319 (25.7)	
2012	3390 (44.1)	58,950 (25.1)	59,885 (22.5)	
Age median, n (IQR)	62 (52–71)	62 (52–72)	65 (54–74)	<0.0001
Age group, n (%), y				<0.0001
<18	5 (0.1)	1028 (0.4)	1793 (0.7)	
18–54	2420 (31.5)	70,024 (29.8)	67,745 (25.4)	
55–64	1997 (26.0)	58,887 (25.0)	61,249 (23.0)	
65–74	2009 (26.1)	59,122 (25.1)	69,537 (26.1)	
≥75	1255 (16.3)	46,020 (19.6%)	65,939 (24.8)	
Sex, n (%)				<0.0001
Women	4467 (58.1)	124,605 (53.2)	147,300 (55.4)	
Race, n (%)				<0.0001
White	5830 (79.0)	174,701 (81.3)	188,338 (80.1)	
Diagnosis, n (%)				
Colon cancer	1985 (25.8)	80,410 (34.2)	100,076 (37.6)	<0.0001
Diverticulitis	3328 (43.3)	85,460 (36.4)	80,780 (30.3)	<0.0001
IBD	147 (1.9)	8333 (3.5)	12,084 (4.5)	<0.0001
Comorbidities, n (%)[a]				
CHF	160 (2.1)	6965 (3.0)	14,237 (5.3)	<0.0001
Diabetes mellitus	1142 (14.9)	38,032 (16.2)	49,902 (18.7)	<0.0001
Hypertension	3415 (44.4)	108,069 (46.0)	125,113 (47.0)	0.0015
Chronic pulmonary disease	1085 (14.1)	31,129 (13.2)	42,148 (15.8)	<0.0001
Peripheral vascular disease	170 (2.2)	6620 (2.8)	11,984 (4.5)	<0.0001
Renal failure	268 (3.5)	8287 (3.5)	14,205 (5.3)	<0.0001
Insurance, n (%)				<0.0001
Commercial	3927 (51.1)	119,306 (50.8)	105,440 (39.7)	
Medicaid	285 (3.7)	7349 (3.1)	13,989 (5.3)	
Medicare	3228 (42.0)	99,437 (42.4)	132,868 (50.0)	
Annual hospital volume median, n (IQR)[b]	155 (95–245)	141 (86–232)	118 (62–196)	<0.0001
Annual hospital volume group, n (%)[b]				<0.0001
1–92 (low)	1745 (22.7)	65,893 (28.0)	101,946 (38.3)	
93–174 (mid)	2525 (32.8)	80,949 (34.4)	86,952 (32.7)	
175+ (high)	3416 (44.4)	88,237 (37.5)	77,365 (29.1)	
Hospital location, n (%)				<0.0001
Urban	4199 (99.1)	161,438 (92.7)	175,341 (85.9)	
Hospital teaching status, n (%)				<0.0001
Teaching	2328 (54.9)	87,733 (50.4)	97,145 (47.6)	
Hospital region, n (%)				<0.0001
Midwest	1944 (25.3)	52,984 (22.6)	71,046 (26.7)	
Northeast	1766 (23.0)	46,723 (19.9)	48,942 (18.4)	
South	2766 (36.0)	91,266 (38.9)	98,588 (37.0)	
West	1210 (15.7)	43,892 (18.7)	47,547 (17.9)	

IQR = interquartile range; CHF = congestive heart failure.
[a]Data are based on National Inpatient Sample comorbidity software version 3.6.
[b]Volume from 2009 to 2011 is precise from 100% of discharges per hospital, for 2012 volume is a weighted estimate based on a 20% sample.

Outcomes

Outcomes of interest were in-hospital mortality and cardiovascular, pulmonary, infectious, iatrogenic, urinary, and GI complications of surgery, which were determined by *International Classification of Diseases, Ninth Revision, Clinical Modification* diagnosis codes (Table 1). Length of stay is provided for each discharge. Costs were determined by applying group and facility level cost to charge ratios,= and applying a Diagnosis Related Group–based scaling factor to the estimates as recommended by the Healthcare Cost and Utilization Project.[25,26]

Statistical Analysis

Patient demographics, procedure, and hospital characteristics were compared across open, laparoscopic, and robotic procedures in the weighted national sample using

χ^2 tests for categorical variables and Kruskal-Wallis tests for continuous variables. Categorical outcomes between laparoscopic and robotic procedures are also compared using χ^2 tests; length of stay and cost are compared using Wilcoxon rank-sum test. Procedure uptake across years and outcomes by hospital volume are explored graphically. Because of the 2012 NIS redesign, the trend analysis did not include 2012. ORs for in-hospital mortality and complications were created using crude and adjusted hierarchical logistic regression models, which account for clustering of patients within hospitals. Multivariate models were adjusted for procedure side, age, sex, hospital volume, and diagnosis of colon cancer, diverticulitis, IBD, diabetes mellitus, congestive heart failure, hypertension, and chronic lung disease.

RESULTS

A total of 509,029 patients underwent elective colectomy procedures without proctectomy from 2009 to 2012. Of the 509,029 procedures, 266,263 (52.3%) were performed open, 235,080 (46.2%) laparoscopically, and 7686 (1.5%) robotically (Table 1). Mean patient age in the cohort was 62.5 years. The majority of patients were white (80.6%) and women (54.4%). A total of 36% of cases were performed for a diagnosis of cancer. The proportion of open cases decreased slightly over the 3 years (55.5% to 49.0%; $p < 0.0001$), with a corresponding increase in laparoscopy (44.0% to 48.2%; $p < 0.0001$) and robotic surgery procedures (0.6% to 2.8%; $p < 0.0001$). The robotic group tended to have fewer patients aged >75 years, more patients who were women, and was more often performed for benign reasons. MIS procedures were more often performed in patients with commercial insurance when compared with open procedures (51.1% robotic, 50.8% laparoscopic, and 39.7% open; $p < 0.0001$).

The majority of minimal access cases are still being performed at high-volume centers (37.5% of laparoscopic, 44.4% of robotic; $p < 0.0001$) compared with midvolume (34.4% of laparoscopic, 32.8% of robotic; $p < 0.0001$) or low-volume centers (28.0% of laparoscopic, 22.7% of robotic; $p < 0.0001$). From 2009 to 2011, where we had MIS-specific billing codes, there was an increase in the number of MIS procedures, accompanied by a decrease in open procedures from low-volume centers. In midvolume facilities the volume of MIS was stable, but there was a decrease in the volume of open procedures. Finally, in high-volume facilities there was an increase in case volume for both MIS and open procedures, but the increase was much larger for MIS surgeries (Fig. 1).

Differences between laparoscopy versus robotic procedure were not significant in bivariate or multivariable analyses of cardiovascular complications, mortality, and urinary, GI, or pulmonary complications (Tables 2 and 3).

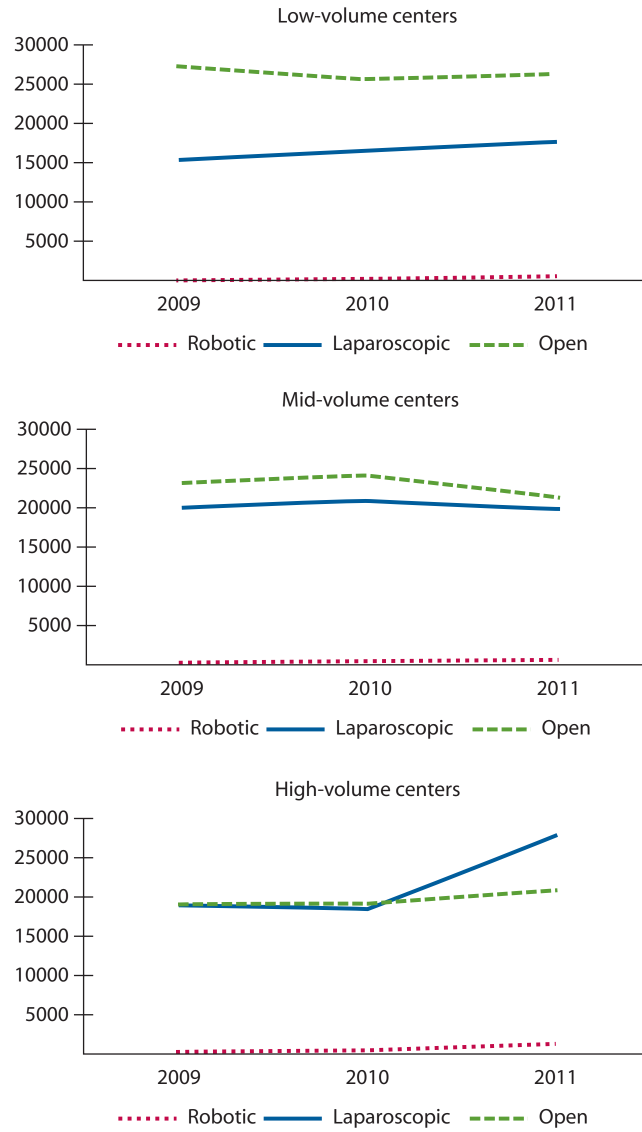

FIGURE 1. Number of procedures from 2009 to 2011 by type (open, laparoscopic, robotic) in (A) low-volume (1–92 colectomies per year), (B) midvolume (93–174 colectomies per year), and (C) high-volume centers (175 or more colectomies per year).

However, the probability of iatrogenic complications (accidental puncture and bleeding complicating surgery) was significantly higher for robotic surgery (OR = 1.73 (95% CI, 1.20–2.47)); meanwhile, the median estimated costs of robotic surgery were higher at $15,649 (interquartile range, $11,840–$20,183) versus $12,071 (interquartile range, $9338–$16,203; $p < 0.0001$) for laparoscopic surgery. Rates of iatrogenic complications during robotic colectomy were not found to be significantly different based on hospital volume. Furthermore, the variation in hospital outcomes among robotic, laparoscopic, and open surgeries appears to be consistent across hospital volume groups (Fig. 2). The median length of stay was significantly less for both laparoscopic and robotic colectomies as compared with open colectomy (4 days, 4 days, and 6 days;

TABLE 2. Unadjusted outcomes of robotic and laparoscopic colectomy

Variable	*Robotic (n = 7686)*	*Laparoscopic (n = 235,080)*	*p*	*Open (n = 266,263)*
In-hospital mortality, n (%)	25 (0.3)	980 (0.4)	0.5368	4700 (1.8)
Complications, n (%)				
Mortality/stroke/MI	142 (1.8)	4391 (1.9)	0.9408	11,038 (4.1)
Cardiovascular complications	494 (6.4)	17,710 (7.5)	0.0789	30,000 (11.3)
Pulmonary complications	425 (5.5)	14,273 (6.1)	0.3596	34,451 (12.9)
Infectious complications	362 (4.7)	10,255 (4.4)	0.5175	29,843 (11.2)
Iatrogenic complications	299 (3.9)	5445 (2.3)	0.0015	13,315 (5.0)
Urinary complications	35 (0.4)	2135 (0.9)	0.009	2808 (1.1)
GI complications	570 (7.4)	19,187 (8.2)	0.2689	32,343 (12.1)
Median length of stay, n (IQR), d	4 (3–5)	4 (3–6)	<0.0001	6 (5–9)
Median total charges, n (IQR), $	50,877 (35,380–74,662)	38,601 (27,255–56,176)	<0.0001	43,716 (29,235–70,645)
Median estimated cost, n (IQR), $	15,649 (11,840–20,183)	12,071 (9338–16,203)	<0.0001	14,141 (10,209–21,234)

MI = myocardial infarction; IQR = interquartile range.

$p < 0.0001$). The statistical difference seen between robotic and laparoscopic colectomies can be explained by skewed data, with larger differences seen in longer lengths of stay in the laparoscopic group.

DISCUSSION

In this national cohort study we found that the majority of colectomies in the United States are still being done using an open method. In mid- and high-volume centers, laparoscopy is rapidly approaching 50%. We demonstrate a trend toward increased volume and rate of laparoscopic surgery at specialty centers, showing that some regionalization is taking place. This is the first study to demonstrate that now the majority of cases are being done at mid- and high-volume centers. Robotic colectomy still appears to be at the learning stage/curve' with a higher rate of iatrogenic complications, albeit a similar rate of overall complications, associated with robotic colectomy compared with laparoscopy.

It has been more than a decade since studies first showed benefit from both laparoscopic colectomy and surgery at high-volume hospitals.[27] There have been conflicting data on the national trends in regionalization and surgical techniques currently being used, much attributed to issues with coding. Since 2009, specific coding for MIS has been available that allows us to properly examine trends in the national cohort and to characterize the current use of MIS and patterns of regionalization.

Previous authors have suggested that laparoscopic colectomy was being used in ≈50% of cases nationally and that earlier concerns of lack of use were unwarranted.[15] Our data, with improved coding, show that open procedures are still being performed in the majority of cases, although laparoscopy use does appear to be increasing. Some previous studies show that minimally invasive techniques are more likely to be performed at higher-volume centers.[28,29] We substantiated these results in our study, and in our patient cohort we found the greatest increase in the last few years and primarily at high-volume centers. We found a trend toward increased regionalization, especially in the MIS procedures. Although many questions remain as to how much regionalization can happen given practical constraints, such as patient accessibility to high-volume centers and resource availability, our data support that regionalization is taking place. In addition, we found that MIS procedures were more often performed in patients with commercial insurance when compared with open procedures. We believe that this may be reflective of ongoing healthcare delivery disparities, because minorities and underserved have been shown to be less likely to be insured and less likely to have MIS procedures.[30]

Advocates of robotic surgery argue in the literature that the robotic platform offers improved range of motion, stable 3-dimensional vision, and ease with intracorporeal suturing.[31] In this first U.S.-based national study we found that iatrogenic injuries have been higher after robotic surgery. There might be a number of reasons, such as early learning curve, device failure, and the lack of tactile sensation.[32] To our knowledge, this is the first study to demonstrate increased iatrogenic injury associated with the use of robotic surgery in patients undergoing colec-

TABLE 3. Crude and adjusted OR for complications of robotic vs laparoscopic colectomy

Variable	*Crude OR (95% CI)*	*Adjusted OR (95% CI)[a]*
Mortality/stroke/MI	0.99 (0.66–1.47)	1.07 (0.59–1.94)
Cardiovascular complications	0.84 (0.68–1.04)	0.96 (0.7–1.32)
Pulmonary complications	0.91 (0.72–1.14)	0.99 (0.72–1.35)
Infectious complications	1.08 (0.85–1.38)	1.05 (0.75–1.48)
Iatrogenic complications	1.71 (1.3–2.24)	1.73 (1.2–2.47)
Urinary complications	0.49 (0.24–1.01)	0.59 (0.23–1.5)
GI complications	0.9 (0.73–1.11)	0.89 (0.66–1.19)

MI = myocardial infarction; IQR = interquartile range.
[a]Models were adjusted for left- or right-side procedure, age (>65 years), sex, hospital volume, and diagnosis of colon cancer, diverticulitis, IBD, diabetes mellitus, congestive heart failure, hypertension, and chronic lung disease.

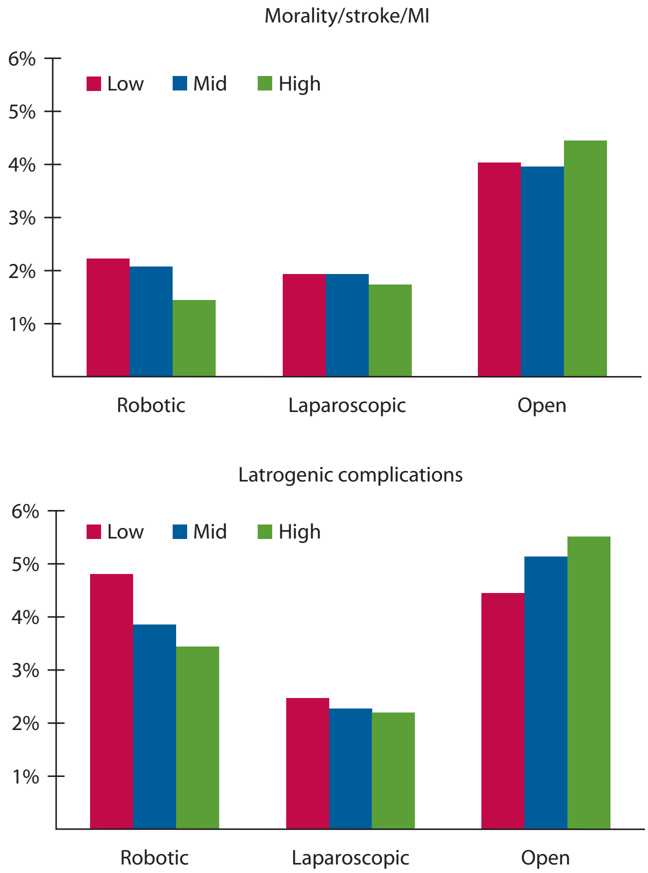

FIGURE 2. Percentage of patients with (A) in-hospital mortality, stroke, or myocardial infarction (MI) and (B) iatrogenic complications by hospital volume and procedure type.

tomy in a national data set. Two other studies using national data sets found a higher postoperative bleeding rate when comparing robotic-assisted colorectal surgery with conventional laparoscopic colectomy.[33,34] As surgeons gain more experience with robotic surgery, complication rates may decrease similar to trends seen in laparoscopic colectomy and cholecystectomy over time.[35,36]

However, because of concerns of increased iatrogenic complications and a lack of demonstrable benefits of the robotic technique in colon surgery, outcomes after robotic colectomy should be monitored closely within a registry over the next several years, especially in light of higher costs. We believe that the difference in cost between the robotic and laparoscopic groups likely reflects the higher hospital charges and longer operative times in robotic surgery that have been reported previously.[33,34,37] In contrast, the difference in cost between the laparoscopic and open groups, however, likely reflects the shorter length of stay seen in the laparoscopic group. Despite the higher cost of robotic surgery and apparent lack of clinical benefit, 2 possible reasons to explain the continued adoption of robotic colectomy include perceived improved visualization and as a part of hospital marketing strategy.[38] Given the increased cost of robotic surgery, better understanding of the learning curve for robotic performance is critical to reduce complications and approach national concerns about the cost of healthcare spending.

Groups such as the Idea, Development, Exploration, Assessment, Long-term Follow-up collaboration and the American College of Surgeons National Quality Improvement Project have begun supporting a culture of evaluating care and procedures as they are introduced into the practice. The goal of these collaborations is to provide opportunities to improve outcomes and lower the costs.[39,40] On a national level, these data provide a starting point with which to begin the dialogue about the surgical quality and the importance of registries in helping track novel procedures and technologies. This will be particularly valuable to ensure unfettered access to outcomes of all novel technologies, including robotics, as the surgical community becomes familiar with their advantages and disadvantages. As in any study using administrative databases, there are limitations inherent in the data. Surgeon choice regarding patient management has the potential to show selection bias. To account for this, we made multivariable adjustments for comorbidities, age, and patient factors. However, other demographic factors, such as BMI and immune suppression, may be unaccounted for. In addition, there are limitations in the measures of disease severity. Our multivariable analysis accounts for patient health status using comorbidities, but these are only surrogates for actual patient health. In addition, because the database relies on billing codes, there may be inaccuracies such as underreporting. We believe that this could actually make positive results about complications more robust. Because we opted to perform an intention-to-treat analysis by not separating out those patients who underwent conversion, this may skew data in the laparoscopic group to worse outcomes. We believe that this approach, however, is less prone to coding inaccuracies and more accurately reflects the risks of selecting a laparoscopic approach in patients who may have ultimately required conversion to open colectomy.

CONCLUSION

The volume-outcome relationship in colectomy is still strong, and there are trends toward regionalization of care to high-volume centers, particularly for newer techniques. As new techniques are being developed, we need to reflect on the higher risks associated with these techniques and monitor the outcomes. We found a higher rate of iatrogenic complications, albeit comparable with overall complication rates, during robotic as compared with laparoscopic colectomies, and our data did not show a reduction in high-volume institutions. Still, we believe that a national registry of colorectal procedures and improved coding measures should be considered to help clarify advantages and disadvantages of MIS techniques today and in the future. As our nation looks to improve patient outcomes and to control costs, involvement of patients, physicians, and professional societies in constructing high-quality databases will give us an opportunity to further elevate patient care.

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