SCIENTIFIC PAPER JSLS

Robotic-Assisted Versus Laparoscopic Colectomy: Cost and Clinical Outcomes

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ABSTRACT

Background and Objectives: Laparoscopic colectomies, with and without robotic assistance, are performed to treat both benign and malignant colonic disease. This study compared clinical and economic outcomes for laparoscopic colectomy procedures with and without robotic assistance.

Methods: Patients aged ≥18 years having primary inpatient laparoscopic colectomy procedures (cecectomy, right hemicolectomy, left hemicolectomy, and sigmoidectomy) identified by *International Classification of Diseases, Ninth Edition* procedure codes performed between 2009 and the second quarter of 2011 from the Premier Hospital Database were studied. Patients were matched to a control cohort using propensity scores for disease, comorbidities, and hospital characteristics and were matched 1:1 for specific colectomy procedure. The outcomes of interest were hospital cost of laparoscopic robotic-assisted colectomy compared with traditional laparoscopic colectomy, surgery time, adverse events, and length of stay.

Results: Of 25 758 laparoscopic colectomies identified, 98% were performed without robotic assistance and 2% were performed with robotic assistance. After matching, 1066 patients remained, 533 in each group. Lengths of stay were not significantly different between the matched cohorts, nor were rates of major, minor, and/or surgical complications. Inpatient procedures with robotic assistance were significantly more costly than those without robotic assistance (\$17 445 vs \$15 448, $P = .001$). Operative times were significantly longer for robotic-assisted procedures (4.37 hours vs 3.34 hours, $P < .001$).

Conclusion: Segmental colectomies can be performed safely by either laparoscopic or robotic-assisted methods. Increased per-case hospital costs for robotic-assisted procedures and prolonged operative times suggest that further investigation is warranted when considering robotic technology for routine laparoscopic colectomies.

Key Words: Robotic assisted, Colectomy, Laparoscopic, Outcomes.

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Acknowledgment: The authors acknowledge the work of Sara Haas, MS, who contributed to this study in the phases of concept and design, as well as analysis. Sara Haas, MS, statistician, was an employee of S^2 Statistical Solutions, which is a paid consultant to Ethicon Endo-Surgery.

Conflicts of interest and source of funding: This study was funded by Ethicon Endo-Surgery, Cincinnati, Ohio. B.R.D. is a consultant for Ethicon Endo-Surgery and receives honoraria for course instruction. A.C.Y. is an employee of Ethicon Endo-Surgery, the sponsor of the study. M.M. was an employee of Ethicon Endo-Surgery, the sponsor of the study, at the time this research was completed. M.M. is now an employee of Edwards Lifesciences. C.G. is President of S^2 Statistical Solutions, Inc., which is a paid consultant to Ethicon Endo-Surgery.

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DOI: 10.4293/108680813X13753907291035

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INTRODUCTION

Recent data suggest that approximately 1 110 000 men and women in the United States have a history of cancer of the colon and rectum.[1] Colectomy, often used to treat colorectal cancer, can be performed by various techniques. An open approach is the most frequent, but laparoscopic techniques are also used and well accepted.[2–4] The rate of laparoscopic techniques is increasing particularly in urban centers, in which laparoscopic colectomies are performed at a higher rate than in other settings.[2,3,5,6] Within the large Premier Hospital Database,[7] from 2009 through the second quarter of 2011, approximately one-third of segmental colectomies (cecectomy, right hemicolectomy, left hemicolectomy, and sigmoidectomy) were identified as having a laparoscopic procedural code.

Laparoscopic techniques have minimized the perioperative morbidity associated with many types of surgery, including colectomy.[8–10] Several prospective randomized trials have shown that laparoscopic colectomy has equivalent oncologic outcomes to the traditional open surgical approach. Additional advantages with regard to pain, blood loss, return of bowel function, length of hospitalization, and overall recovery time have been shown.[11–15]

Fewer postoperative complications have also been noted.[16] In addition, resource use is lower for laparoscopic colectomy, including reduced length of stay, fewer readmissions, and less use of skilled nursing facilities.[16,17]

Robotic-assisted surgery is an emerging approach in the field of laparoscopic colorectal surgery. Currently, there is only one commercially available robotic device cleared by the US Food and Drug Administration for laparoscopic procedures (da Vinci Surgical System; Intuitive Surgical, Sunnyvale, California). Several authors have published their experiences and case series related to robotic-assisted laparoscopic colectomy.[18,19] Although no specific large randomized controlled trials have evaluated robotic-assisted versus traditional laparoscopic colectomies, clinical outcomes suggest that robotic-assisted laparoscopic surgery is equivalent to conventional laparoscopy when considering important endpoints such as conversion to open surgery, hospital stay, and recovery time.[20,21]

In this era of comparative effectiveness and health care reform in the United States, and with concerns about optimal resource utilization at the forefront, the use of robotic-assisted laparoscopic surgery deserves further evaluation. Given this background, this study examined clinical and economic outcomes (cost and utilization) in patients undergoing laparoscopic colectomy performed with and without robotic assistance.

MATERIALS AND METHODS

Data Source

The Premier Hospital Database was used as the data source for this study.[7] This database contains complete patient billing, hospital cost, and coding histories from more than 600 health care facilities throughout the United States. The data from which this study was derived were extracted from more than 25 million inpatient discharges and 175 million hospital outpatient visits from acute care facilities, ambulatory surgery centers, and clinics across the nation.

A protocol describing the analysis objectives, criteria for patient selection, data elements of interest, and statistical methods was submitted to the New England Institutional Review Board, and exemption was obtained.

Eligible patients were aged ≥18 years and had undergone a laparoscopic colectomy during the period from 2009 to the second quarter of 2011. Patients were categorized according to the following 4 types of laparoscopic segmental colectomies: laparoscopic cecectomy (17.32), laparoscopic right hemicolectomy (17.33), laparoscopic left hemicolectomy (17.35), and laparoscopic sigmoidectomy (17.36). These procedures were chosen because the laparoscopic approach has been shown to have equivalent oncologic outcomes with documented perioperative morbidity benefits compared with open surgery. Other procedures, such as low anterior resection, where traditional laparoscopy has not yet been established to be equivalent to open surgery, were not included. Laparoscopic colectomy procedures using robotic technology were identified if one of two conditions was met: (1) a robotic *International Classification of Diseases, Ninth Edition* (ICD-9) procedure code accompanied the primary procedure code of interest or (2) "text" fields were found when mining the hospital charge master file for each patient indicating use of the robot.

For all eligible patients, elements describing hospital cost, surgery time, length of stay, use of the robot, colectomy type, and indication for colectomy were obtained from the data. Cost analysis (calculation) reflected the cost to the hospital for the colectomy procedures but did not include capital costs. This analysis was limited to the total cost per patient episode and did not break out costs at the level of disposables, operating room time, or other patient care costs. The specific cause of total cost differences was not formally evaluated. The preoperative All Patient Refined Diagnosis Related Groups severity level was used as an index of comorbidity. The 3M All Patient Refined Diagnosis Related Groups Classification System is a widely adopted proprietary risk-adjustment classification tool that uses information from routine claims data to produce valid and reliable severity measurement and risk-adjustment scores.[22] It is used to account for differences related to an individual's severity of illness or risk of death in large datasets. Comorbid conditions that might influence procedure selection or outcomes of interest, such as the presence of cardiovascular or pulmonary disease, cancer, or diabetes mellitus, were obtained by use of ICD-9 diagnosis codes. Comorbid conditions were grouped into 11 categories based on the Medical Expenditure Panel Survey data lists: arthritis, malignant neoplasms, mental disorders, metabolic diseases, diseases of the digestive system, diseases of the genitourinary system, diseases of the circulatory system, diseases of the musculoskeletal system and connective tissue, diseases of the nervous system, diseases of the respiratory system, and diseases of the cutaneous system.[23] **Appendix A** provides a detailed listing of all ICD-9 codes for each condition within each category. Information on sociodemographic characteristics and health insurance status was also included, as were descriptors of the care setting, namely census region, urban or rural setting, teaching hospital status, and facility bed count.

Adverse events identified by ICD-9 codes that occurred intraoperatively and ≤30 days postoperatively, which included pulmonary, cardiac, vascular, neurologic, and "other," were flagged and included in the analysis. The "other" category encompassed shock and perforations or fistulae of organs or vessels not included in the aforementioned organ systems. Minor and major bleeding was categorized by ICD-9 diagnosis as well as procedure codes related to hemorrhage and transfusions. A detailed list of each event and the corresponding ICD-9 code is found in **Appendix B**.

Each specific adverse event identified by ICD-9 code was organized as either major or minor categories based on clinical experience. These were then evaluated and characterized based on whether they were related to the surgical technique (bleeding, abscess, wound infection, and so on). Information on adverse events among matched data by analysis groups appears in **Appendix B**. Stoma procedures were identified and treated separately from the complications (**Appendix C**). Because of limitations of the dataset, it could not be determined whether these were planned stomas or due to a complication.

Statistical Analyses

The study objective was to use the Premier Hospital Database to compare clinical and economic outcomes in patients undergoing laparoscopic colectomy with and without the use of robotic assistance. Outcomes of interest included adverse events (minor, major, and surgical), whether a stoma was performed, hospital costs, length of stay, and surgery time.

A "quasi-randomization" method for limiting bias called propensity scoring was used to create groups of analyzable patients who were well matched.[24–26] Propensity scores were assigned based on likely predictors of the outcome of interest. Covariates on which to match were selected based on their availability in the Premier Hospital Database, as well as their general acceptance as factors associated with the outcomes of interest. The goal of this propensity matching analysis was to find pairs of patients receiving and not receiving a robotic laparoscopic colectomy who share like propensities for candidacy for the procedure based on the matching variables. An SAS macro from the Mayo Clinic used "nearest-neighbor matching" on the estimated propensity scores to choose matches for the patients who had a robotic procedure.[27] Propensity scores were calculated for receipt of robotic procedures for each of the patients included in the analysis based on a nonparsimonious multivariable logistic regression model. Patients were matched on the following 13 characteristics: age, gender, race, insurance type, primary ICD-9 procedure code, region of facility, urban versus nonurban classification of facility, teaching status of facility, number of beds at facility, and presence or absence of 4 comorbid conditions that were shown to be statistically significant before matching—skin cancer, colon cancer, hyperlipidemia, and hypothyroidism. The robotic and nonrobotic patients were randomly ordered, and the nonrobotic patient with the propensity score closest to that of the first robotic patient was chosen. Finally, a 1:1 match was obtained for their specific colectomy procedure type. Assessment of residual bias was conducted by evaluating the differences in the distribution of patient characteristics before and after matching.

To assess the extent to which the propensity matching reduced confounders, the distributions of several variables before and after matching were compared—including age, gender, race, insurance type, health status, region, location, facility type, primary ICD-9 procedure code, comorbid conditions, and cancer versus noncancer—based on the top 10 most frequently occurring ICD-9 diagnosis codes among the patients in the cohorts. Group comparisons were made by use of *t* tests and χ^2 tests after confirmation of approximately symmetric distribution of the variables and comparable variability before and after the match. We used *t* tests to test for differences between the matched cohorts in the 3 continuous variables of interest: hos-

Table 1.
Attrition Process

Description	No. of Patients Remaining	No. of Patients Dropped for Reason Listed
Total patients in Premier Hospital Database 2009 Q1[a] to 2011 Q2[a]	102 914 774	
Patients with primary procedure code for colectomy (17.32, 17.33, 17.35, 17.36)	25 977	102 888 797
Patients aged ≥18 y at date of procedure	25 883	94
Patients with inpatient visits only	25 758	125

[a]Q1 = first quarter; Q2 = second quarter.

Table 2.
Patient Demographics

	Robot	Nonrobot	*P* Value
Total n (% of total N = 25 758)	548 (2.1)	25 210 (97.9)	
Age [mean (minimum-maximum)]	61.36 (18–89)	62.08 (18–89)	.257
18–40 y	7.85	7.91	.493
41–50 y	15.33	13.19	
51–60 y	21.9	23.19	
61–70 y	26.09	25.03	
71–80 y	19.89	19.78	
>80 y	8.94	10.91	
Gender			
Female	54.2	53.09	.858
Male	45.8	46.91	
Unknown	0	0.01	
Insurance type			
Government	49.27	48.23	.543
Managed care	40.51	40.02	
Other	10.22	11.75	
Race			
White	68.25	71.15	<.001
African American	7.12	8.32	
Hispanic	12.41	5.00	
Other	12.23	15.53	
Health status			
APR-DRG[a] severity level 1 or 2	85.4	81.82	.031
APR-DRG severity level 3 or 4	14.6	18.18	
Primary ICD-9 procedure code			
17.32 laparoscopic cecectomy	2.19	5.01	<.001
17.33 laparoscopic right hemicolectomy	37.04	45.66	
17.35 laparoscopic left hemicolectomy	7.66	9.61	
17.36 laparoscopic sigmoidectomy	53.10	39.73	
Top 10 primary ICD-9 diagnosis codes			
Diverticulitis, colon (562.11)	35.22	27.97	<.001
Neoplasm, benign large intestine (211.3)	12.77	18.06	.001
Neoplasm malignant ascending colon (153.6)	9.49	10.38	.496
Neoplasm malignant sigmoid colon (153.3)	10.22	7.47	.016
Neoplasm malignant cecum (153.4)	7.12	7.08	.974
Diverticulitis, colon without hem (562.10)	2.74	2.25	.451
Neoplasm malignant hepatic flexure (153.0)	2.01	1.98	.958
Neoplasm malignant descending colon (153.2)	1.28	1.62	.526
Neoplasm malignant transverse colon (153.1)	1.09	1.6	.348
NEOP, UB, stomach/intestine (235.2)	2.37	1.5	.096

[a]APR-DRG = All Patient Refined Diagnosis Related Groups NEOP, UB = Neoplasm, Uncertain Behavior.

Table 3.
Hospital Demographics Based on Patient Counts

	Robot Patients	Nonrobot Patients
Total n (% of total N = 25 758)	548 (2.1)	25 210 (97.9)
Census region (%)		
Northeast	30.11	20.13
West	8.94	21.31
South	56.02	41.49
Midwest	4.93	17.08
Location (%)		
Urban	98.72	91.55
Nonurban	1.28	8.45
Type (%)		
Teaching	64.6	36.46
Non-teaching	35.4	63.54
Bed count (%)		
≤50	0.00	0.65
51–100	0.73	3.17
101–200	1.64	10.09
>200	97.63	86.09

pital cost, surgery time, and length of stay. Logistic regression models were used to test for significant differences between the two groups and to generate odds ratios on the following categories of adverse events and complications: major, minor, and surgical and whether the patient also received a stoma. Residuals and Akaike information criterion were checked for goodness of fit of the logistic regression models. Analyses were performed with SAS, version 9.2 (SAS Institute, Cary, North Carolina).

RESULTS

A total of 25 758 patient records from 364 hospitals were analyzed. The patient attrition process is shown in **Table 1**. Ninety-eight percent of all laparoscopic colectomies included in this analysis were performed without the use of robotic assistance (n = 25 210). Robotic assistance was used in 548 procedures, or approximately 2% of the total colectomies. The procedural breakdown was as follows: laparoscopic cecectomy, 12; right hemicolectomy, 203; left hemicolectomy, 42; and sigmoidectomy, 291 (**Table 2**).

Before matching, distributions were similar for age, gender, insurance, and most primary diagnosis codes for patients in both groups (**Table 2**). Furthermore, few differences in comorbidities or illness severity index were noted between the robotic and nonrobotic groups. The characteristics of the 364 hospitals with colectomy procedures were similar with regard to census region and location (urban vs rural). There were notable differences, however, in teaching versus nonteaching and bed count, with most robotic procedures being performed in teaching hospitals with >200 beds, as compared with nonrobotic procedures, with the majority coming from nonteaching hospitals with greater variation in bed size (**Table 3**). After matching, 1066 patients remained, with 533 patients in each group. Patient characteristics, comorbid conditions, and hospital characteristics after matching are represented in **Table 4**. After matching, patients were balanced with respect to demographics, comorbid conditions, and hospital characteristics, with the exception of hospital location (urban vs nonurban), which was statistically significantly different between the two groups ($P = .017$).

After matching, clinical endpoints and adverse events occurring in the postoperative period ≤30 days after discharge were tabulated and grouped into 4 categories: major, minor, surgical, and stoma related. Complications (major, minor, and surgical) and stoma procedures were not significantly different between the robotic and nonrobotic surgery cohorts, regardless of whether they were examined within a perioperative 30-day period or only within the original perioperative hospital stay (**Table 6**).

Cohorts were also tested for differences in average hospital costs, surgery time, and length of stay (**Table 5**). The average length of stay of the two cohorts was not statistically different (5.74 days for robotic vs 6.09 days for nonrobotic, $P = .344$). The inpatient surgery time was significantly longer for robotic-assisted procedures (4.37 hours; 95% confidence interval [CI], 4.24–4.51 hours) than for nonrobotic procedures (3.34 hours; 95% CI, 3.23–3.46 hours) ($P < .001$). Hospital costs were substantially higher for robotic-assisted laparoscopic colectomy than for procedures without robotic assistance ($17 445 vs $15 448, $P = .001$).

DISCUSSION

This study showed that in a real-world setting, one-third of all segmental colectomies are performed by a minimally invasive approach, the vast majority without robotic assistance (98%). When well-matched cohorts are compared, the results of laparoscopic colectomy with and without robotic assistance are similar with respect to clinical outcomes (length of stay) and when considering perioperative complications. Robotic-assisted procedures were associated with higher hospital costs and longer surgery times.

Table 4.
Matched Cohorts

	Robot	Nonrobot	*P* Value
Total n	533	533	
Age [mean (SD)]	61.09 (14.19)	61.2 (13.95)	.903
18–40 y	7.88	8.63	.943
41–50 y	15.57	14.07	
51–60 y	22.14	22.70	
61–70 y	26.45	27.77	
71–80 y	19.51	19.51	
>80 y	8.44	7.32	
Gender			
Female	53.85	54.22	.902
Male	46.15	45.78	
Insurance type			
Government	48.41	49.16	.574
Managed care	41.28	42.40	
Other	10.32	8.44	
Race			
White	68.29	66.42	.861
African American	7.32	7.50	
Hispanic	11.82	13.51	
Other	12.57	12.57	
Health status			
APR-DRG[a] severity level 1 or 2	85.18	87.43	.285
APR-DRG severity level 3 or 4	14.82	12.57	
Region			
Northeast	30.96	27.02	.400
West	9.19	8.07	
South	54.78	59.66	
Midwest	5.07	5.25	
Location			
Urban	98.69	96.44	.017
Nonurban	1.31	3.56	
Facility type			
Teaching	63.60	62.66	.751
Nonteaching	36.40	37.34	

Table 4. (continued)
Matched Cohorts

	Robot	Nonrobot	*P* Value
Comorbid conditions			
Arthritis			
Rheumatoid arthritis	1.69	1.13	.435
Psoriatic arthritis	0.00	0.75	.157
Ankylosing spondylitis	0.38	0.00	.045
Malignant neoplasms			
Skin cancer	0.00	0.00	NA
Colon cancer	12.57	12.95	.854
Lung, bronchus, or trachea	0.19	0.38	.563
Diseases of digestive system			
GERD[a]	12.57	13.13	.784
Gastritis	5.25	6.00	.595
Gastric ulcer	0.56	0.94	.478
Crohn disease	1.13	1.31	.780
Ulcerative colitis	0.56	0.38	.654
Diverticulitis of colon	24.58	23.26	.615
Disease of genitourinary system			
Kidney stones	2.25	0.94	.087
Cystitis	1.31	0.75	.363
Mental disorders			
Depressive disorders	6.94	6.57	.807
Neurotic disorders	4.32	4.32	<.999
Diseases of circulatory system			
Coronary artery disease	11.44	9.94	.428
Heart failure	3.56	4.32	.529
MI[a] (any)	3.56	3.19	.735
Stroke	0.75	0.94	.738
Cardiac dysrhythmias	8.82	9.94	.529
Hypertension	31.71	33.02	.647
Diseases of musculoskeletal system and connective tissue			
Irritable bowel syndrome	1.50	2.06	.487
Lumbar disk disease	1.50	2.81	.140
Osteoporosis	4.69	2.81	.107
Osteoarthritis	6.75	7.88	.480

The findings related to higher hospital costs associated with robotic surgery are consistent with similar studies in the literature evaluating other laparoscopic surgical procedures. Although there is a difference in hospital charges versus

Table 4. (continued) Matched Cohorts			
	Robot	Nonrobot	*P* Value
Diseases of nervous system			
Parkinson disease	0.00	0.75	.045
Multiple sclerosis	0.38	0.00	.157
Migraine	2.06	1.69	.652
Diseases of respiratory system			
Chronic bronchitis	0.94	1.69	.282
Emphysema	0.38	1.31	.094
Asthma	5.63	6.00	.794
COPD[a]	4.88	5.63	.583
Diseases of skin			
Eczema (dermatitis)	0.56	0.00	.083
Sebaceous gland diseases	0.19	0.19	<.999
Metabolic diseases			
Diabetes	13.51	11.07	.225
Hyperlipidemia	20.26	19.70	.818
Hypothyroidism	7.88	7.32	.729
Primary ICD-9 procedure code			
17.32: laparoscopic cecectomy	2.06	2.06	<.999
17.33: laparoscopic right hemicolectomy	36.77	36.77	
17.35: laparoscopic left hemicolectomy	7.69	7.69	
17.36: laparoscopic sigmoidectomy	53.47	53.47	
Cancer diagnosis			
Cancer	30.77	27.58	.284
Non-cancer	53.66	55.91	

[a]APR-DRG = All Patient Refined Diagnosis Related Groups; COPD = chronic obstructive pulmonary disease; GERD = gastroesophageal reflux disease; MI = myocardial infarction; NA = Not Applicable.

costs, charges are directly correlated to costs, and the trend is still the same, with robotic surgery consistently costing more. For example, Rodgers et al[28] compared the cost of robotic-assisted tubal reanastomosis with mini-laparotomy and also found that the cost of the robotic procedure was higher, with a median cost difference of $1446 (95% CI, $1112–$1812; $P < .001$). This is a consistent finding among other surgery types.[29,30] Although not all of these studies examined colectomies specifically, these results do provide directional understanding of cost comparisons for other robotic-assisted minimally invasive procedures.

Table 5. Hospital Costs, Surgery Time, and Length of Stay After Matching			
	Robot	Nonrobot	*P* Value
Total n	533	533	
Hospital costs ($)			
Mean	17 445	15 448	.001
SD	9435	9875	
Median	15 010	12 883	
Surgery time (h)			
Mean	4.37	3.34	<.001
SD	1.55	1.31	
Median	4.00	3.00	
Length of stay (d)			
Mean	5.74	6.09	.344
SD	6.13	6.10	
Median	4.00	4.00	

Two other clinical studies have directly compared robotic-assisted and laparoscopic left- and right-sided colectomies (**Table 7**). Rawlings et al[30] found an increase in mean operative time, similar mean length of stay, and similar mean total hospital cost for right-sided colectomies. The reported comparison for sigmoid colectomies showed a similar mean operative time, mean length of stay, and mean total hospital cost. In a retrospective review, Deutsch et al[20] showed similar means for operative time and length of stay. There was a difference in operative time and a similar length of stay for left-sided colectomies.

In this Premier dataset, before matching for right- and left-sided procedures, the right-sided procedures showed a significant difference in operative time and a similar length of stay. The left-sided procedures also showed a difference in operative time and a similar length of stay. For both robotic and traditional cases, there was a considerable reporting difference between the reported operative time and length of stay of the retrospective cases series by Deutsch et al[20] and Rawlings et al[30] compared with those reported in the Premier dataset. This may reflect the differences between a single site, surgeon and hospital learning curves, and heterogeneity in patient populations. Further analysis around the clinical and economic outcome differences between aggregated

Table 6.
Adverse Events After Matching

	Odds Ratio Estimate	Lower CI[a]	Upper CI	*P* Value
During hospital stay or 30-d follow-up				
Major[b]	0.942	0.729	1.217	.648
Minor[c]	0.827	0.617	1.109	.205
Surgical[d]	0.945	0.737	1.212	.656
Enterostomy[e]	1.038	0.609	1.77	.892
During hospital stay only				
Major	0.905	0.694	1.179	.458
Minor	0.752	0.552	1.025	.071
Surgical	0.859	0.665	1.108	.242
Enterostomy	1.00	0.578	1.729	<.999

[a]CI = confidence interval.

[b]Major: acute respiratory failure, spontaneous tension pneumothorax, atelectasis/pulmonary collapse, empyema, bronchopleural fistula, air leak and other pneumothorax, chylothorax, pneumonia, other pulmonary infections and inflammation, acute myocardial infarction, acute heart failure/pulmonary edema, acute pulmonary embolism/infarction, acute deep venous thrombosis of extremities, acute cerebrovascular accident (stroke), transient cerebral ischemia/transient ischemic attack, intracranial hemorrhage (includes hemorrhagic stroke), dehiscence, perforations of organ or vessels, in-hospital death, sepsis, other postoperative complications, accidental puncture or laceration during procedure, other postoperative infection, peritoneal abscess, other retroperitoneal abscess, abscess of intestine, fistula of intestine, excluding rectum and anus, ureteral fistula, intestinoureteral fistula, intestinovesical fistula, digestive–genital tract fistula, female, persistent postoperative fistula, other specified intestinal obstruction, unspecified intestinal obstruction, intestinal or peritoneal adhesions with obstruction (postoperative), peritonitis (acute), generalized, other suppurative peritonitis, other retroperitoneal infections, unspecified peritonitis, iatrogenic pulmonary embolism and infarction.

[c]Minor: hematoma/seroma complicating procedure, cellulitis, other postoperative infection, including other (non-cellulitis) wound infection, other digestive system complications, paralytic ileus, perioperative autologous transfusion of whole blood or blood components, transfusion of previously collected autologous blood, other transfusion of whole blood, transfusion of packed cells, hemorrhage complicating procedure, hematoma complicating procedure.

[d]Surgical: chylothorax, dehiscence, hematoma/seroma complicating procedure, cellulitis, other postoperative infection, including other (non-cellulitis) wound infection, perforations of organ or vessels, in-hospital death, sepsis, other postoperative complications, other digestive system complications, paralytic ileus, accidental puncture or laceration during procedure, other postoperative infection, peritoneal abscess, other retroperitoneal abscess, abscess of intestine, fistula of intestine, excluding rectum and anus, ureteral fistula, intestinoureteral fistula, intestinovesical fistula, digestive–genital tract fistula, female, persistent postoperative fistula, other specified intestinal obstruction, unspecified intestinal obstruction, intestinal or peritoneal adhesions with obstruction (postoperative), peritonitis (acute), generalized, other suppurative peritonitis, other retroperitoneal infections, unspecified peritonitis, perioperative autologous transfusion of whole blood or blood components, transfusion of previously collected autologous blood, other transfusion of whole blood, transfusion of packed cells, hemorrhage complicating procedure, hematoma complicating procedure.

[e]Enterostomy: colostomy and enterostomy complication unspecified, infection of colostomy or enterostomy, mechanical complication of colostomy or enterostomy, other complication of colostomy or enterostomy, exteriorization of large intestine, colostomy, not otherwise specified, temporary colostomy, permanent colostomy, exteriorization of small intestine, ileostomy, not otherwise specified, temporary ileostomy, continent ileostomy, other permanent colostomy, other enterostomy.

payor reporting database outcomes and historic single-center series may provide future insight into the complexities of clinical outcomes research, especially when assessing new and evolving technologies.

In highly complex or technically challenging cases, robotic technology may offer the potential for advancing minimally invasive surgery. However, this research indicates that the traditional laparoscopic approach achieves similar clinical outcomes for segmental colon resections at a significantly decreased cost to the hospital. Although subsequent generations of robotic technology may represent the future, economically, it is difficult to justify the uptake in robotic surgery for procedures such as routine colectomies.

Important strengths of this analysis included the prospectively developed protocol that directed the analysis, the quasi-randomization propensity scoring methodology that was used, the broad geographic and demographic representation of US hospitals included in the sample, and the fact that these data are relatively recent and represent the real-world set-

Table 7.
Right and Left Colectomies: Operative Parameters

	Right-Sided Laparoscopic	Right-Sided Robotic	*P* Value for Right Side	Left-Sided Laparoscopic	Left-Sided Robotic	*P* Value for Left Side
Rawlings et al[30]						
No. of patients	15	17		13	12	
Operative time (min)	169.2 ± 37.5	218.9 ± 44.6	.002	199.4 ± 44.5	225 ± 37.1	.128
Length of stay	5.5 ± 3.4	5.2 ± 5.8	.862	6.6 ± 8.3	6 ± 7.3	.854
Total hospital cost ($)	8073 ± 2805	9255 ± 5075	.430	10 697 ± 11 719	12 335 ± 12 162	.735
Deutsch et al[20]						
No. of patients	47	18		44	61	
Operative time (min)	214.4 ± 63.2	219.2 ± 39.2	.7529	254.7 ± 53.3	289.7 ± 61.8	.0006
Length of stay	6.3 ± 6.4	4.3 ± 2.5	.1328	4.2 ± 1.2	4.1 ± 1.5	.7067
Premier data						
No. of patients	207	207		326	326	
Operative time (min)	179 ± 64.2	247 ± 90	<.001	213.6 ± 84	272.4 ± 93.6	<.001
Length of stay	6.93 ± 7.22	6.46 ± 7.41	.515	5.56 ± 5.20	5.28 ± 5.12	.485
Total hospital cost ($)	16 396 ± 12 497	18 515 ± 9803	.057	14 845 ± 7724	16 772 ± 9147	.004

Data are shown as mean ± SD.

ting. This study also had some noteworthy limitations. Because the data were mined from a hospital administrative database used for billing purposes, certain data points were unable to be captured or could not be clearly identified. Examples include body mass index, patient behaviors such as smoker versus nonsmoker, and complications resulting in an unplanned enterostomy or specific complications related to anastomotic leaks. Enterostomies could not be identified as being planned or related to some complication and thus were evaluated separately from complications. Because there is no specific ICD-9 code for "anastomotic complication," this analysis had to rely on existing diagnosis codes, which often result from anastomotic complications but are not exclusive or specific. Furthermore, data regarding the precision of robotic versus nonrobotic procedures, including surgical margins and adequacy of lymph node dissection, could not be evaluated. The analysis was limited to a 30-day perioperative period, which limits analysis related to long-term survival or potential long-term complications. Other limitations of this analysis include lack of comparison between rates of conversion to an open approach and differentiation between hand-assisted and total laparoscopic approaches. However, these limitations are inherent to the data source and could be rationalized to impact both cohorts similarly. As a result, the risk of bias in one cohort is lessened. Finally, surgeon and institutional learning curve relative to using robotic technology could not be evaluated.

CONCLUSION

This study represents the most up-to-date and expansive analysis of cost and effectiveness outcomes associated with robotic-assisted laparoscopic segmental colectomy in a real-world setting. These findings show few clinical differences in perioperative adverse events. Coupled with the increased per-case cost of the robot and increased operative times, the results suggest that further consideration is warranted before using this technology for segmental laparoscopic colectomies when standard laparoscopic means yielding comparable results are available. Future studies evaluating cost relative to robotic-assisted case volume and prospective randomized controlled studies focusing on comparative effectiveness between traditional and robotic-assisted laparoscopic segmental colectomy procedures are needed.

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Appendix A.
Comorbid Conditions

Condition	ICD-9 Diagnosis Codes
Arthritis	
Rheumatoid arthritis	714.0
Psoriatic arthritis	696.0
Ankylosing spondylitis	720.0
Malignant neoplasms	
Skin cancer	176.0, 209.31–209.36, 172.x, 173.x
Colon cancer	153.x
Lung, bronchus, or trachea	162.x
Diseases of digestive system	
GERD[a]	530.81
Gastritis	535.xx (except 535.6x)
Gastric ulcer	531.xx
Crohn disease	555.xx
Ulcerative colitis	556.xx
Diverticulitis	562.11, 562.13
Disease of genitourinary system	
Kidney stones	592.0
Cystitis	595.xx
Mental disorders	
Depressive disorders	311, 300.4, 309.0, 309.1, 309.28, 298.0, 296.2x, 296.3x, 296.4x, 296.5x
Neurotic disorders	300.xx (without 300.4) + 309.81
Diseases of circulatory system	
Coronary artery disease	414.0x, 414.2, 414.3
Heart failure	398.91, 402.x1, 404.x1, 404.x3, 428.xx
MI[a] (any)	410.x1, 410.x2, 412
Stroke	430, 431, 432.x, 433.x1, 434.x1, 997.02
Cardiac dysrhythmias	427.xx
Hypertension	401.x, 402.xx, 404.xx, 405.xx
Diseases of musculoskeletal system and connective tissue	
Irritable bowel disease	564.1
Lumbar disk disease	722.10, 722.73, 722.52, 722.93
Osteoporosis	733.0x
Osteoarthritis	721.x, 715.xx

Appendix A. (continued)
Comorbid Conditions

Condition	ICD-9 Diagnosis Codes
Diseases of nervous system	
Parkinson disease	332.x
Multiple sclerosis	340
Migraine	346.xx
Diseases of respiratory system	
Chronic bronchitis	491.xx
Emphysema	492.x
Asthma	493.xx
COPD[a]	491.x (except 491.0), 492.x, 493.2x, 494.x, 496
Diseases of skin	
Eczema (dermatitis)	692.9
Sebaceous gland diseases	706.x
Metabolic diseases	
Diabetes	249.xx, 250.xx
Hyperlipidemia	272.4
Hypothyroidism	243, 244.x

[a]COPD = chronic obstructive pulmonary disease; GERD = gastroesophageal reflux disease; MI = myocardial infarction.

Appendix B.
Adverse Events, Codes, and Counts of Major, Minor, and Surgical Complications

Type	Description of Event	ICD-9 Code	Robot		No Robot	
			During Procedure (n = 533)	During or After Procedure (n = 533)	During Procedure (n = 533)	During or After Procedure (n = 533)
Major	Acute respiratory failure	518.81, 518.84, 518.5	2.81	3.19	3.00	3.19
Major	Spontaneous tension pneumothorax	512.0	0.00	0.00	0.00	0.00
Major	Atelectasis/pulmonary collapse	518.0	4.32	4.88	4.69	5.07
Major	Empyema	510.9	0.00	0.00	0.00	0.00
Major	Bronchopleural fistula	510.0	0.00	0.00	0.00	0.00
Major	Air leak and other pneumothorax	512.1, 512.8	0.38	0.38	0.19	0.19
Major	Pneumonia	480.x to 486, 507.0	2.25	3.56	1.50	1.88
Major	Other pulmonary infections and inflammation	487.0, 490, 491.21–491.22, 511.0–511.1, 511.89, 511.9, 513.x, 519.01	1.13	1.88	1.88	3.19
Major	Acute myocardial infarction	410.xx	1.31	1.50	0.75	0.94
Major	Acute heart failure/pulmonary edema	428.1, 428.21, 428.23, 428.31, 428.33, 428.41, 428.43, 514, 518.4	0.19	0.38	0.38	0.38
Major	Acute pulmonary embolism/infarction	415.1x	0.38	0.75	0.38	0.75
Major	Acute deep venous thrombosis of extremities	453.4x, 453.8, 453.9	1.13	1.50	0.56	0.75
Major	Acute cerebrovascular accident (stroke)	433.x1, 434.x1, (997.02)	0.00	0.00	0.00	0.00
Major	Transient cerebral ischemia/transient ischemic attack	435.x , 437.1	0.00	0.00	0.19	0.38
Major	Intracranial hemorrhage (includes hemorrhagic stroke)	430–432.x	0.00	0.00	0.00	0.00
Major/surgical	Chylothorax	457.8	0.00	0.00	0.00	0.00
Major/surgical	Dehiscence	998.30, 998.31, 998.32, 998.3	0.75	1.50	0.19	0.56
Major/surgical	Perforations of organ or vessels	998.2	1.50	1.50	1.69	1.69
Major/surgical	Sepsis	038.xx, 790.7, 995.9x	1.88	2.63	1.69	2.06
Major/surgical	Other postoperative complications	997.xx except 997.02, 998.0, 998.11, 998.33, 998.4, 998.6, 998.7, 998.8x, and 998.9	10.13	11.63	11.63	13.70
Major/surgical	Accidental puncture or laceration during procedure	998.2	1.50	1.50	1.69	1.69
Major/surgical	Peritoneal abscess	567.22	1.69	2.25	0.94	1.31
Major/surgical	Other retroperitoneal abscess	567.38	0.00	0.19	0.00	0.00
Major/surgical	Abscess of intestine	569.5	4.69	4.69	6.19	6.19

Appendix B. (continued)
Adverse Events, Codes, and Counts of Major, Minor, and Surgical Complications

Type	Description of Event	ICD-9 Code	Robot		No Robot	
			During Procedure (n = 533)	During or After Procedure (n = 533)	During Procedure (n = 533)	During or After Procedure (n = 533)
Major/surgical	Fistula of intestine, excluding rectum and anus, intestinal or peritoneal adhesions with obstruction (postoperative)	569.81	0.94	0.94	0.56	0.75
Major/surgical	Ureteral fistula, intestinoureteral fistula	593.82	0.00	0.00	0.00	0.00
Major/surgical	Intestinovesical fistula	596.1	1.88	2.06	0.94	0.94
Major/surgical	Digestive–genital tract fistula, female	619.1	0.94	0.94	0.94	1.13
Major/surgical	Persistent postoperative fistula	998.6	0.19	0.38	0.00	0.19
Major/surgical	Other specified intestinal obstruction	560.89	2.06	2.25	2.63	3.19
Major/surgical	Unspecified intestinal obstruction	560.9	1.50	2.25	2.06	2.44
Major/surgical	Peritonitis (acute), generalized	567.21	0.38	0.38	0.38	0.38
Major/surgical	Other suppurative peritonitis	567.29	0.56	0.56	0.38	0.38
Major/surgical	Other retroperitoneal infections	567.39	0.00	0.00	0.00	0.00
Major/surgical	Unspecified peritonitis	567.9	0.19	0.38	0.19	0.19
Minor/surgical	Hematoma/seroma complicating procedure	998.12–998.13, 998.51	1.31	2.25	0.94	1.88
Minor/surgical	Cellulitis	998.59 plus 682.2	2.06	4.32	2.63	3.38
Minor/surgical	Other postoperative infection, including other (noncellulitis) wound infection	998.59 when 510.9, 510.0, 038.xx, 790.7, 995.9x, 682.2 are not also present	0.75	1.88	1.13	1.88
Minor/surgical	Paralytic ileus	560.1	9.01	9.19	10.51	11.44
Minor/surgical	Other digestive system complications	997.49	0.00	0.00	0.00	0.00
Minor/surgical	Perioperative autologous transfusion of whole blood or blood components	99.00	0.00	0.00	0.00	0.00
Minor/surgical	Transfusion of previously collected autologous blood	99.02	0.00	0.00	0.00	0.00
Minor/surgical	Other transfusion of whole blood	99.03	0.00	0.00	0.00	0.00
Minor/surgical	Transfusion of packed cells	99.04	7.88	9.57	11.63	12.01
Minor/surgical	Hemorrhage complicating procedure	998.11	0.75	1.31	1.88	2.44
Minor/surgical	Hematoma complicating procedure	998.12	1.13	1.50	0.75	1.13

Appendix C.
Enterostomy Codes and Counts

Type	Description of Event	ICD-9 Code	Robot		No Robot	
			During Procedure (n = 533)	During or After Procedure (n = 533)	During Procedure (n = 533)	During or After Procedure (n = 533)
Enterostomy	Colostomy and enterostomy complication, unspecified	569.60	0.00	0.00	0.00	0.00
Enterostomy	Infection of colostomy or enterostomy	569.61	0.00	0.00	0.00	0.00
Enterostomy	Mechanical complication of colostomy or enterostomy	569.62	0.00	0.00	0.38	0.38
Enterostomy	Other complication of colostomy or enterostomy	569.69	0.00	0.19	0.19	0.19
Enterostomy	Exteriorization of large intestine	46.03	0.38	0.38	0.19	0.19
Enterostomy	Colostomy, not otherwise specified	46.10	2.25	2.44	2.44	2.44
Enterostomy	Temporary colostomy	46.11	0.38	0.38	1.31	1.31
Enterostomy	Permanent colostomy	46.13	0.38	0.38	0.00	0.00
Enterostomy	Exteriorization of small intestine	46.01	0.94	1.13	0.75	0.75
Enterostomy	Ileostomy, not otherwise specified	46.20	0.56	0.56	0.38	0.38
Enterostomy	Temporary ileostomy	46.21	0.00	0.00	0.19	0.38
Enterostomy	Continent ileostomy	46.22	0.00	0.00	0.00	0.00
Enterostomy	Other permanent colostomy	46.23	0.19	0.19	0.00	0.00
Enterostomy	Other enterostomy	46.39	0.19	0.19	0.00	0.00