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Robotic versus laparoscopic colectomy for stage I–III colon cancer: oncologic and long-term survival outcomes

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Abstract

Background While short-term data suggest that robotic resections are safe for oncologic operations, long-term outcomes remain uncertain. This study evaluates the impact of robotic and laparoscopic approaches on oncologic and survival outcomes in partial and total colectomies for colon cancer.

Methods The US National Cancer Database (2010–2012) was reviewed for patients with stage I–III adenocarcinoma of the colon, who underwent robotic and laparoscopic partial or total colectomies. Lymph node retrieval, surgical margins, and survival were compared between surgical approaches with linear and logistic regressions. Propensity score matching was then used to create comparable laparoscopic and robotic cohorts and compare survivor functions.

Results Of 15,112 patients, 5.1% underwent robotic approaches ($n=765$, conversion rate 10.6%), and 94.9% laparoscopic ($n=14{,}347$, conversion rate 15.1%). Robotic approach was associated with Hispanic race ($p=0.009$), private insurance ($p=0.001$), and earlier stage ($p=0.028$). There was no difference in number of lymph nodes retrieved ($p=0.6200$) or negative surgical margins ($p=0.6700$). In multivariate analysis, robotic approaches were associated with an improved hazard of mortality (HR 0.79, $p=0.027$). Linear regression found no difference in lymph node retrieval (− 0.39, $p=0.285$). Logistic regression found no difference in rates of positive margins (OR 1.09, $p=0.649$). After propensity score matching, robotic approaches were associated with improved survival in stage II (5YS 66.9% vs. 56.8%, $p=0.0189$) and III disease (5YS 78.6% vs. 64.9%, $p=0.0241$).

Conclusion Robotic approaches to partial and total colectomies for stage I–III colon cancer offer comparable oncologic outcomes as laparoscopic approaches. Relative to laparoscopic approaches, robotic approaches appear to offer improved long-term survival.

Keywords Colon cancer · NCDB · Robotic surgical approach · MIS

In 2004, the Clinical Outcomes of Surgical Therapy (COST) trial concluded that laparoscopic approaches to colon cancer were feasible and could be performed without compromising oncologic outcomes [2]. Meta-analyses of multiple randomized trials confirmed comparable long-term outcomes between open and laparoscopic approaches [3, 4]. Surgeons readily adopted the use of minimally invasive surgical (MIS) techniques and began to explore the use of robotic surgery for diseases of the colon.

Robotic surgery offers several theoretical advantages including improved visualization, increased degrees of freedom, and stabilization of tremors [5]. However, these advantages come at significant financial costs, increased operative times, and loss of haptic feedback [5–7]. Several studies have reported comparable or improved short-term outcomes between robotic and laparoscopic approaches to colectomies [6, 8–12]. Robotic approaches have been associated with shorter hospital length of stay (LOS), lower postoperative complications, faster recovery of bowel function, but longer operative times and higher costs [7, 9–11, 13]. Although short-term outcomes support the feasibility and safety of robotic colon resections, long-term and oncologic outcomes remain unclear.

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The objective of this study was to evaluate the impact of surgical approach on oncologic and long-term survival outcomes in partial and total colectomies for colon cancer.

Methods

Data

This was a retrospective cohort study using data from the National Cancer Database (NCDB). The NCDB is a clinical oncology database, sourced from hospital registry data collected from over 1500 Commission on Cancer accredited facilities across the United States. The NCDB captures approximately 80% of cancer cases in the United States from 1998 to 2012. This was a retrospective cohort study of clinical data from this registry from 2010 to 2012. The NCDB contains de-identified data, and therefore this study was deemed exempt by our institutional review board.

Patient selection

The NCDB Colon Participant User File (PUF) was reviewed for patients diagnosed with pathological stage I–III adenocarcinoma of the colon, identified using histology ICD-O-3 code 8140/3, who underwent partial or total colectomies. The database only began collecting data for surgical approach in 2010, and thus diagnoses prior to 2010 and those missing surgical approach data were excluded. Patients with missing or incomplete data were excluded. Patients who underwent local excision ($n=261$) or unspecified surgical procedures ($n=152$) were also excluded. The study population ($n=15{,}112$) was stratified by surgical approach: robotic and laparoscopic. Furthermore, we defined surgical approach based on an intention to treat basis, so conversions to an open procedure were retained in the original treatment stratum.

Outcomes and covariates

The primary outcomes assessed were lymph node retrieval, surgical margins, and overall survival. Univariate analyses compared demographic data including age, sex, race, insurance type (private, Medicare, Medicaid, and other government programs, unknown, not insured), median income and the Charlson/Deyo comorbidity index (CCI), an index of 15 comorbidities including myocardial infarction, congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic pulmonary disease, rheumatologic disease, peptic ulcer disease, mild liver disease, diabetes, diabetes with chronic complications, hemiplegia or paraplegia, renal disease, moderate or severe liver disease, and AIDS [14, 15]. Treatment facilities were stratified by facility type (community, comprehensive community, academic or research institution, other), and geographic region (Northeast, South, Midwest, West). Disease was characterized by the American Joint Committee on Cancer (AJCC) clinical stage, pathologic variables (regional lymph nodes sampled, positive regional lymph nodes, and pathological stage). Treatment was characterized by surgical approach (robotic, laparoscopic, open), surgery type (partial or hemicolectomy, or total colectomy), and receipt of adjuvant therapy.

Statistical analysis

Statistical analyses were performed with Stata software (version 12.1, StataCorp, College Station, TX, USA). Patient demographics, disease characteristics, and treatment types were compared between groups using student's t-test for continuous variables, and Chi-square tests for categorical variables. Kaplan–Meier analyses were performed to assess overall survival by clinical stage, and survivor curves were compared using a log-rank test. Median survival time was computed based on the Kaplan–Meier analysis.

Linear regression was used to assess factors impacting the number of lymph nodes retrieved and logistic regression was used to analyze factors impacting positive surgical margins. Kaplan–Meier analysis revealed violation of the proportional hazards assumption, and thus a multivariate Weibull model, controlling for patient, disease, and treatment covariates, was performed. Next, a prediction model was created using linear regression to predict the use of a robotic approach as a function of patient, disease, and treatment characteristics (including age, sex, race, insurance coverage, median income, comorbidities, facility type, facility location, surgical margins, pathological stage, and receipt of chemotherapy). Patients were then matched 1:1 without replacement using a nearest-neighbor approach with caliper restrictions. After matching, there were no significant differences in patient, disease, and treatment characteristics (including age, sex, race, insurance coverage, median income, comorbidities, facility type, facility location, surgical margins, pathological stage, and receipt of chemotherapy). The results of the propensity score matching were used to form a laparoscopic ($n=765$) and a robotic ($n=765$) cohort. Kaplan–Meier survival analyses were then performed on the matched cohorts for each pathological stage.

Results

Five-year overall survival (5YS) was 75.2% for the stage I cohort, 52.8% for stage II, and 53.9% for stage III, Fig. 1. Five-year overall survival rates of 82.7, 70.3, and 58.3% are reported by the AJCC.

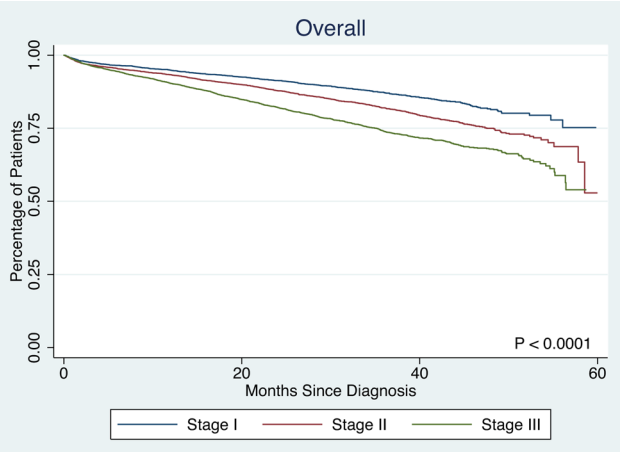

Fig. 1 Five-year overall survival

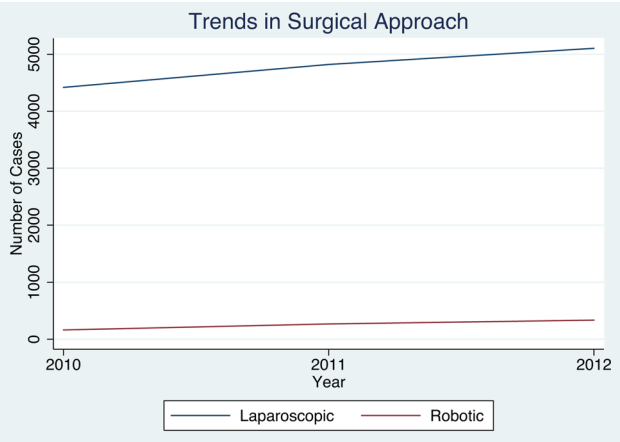

Fig. 2 Trends in minimally invasive approaches over time

Utilization of the robotic approach more than doubled, while the laparoscopic approach increased by 15% over the 3-year period from 2010 to 2012 (Fig. 2). Robotic conversions decreased from 16.0 to 9.3% from 2010 to 2011. Laparoscopic conversions decreased from 16.1 to 13.7% from 2010 to 2011.

Of the 15,112 patients included in this study, 5.1% underwent a robotic approach $n=765$, and 94.9% underwent a laparoscopic approach ($n=14{,}347$), Table 1. Patients who received a robotic procedure were associated more likely to be Hispanic (11.5 vs. 8.6%, $p=0.009$), have private insurance (37.8% vs. 32.7%, $p=0.001$), and be diagnosed with an earlier pathological stage disease (stage 1 30.7% vs. 26.4%, $p=0.028$) but not clinical stage disease ($p=0.3120$). There was no significant difference between number of lymph nodes retrieved (19.8 vs. 20.0, $p=0.6200$), or negative surgical margins (95.7% vs. 95.9%, $p=0.6700$). Laparoscopic approaches were associated with a significantly greater conversion rate (15.1% vs 10.6%, $p=0.001$).

After controlling for patient, disease, and treatment characteristics, robotic approaches were associated with an improved hazard of mortality relative to laparoscopic (HR 0.79, $p=0.027$), Fig. 3. Increased age (80–90 HR 3.72, $p<0.001$), coverage by Medicare (HR 1.27, $p<0.001$) or Medicaid (HR 1.61, $p<0.001$), lack of insurance (HR 1.68, $p<0.001$), greater comorbidities (CCI score 2: HR 1.98, $p<0.001$), macroscopically positive margins (HR 2.71, $p<0.001$), and greater pathological stage (stage III: HR 3.03, $p<0.001$) were associated with greater hazards of mortality. Female sex (HR 0.83, $p<0.001$), higher income (> $93,000 HR 0.78, $p<0.001$), and receipt of chemotherapy (HR 0.53, $p<0.001$) were associated with improved hazards of mortality.

Linear regression found no significant association between lymph node retrieval and robotic approaches (-0.39, $p=0.285$), Table 2. Logistic regression found no significant difference in rates of positive margins with robotic approaches (OR 1.09, $p=0.649$).

There was no difference in 5YS between robotic and laparoscopic approaches in stage I–II disease (stage I: robotic 74.6% vs laparoscopic 75.2%, $p=0.6808$, stage II: robotic 66.9% vs laparoscopic 52.6%, $p=0.1923$). However, robotic approach was associated with significantly improved 5YS in stage III disease (78.6% vs 53.3%, $p=0.0409$).

After propensity score matching, robotic approach was associated with significantly improved survival over laparoscopic approach in stage II (5YS 66.9% vs. 56.8%, $p=0.0189$) and III disease (5YS 78.6% vs. 64.9%, $p=0.0241$), Figs. 4, 5, and 6. There was no statistically significant difference in survival in stage I disease ($p=0.1477$).

Discussion

The results of this study suggest that robotic approaches are increasingly being used to perform partial and total colectomies for stage I–III colon cancer, and that they offer comparable oncologic outcomes to laparoscopic approaches. Robotic approaches also appear to offer better long-term survival in this patient population.

This study found that utilization of robotic approaches more than doubled in a three-year timespan, while laparoscopic approaches increased by 15%. MIS approaches have demonstrated an upward trend for several years. A survey study using the American Hospital Association reported 27.4% of hospitals adopted robotic-assisted surgery for colorectal cancer in 2012 as compared to 20.1% in 2010 [16]. A review of the Nationwide Inpatient Sample reported that the percentage of patients with colorectal cancer treated with robotic-assisted surgery increased from 1.5% in 2010

Table 1 Patient, disease, and treatment characteristics

Variable	Robotic ($n=765$)	Laparoscopic ($n=14,347$)	p value
Age	67.96	68.90	0.0519
18–59	28.0%	24.5%	
60–69	25.6%	23.6%	
70–79	23.8%	27.5%	
80–90	22.6%	24.4%	
Sex			0.376
Male	47.6%	49.2%	
Female	52.4%	50.8%	
Race			0.009
White (non-Hispanic)	75.8%	77.1%	
Black (non-Hispanic)	10.3%	10.5%	
Other (non-Hispanic)	2.4%	3.9%	
Hispanic	11.5%	8.6%	
Insurance			0.001
Private	37.8%	32.7%	
Medicare	57.5%	59.2%	
Medicaid & other gov	3.0%	4.1%	
Unknown	0.7%	1.2%	
Not insured	1.0%	2.9%	
Median income			0.466
< 58,000	16.3%	15.8%	
58,000–74,000	20.8%	23.1%	
74,000–93,000	27.5%	27.2%	
> 93,000	35.2%	33.4%	
Comorbidities			0.83
CCI score 0	67.7%	67.2%	
CCI score 1	23.1%	24.0%	
CCI score 2	9.2%	8.8%	
Facility type			0.075
Community	11.2%	13.2%	
Comprehensive community	52.2%	53.2%	
Academic/research	29.3%	25.5%	
Other	0.1%	0.2%	
Facility location			< 0.0001
Northeast	12.4%	21.4%	
South	43.4%	38.6%	
Midwest	25.8%	22.3%	
West	16.7%	15.9%	
Clinical stage			0.312
Stage I	45.4%	42.9%	
Stage II	35.0%	35.5%	
Stage III	19.6%	21.6%	
Surgery type			0.035
Partial colectomy	95.6%	96.5%	
Total colectomy	4.4%	3.5%	
Number of regional lymph nodes removed	19.78	19.96	0.62
Positive regional lymph nodes	1.72	1.63	0.719
Surgical margins			0.67
No residual tumor	95.7%	95.9%	
Residual tumor, NOS	2.1%	1.7%	

Table 1 (continued)

Variable	Robotic ($n = 765$)	Laparoscopic ($n = 14{,}347$)	p value
Microscopic residual tumor	1.8%	1.9%	
Macroscopic residual tumor	0.0%	0.2%	
Indeterminate or unknown	0.4%	0.4%	
Pathological stage			0.028
Stage 1	30.7%	26.4%	
Stage 2	35.3%	38.3%	
Stage 3	34.0%	35.3%	
Systemic therapy			0.467
None	70.2%	68.9%	
Chemotherapy	29.8%	31.1%	
Conversion rate	10.6%	15.1%	0.001

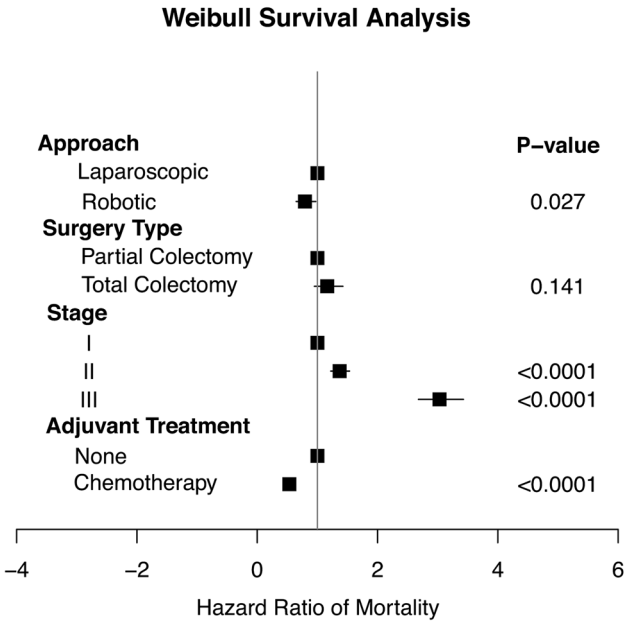

Fig. 3 Factors associated with increased hazards of mortality

to 3.6% in 2012 [16]. They noted that robotic approaches are increasing more rapidly for patients with rectal cancer than patient with colon cancer [16].

In this national study, robotic approaches were associated with a significantly lower conversion rate (10.6%) as compared to laparoscopic approaches (15.1%). This may reflect a selection bias, with higher standards applied to patients selected for robotic approach. However, this was not apparent in comparing patient CCI scores and other demographics. A systematic review by Duan et al. also found that robotic approaches in colon cancer were associated with lower conversion rates, as did a retrospective review evaluating colon and rectal resections by Rashidi et al. [9, 10]. A study of 101 robotic-assisted resections and 162 laparoscopic resections for colon cancer reported no significant differences in the rate of conversion [17]. Another study, by deSouza et al., comparing 40 robotic-assisted right hemicolectomies to 135 laparoscopic right hemicolectomies also reported no significant difference in conversion rate [7]. It appears that robotic approaches have comparable or improved conversion rates as compared to laparoscopic approaches.

MIS for cancer must not only be technically safe and feasible, but also remove all aspects of the tumor by affording sufficient number of lymph nodes and negative surgical margins. This study found no difference in the number of lymph nodes retrieved or rate of negative surgical margins between the two cohorts. The majority of existing literature evaluating oncologic outcomes comes from small, single institutional studies, and centers mostly around rectal cancer. This is the first study to evaluate national oncologic outcomes exclusively in colon cancer.

The single institutional study by deSouza et al. reported no significant difference in lymph node harvest, but did not assess surgical margins [7]. A meta-analysis comparing robotic and laparoscopic right colectomies found no difference in the number of retrieved lymph nodes [18, 19]. A study of 64 patients who underwent robotic total mesorectal excision reported a median number of harvested lymph nodes of 14.5 and a median distal margin length of 3.4 cm [20]. A meta-analysis of robotic vs. laparoscopic proctectomy for rectal cancer also reported comparable lymph node yield and circumferential margin involvement [21]. Ferrara et al.'s single-center study of 42 robotic cases and 58 laparoscopic cases in patients with colorectal cancer who underwent right colonic, left colonic, or rectal resections reported a higher number of harvested lymph nodes with the robotic approach and no difference in surgical margins [22]. This body of literature suggests that robotic approaches offer equivalent or improved oncologic outcomes. Robotic surgery allows for greater articulation than laparoscopic surgery. This combined with an inherent selection bias likely accounts for improved overall survival in the robotic cohort.

Table 2 Factors impacting number of lymph nodes retrieved and factors impacting positive margins

Variable	Factors impacting number of lymph nodes retrieved				Factors impacting positive margins			
	Coefficient	95% Confidence Interval		*p* value	Coefficient	95% Confidence Interval		*p* value
		Lower	Upper			Lower	Upper	
Approach								
Laparoscopic	Reference				Reference			
Robotic	− 0.39	− 1.12	0.33	0.29	1.09	0.76	1.56	0.65
Age								
18–59	Reference				Reference			
60–69	− 1.42	− 1.92	− 0.93	< 0.001	0.81	0.62	1.05	0.11
70–79	− 1.80	− 2.36	− 1.24	< 0.001	1.04	0.78	1.38	0.79
80–90	− 2.44	− 3.02	− 1.85	< 0.001	1.06	0.79	1.42	0.71
Sex								
Male	Reference				Reference			
Female	0.75	0.43	1.06	< 0.001	0.97	0.83	1.14	0.73
Race								
White (non-Hispanic)	Reference				Reference			
Black (non-Hispanic)	− 0.75	− 1.30	− 0.20	0.01	0.94	0.71	1.26	0.70
Other (non-Hispanic)	− 0.19	− 1.04	0.66	0.66	1.15	0.77	1.70	0.50
Hispanic	− 0.14	− 0.71	0.43	0.63	1.00	0.74	1.33	0.98
Insurance								
Private	Reference				Reference			
Medicare	− 0.52	− 0.98	− 0.06	0.03	0.97	0.76	1.23	0.81
Medicaid & other gov	− 0.77	− 1.61	0.07	0.07	1.40	0.96	2.04	0.08
Unknown	− 1.59	− 3.11	− 0.08	0.04	0.70	0.28	1.73	0.44
Not insured	− 0.46	− 1.46	0.54	0.37	1.21	0.75	1.95	0.43
Median income								
< 58,000	Reference				Reference			
58,000–74,000	0.15	− 0.37	0.67	0.57	1.13	0.85	1.51	0.38
74,000–93,000	0.49	− 0.02	1.00	0.06	1.31	1.00	1.73	0.05
> 93,000	0.74	0.24	1.25	0.00	1.24	0.94	1.63	0.12
Comorbidities								
CCI score 0	Reference				Reference			
CCI score 1	− 0.70	− 1.08	− 0.32	< 0.001	0.89	0.73	1.09	0.27
CCI score 2	− 1.41	− 1.98	− 0.83	< 0.001	0.73	0.52	1.01	0.06
Facility type								
Community	Reference				Reference			
Comprehensive community	0.37	− 0.04	0.78	0.08	0.97	0.79	1.19	0.75
Academic/research	1.22	0.75	1.69	< 0.001	0.85	0.67	1.08	0.18
Other	− 6.18	− 10.09	− 2.26	0.00	1.00	0.00	0.00	< 0.001
Facility location								
Northeast	Reference				Reference			
South	− 1.25	− 1.70	− 0.81	< 0.001	0.94	0.75	1.17	0.55
Midwest	1.08	0.60	1.57	< 0.001	0.79	0.61	1.01	0.06
West	− 0.09	− 0.62	0.44	0.73	1.04	0.81	1.34	0.77
Surgery type								
Partial colectomy	Reference				Reference			
Total colectomy	5.08	4.22	5.94	< 0.001	1.42	0.97	2.08	0.07

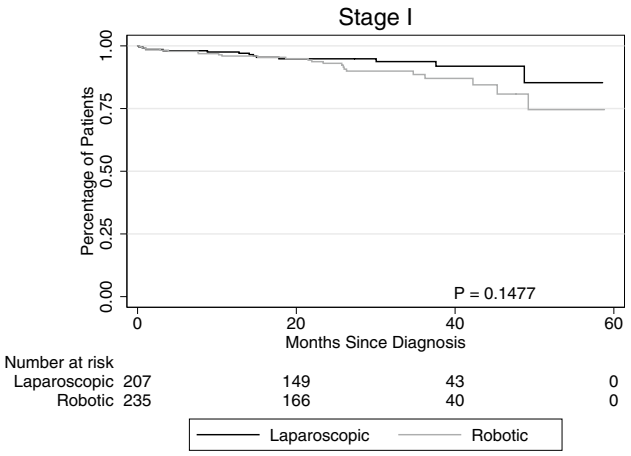

Fig. 4 Survival in stage I disease by surgical approach in propensity score matched groups

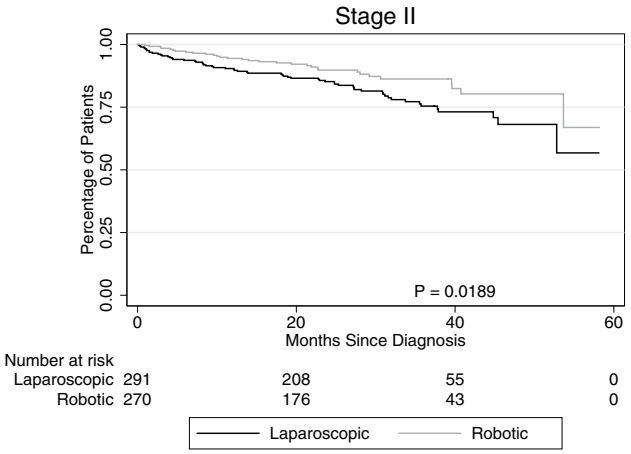

Fig. 5 Survival in stage II disease by surgical approach in propensity score matched groups

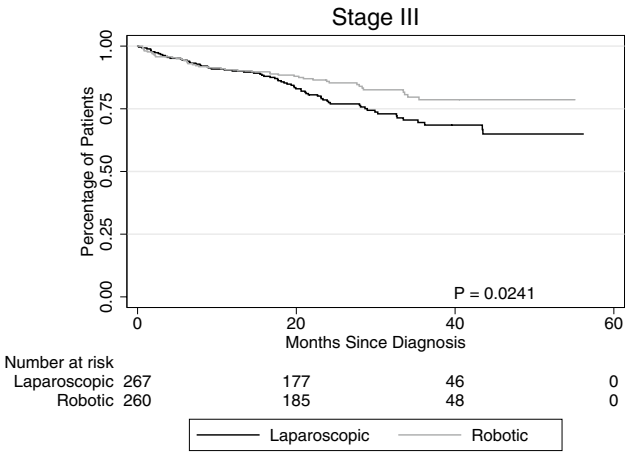

Fig. 6 Survival in stage III disease by surgical approach in propensity score matched groups

This study found improved 5-year overall survival in robotic approaches as compared to laparoscopic approaches. Again, though there may be a selection bias present, this was not apparent in our demographic comparisons, and was accounted for in the propensity score matching. There are very little data on long-term outcomes in robotic resections for colon cancer. A Korean study of 180 patients from 2006 to 2008 who underwent robotic-assisted or laparoscopic anterior resections for sigmoid colon cancer found similar 3-year overall survival between the two groups [23]. An Italian study of 50 patients with colon cancer who underwent a robotic right colectomy reported an overall survival of 94.1, 92.3, and 66.7% for stage II, III, and IV, respectively, at a median follow-up of 36 months [24]. The data from this study reflect CoC-accredited facilities ranging from community hospitals to large academic research centers in the United States, and thus are applicable to a diverse array of Western facilities. The improved overall survival in the robotic cohort may reflect, in part, a selection bias. To best evaluate long-term survival in colon cancer, randomized controlled trials are still needed.

To our knowledge, this study represents the largest and most contemporary study of oncologic outcomes and long-term survival in MIS approaches for colon cancer. However, there are some important limitations to consider when interpreting the results. The NCDB is a large database, subject to the possibility of coding errors and inconsistencies. Despite its prominence as the nation's premiere cancer registry, it lacks a number of factors of interest such as reason for conversion, postoperative complications, chemotherapy regimen, quality of life, and disease-specific recurrence. Furthermore, there is no surgeon-specific data to differentiate patients operated on by a robotic novice as opposed to expert. Additionally, as previously discussed, though demographics between the two cohorts were similar, there likely exists a selection bias, with surgeons carefully choosing which patients to attempt robotically. Propensity score matching was used to address this selection bias, but of course this can only control for observable sources of selection bias that are exhibited in covariate imbalance. Limitations aside, this study provides a comprehensive and reliable perspective into MIS practices across the United States.

Conclusion

In conclusion, robotic partial and total colectomies for stage I–III colon cancer offer comparable oncologic outcomes (including lymph node harvest and surgical margins) to laparoscopic approaches. Relative to laparoscopic approaches, robotic approaches offer improved long-term survival in this patient population. Further study characterizing disease-specific recurrence is warranted.

Disclaimer The National Cancer Data Base (NCDB) is a joint project of the Commission on Cancer (CoC) of the American College of Surgeons and the American Cancer Society. The CoC's NCDB and the hospitals participating in the CoC NCDB are the source of the deidentified data used herein; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

Compliance with ethical standards

Disclosures The authors Katelin A. Mirkin, Audrey S. Kulaylat, Christopher S. Hollenbeak, and Evangelos Messaris declare that they have nothing to disclose.

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