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ORIGINAL ARTICLE

Robotic colectomy with intracorporeal anastomosis is feasible with no operative conversions during the learning curve for an experienced laparoscopic surgeon developing a robotics program

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Abstract

The benefits of performing a colectomy robotically instead of laparoscopically have not conclusively been demonstrated. Evaluation of studies is limited by sample size, retrospective design, heterogeneity of operative techniques, sparse adjustment for learning curve, and mixed results. Consequently, adoption of robotic colectomy by surgeons has been expectedly slow. The objectives of the study were to compare the outcomes of robotic colectomy to laparoscopic colectomy for patients with right-sided tumors undergoing a standardized completely intracorporeal operation and to examine the impact of prior experience with laparoscopic right colectomies on the performance of robotic right colectomies. Retrospective review of outcomes of consecutive patients undergoing a robotic right colectomy (robot) compared to those undergoing laparoscopic colectomy (LAP). LAP patients were further subdivided into a group during the learning curve (LC) and after the learning curve (post-LC). Data collected included operative time (OT), conversion to laparotomy, lymph nodes harvested (LN), length of stay (LOS), 30-day morbidity, and mortality. Comparison of continuous and categorical variables was assessed with the independent samples *t* test and Chi-square test, respectively. Data are expressed as mean ± SD, and significance defined as $p<0.05$. 122 patients underwent robot ($n=21$), LAP ($n=101$), LC ($n=51$), or post-LC ($n=50$). OT was decreased for post-LC compared to LC (198 vs. 228 min). There were no conversions in robot and five with LAP. Morbidity was similar for robot (14%) compared to LAP (22%), LC (24%), or post-LC cases (20%). Median LOS was similar for robot vs. LAP (3 vs. 5 days). Robot had greater mean LN yield vs. LAP (19 vs. 14, $p=0.02$). The initial outcomes with completely intracorporeal colectomy achieved robotically were equivalent to results during or after LC for laparoscopic resection. Proficiency gained with LAP seems to positively impact the initial results with the robot.

Keywords Robotic colon surgery · Laparoscopic colon surgery · Colon tumor

Introduction

Widespread adoption of minimally invasive colon surgery is associated with improved outcomes for patients undergoing colon surgery in the United States [1]. Despite this progress, there appears to be no consensus regarding the ideal minimally invasive approach for removing the colon. Techniques vary considerably with limited randomized studies to guide the best practices for minimally invasive colectomy. Varied laparoscopic techniques include hand-assisted laparoscopic colectomy and laparoscopic colectomy with extracorporeal or intracorporeal anastomosis. In addition, the robotic platform may be a superior technical platform with advanced robotic tools which include 3-D visualization, wristed instruments that enhance dexterity enabling finer dissection and easier intracorporeal suturing, and a unique "smart" stapler that detects and provides feedback when the jaws are adequately closed on the tissue. These advantages could potentially improve the performance of colon and rectal operations.

Surgeons have been slower to transition to robotic surgery for the treatment of colon tumors compared to rectal

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tumors [2]. This trend is also apparent in recently credentialed colorectal surgeons who perform 46% of all minimally invasive proctectomies robotically compared to only 22% of minimally invasive colectomies with the robot [3]. Adoption of robotics may be hampered by multiple factors including perceived safety of the technology and higher cost arising from the reports of increased iatrogenic complications and cost in patients undergoing robotic compared to laparoscopic colectomy [4].

While the majority of minimally invasive colectomies are currently being performed laparoscopically, multiple studies challenge this approach as the gold standard for colon cancer surgery. Laparoscopic colon surgery has been shown to be oncologically efficacious for the treatment of colon cancer compared to open surgery, but the functional benefits have not been fully realized due to high conversion rates. Conversion rates in randomized cancer trials have been high ranging from 25 to 27% in the COST, COLOR, and CLASICC trials associated with worse overall quality-of-life benefits compared to open colectomy [5–7]. In the ALCCaS trial, operative conversion was 14.6% associated with increased intraoperative complications in the laparoscopic group compared to the open group (10.5% vs 3.7%) with only a 1-day shorter hospitalization for laparoscopic patients [8]. Although oncologic outcomes for laparoscopic and open cases were equivalent in the Barcelona trial, functional outcomes were not reported [9]. The negative impact of operative conversion was well documented in a multicenter trial in Germany that showed increased morbidity, mortality, blood transfusion requirement, and hospitalization for patients requiring operative conversion [10].

Since surgeon experience with laparoscopic surgery is an independent predictor of operative conversion [11], conversion rates would be expected to decrease over time with proficiency in laparoscopy. However, longitudinal studies have not seen a reciprocal decline in conversion rates suggesting inherent technical limitations of laparoscopic surgery [12]. Laparoscopic conversions are increased for patients with adhesions, obesity, ascites, and colorectal cancer [12]. In contrast, these patient factors do not appear to increase conversion risk for patients undergoing robotic colectomy [12]. Multiple studies including a recent meta-analysis comparing laparoscopic to robotic right colectomy have demonstrated a significantly reduced conversion risk associated with robotic surgery further supporting the view that the robotic platform provides superior tools for performing minimally invasive colon surgery [12, 13]. While studies lend support for the technical advantages of the robotic platform, multicenter randomized colon cancer trials are sparse questioning the long-term oncologic equivalency of robotic compared to laparoscopic surgery. A recent study addressing this concern examined surgical outcomes in over 15,000 patients undergoing either robotic or laparoscopic surgery for stages I–III colon cancers [14]. Results showed equivalent lymph nodes harvested and negative surgical margins with an overall survival benefit for patients undergoing robotic surgery. However, no differences in disease specific survival could be determined due to lack of maturity of the data.

While awaiting the long-term results from randomized-controlled trials [15], retrospective studies have been a primary method to compare the functional and oncological benefits of robotic-to-laparoscopic surgery for colorectal cancer. However, these studies often include heterogeneous operations that complicate comparative analyses of the oncologic and functional outcomes of the robotic vs. laparoscopic platform. For instance, one study demonstrated that robotic surgery was associated with increased lymph-node yield compared to laparoscopic and open surgery for right-sided colon tumors but was confounded by varied mesenteric resection techniques practiced by six surgeons [16]. Since the mesenteric dissection technique was not standardized, patients operated on robotically were more likely to undergo transection of the mesenteric vessels intracorporeally compared to laparoscopic patients. The increased lymph-node yield associated with robotics in this study may have been the result of differing mesenteric dissection techniques of surgeons as opposed to any advantages of the robotic platform. Two meta-analysis comparing different laparoscopic techniques for anastomotic construction following right colectomy also demonstrated that varied operative techniques may also confound the comparative evaluation of functional outcomes obtained with robotic or laparoscopic surgery [17, 18]. These studies demonstrated that outcomes of patients with anastomoses constructed intracorporeally were not equivalent to those performed extracorporeally, with a better postoperative recovery for patients undergoing an intracorporeal anastomosis. Despite these results, multiple studies have attempted to compare the outcomes of robotic-to-laparoscopic right colectomy without controlling for the anastomotic technique performed. In addition, other studies have reported the results of robotic right colectomy without a comparative laparoscopic or open surgical control. Because of these biases, it is difficult to conclusively determine whether robotic is superior to laparoscopic as a platform to assist surgeons with resection of right-sided colon tumors [19–30].

Studies comparing robotic-to-laparoscopic colectomy using similar techniques for resection and anastomotic construction have been sparse, limiting evaluation of the relative efficacy of these two minimally invasive surgery platforms. The primary objective of this present study was to examine the potential benefits of performing a right colectomy using the robotic compared to the laparoscopic platform with a previously described standardized technique for intracorporeal high ligation of mesenteric vessels and intracorporeal anastomosis [31, 32]. The secondary objective was to examine the impact of prior experience with laparoscopic right colectomy with intracorporeal anastomosis on the performance of robotic right colectomies with intracorporeal anastomosis during the learning curve in a start-up robotic colon surgery program without mentorship.

Materials and methods

Study cohort

This was a retrospective review of patients of a single surgeon. Consecutive patients undergoing robotic right hemicolectomy with intracorporeal anastomosis were compared to a consecutive series of patients who underwent laparoscopic right hemicolectomy with intracorporeal anastomosis, approved by the Institutional Review Boards [30]. From November 2003 to July 2016, laparoscopic colectomy was offered to all patients with colon cancer or polyps with exclusion of patients with T4 tumors, obstructing tumors, and perforating tumors. During this time-period, the initial 159 consecutive laparoscopic colectomy cases performed were entered into a database and the results of this cohort previously reported [33]. During the same time-period, there were 1263 additional laparoscopic colectomies and proctectomies performed for diverticulitis, rectal prolapse, and rectal tumors by the single surgeon but outcomes not recorded.

As of July 31, 2016, the single surgeon completed all prerequisite Da Vinci training in an effort to begin a robotic colon surgery program with recruitment to a new community-based hospital. All minimally invasive colectomies were attempted robotically and laparoscopic colectomy was not offered to patients. From August 2016 to April 2018, all patients with colon cancer or polyps with the exclusion of patients with T4 tumors, obstructing tumors, and perforating tumors were offered a robotic colectomy. Patient data were retrospectively collected and recorded. Data collected included age, sex, body mass index (BMI), Anesthesiology Society of Anesthesiology Class (ASA), operative indication, operative time (OT), estimated blood loss (EBL), conversion to laparotomy, case frequency during the learning curve, pathology, frequency of lymph nodes harvested (LN), length of stay (LOS), 30-day morbidity, and mortality. Obesity was defined as a BMI $\geq$ 30 kg/m^2 and morbid obesity as BMI $\geq$ 35 kg/m^2. Conversion to laparotomy was defined as any incision length > 5 cm, except when extracting large tumors. Patients were followed for a minimum of 30 days with office appointments.

Surgical technique

Laparoscopic colectomy with intracorporeal anastomosis

The technique has been previously described [30]. Briefly, the technique included 4–5 laparoscopic ports (Versa Step, Covidien Surgical): 1 or two 5-mm and three 12-mm laparoscopic ports. The colon was mobilized laterally first with sharp dissection with the Harmonic Ace (Ethicon Inc, Cincinnati, OH). The mesenteric vessels were divided at their origins with an Endo-GIA Universal stapler with white loads after skeletonizing the vessels with the Harmonic Ace. The small bowel and colon were divided with an Endo-GIA 60, 3.5-mm staple load and an end-side intracorporeal anastomosis was created with an Endo-GIA 60 with 3.5-mm staple loads after a small enterotomy was made with the Harmonic Ace at each end of the bowel. The common channel was closed with an Endo-GIA 60, 3.5-mm staple loads. The specimen was extracted in a large impermeable endocatch bag.

Robotic colectomy with intracorporeal anastomosis

After insufflation of the abdomen with a Veress needle, multiple ports were placed under direct visualization with a laparoscopic camera. The Da Vinci Si robot (Intuitive Surgical, Sunnyvale, CA) was used in all the cases. The robotic ports used included: a 13-mm port placed in the left upper quadrant of the abdomen for arm 1, an 8-mm port placed in the suprapubic area for arm 2, an 8 mm port placed directly to the left of the falciform ligament for arm 3, and a 12 mm and a 5 mm port placed in the left lower quadrant of the abdomen for the camera and assistant, respectively. The liver, peritoneal cavity, and omentum were examined with a 10 mm 30° laparoscopic camera to detect any metastases and the ileocolic pedicle was identified. The small bowel was retracted to the left for optimal exposure, and then, the robot was docked along the patient's right side. The dissection was performed with a 30°, 10 mm robotic camera with a vessel sealer, a fenestrated bipolar, and a small grasping retractor. The dissection proceeded from medial to lateral with dissection of the small bowel and right colon mesentery away from the retroperitoneum. The ileocolic and right branches of the middle colic arteries were dissected and divided at their origins using the vessel sealer. The duodenum and pancreas were dissected away from the mesentery of the proximal transverse colon until the bare area of the liver was visualized. The omentum was separated from the proximal transverse colon and the hepatic flexure mobilized. The mesentery of the right colon and transverse colon were divided with the vessel sealer. The ileum (5 cm from ileocecal valve) and the transverse colon were divided the robotic stapler using 3.5 mm staple loads. The terminal ileum and distally divided transverse colon were aligned with a 3-O vicryl suture with 6 cm segments of bowel. An enterotomy was created in the small bowel and transverse colon using the monopolar scissors, and a side–side isoperistaltic anastomosis was created using the robotic stapler with 3.5 mm staple loads. The common channel was closed with the robotic stapler using 3.5 mm staple loads. The robot was undocked and the specimen extracted with an Alexis wound protector (Applied Medical, Santa Margarita, CA) using the 13 mm port.

Outcomes measured

The surgical outcomes of 21 consecutive patients who underwent robotic right colectomy with intracorporeal anastomosis during the learning curve were compared to 101 consecutive patients who underwent laparoscopic right colectomy with intracorporeal anastomosis. Outcomes of robotic cases were additionally compared to patients undergoing laparoscopic colectomy during the learning curve (LC) and after the learning curve (post-LC). Laparoscopic cases were designated as LC (case 1–51) or post-LC (case 52–101) based on the previous work from the Cleveland Clinic that defined the actual frequency of cases required for the learning curve for laparoscopic colectomy using a risk-adjusted Cumulative Sum model [11].

Statistical analysis

Comparison of continuous and categorical variables was assessed with the independent samples t test and Chi-square test with Fisher's exact test, respectively. Simple linear regression was used to examine continuous relationships. Data are expressed as mean ± SD, odds ratio (OR) with 95% confidence intervals (CI), and significance defined as $p \leq 0.05$. Statistical comparisons were performed using SPSS software version 24 (IBM Inc., Armonk NY).

Results

There were 21 consecutive patients who underwent robotic right colectomy with intracorporeal anastomosis (robotic). Of 159 laparoscopic colectomies performed and data recorded, there were 58 left colectomies that were excluded from this analysis with data available from 101 consecutive patients who underwent laparoscopic right colectomy with intracorporeal anastomosis (LAP) that were analyzed. For patients undergoing LAP, linear regression modeling confirmed a significant negative correlation (Spearman $R^2 = -0.27$, $p = 0.007$) between case number and OT (Fig. 1). There was a significant reduction ($p = 0.02$) in the

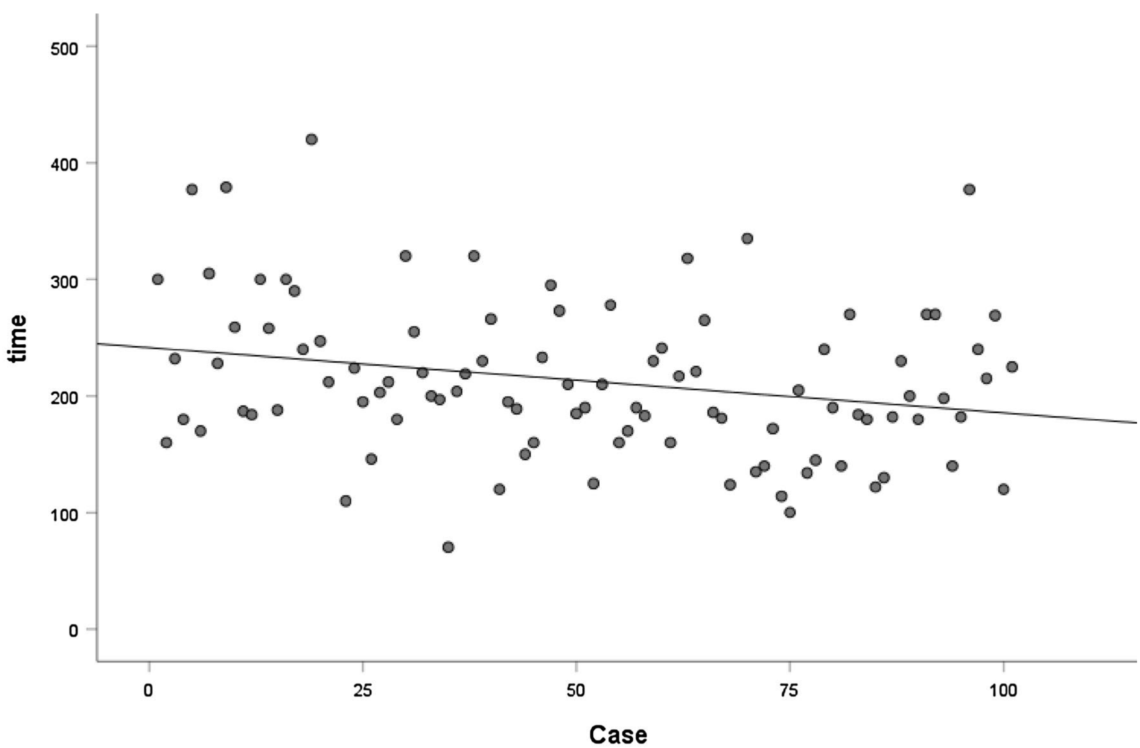

Fig. 1 Learning curve for laparoscopic right hemicolectomy with intracorporeal anastomosis ($n = 101$). X-axis—case number (1–101), Y-axis—operative time (minutes)

OT for post-LC cases (198 ± 61 min) compared to LC cases (228 ± 69 min).

The demographics (Table 1) for robotic ($n = 21$) were compared to all the LAP cases ($n = 101$), LC cases ($n = 51$), and post-LC cases ($n = 50$). Age, gender, and indications for resection were similar for all the groups. BMI was comparable ($p = 0.26$) between robotic and LAP cases with 38% of robotics and 34% of LAP cases performed in obese (BMI ≥ 30) patients. Robotic and LC cases had a higher BMI ($p = 0.001$) compared to post-LC cases. Robotic cases had more advanced ASA Class III compared to LAP cases (OR = 1.2, 95% CI of 1.0–1.4, $p = 0.05$) and post-LC cases (OR = 1.4, 95% CI of 1.0–1.9, $p = 0.03$).

Intraoperative and postoperative outcomes (Table 2) were compared for cases performed robotic ($n = 21$), LAP ($n = 101$), LC ($n = 51$), and post-LC ($n = 50$). OT was longer ($p = 0.001$) for robotic compared to either LAP, LC, or post-LC cases. OT for post-LC cases was significantly ($p = 0.02$) shorter than LC cases despite a greater frequency ($p = 0.04$) of performing adhesiolysis in post-LC cases compared to LC cases (OR = 1.6, 95% CI of 1.0–2.7). OT for robotic cases significantly ($p = 0.01$) correlated (Spearman $R^2 = 0.54$) with BMI (Fig. 2) with no significant correlations with either EBL or ASA. There was no difference in EBL, percentage of operative conversions, LOS, total complication, or mortality between any groups.

Postoperative complications occurred in 25 patients (25%) for the entire cohort of 122 patients. Complications were more common ($p = 0.04$, OR 2.4, 95% CI of 1.0–6.0) in patients undergoing surgery for cancer (29%) compared to polyps (14%). Complications were no different for patients age ≥ 75 vs. < 75 (18% vs. 22%, $p = 0.41$), female vs. male (17% vs. 24%, $p = 0.23$), ASA III vs. I/II (18% vs. 23%, $p = 0.36$), BMI ≥ 30 vs < 30, (22% vs. 18%, $p = 0.40$), BMI ≥ 35 vs < 35 (19% vs. 20%, $p = 0.61$), and adhesions lysed vs. no lyses (24% vs. 19%, $p = 0.30$).

Individual postoperative complications and reoperation rates were no different between robotic compared to LAP. There were 20 Clavien–Dindo Grade 2 or higher complications occurring in 3 patients (14%) undergoing robotic compared ($p = 0.53$) to 17 undergoing laparoscopic surgery (17%). There were no intraoperative complications in either group. Total complications occurred in three robotic cases (14%) including an anastomotic leak that completely resolved with conservative management with percutaneous drainage, a small bowel obstruction related to a postoperative hematoma requiring reoperation, and a pneumonia that resolved with antibiotics without need for mechanical ventilation. There were 22 complications (22%) following LAP including pneumonia ($n = 5$), superficial surgical site infection ($n = 4$), superficial surgical site infection and UTI ($n = 1$), deep space surgical site infection ($n = 1$), anastomotic bleed ($n = 6$), pneumothorax ($n = 1$), small bowel obstruction secondary to a port-site hernia requiring reoperation ($n = 2$), rectus sheath hematoma requiring blood transfusion ($n = 1$), and ileus ($n = 1$). There were no mortalities in either surgical group.

Table 1 Demographics of patients undergoing robotic colectomy ($n = 21$), all patients undergoing laparoscopic colectomy ($n = 21$) and patients undergoing laparoscopic colectomy during the learning curve ($n = 51$) or after the learning curve ($n = 50$)

Characteristics	Robotic ($n = 21$)	Lap ($n = 101$)	LC ($n = 51$)	Post-LC ($n = 50$)	p value
Age (years)					
Mean (SD)	65 (10)	68 (12)	70 (12)	67 (12)	NS
Range	46–81	42–96	45–96	42–91	
Gender					
Female	14 (67%)	50 (49%)	24 (47%)	26 (52%)	NS
Male	7 (33%)	51 (51%)	27 (53%)	24 (48%)	
BMI (kg/m^2)					
Mean (SD)	30 (7)	28 (7)	30 (6)	25 (4)	0.001[c,d]
Range	21–46	16–49	19–49	16–38	
ASA class					
I	0 (0%)	8 (7%)	5 (10%)	3 (6%)	0.05[a]
II	6 (39%)	43 (43%)	18 (35%)	25 (50%)	0.03[c]
III	15 (71%)	50 (50%)	28 (55%)	22 (44%)	
Indication					
Colon polyp	12 (57%)	58 (58%)	29 (58%)	29 (58%)	NS
Colon cancer	9 (43%)	43 (42%)	22 (42%)	21 (42%)	

[a]Robotic vs. LAP
[b]Robotic vs. LC
[c]Robotic vs. post-LC
[d]LC vs. post-LC

Table 2 Surgical outcomes of patients undergoing robotic colectomy ($n=21$), all patients undergoing laparoscopic colectomy ($n=21$), and patients undergoing laparoscopic colectomy during the learning curve ($n=51$) or after the learning curve ($n=50$)

Characteristics	Robotic ($n=21$)	Laparoscopic ($n=101$)	LC ($n=51$)	Post-LC ($n=50$)	p value
OT (min)					
Mean (SD)	330 (100)	212 (66)	228 (69)	198 (61)	0.001[a,b,c]
Range	147–608	70–420	70–420	100–377	0.02[d]
Estimated blood loss (mL)					
Mean (SD)	100 (58)	100 (153)	133 (250)	102 (60)	NS
Range	100–250	0–1500	0–1500	0–300	
Adhesiolysis	7 (33%)	34 (34%)	12 (24%)	22 (44%)	0.04[d]
Conversion rate	0 (0%)	5 (5%)	1 (2%)	3 (8%)	NS
Length of stay (days)					
Median (SD)	3.0 (6.4)	5.0 (1.7)	5.0 (1.7)	4.5 (1.7)	NS
Range	3–30	2–11	2–11	3–11	
Complications (total)	3 (14%)	22 (22%)	12 (24%)	10 (20%)	NS
Mortality rate (30 days)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	NS

[a]Robotic vs. laparoscopic
[b]Robotic vs. LC
[c]Robotic vs. post-LC
[d]LC vs.post-LC

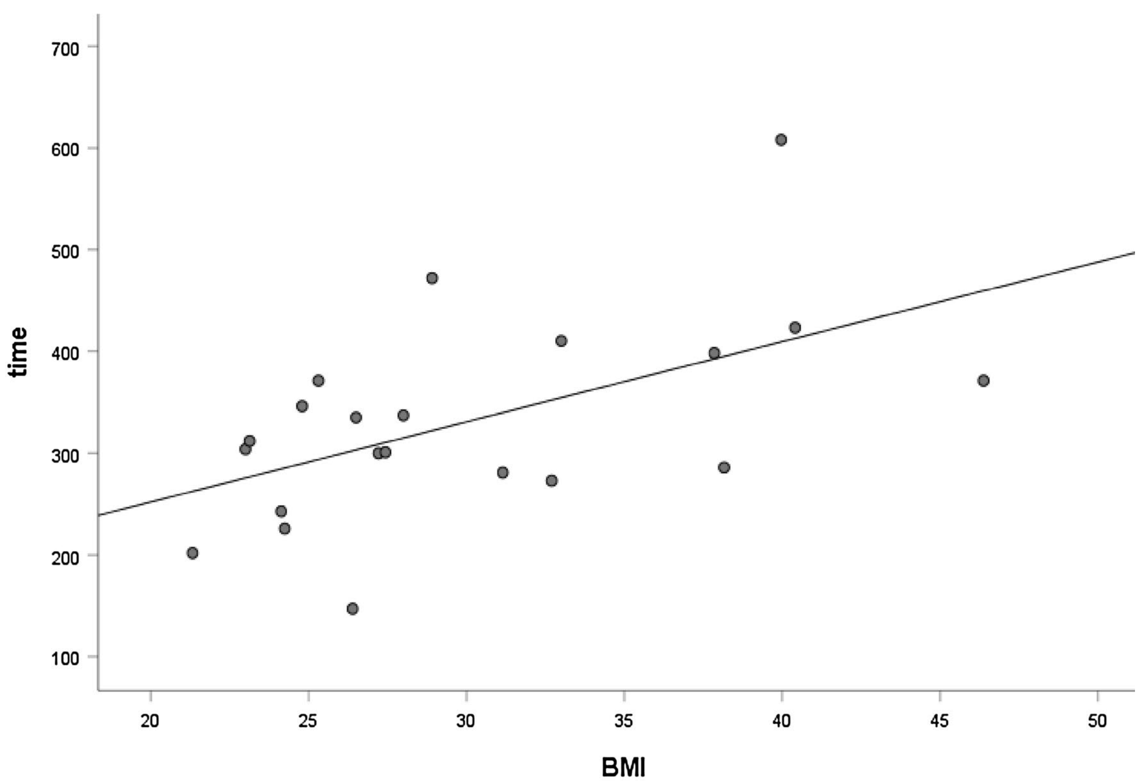

Fig. 2 Correlation of body mass index (BMI) with operative time in patients undergoing robotic right hemicolectomy with intracorporeal anastomosis ($n=21$). X-axis—BMI (kg/m^2) and Y-axis—operative time (minutes)

The oncologic results were compared for patients undergoing robotic and LAP (Table 3). There were no differences between the two groups in the frequency of invasive cancer or AJCC stage of disease. All patients underwent resection with negative surgical margins. The average LN yield was five more nodes ($p=0.02$) when using a robotic approach

Table 3 Oncologic outcomes of patients undergoing robotic colectomy ($n = 21$) compared to all patients undergoing laparoscopic colectomy ($n = 101$)

Characteristics	Robotic ($n = 21$)	Laparoscopic ($n = 101$)	p value
Stage			
0	12 (52%)	58 (57%)	NS
I	4 (19%)	13 (13%)	
II	4 (19%)	15 (15%)	
III	1 (10%)	9 (9%)	
IV	0 (0%)	4 (4%)	
Lymphoma		1 (1%)	
Neuroendocrine		1 (1%)	
Negative margins	21 (100%)	101 (100%)	NS
Lymph nodes			
Mean (SD)	19 (11)	14 (8)	0.02
Range	0–43	0–43	

compared to a laparoscopic approach. There was no difference ($p = 0.53$) between LN yield for LC cases compared to post-LC cases (15 ± 8 vs. 14 ± 8, respectively).

Discussion

Although robotic surgery for colon tumors offers many potential benefits compared to laparoscopic colectomy, adoption by surgeons has been slow. The percentage of rectal cancer cases performed robotically increased from 1.9 to 5.1% from 2010 to 2012 in the United States compared to a relatively smaller increase of 0.6–1.6% for colon cancer cases during this same time-period [2]. Adoption has been impeded by multiple factors including low-volume experience of trainees, lack of mentorship for junior surgeons, access to a robot, inadequate assistance, and a preference for laparoscopic colectomy [3]. Robotic colon experience is marginal during general residency programs with only 2% of residents completing more than 25 cases. In addition, while the majority of colorectal surgery residents performed more than 50 laparoscopic cases, only 4.6% completed greater than 50 robotic cases [3]. Unfortunately, implementation of a national robotics training program during colorectal surgery residency did not succeed in increasing the percentage of surgeons who adopted robotic colon surgery [3].

Adoption of robotic colectomy has been further hampered by the mixed clinical results. While a recent study showed that robotic colectomy was associated with increased intraoperative complications and cost compared to laparoscopic colectomy [4], the other investigators reported great promise for the robotics platform with decreased complications and length of stay noted for robotic colectomy compared to laparoscopic colectomy patients [30]. These conflicting results may be potentially explained by inclusion of cases during the learning curve, lack of standardized operative techniques, or other biases inherent in retrospective studies.

Robotics may be a superior platform to laparoscopy for performing colectomies, because it facilitates a completely intracorporeal operation. A completely intracorporeal laparoscopic colectomy reduces the need for excessive mobilization and tension of the colon which may result in tearing of the bowel and mesentery potentially occurring with an extracorporeal anastomosis, particularly in obese individuals. We were among the first investigators to demonstrate the salutary benefits of using a completely intracorporeal laparoscopic technique to remove colon tumors in obese patients [31]. Multiple studies demonstrate the improved outcomes for patients undergoing laparoscopic colectomy with intracorporeal anastomoses compared to extracorporeal anastomoses with decreased blood loss, less complications, and shorter length of stay noted [17, 18]. However, a laparoscopic intracorporeal anastomosis is felt to be technically challenging limiting the broad application of this surgical advance [29]. In contrast, robotics enables intracorporeal suturing potentially simplifying construction of an intracorporeal anastomosis, which likely accounts for robotic adoption by surgeons not performing LAP intracorporeal anastomosis [29] as well as surgeons that are facile with construction of an intracorporeal anastomosis laparoscopically [34].

Conclusions drawn from studies evaluating the utility of robotic colectomy with intracorporeal anastomosis for right-sided colon tumors are limited by small case numbers (< 600 in 11 studies), retrospective design with only one randomized prospective study that was underpowered, and a limited comparable control group of patients undergoing laparoscopic colectomy with intracorporeal anastomosis (Table 4). The objectives of this present study were to (1) determine the comparative outcomes achieved for patients with right-sided colon tumors undergoing a standardized intracorporeal, minimally invasive colectomy performed either robotically or laparoscopically, and (2) to examine the impact of laparoscopic experience with a completely intracorporeal colectomy on performance of a completely intracorporeal colectomy performed robotically. The outcomes of the first 21 robotic cases performed by a single surgeon were compared to the initial 101 consecutive laparoscopic cases performed.

We chose to examine the first 101 consecutive cases and not more recent cases, because these data were readily available to us in a database that had previously undergone peer review [33]; we expected that these cases should include cases during and just after the learning curve and studies have indicated a plateau in results after 125 cases [11]. Proficiency in LAP was demonstrated by a significant negative correlation ($R^2 = -0.27$) between OT and the chronologic

Table 4 Literature review of surgical outcomes of patients undergoing robotic right hemicolectomy with intracorporeal anastomosis from 2007 to 2015 from 11 studies with comparative outcomes from the current study

Author (date)	Study design	Robotic lap cases (*N*)	ICA:ECA	Mean OT (min)	Mean EBL (mL)	Conversion rate (%)	Morbidity (%)	Mean LOS (days)	Mean LN yield
Rawlings [35]	Retrospective								
	Robot	17	17:0	219	40	0	5.9	5.2	–
	Lap	15	0:15	170	66	13	13.3	5.5	
Park et al. [20]	Randomized								
	Robot	35	30:5	195	36	0	17.1	7.9	29.5
	Lap	35	7:28	130	56	0	19.4	8.3	30.8
D'Annibale [36]	Prospective								
	Robot	50	45:5	224	20	0	2	7	18.8
Trastulli et al. [22]	Retrospective								
	Robot	20	20:0	328	55	0	5	4.5	17.6
Morpurgo et al. [23]	Retrospective								
	Robot	48	48:0	266	–	–	16.7	7.5	26
	Lap	48	0:48	223	–	–	37.5	9.0	25
Trastulli et al. [24]	Retrospective								
	Robot	102	102:0	287	30	3.9	23	4[a]	20
	Lap	134	40:94	204:208	10:45	15:8.5	22:20	5.5[a]:7[a]	19:19.5
Lujan et al. [25]	Retrospective								
	Robot	58	52:6	193	48	0	19	3.7	20.7
Parisi et al. [26]	Retrospective								
	Robot	108	108:0	286	76	8.3	19.4	4[a]	18.9
Kelley et al. [27]	Retrospective								
	Robot	21	21:0	250	–	0	14.0	4	26
Lujan et al. [28]	Retrospective								
	Robot	89	89:0	–	38	2.3	25.8	3.5	14.1
	Lap	135	0:135		61	6.7	32.6	3.5	11.9
Reitz et al. [29]	Retrospective								
	Robot	49	29:20	144	48	8.2	10.0	3.2	19.5
All studies	Robotic	597	561:36	144–328	20–76	0–8.3	2–25.8	3.2–7.9	14.1–29.5
	Lap	373	47:326	130–223	10–66	0–15	13.3–37.5	3.5–9.0	11.0–30.8
Current study (2018)	Retrospective								
	Robot	21	21:0	330	100	0	14.0	3.0[a]	18
	Lap	101	96:5	212	100	5	22.0	5.0[a]	14

[a]Median LOS

time that cases were performed. Analogously, the OT of LAP cases performed post-LC was reduced compared to LC cases. The proficiency gained with LAP is further supported by reduced operative time of post-LC cases despite the more frequent need for adhesiolysis in these cases. While the OT was significantly longer for robotic cases compared to all the LAP cases, the prolonged OT may partly be explained by more difficult robotic cases as 38% of cases were performed in obese patients. The OT of robotic cases strongly correlated ($R^2=0.54$, $p=0.01$) with body mass index. While obesity is associated with the higher conversion rates of minimally invasive colectomies [11], there were remarkably no intraoperative complications nor conversions in this present series of 21 robotic cases. Similarly, we have previously reported that a standardized completely intracorporeal laparoscopic colectomy enables minimal intraoperative complications and operative conversion, and leads to comparable surgical outcomes in obese and thin patients [31, 32]. The ability to achieve a successful operation without any conversions in the robotic cases is also noteworthy as these cases occurred during the learning curve and the majority (71%) had advanced ASA III, a known risk factor for operative conversion [11]. In fact, a greater proportion of robotic cases were ASA III compared to the LAP cases. In a previous report by my group, comparing patients high risk (BMI ≥ 30, and/or ASA III/IV) to those patients low risk (BMI < 30, ASA I/II) for conversion, operative conversion rates for patients undergoing LAP were similarly low between groups, with conversion rate for high-risk patients significantly reduced compared to the rate predicted by the Cleveland Clinic Foundation operative conversion risk calculator [34]. A study of laparoscopic right colectomies with intracorporeal anastomoses performed for cancer and Crohn's disease in a cohort of 243 patients with a high incidence of obesity and high ASA class corroborates our findings of low conversion rates for patients undergoing LAP [37].

Our conversion rate of 0% for robotic cases compares favorably to conversion rates of the other studies (Table 4) of robotic (range of 0–8.3%) and LAP cases (range of 0–15%). In this present study, experience and proficiency with laparoscopic colectomy with intracorporeal anastomosis clearly enabled achieving success without any operative conversions despite being performed during the robotic learning curve. In contrast to this present study, transitioning to robotics with limited laparoscopic experience is associated with high operative conversion rates (15.9–20%) during the robotic learning curve [26, 29] with no notable decreases in operative conversion rates until completion of 90 cases in one study [26]. In the present study, the overall morbidity of 14% compares well with the other reports (Table 4) with morbidity ranging from 2 to 26% for robotic cases. In addition, EBL of robotic cases in the current study was similar to LAP cases and there were no intraoperative complications that compares well with the reports of a higher incidence of bleeding and organ puncture occurring during robotic colectomy compared to laparoscopic colectomy [4]. In the current study, there was no difference in LOS between robotic and LAP cases with LOS for both groups within the range of reported studies comparing these two minimally invasive techniques (Table 4). Lymph-node yield was significantly greater in robotic compared to LAP cases in this present report. These results are consistent with another study, suggesting that the robotic platform may improve lymph-node yield [16].

This current study suggests that proficiency with a completely intracorporeal laparoscopic right colectomy enables the completion of the same operation robotically with a high degree of success, even during the learning curve. These results were achieved in the process of starting a robotic colon surgery program at a community-based hospital with no other surgeons trained in robotic colon surgery to provide direct mentorship. The correlation of proficiency in a completely intracorporeal colectomy and successful robotic outcomes in this present study is further corroborated by data, indicating that lack of experience with a completely intracorporeal technique is associated with a prolonged robotic learning curve with high operative conversion rates (15.9%) during the initial cases [26]. The impact of skills gained from other laparoscopic colorectal surgery cases (> 1200 cases) performed, however, cannot be discounted as a factor contributing to the positive robotic outcomes achieved in this study.

These findings should have broad reaching implications for surgeons interested in training in robotic colon surgery. It is expected that this study will generate a more optimistic attitude among surgeons reluctant to adopt robotics because of concerns of either technical difficulty or increased intraoperative complications during the learning curve [4, 26]. Surgeons skilled at laparoscopic colectomy may find the robotic platform easier to adopt than they predicted, while young surgeons may find similar success in robotic colon surgery by first honing their skills at laparoscopic colon surgery. This present study will hopefully pave the way for additional surgeons to consider transitioning to robotics to perform a completely intracorporeal colectomy. The robotic platform may provide better tools enabling surgeons to perform minimally invasive colectomies with a high degree of success, even in patients with obesity and high ASA class. While critics of robotic surgery point out that morbidity are similar, but costs of robotic colectomy exceed laparoscopic colectomy, there are emerging data demonstrating lower conversion rates for the robotic platform [12, 13] with anticipation of better outcomes and lower costs for robotics in the future [38]. Upgrades in robotic technology and ongoing acquisition of robotic skills by surgeons still in the learning curve hold great promise that this technology may be useful in improving patient outcomes while reducing healthcare expenditure in the United States.

The strengths of this present study include its (1) size: being one of the largest comparative studies examining surgical outcomes in patients undergoing a completely intracorporeal right hemicolectomy; (2) standardization of operative technique with laparoscopic and robotic cases being operated on using completely intracorporeal high ligation of mesenteric vessels and creation of an intracorporeal anastomosis; (3) inclusion of consecutive cases during and after the learning curve. The limitations of the study include its retrospective design, use of historical controls, and relatively small number of robotic patients. Further controlled studies comparing robotic and laparoscopic right hemicolectomy are needed to help guide surgeons to decide which platform will best optimize surgical outcomes.

Compliance with ethical standards

Conflict of interest David Blumberg, M.D. declares that he no conflicts of interest.

Ethical standards All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000. Data collection, informed consent, and presentation of this data were in compliance with the Lifebridge Health IRB protocol obtained prior to beginning this retrospective study.

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