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Robotic-assisted Colorectal Surgery in the United States: A Nationwide Analysis of Trends and Outcomes

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Abstract
Background While robotic-assisted colorectal surgery (RACS) is becoming increasingly popular, data comparing its outcomes to other established techniques remain limited to small case series. Moreover, there are no large studies evaluating the trends of RACS at the national level.
Methods The Nationwide Inpatient Sample 2009–2010 was retrospectively reviewed for robotic-assisted and laparoscopic colorectal procedures performed for cancer, benign polyps, and diverticular disease. Trends in different settings, indications, and demographics were analyzed. Multivariate regression analysis was used to compare selected outcomes between RACS and conventional laparoscopic surgery (CLS).
Results An estimated 128,288 colorectal procedures were performed through minimally invasive techniques over the study period, and RACS was used in 2.78 % of cases. From 2009 to 2010, the use of robotics increased in all hospital settings but was still more common in large, urban, and teaching hospitals. Rectal cancer was the most common indication for RACS, with a tendency toward its selective use in male patients. On multivariate analysis, robotic surgery was associated with higher hospital charges in colonic ($11,601.39; 95 % CI 6,921.82–16,280.97) and rectal cases ($12,964.90; 95 % CI 6,534.79–19,395.01), and higher rates of postoperative bleeding in colonic cases (OR = 2.15; 95 % CI 1.27– 3.65). RACS was similar to CLS with respect to length of hospital stay, morbidity, anastomotic leak, and ileus. Conversion to open surgery was significantly lower in robotic colonic and rectal procedures (0.41; 95 % CI 0.25–0.67) and (0.10; 95 % CI 0.06–0.16), respectively.
Conclusions The use of RACS is still limited in the United States. However, its use increased over the study period despite higher associated charges and no real advantages over laparoscopy in terms of outcome. The one advantage is lower conversion rates.

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Introduction

Robotic surgery was developed in the early 1990s and has been applied in several surgical specialties. The technical benefits it offered regarding instrument manipulations and three-dimensional visualizations were seen as advantages over traditional laparoscopy [1, 2]. In prostate surgery, the robot has demonstrated its safety but has not offered any major advantages in terms of short-term or long-term outcomes compared to open radical prostatectomy [3–5]. Despite this lack of major benefit, robotic prostatectomy accounted for 67 % of radical prostatectomies performed in the United States in 2010 [6]. Likewise, a growing number of hysterectomies are being performed with robotic assistance [7].

The first robotic-assisted colorectal procedure was reported in July 2001 [8]. This was followed by several case series demonstrating the safety and feasibility of this technique in both benign and malignant colorectal disease processes [9, 10]. These reports fueled more interest in robotic techniques, and several studies comparing robotic surgery to conventional laparoscopy (CLS) have been published [11–18]. Robotic-assisted colorectal surgery (RACS) has been found to be equivalent to laparoscopic surgery in terms of return of bowel function [12, 19, 20], length of hospital stay [12–14, 19], postoperative quality of life [21], and oncologic outcomes [16, 18]. Several reports have highlighted the possible technical advantages, especially for rectal procedures deep in the pelvis [22, 23]. However studies evaluating the outcomes of RACS come from highly specialized referral centers and have thus been limited by small sample sizes. There have been no studies examining the trends of RACS at the national level in different hospital settings and comparing its outcomes to CLS. Using the power of a nationwide database, we aimed to examine the short-term outcomes of RACS and investigate whether this technique offers any additional benefits over CLS. This article presents a large retrospective review, looking at the trends of RACS in the United States and comparing its outcomes to conventional laparoscopic surgery (CLS).

Methods

Using the Healthcare Cost and Utilization Project Nationwide Inpatient Sample (NIS) database, we conducted a retrospective analysis of elective colorectal surgeries performed laparoscopically or robotically in the United States between January 1st 2009 and December 31st 2010. Cases were divided into two groups: group 1 includes cases performed using CLS and group 2 consists of cases performed with robotic assistance (RACS).

The NIS is the largest all-payer inpatient care database in the United States and contains information from nearly 8 million hospital stays each year across the country. The data set approximates a 20 % stratified sample of American community, nonmilitary, nonfederal hospitals, resulting in a sampling frame that comprises approximately 95 % of all hospital discharges in the United States. Data elements within the NIS are drawn from hospital discharge abstracts that allow determination of patient characteristics, procedures performed during a given hospitalization, length of stay, overall and specific postoperative morbidity, and in-hospital mortality [24]. Approval for the use of the NIS patient-level data in this study was obtained from the institutional review board of the University of California-Irvine Medical Center and the NIS.

Study aims

The study had two aims: (1) to investigate the trends of RACS in the United States for different disease states, procedure types, and in different hospital settings and (2) to examine whether RACS is associated with better or worse short-term outcomes compared with CLS. The following short-term outcomes were examined on multivariate regression analysis: total hospital charge, length of hospital stay, conversion to open surgery, anastomotic complications, ileus, postoperative bleeding, and overall morbidity (which includes cerebrovascular accidents, cardiac complications, respiratory failure, pneumonia, urinary tract infections, urinary retention, wound complications, ileus, and anastomotic leak). These outcome measures were chosen a priori after reviewing previously published series.

Inclusion and exclusion criteria

All elective cases with an ICD-9 CM diagnosis code for colon benign polyps (211.3, 230.3, V12.72), colon cancer (153.0–153.9), rectal benign polyps (211.4, 230.4, 230.5, 569.0), rectal cancer (154.0–154.2, 154.8), and diverticular disease (562.10, 562.11, 562.12, 562.13) that were treated with RACS or CLS were included in our analysis.

In 2008, new specific ICD-9 CM procedure codes for robotic and laparoscopic colorectal surgery were introduced. The ICD-9 CM procedures codes 17.41(open robotic-assisted procedure), 17.42 (laparoscopic robotic-assisted procedure), and 17.49 (unspecified robotic-assisted procedure) were used to identify robotic-assisted cases. These codes have been used in previously published data [25] and are frequently used by medical coders to identify robotic-assisted procedures. The following procedure types were considered in our analysis: right hemicolectomy, left hemicolectomy, sigmoidectomy, anterior resection (AR), and abdominoperineal resection (APR). Any RACS and CLS cases converted to open surgery were identified with the ICD-9 diagnosis code V64.41 (conversion to open surgery) and were included in their respective groups in the analysis on an intention-to-treat basis. Missing data on ethnicity, primary payer type, hospital information, and mortality were excluded from our analysis.

Study variables

Age, gender, ethnicity, payer type, and preselected admission co-morbidities provided by NIS (see Table 3), as well as a co-morbidity score based on the Elixhauser-Van Walraven model [26], were listed for both groups. Hospital characteristics such as hospital type (teaching vs. non-teaching), location (urban vs. rural), and size (small vs. medium vs. large) were also listed. Disease type (benign vs. malignant vs. diverticular disease) and procedure types as well as the use of fecal diversion were also examined. These variables were accounted for on multivariate regression analysis.

Statistical analysis

All statistical analyses were conducted with SAS, version 9.3 and the R Statistical Environment. Demographic and co-morbidity data were summarized using mean and interquartile range for continuous variables and proportions for categorical variables. *p* Values were not reported for these data, as information from these variables are descriptive in nature. Formal statistical tests on these variables would have to take into account the inflation of type I error due to multiple comparisons. Because of the different complexities between colonic and rectal cases, their outcomes were listed and analyzed separately in multivariate risk-adjusted analysis. The colonic subgroups include right hemicolectomy, left hemicolectomy, and sigmoidectomy. The rectal subgroup includes AR and APR. We controlled for age, gender, ethnicity, payer type, co-morbidity scores, hospital factors, disease types, and different procedure types. In the rectal subgroup, APR and AR with colostomy were excluded from the anastomotic complication analysis. We also controlled for the use of fecal diversion. Estimates of adjusted mean differences and adjusted odds ratios (OR) were obtained with 95 % confidence intervals (CI). Holm's method was used to account for multiple comparisons [27]. We used the weighting coefficient provided by NIS and the Horvitz–Thompson estimator to obtain national numbers of laparoscopic and robotic cases.

Results

An estimated 3,568 robotic-assisted colorectal procedures were performed in the United States (U.S.) in 2009 and 2010, in contrast to 124,720 cases that were performed using CLS. RACS accounted for 2.78 % of all minimally invasive colorectal surgical cases in the United States over the study period. The use of RACS increased by 100 % from 1,188 cases in 2009 to 2,380 cases in 2010. In contrast, the use of laparoscopy increased only by 1.15 %.

Table 1 shows the use of RACS and CLS in different hospital settings. From 2009 to 2010, the use of RACS increased in different hospital settings. This increase was most remarkable for medium-sized hospitals (7.7-fold), followed by non-teaching hospitals (2.5-fold), urban hospitals (1.9-fold), teaching hospitals (1.7-fold), small hospitals (1.6-fold), and large hospitals (1.3-fold). The majority of RACS cases were performed in large, urban, teaching hospitals.

The use of laparoscopic and robotic techniques according to different indications and procedure types is listed in Table 2. The most common indication for RACS was rectal cancer (39.52 %), followed by diverticular disease. In contrast, CLS was most commonly used for diverticular disease, followed by colon cancer. Rectal cancer accounted only for 7.23 % of cases performed using CLS (Table 2). From 2009 to 2010, the use of RACS increased for all disease types but most remarkably for diverticular disease (2.6-fold). AR was the most commonly performed robotic procedure (40.09 %), whereas right hemicolectomy was the most commonly performed laparoscopic procedure. The use of fecal diversion in AR (not shown in the table) was similar between the laparoscopic and robotic group (2.96 vs. 2.54 %). APR accounted for 10.62 % of RACS cases, whereas it only accounted for 2.49 % of CLS cases. From 2009 to 2010, the use of RACS

Table 1 Use of laparoscopic and robotic techniques per year by hospital type, location, and bed size

Hospital	2009			2010		
	Laparoscopic	Robotic	Total	Laparoscopic	Robotic	Total
Type						
Teaching	32,074 (97.07)	967 (2.93)	33,041 (100)	29,803 (94.41)	1,764 (5.59)	31,567 (100)
Non-teaching	29,234 (99.25)	221 (0.75)	29,455 (100)	32,118 (98.23)	580 (1.77)	32,698 (100)
Missing	694	0	694	797	36	833
Total	62,002	1,188	63,190	62,718	2,380	65,098
Location						
Urban	56,788 (97.95)	1,188 (2.05)	57,976 (100)	56,603 (96.03)	2,339 (3.97)	58,942 (100)
Rural	4,520 (100)	0	4,520 (100)	5,318 (99.91)	5 (0.09)	5,323 (100)
Missing	694	0	694	797	36	833
Total	62,002	1,188	63,190	62,718	2,380	65,098
Bed size						
Small	6,268 (96.82)	206 (3.18)	6,474 (100)	6,949 (95.28)	344 (4.72)	7,293
Medium	15,004 (99.38)	94 (0.62)	15,098	15,021 (95.22)	754 (4.78)	15,775
Large	40,036 (97.83)	888 (2.17)	40,924	39,951 (96.96)	1,246 (3.04)	41,204
Missing	694	0	694	797	36	833
Total	62,002	1,188	63,190	62,718	2,380	65,098

Total numbers are provided. Percentages are listed in brackets increased for all procedure types, most notably for AR (2.3-fold), followed by sigmoidectomy (1.8-fold).

While the total number of robotic colonic cases was higher than robotic rectal cases because of the indications considered in our analysis, we observed a selective application of robotic-assisted techniques for rectal procedures. In fact, robotic-assisted rectal surgery accounted for 13.58 % of the 10,497 rectal cases performed through minimally invasive techniques, whereas only 1.82 % of the 117,791 colonic cases were performed using robotic-assisted techniques.

Table 3 lists the patient demographics and co-morbidities. The mean age of patients undergoing RACS was 61 years, compared with 63 years for patients undergoing CLS. Gender distribution was similar in the RACS and CLS groups; however, on subgroup analysis (not shown in the table) we observed a tendency toward a higher use of robotic-assisted techniques in males undergoing AR for rectal cancer. In fact, 58.0 % of patients undergoing robotic-assisted AR compared with 52.4 % for laparoscopic AR ($p = 0.08$). Private insurance, including HMO, was the most common payer type for the two groups. Co-morbidity scores were similar in RACS and CLS patients.

The unadjusted incidences of several outcomes and complications are listed in Table 4. No deaths occurred among patients undergoing robotic-assisted colon resections, and the mortality rate in the CLS group was low (0.51 %). A similar observation was made for rectal cases. Because the numbers were small, mortality was excluded from the multivariate analysis. Length of hospital stay was short, with a mean of 6 days for laparoscopic colon resection, robotic colon resections, and robotic rectal resections, whereas it was 7 days for laparoscopic rectal resections. There was a tendency toward lower anastomotic complications in the robotic group for all procedures; this, however, did not achieve statistical significance.

Table 5 lists the adjusted OR and mean differences for selected endpoints. On multivariate regression analysis, robotic colonic cases were associated with higher total hospital charges by 11,601 $US ($p < 0.001$), and higher rates of postoperative bleeding (OR = 2.15; 95 % CI: 1.27–3.27). The use of robotic techniques in colon resections was associated with a 59 % reduction in the odds of conversion to open surgery ($p = 0.002$). When examining rectal procedures, we found that robotic cases were again associated with higher hospital charges by 12,965 $US ($p < 0.001$) and a 90 % reduction in the odds of conversion to open surgery ($p < 0.001$). Robotic rectal procedures were not associated with a higher risk of postoperative bleeding; however, a tendency toward higher bleeding rates was observed here. Other short-term outcomes, such as length of stay, overall morbidity, anastomotic leak, and ileus were similar in RACS and CLS.

Discussion

RACS addresses some of the technical limitations of CLS [22, 28]. Despite the proposed technical advantages of robotic surgery, our data show that its use is still limited in the United States. Perhaps the most important factor limiting the adoption of robotics may be economical in nature. Our results show significantly higher hospital charges associated with the use of RACS in both colonic and rectal

Table 2 Use of laparoscopic and robotic techniques according to different indications and procedure types

	Laparoscopic			Robotic		
	2009 ($n = 62{,}002$)	2010 ($n = 62{,}718$)	Total ($n = 124{,}720$)	2009 ($n = 1{,}188$)	2010 ($n = 2{,}380$)	Total ($n = 3{,}568$)
Indications						
Colon benign polyps	21.40	20.29	20.84	12.40	13.36	13.03
Colon cancer	34.15	34.79	34.47	17.36	15.09	15.86
Diverticular disease	37.37	37.46	37.42	25.21	34.27	31.16
Rectal benign polyps	0.05	0.04	0.04	0.41	0.43	0.42
Rectal cancer	7.03	7.43	7.23	44.63	36.85	39.52
Procedures						
Right hemicolectomy	43.41	42.25	42.82	21.07	17.67	18.84
Left hemicolectomy	8.99	8.44	8.72	2.89	3.66	3.40
Sigmoid-ectomy	39.53	41.07	40.31	27.69	26.72	27.05
Anterior resection	5.63	5.69	5.66	35.54	42.46	40.09
APR	2.43	2.55	2.49	12.81	9.48	10.62

Data are provided as percentages

APR abdominoperineal resection

Table 3 Patients characteristics in the laparoscopic and robotic groups

	Laparoscopic ($n = 124{,}720$)	Robotics ($n = 3{,}568$)
Age, years	63 (53–73)	61 (52–69)
Gender		
Male	48.04	50.85
Female	51.57	49.15
Missing	0.39	0
Ethnicity		
White	72.34	72.80
Black	7.00	4.53
Hispanic	5.36	10.20
Asian or Pacific Islander	1.55	3.68
Native American	0.32	0.28
Other	2.00	2.55
Missing	11.43	5.95
Primary payer		
Medicare	43.58	36.54
Medicaid	2.87	4.11
Private including HMO	49.77	55.24
Self-pay	1.37	1.13
No charge	0.22	0.42
Other	2.05	2.55
Missing	0.13	0
Co-morbidities		
Deficiency anemias	12.91	11.19
Congestive heart failure	3.05	1.27
Chronic pulmonary disease	13.28	11.76
Diabetes	16.63	16.15
Hypertension	51.15	45.89
Liver disease	1.63	0.57
Obesity	10.57	9.63
Chronic kidney disease	3.30	2.41
Valvular heart disease	3.59	2.55
Co-morbidity score[a]	2 (0–3)	2 (0–4)

Continuous variables are reported as mean and interquartile range, and categorical variables are reported as percent proportions

[a] Co-morbidity score based on the Elixhauser-Van Walraven model

resections. Of note is that, while hospital charges are a good reflection of cost, these two measures are different. Charges are directly available from the NIS data set, and a cost-to-charge program should be used to determine cost. The higher hospitals charge observed in robotic cases can be attributed to the price of the robotic platform, which at the time these data were collected was approximately $1.65 million [29], with an additional 100,000 $US in yearly maintenance costs [11]. Longer operative times are another factor that may explain the higher charges of RACS as reported in several studies [11, 17, 30]. Docking and repositioning of the robot during a multiquadrant colorectal case can increase operative time considerably [11]. However, several reports suggest that operative times and hence charges will reduce as more experience is gained in docking and repositioning the robot [19, 31], or by modifying surgical techniques [22, 32].

The limited adoption of RACS is reminiscent of the slow adoption of laparoscopic colorectal surgery in its early days. The first robotic-assisted colorectal procedure was reported in 2001 [8], and 9 years later our data show that the use of RACS accounted for 2.78 % of minimally invasive colorectal surgical cases. In comparison, laparoscopic colorectal surgery was first reported in 1991 [33], and 9 years later the use of laparoscopy in colorectal surgery was limited to 3 % of all colorectal cases in the United States [34]. Publication of several randomized trials demonstrating the safety and benefits of laparoscopic colorectal surgery [35, 36] has boosted an increase in the use of this technique to 42.6 % of cases in 2009 [37]. To our knowledge, there is only one properly designed randomized trial comparing robotic to laparoscopic right colectomy [38], and that trial did not demonstrate any advantage of the robotic technique over CLS. Moreover, large prospective randomized controlled trials comparing robotic to laparoscopic resection for rectal cancer are still lacking, with two currently underway; namely, the COLRAR [39] and ROLARR trials [40]. Thus, the potential benefits of RACS have yet to be demonstrated. The lack of strong clinical evidence and the high associated costs of the procedure represent major limiting factors in the adoption of RACS.

It is interesting to see that, despite higher associated charges, the use of robotics increased from 2009 to 2010 in all hospital settings and for all indications. Patient demand and the favorable learning curve associated with the robot [16] could potentially explain this finding. While rectal cancer remained the most common indication for robotic-assisted procedures, the use of RACS increased substantially for other indications, such as diverticular disease. In diverticular disease, post-inflammatory adhesions and fibrotic tissue make laparoscopic dissection difficult, resulting in high conversion rates ranging from 25 to 33 % [41]. In a recent case-series of 24 patients with recurrent diverticulitis it was shown that robotic surgery was safe and feasible. There were no intraoperative complications and no conversion to open surgery [42].

The rapid increase in the use of RACS probably serves to explain why postoperative bleeding complications were higher in robotic-assisted colonic resections. Surgeons early in their learning curve start by using the robot for colonic procedures. The relative lack of robotic experience along with the loss of tactile feedback in robotic cases may serve to explain this finding. The clinical impact of this

Table 4 Outcomes of laparoscopic and robotic colorectal surgery

	Laparoscopic	Robotic
Colonic cases	(*n* = 115,648)	(*n* = 2,143)
Length of hospital stay, days	6 (3–6)	6 (3–6)
Total charge, $US	45,557 (26,677–55,076)	62,761 (39,377–74,387)
Mortality	0.51	0
Missing	0.03	0
Complications		
CVA	0.04	0
Cardiac complications	1.40	1.40
Respiratory failure	1.18	0.64
Pneumonia	1.54	0.32
Ileus/bowel obstruction	14.61	11.21
Acute renal failure	4.04	4.33
Urinary tract infection	2.52	1.14
Urinary retention	2.11	1.12
Wound complications	3.05	3.20
Postoperative bleeding	2.14	4.34
Rectal cases	(*n* = 9,075)	(*n* = 1,425)
Length of hospital stay, days	7 (4–8)	6 (4–7)
Total charge, $US	45,557 (35,240–73,835)	74,327 (45,347–84,658)
Mortality	0.72	0
Missing	0.02	0
Complications		
CVA	0.03	0
Cardiac complications	2.14	2.50
Respiratory failure	1.04	1.11
Pneumonia	1.74	0.63
Ileus/bowel obstruction	16.61	14.84
Acute renal failure	5.42	4.80
Urinary tract infection	3.70	3.14
Urinary retention	4.13	2.20
Wound complications	4.53	3.65
Postoperative bleeding	2.14	3.40
Anastomotic complications (overall)	10.28	8.56
Procedure specific		
Right hemicolectomy	10.77	6.02
Left hemicolectomy	12.52	8.33
Sigmoidectomy	9.07	7.85
Anterior resection	12.32	10.79
Conversion rates (overall)	13.38	5.38
Procedure-specific		
Right hemicolectomy	9.67	4.51
Left hemicolectomy	17.86	4.17
Sigmoidectomy	12.22	5.76
Anterior resection	43.61	4.95
APR	11.69	8

Numbers for mortality, complications, anastomotic complications, and conversion rates are provided as percentages

Table 5 Adjusted mean difference for hospital charge and length of stay and adjusted odds ratios for the remaining endpoints (95 % CI)

	Adjusted mean difference/odds ratio	p Value
Colonic procedures		
Length of hospital stay, days	−0.33 (−0.73, 0.07)	0.44
Total charge, $US	11,601.39 (6,921.82, 16,280.97)	<0.001
Morbidity	0.91 (0.70, 1.17)	0.76
Conversion rate	0.41 (0.25, 0.67)	0.002
Anastomotic complications	0.78 (0.52, 1.17)	0.23
Ileus	0.83 (0.59, 1.16)	0.27
Postoperative bleeding	2.15 (1.27, 3.65)	0.005
Rectal procedures		
Length of hospital stay, days	−0.28 (−0.89, 0.34)	0.76
Total charge, $US	12,964.90 (6,534.79, 19,395.01)	<0.001
Morbidity	0.86 (0.66, 1.12)	0.75
Conversion rate	0.10 (0.06, 0.16)	<0.001
Anastomotic complications	0.87 (0.56, 1.37)	0.56
Ileus	0.97 (0.70, 1.35)	0.84
Postoperative bleeding	1.68 (0.83, 3.43)	0.15

[a] The conventional laparoscopy group was used as a reference

finding remains uncertain as the overall morbidity, length of hospital stay, and mortality were not affected. This finding, however, raises the question of whether RACS should be selectively applied to rectal procedures, as some authors have already questioned its use in certain colonic procedures, given the significantly increased charge, similar outcomes, and no added benefits over CLS [30, 38]. This finding also calls for more standardized training and certification prior to using the robot.

Examining outcomes, we found that RACS is equivalent to CLS in terms of length of hospital stay, a finding in line with a recent meta-analysis demonstrating similar length of hospital stay between RACS and CLS [43]. Because the mean length of stay in our results was short in both groups, it may be difficult to improve on the already favorable outcome that CLS offers.

Although it has no major benefits over CLS, RACS appears to be safe. In our series, we did not record any deaths, which correlates well with previously published data [16, 17, 21, 22, 42, 44]. Moreover, when compared to CLS, RACS has a similar morbidity, which is in line with previously published data [13, 16, 17, 21, 44]. Also, the incidences of ileus and anastomotic leak are similar with RACS. The rate of anastomotic complications related to leak and intra-abdominal abscesses is relatively high in our results compared to previously published data [45], especially considering that many cases in the laparoscopic group were done with ileocolonic anastomoses. There are multiple reasons for these high numbers. First, most published series investigating anastomotic leak following colorectal procedures come from specialized centers where experienced surgeons perform a high number of cases and thus have lower leak rates. In contrast, our data come from a wide range of hospital settings and different levels of expertise. Second, we included enteric fistulas and abdominopelvic abscesses in the definition of leak to increase the sensitivity to detect this complication. Third, the NIS database does not provide any information about whether the anastomotic leak is clinical. Thus minor radiographic leak may be counted as well.

Perhaps the only outcome measure that appears more favorable in RACS is the lower conversion rate to open surgery. Conversion to open surgery has been associated with longer length of hospital stay, increased total hospital charge, as well as higher morbidity and mortality [46]. Our results are in line with a recent meta-analysis showing that conversion rates for robotic proctectomy were lower than that for laparoscopic proctectomy [47]. Further studies are needed to demonstrate whether this is a result of superior technical proficiency on the part of robotic rectal surgeons or of the technical advantages of the robotic system. The technical features of the robotic system may explain the tendency toward a selective use of RACS in male patients undergoing rectal cancer surgery. The narrow male pelvis makes laparoscopy technically challenging, and the robot may help in overcoming this limitation by allowing superior visualization deep in the pelvis, as well as higher degrees of freedom and better ergonomics [23, 31, 42, 48]. This translates into finer dissection and lower rates of circumferential margin positivity [18, 20, 48]. For these reasons, some authors preferentially treat lower rectal tumors with the robotic approach [44]. Therefore, RACS may find a more widespread application in the treatment of low rectal tumors.

The main limitation of our study lies in its retrospective nature and its inherent biases. Retrospective reviews are prone to selection bias, and the NIS does not provide specific information such as surgeons' experience, which may introduce a bias favoring one approach or the other depending on surgeon's preference. We tried to account for this limitation by adjusting for different hospital factors as surgeon factors are not available in NIS. Coding errors exist because of the use of discharge data [49]; however, we used a combination of diagnosis and procedure codes to limit their occurence. Information such as tumor stage, use of neoadjuvant therapy, distance from the anal verge, and level of the anastomosis is also not available. The similar rate of fecal diversion in AR observed in our results may indicate that patients in both groups had similar cancer-related issues. The NIS database has no information available on complications or mortality after discharge; hence the 30-day mortality is unknown. However, these limitations are likely to affect all groups. In addition, NIS does not provide information on conversion rates from robotic to laparoscopic surgery. Because this rate is low, as observed in previously published series, it does not affect outcomes in a measurable way [47]. Nevertheless, to our knowledge, this study represents the largest series of robotic colorectal cases performed for different indications in different settings, and it is the only study evaluating trends at the national level.

Conclusions

The use of RACS has increased in the U.S. but is still considerably limited compared to CLS. Although the technique is safe, with similar morbidity and no mortality compared to CLS, it comes with significantly higher associated charges and higher rates of postoperative bleeding in colonic cases. The only advantage over CLS appears in the lower associated conversion rates to open surgery. Based on these results, the use of the robot may be of no added benefit in routine colon resections where conversion rates are already low and the safety and cost-effectiveness of laparoscopy have already been established. Its selective use in complex rectal cancer procedures, where it leads to a marked reduction in conversion rates, may prove its long-term benefits. This has yet to be proven by randomized controlled trials, two of which are now underway [39, 40].

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