ORIGINAL CONTRIBUTION

Outcomes of Robot-Assisted Versus Laparoscopic Surgery for Colorectal Cancer in Adults Aged 75 Years and Older: A Propensity Score–Matched Analysis of the US Nationwide Inpatient Sample

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BACKGROUND: Robot-assisted surgery has been increasingly adopted in colorectal cancer resection.

OBJECTIVE: The study aimed to compare the inpatient outcomes of robot-assisted versus conventional laparoscopic colorectal cancer resection in patients aged 75 years and older.

DESIGN: A retrospective, population-based study.

SETTINGS: This study analyzed data from the United States Nationwide Inpatient Sample from 2005 to 2018.

PATIENTS: Patients with colorectal cancer aged 75 years and older and who underwent robot-assisted or conventional laparoscopic resection.

MAIN OUTCOME MEASURES: Postoperative complications, prolonged length of stay, and total hospital costs were assessed.

RESULTS: Data from 14,108 patients were analyzed. After adjustment, any postoperative complications (adjusted OR = 0.87; 95% CI, 0.77–0.99; $p = 0.030$) and prolonged length of stay (adjusted OR = 0.78; 95% CI, 0.67–0.91; $p = 0.001$) were significantly less in the robotic than the laparoscopic group. In addition, robotic surgery was associated with significantly higher total hospital costs (26.06 USD greater cost; 95% CI, 21.35–30.77 USD; $p < 0.001$).

LIMITATIONS: The analysis was limited by its retrospective and observational nature, potential coding errors, and the lack of intraoperative factors, such as operative time, laboratory measures, and information on surgeons' experience.

CONCLUSIONS: In the United States, in patients with colorectal cancer aged 75 years and older who were undergoing tumor resections, compared to conventional laparoscopic surgery, robotic surgery is associated with better inpatient outcomes in terms of complication rate and risk of prolonged length of stay. This finding is especially true among patients with colon cancer. However, robotic surgery is associated with higher total hospital costs. See **Video Abstract**.

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RESULTADOS DE LA CIRUGÍA ASISTIDA POR ROBOT FRENTE A LA CIRUGÍA LAPAROSCÓPICA PARA EL CÁNCER COLORRECTAL EN ADULTOS ≥ 75 AÑOS DE EDAD: UN ANÁLISIS EMPAREJADO POR PUNTUACIÓN DE PROPENSIÓN DE LA MUESTRA NACIONAL DE PACIENTES HOSPITALIZADOS DE ESTADOS UNIDOS

ANTECEDENTES: La cirugía asistida por robot se ha adoptado cada vez más en la resección del cáncer colorrectal.

OBJETIVO: El estudio tuvo como objetivo comparar los resultados hospitalarios de la resección del cáncer colorrectal asistida por robot versus la laparoscópica convencional en pacientes ≥ 75 años.

DISEÑO: Estudio retrospectivo de base poblacional.

AJUSTES: Este estudio analizó datos de la Muestra Nacional de Pacientes Hospitalizados de Estados Unidos de 2005 a 2018.

PACIENTES: Pacientes con cáncer colorrectal ≥ 75 años y sometidos a resección laparoscópica convencional o asistida por robot.

PRINCIPALES MEDIDAS DE RESULTADO: Se evaluaron las complicaciones posoperatorias, la duración prolongada de la estancia hospitalaria y los costos hospitalarios totales.

RESULTADOS: Se analizaron datos de 14.108 pacientes. Después del ajuste, cualquier complicación posoperatoria (aOR = 0,87; IC del 95 %: 0,77-0,99, p = 0,030) y duración prolongada de la estancia hospitalaria (aOR = 0,78; IC del 95 %: 0,67-0,91, p = 0,001) fueron significativamente menores en el grupo robótico que el grupo laparoscópico. Además, la cirugía robótica se asoció con costos hospitalarios totales significativamente mayores ($26,06 USD mayor costo; IC 95%: 21,35-30,77 USD, $p < 0,001$).

LIMITACIONES: El análisis estuvo limitado por su naturaleza retrospectiva y observacional, posibles errores de codificación y la falta de factores intraoperatorios como el tiempo operatorio, medidas de laboratorio e información sobre la experiencia de los cirujanos.

CONCLUSIONES: En Estados Unidos, los pacientes con cáncer colorrectal ≥ 75 años que se sometieron a resecciones tumorales, en comparación con la cirugía laparoscópica convencional, la cirugía robótica se asocia con mejores resultados hospitalarios en términos de tasa de complicaciones y riesgo de estadía prolongada, especialmente entre pacientes con cáncer de colon. Sin embargo, la cirugía robótica se asocia a costes hospitalarios totales más elevados. *(Traducción—Yesenia Rojas-Khalil)*

KEY WORDS: Colorectal cancer; Elderly; Laparoscopic surgery; Nationwide Inpatient Sample; Outcome; Robot-assisted.

Colorectal cancer (CRC) is one of the leading causes of cancer-related death in men and women worldwide.[1,2] Many CRC treatment options are currently available, including surgery, chemotherapy, radiation therapy, targeted therapy, and immunotherapy. Depending on the tumor stage, they can be applied as local treatments, systemic treatments, or mixed therapeutic techniques.[3] Surgery is the cornerstone of curative intent treatment. The quality of CRC resection is crucial for achieving good outcomes and can be evaluated with objective parameters. Postoperative imaging studies have indicated that the quality of CRC resection can be further optimized.[4] Traditional laparotomy in patients with CRC can effectively remove the tumor, but it has disadvantages, such as a high degree of surgical trauma and slow postoperative functional recovery, which results in its clinical application being limited by a patient's overall health status.[5]

Minimally invasive surgery (MIS) has become a common method for the treatment of CRC because of its technical advantages and favorable postoperative outcomes, such as less pain, shorter hospital stays, and fewer complications.[6] Laparoscopic surgery is one of the earliest types of MIS and can be performed through small incisions.[7] In recent years, technological developments have led to laparoscopic-assisted radical resection of CRC, and the procedure has gradually become popular. This surgical approach can reduce trauma and surgery-related complications, improve postoperative functional recovery, and has been demonstrated to be an effective and safe treatment for CRC.[8] Laparoscopic radical resection of CRC is thought to provide high-quality colorectal resection with minimal surgical damage to surrounding tissues and organs.

Another MIS is robotic surgery that provides a magnified 3-dimensional view of the surgical site and helps surgeons perform precise and controlled manipulations.[9,10] The robotic surgical system is designed to overcome the limitations of laparoscopic surgery by providing a stable 3-dimensional view, significantly improved ergonomics, and tremor filtering through a surgeon-controlled camera.[11] Robotic surgery for CRC has many advantages over conventional surgery with respect to performing precise dissection.[12] It has been increasingly adopted in many surgical specialties over the past 10 years and is increasingly used in colorectal, and especially rectal, surgery.[13] With the growing acceptance, many studies have compared the postoperative and oncological outcomes between robot-assisted and conventional laparoscopic surgery for CRC.[7,14,15]

More than half of patients with newly diagnosed CRC are aged 70 years and older, and the number of older patients with CRC is gradually increasing as life expectancy increases.[16] Surgery for elderly patients is a unique challenge that requires careful perioperative risk assessment and careful selection of the surgical procedure.[17] Because the elderly are at greater risk of complications of surgery, minimally invasive laparoscopic colectomy is uniquely advantageous for elderly patients with CRC. Several observational studies have suggested that laparoscopic surgery results in better short-term outcomes than open surgery in elderly patients with CRC.

In a previous population-based study, it was found that elderly patients aged 75 years and older undergoing

CRC surgery experienced an overall mortality rate of 20% to 23% within the first year after the operation.[18] Also, patients in this age group exhibited higher postoperative 30-day mortality compared to their younger counterparts.[19] These findings underscore the importance of treating patients older than 75 years as a distinct cohort, warranting specialized consideration regarding surgical approaches and risk assessment.

Furthermore, recent studies have shown that in the general adult population, robot-assisted CRC resection may have comparable or even better short-term and long-term outcomes compared to laparoscopic surgery.[20–22] However, although robot-assisted surgery has demonstrated some advantages over conventional laparoscopic techniques in the general adult population, comparisons of the 2 methods for the treatment of CRC in patients aged 75 years and older are scarce.

Following the context, therefore, the purpose of this study was to compare the inpatient outcomes of robot-assisted versus conventional laparoscopic CRC resection in elderly patients aged 75 years and older using a large, nationally representative data set. We hypothesized that robot-assisted outcomes would surpass those of laparoscopic surgery within this particular subgroup of patients.

MATERIALS AND METHODS

Study Design and Data Source

This study was a population-based retrospective observational study. The United States National Inpatient Sample (NIS) database is the largest fully paid continuum of hospital care database in the United States, including data on approximately 8 million hospitalizations per year. All data sources for this study were obtained from the US NIS database. The Health Care Cost and Utilization Project (HCUP) of the National Institutes of Health manages the NIS database. NIS has data on primary and secondary diagnoses, primary and secondary procedures, length of stay (LOS), patient demographics, admission and discharge status, expected source of payment, and hospital characteristics. Hospital characteristics included bed size, location, teaching status, and hospital geographic area. The NIS database is updated annually and draws patient data from approximately 1050 hospitals in 44 US states, representing a stratified sample of 20% of US community hospitals as defined by the American Hospital Association.

Ethics Statement

This study complies with the data use agreement between NIS and the HCUP. All data were obtained at the request of the Online HCUP Central Distributor, which manages the database. Because this study analyzed secondary data from the NIS database, patients and the public were not directly involved. Because all data in the NIS database are de-identified, the requirement for informed consent is also waived.

Study Population

International Classification of Diseases, Ninth Revision (ICD-9) and Tenth Revision (ICD-10), diagnostic codes were used to identify elderly adults aged 75 years and older in the NIS database admitted to US hospitals between 2005 and 2018 who had a diagnosis of CRC (ICD-9: 153.0–153.9, 154.0–154.2,154.8; ICD-10: C18-C19, and C20) and underwent robot-assisted resection (ICD-9-PCS: 45.81, 48.42, 48.51, 17.31-17.36-17.39; ICD-10-PCS: 0DTE, 0DTF, 0DTG, 0DTH, 0DTJ, 0DTK, 0DTL, 0DTM, 0DTN, 0DTP which ended with 4ZZ, 8ZZ, FZZ; and 0DBE, 0DBF, 0DBG, 0DBG, 0DBH, 0DBJ, 0DBK, 0DBL, 0DBM, 0DBN, 0DBP which ended with 3ZZ, 4ZZ, 8ZZ) or laparoscopic resection (ICD-9-PCS: 17.41-17.44, 17.49; ICD-10-PCS: 8E0W0CZ, 8E0W3CZ, 8E0W4CZ, 8E0W7CZ, 8E0W8CZ). Patients with metastatic disease (ICD-9: 196.0-199.1 or CM_METS=1; ICD-10: C77-C80) or without complete data of mortality, LOS, or hospital cost were excluded.

Study Variables and Outcome Measures

Primary outcomes were 1) incidence of any major postoperative complication that occurred during admission; 2) prolonged LOS, defined as a LOS of >75th percentile; and 3) total hospital cost in US dollars. Major postoperative complications included death, acute myocardial infarction, cerebrovascular accident, venous thromboembolism (VTE), pneumonia, sepsis, surgical site infection, respiratory failure, mechanical ventilation, acute kidney injury, shock, bleeding, wound disruption, device complications, nervous system complications, and digestive system complications (ie, postprocedural intestinal obstruction, hepatic failure, hepatorenal syndrome, and peritoneal abscess).

Covariates

Patients' characteristics evaluated included age, sex, race, household income level, insurance status (primary payer), admission type (elective), tumor location (colon or rectum), and smoking status. Major comorbidities including ischemic heart disease, congestive heart failure, atrial fibrillation, diabetes, anemia, hypertension, dyslipidemia, chronic obstructive pulmonary disease, cerebrovascular disease, obesity, severe liver disease, rheumatic disease, chronic kidney disease, and coagulopathy were identified using ICD-9 and ICD-10 diagnostic codes. Hospital-related characteristics (bed number, location/teaching status, hospital region) were extracted from the database as part of the comprehensive data available for all patients.

Statistical Analysis

The NIS database includes a 20% sample of US annual inpatient admissions, weighted samples (before 2011 using TRENDWT and after 2012 using DISCWT), stratum (NIS_STRATUM), and cluster (HOSPID) were used to produce national estimates for all analyses. Patient descriptive statistics are presented as number (n) and weighted percentage (%) or mean and SE. The patients who received laparoscopic and robotic resection were propensity score (PS) matched at a 1:1 ratio calculated from the probability of undergoing robot-assisted resection, adjusting for the following variables: age in category, sex, race, tumor location, and hospital location/teaching status. Comparisons of proportions between groups for categorical variables were performed using the Pearson χ^2 test or the Fisher exact probability test. Univariate and multivariable logistic regression analyses were performed to determine the associations between study variables, postoperative complication, and prolonged LOS, and data were reported as OR and 95% CI. Linear regressions were performed to determine factors associated with total hospital cost. Multivariable regression was adjusted for variables that were significant in the univariate analysis. All p values were 2 sided, and p values of <0.05 were considered statistically significant. All statistical analyses were performed using the statistical software package SAS version 9.4 (SAS Institute Inc, Cary, NC).

RESULTS

The study selection process for the inclusion of patients is shown in Figure 1. A total of 23,892 patients with CRC aged 75 years and older were identified in the NIS database from 2005 to 2018. Patients with missing sex, information on in-hospital mortality, and total hospital costs, as well as those admitted emergently (n = 5456), were excluded. A total of 4328 patients with metastatic disease were also excluded. Ultimately, 14,108 patients were included in the study, of whom 2215 (15.7%) underwent robot-assisted resection. After PS matching, a total of 4096 patients remained and were included in the analysis (Fig. 1).

Patient Characteristics

Patient demographic characteristics, comorbid conditions, and hospital characteristics are summarized in Table 1. Before matching, the mean and median age of all patients were 81.2 and 80.0 years, respectively. Among these patients, 7739 patients (54.8%) were women, and 11,089 (83.7%) were White. Compared to patients who underwent laparoscopic resection, those who underwent robot-assisted surgery were younger, had a larger proportion of men, were Hispanic race, and had tumors located at the rectum. The frequency of smokers was higher in the robot-assisted group than in the laparoscopic group.

The proportions of patients with anemia, hypertension, dyslipidemia, obesity, and coagulopathy were significantly different between the 2 groups (all, $p < 0.05$). Patients who received robotic surgery had a higher proportion of dyslipidemia, obesity, and coagulopathy and a lower proportion of anemia and hypertension than those who received laparoscopic surgery. A higher proportion of patients who received robotic surgery were treated in an urban teaching hospital ($p < 0.001$).

After PS matching, most of the study variables were balanced between the 2 groups. However, patient characteristics, such as smoking, hypertension, dyslipidemia, obesity, chronic kidney disease, and hospital region, differed significantly between groups.

Inpatient Outcomes

Inpatient outcomes of the 2 groups after PS matching are summarized in Table 2. A total of 1408 (34.3%) patients had at least 1 major postoperative complication. Patients who underwent robotic surgery had a higher percentage of acute kidney injury (8.0% vs 6.3%, $p = 0.037$) and digestive system complications (15.4% vs 13.3%, $p = 0.045$) but a lower percentage of surgical site infection (2.8% vs 4.7%, $p < 0.001$) and bleeding (9.2% vs 16.8%, $p < 0.001$). The robotic surgery group had a lower rate of prolonged LOS than the laparoscopic surgery group (17.1% vs 20.7%, $p = 0.002$). In addition, the robotic surgery group had a greater total hospital cost than laparoscopic surgery (98.0 ± 1.9 vs 71.0 ± 1.3, per 1000 USD, $p < 0.001$; Table 2).

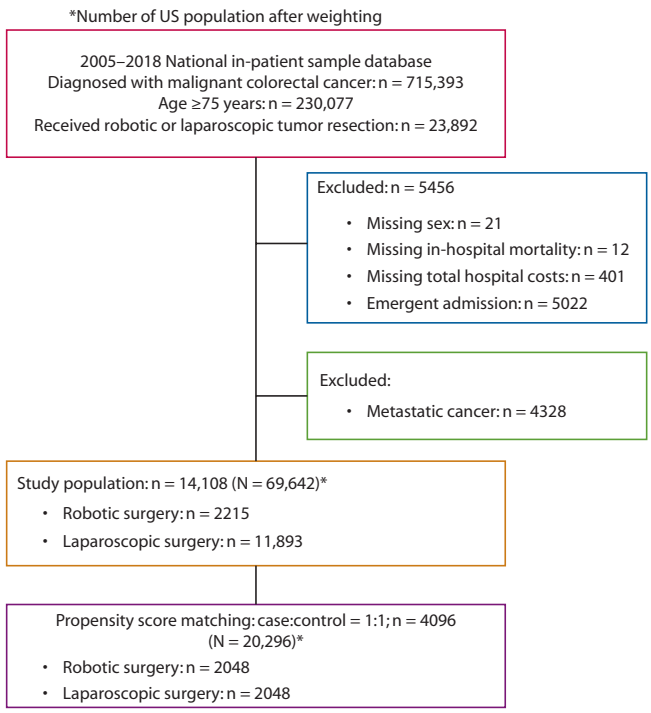

FIGURE 1. Flow diagram of patient inclusion.

TABLE 1. Patient characteristics before and after PS matching

	Before PS matching				*After PS matching*			
		Surgery type				*Surgery type*		
Characteristic	*Total (N = 14,108)*	*Robotic (n = 2215)*	*Laparoscopic (n = 11,893)*	*p*	*Total (N = 4096)*	*Robotic (n = 2048)*	*Laparoscopic (n = 2048)*	*p*
Demographics								
Age, y	81.2 ± 0.04	80.6 ± 0.09	81.1 ± 0.04	**<0.001**	80.7 ± 0.07	80.7 ± 0.09	80.8 ± 0.09	0.463
75–79	5933 (42.1)	1058 (47.8)	4875 (41.1)	**<0.001**	1877 (45.8)	942 (46.0)	935 (45.7)	0.958
80–84	4646 (32.9)	722 (32.6)	3924 (32.9)		1375 (33.5)	687 (33.5)	688 (33.5)	
≥85	3529 (25.0)	435 (19.7)	3094 (26.0)		844 (20.7)	419 (20.5)	425 (20.8)	
Sex								
Male	6369 (45.2)	1109 (50.1)	5260 (44.2)	**<0.001**	2005 (48.9)	1001 (48.9)	1004 (49.0)	0.958
Female	7739 (54.8)	1106 (49.9)	6633 (55.8)		2091 (51.1)	1047 (51.1)	1044 (51.0)	
Race								
White	11,089 (83.7)	1741 (81.5)	9348 (84.1)	**<0.001**	3376 (82.4)	1687 (82.3)	1689 (82.4)	>0.99
Black	801 (6.0)	120 (5.6)	681 (6.1)		228 (5.6)	114 (5.6)	114 (5.6)	
Hispanic	716 (5.4)	140 (6.6)	576 (5.2)		258 (6.3)	130 (6.3)	128 (6.3)	
Others	642 (4.9)	134 (6.3)	508 (4.6)		234 (5.7)	117 (5.7)	117 (5.7)	
Missing	860	80	780					
Household income								
Quartile 1	2936 (21.1)	485 (22.2)	2451 (20.9)	0.588	896 (22.2)	443 (21.9)	453 (22.5)	0.561
Quartile 2	3688 (26.5)	584 (26.7)	3104 (26.5)		1034 (25.6)	538 (26.6)	496 (24.7)	
Quartile 3	3683 (26.4)	568 (25.9)	3115 (26.5)		1058 (26.1)	525 (25.9)	533 (26.3)	
Quartile 4	3617 (25.9)	553 (25.2)	3064 (26.1)		1057 (26.1)	519 (25.6)	538 (26.5)	
Missing	184	25	159		51	23	28	
Primary payer								
Medicare/Medicaid	13,178 (93.5)	2075 (93.7)	11,103 (93.5)	0.769	3826 (93.5)	1921 (93.9)	1905 (93.1)	0.596
Private including HMO	805 (5.7)	119 (5.4)	686 (5.7)		229 (5.6)	108 (5.3)	121 (5.9)	
Self-pay/no-charge/other	114 (0.8)	19 (0.9)	95 (0.8)		37 (0.9)	17 (0.8)	20 (1.0)	
Missing	11	2	9		4	2	2	
Tumor location								
Colon	12,663 (89.8)	1527 (69.0)	11,136 (93.7)	**<0.001**	2976 (72.8)	1488 (72.8)	1488 (72.8)	0.988
Rectum	1445 (10.2)	688 (31.0)	757 (6.3)		1120 (27.2)	560 (27.2)	560 (27.2)	
Smoking (yes)	3776 (26.9)	735 (33.2)	3041 (25.7)	**<0.001**	1247 (30.5)	676 (33.0)	571 (27.9)	**<0.001**
Comorbid condition								
Ischemic heart disease	3599 (25.5)	547 (24.7)	3052 (25.7)	0.297	1052 (25.6)	518 (25.3)	534 (26.0)	0.544
Congestive heart failure	1443 (10.2)	230 (10.4)	1213 (10.2)	0.788	436 (10.7)	219 (10.7)	217 (10.7)	0.960
Atrial fibrillation	2786 (19.8)	447 (20.2)	2339 (19.7)	0.580	817 (20.0)	420 (20.5)	397 (19.4)	0.364
Diabetes	3574 (25.4)	595 (26.8)	2979 (25.1)	0.072	1048 (25.6)	547 (26.7)	501 (24.5)	0.093
Anemia	3691 (26.1)	482 (21.8)	3209 (27.0)	**<0.001**	939 (22.9)	456 (22.3)	483 (23.6)	0.301
Hypertension	9394 (66.5)	1373 (61.9)	8021 (67.4)	**<0.001**	2662 (64.9)	1272 (62.1)	1390 (67.8)	**<0.001**
Dyslipidemia	6361 (45.2)	1065 (48.1)	5296 (44.6)	**0.002**	1906 (46.6)	989 (48.3)	917 (44.8)	**0.021**
COPD	2224 (15.8)	348 (15.7)	1876 (15.8)	0.927	655 (16.0)	320 (15.6)	335 (16.3)	0.498
Cerebrovascular disease	464 (3.3)	70 (3.2)	394 (3.3)	0.743	121 (3.0)	65 (3.2)	56 (2.7)	0.369
Obesity	1263 (9.0)	228 (10.3)	1035 (8.7)	**0.021**	367 (9.0)	211 (10.3)	156 (7.6)	**0.002**
Severe liver disease	29 (0.2)	5 (0.2)	24 (0.2)	0.821	9 (0.2)	4 (0.2)	5 (0.2)	0.768
Rheumatic disease	354 (2.5)	52 (2.3)	302 (2.5)	0.573	98 (2.4)	48 (2.3)	50 (2.5)	0.812
Chronic kidney disease	1670 (11.9)	274 (12.4)	1396 (11.8)	0.436	475 (11.6)	260 (12.7)	215 (10.5)	**0.027**
Coagulopathy	405 (2.9)	80 (3.6)	325 (2.7)	**0.022**	135 (3.3)	68 (3.3)	67 (3.2)	0.879
Hospital characteristics								
Hospital size								
Small	2004 (14.1)	292 (13.2)	1712 (14.3)	0.233	593 (14.4)	279 (13.6)	314 (15.2)	0.394
Medium	3790 (27.0)	632 (28.6)	3158 (26.7)		1156 (28.4)	589 (28.8)	567 (27.9)	
Large	8284 (58.9)	1290 (58.2)	6994 (59.0)		2347 (57.2)	1180 (57.5)	1167 (56.9)	
Missing	30	1	29					
Hospital location/teaching status								
Rural	1036 (7.4)	67 (3.0)	969 (8.2)	**<0.001**	128 (3.1)	63 (3.1)	65 (3.2)	0.980
Urban nonteaching	4530 (32.1)	553 (24.9)	3977 (33.5)		1068 (26.0)	534 (26.0)	534 (26.0)	
Urban teaching	8512 (60.5)	1594 (72.1)	6918 (58.3)		2900 (70.9)	1451 (70.9)	1449 (70.8)	
Missing	30	1	29					

(*Continued*)

TABLE 1. Continued

Characteristic	Before PS matching: Total (N = 14,108)	Before PS matching: Surgery type: Robotic (n = 2215)	Before PS matching: Surgery type: Laparoscopic (n = 11,893)	p	After PS matching: Total (N = 4096)	After PS matching: Surgery type: Robotic (n = 2048)	After PS matching: Surgery type: Laparoscopic (n = 2048)	p
Hospital region								
Northeast	2922 (20.7)	435 (19.6)	2487 (20.9)	0.123	893 (21.8)	419 (20.5)	474 (23.2)	**0.013**
Midwest	3450 (24.4)	570 (25.7)	2880 (24.1)		924 (22.5)	505 (24.6)	419 (20.5)	
South	5017 (35.7)	751 (33.9)	4266 (36.0)		1447 (35.3)	701 (34.3)	746 (36.4)	
West	2719 (19.2)	459 (20.8)	2260 (18.9)		832 (20.3)	423 (20.7)	409 (19.9)	

Categorical variables are presented as unweighted counts (weighted percentage) and analyzed by PROC SURVEYFREQ statement; continuous data were presented as mean ± SE and analyzed by PROC SURVEYREG statement.
P values <0.05 are shown in bold.
COPD = chronic obstructive pulmonary disease; HMO = health maintenance organization; PS = propensity score.

TABLE 2. Inpatient outcomes of colorectal cancer surgery after propensity score matching

Outcomes	After propensity score matching: Total patients (N = 4096)	After propensity score matching: Surgery type: Robotic (N = 2048)	After propensity score matching: Surgery type: Laparoscopic (N = 2048)	p
Postoperative complications				
Any	1408 (34.3)	674 (32.9)	734 (35.7)	0.058
Death	38 (0.9)	20 (1.0)	18 (0.9)	0.641
AMI	41 (1.0)	15 (0.7)	26 (1.2)	0.086
CVA	61 (1.5)	31 (1.5)	30 (1.5)	0.874
VTE	76 (1.8)	39 (1.9)	37 (1.8)	0.799
Pneumonia	79 (1.9)	32 (1.6)	47 (2.3)	0.078
Sepsis	141 (3.4)	67 (3.3)	74 (3.6)	0.547
Surgical site infection	155 (3.8)	58 (2.8)	97 (4.7)	**<0.001**
Respiratory failure	178 (4.3)	86 (4.2)	92 (4.5)	0.632
Mechanical ventilation	90 (2.2)	46 (2.2)	44 (2.2)	0.871
Acute kidney injury	292 (7.2)	163 (8.0)	129 (6.3)	**0.037**
Shock	66 (1.6)	37 (1.8)	29 (1.5)	0.346
Bleeding	536 (13.0)	190 (9.2)	346 (16.8)	**<0.001**
Wound disruption	102 (2.5)	43 (2.1)	59 (2.8)	0.098
Device complication	47 (1.2)	24 (1.2)	23 (1.1)	0.897
Nervous system	4 (0.1)	2 (0.1)	2 (0.1)	0.992
Digestive system	589 (14.4)	315 (15.4)	274 (13.3)	**0.045**
Prolonged LOS[a,b]	769 (18.9)	347 (17.1)	422 (20.7)	**0.002**
Hospital cost (per 1000 USD)	84.5 ± 1.2	98.0 ± 1.9	71.0 ± 1.3	**<0.001**

Categorical variables are presented as unweighted counts (weighted percentage) and analyzed by PROC SURVEYFREQ statement; continuous data are presented as mean ± SE and analyzed by PROC SURVEYREG statement. *P* values <0.05 are shown in bold.
AMI = acute myocardial infarction; CVA = cerebrovascular accident; LOS = length of hospital stay; USD = United States dollar; VTE = venous thromboembolism.
[a]Excluding patients who died in the hospital.
[b]LOS of >75th percentile (7 d).

Univariate and Multivariable Analyses of the Association Between Surgery Type and Outcomes

The associations between surgery type and clinical outcomes are shown in Table 3. After adjustment in the multivariable analysis, compared to the laparoscopic procedure, robotic surgery was significantly associated with lower odds of any postoperative complication (aOR = 0.87; 95% CI, 0.77–0.99; $p = 0.030$) and prolonged LOS (aOR = 0.78; 95% CI, 0.67–0.91; $p = 0.001$). Robotic surgery was associated with significantly higher total hospital costs (26.06 per 1000 USD greater cost; 95% CI, 21.35–30.77 per 1000 USD; $p < 0.001$) than laparoscopic surgery (Table 3).

Stratified Associations Between Surgery Type and Inpatient Outcomes

Results of the stratified analysis according to age group, tumor location, and hospital teaching status are shown in Table 4.

TABLE 3. Univariate and multivariable analyses of associations between surgery type and inpatient outcomes

	Any postoperative complication				*Prolonged LOS*[a,b]				*Total hospital cost (per 1000 USD)*			
Surgery type	*Crude OR (95% CI)*	*p*	*aOR*[c] *(95% CI)*	*p*	*Crude OR (95% CI)*	*p*	*aOR*[c] *(95% CI)*	*p*	*Crude beta (95% CI)*	*p*	*aBeta*[c] *(95% CI)*	*p*
Laparoscopic	Ref		Ref		Ref		Ref		Ref		Ref	
Robotic	0.89 (0.78–1.00)	0.058	**0.87 (0.77–0.99)**	**0.030**	**0.79 (0.68–0.92)**	**0.002**	**0.78 (0.67–0.91)**	**0.001**	**27.00 (22.11–31.90)**	**<0.001**	**26.06 (21.35–30.77)**	**<0.001**

P values <0.05 are shown in bold.
aOR = adjusted OR; LOS = length of hospital stay; Ref = reference; USD = United States dollar.
[a]Excluding patients who died in the hospital.
[b]LOS of >75th percentile (7 d).
[c]Adjusted by related variables in Table 1 after propensity score matching with $p < 0.05$, including smoking, hypertension, dyslipidemia, obesity, chronic kidney disease, and hospital region.

Compared to patients with laparoscopic surgery, robotic surgery was significantly associated with lower odds of any postoperative complication among patients with colon cancer (aOR = 0.86; 95% CI, 0.75–1.00; p = 0.045) but not among those with rectal cancer. Similarly, robotic surgery was significantly associated with lower odds of prolonged LOS among patients with colon cancer (aOR = 0.74; 95% CI, 0.62–0.90; p = 0.002) but not among those with rectal cancer.

In addition, compared to laparoscopic surgery, robotic surgery was significantly associated with lower odds of prolonged LOS among patients aged 75 to 79 years (aOR = 0.75; 95% CI, 0.59–0.94; p = 0.013), but not their older counterparts. Robotic surgery was significantly associated with lower odds of prolonged LOS among patients treated in teaching and nonteaching hospitals (Table 4).

DISCUSSION

This is one of the few studies to compare the inpatient outcomes of robot-assisted versus conventional laparoscopic surgery for patients with CRC aged 75 years and older from a population perspective. Results of this study showed that robotic surgery was independently associated with reduced risk of any postoperative complication and prolonged LOS compared with laparoscopic surgery. This risk reduction was predominant among patients with colon cancer. In contrast, the total hospital cost of robot-assisted resection was significantly higher compared with laparoscopic resection.

The current study specifically concentrates on patients who are aged 75 years and older. This decision was based on literature indicating an increase in CRC prevalence alongside rising life expectancy. Recent literature have highlighted that both the incidence of CRC and the proportion of newly diagnosed patients with CRC aged 70 years and older account for more than half of the cases. Furthermore, more than one-third of deaths from CRC occur in patients aged 80 years and older.[23] Treating elderly patients who require surgery involves unique challenges, including the need for comprehensive perioperative risk assessments and specialized surgical and anesthesia management, particularly because this subgroup of older adults often has a high burden of comorbidities.[24] Accordingly, minimally invasive laparoscopic surgery has become increasingly common for treating elderly patients with CRC who are unsuitable for open surgery, consistently demonstrating better short-term outcomes compared to open surgery.[25]

The introduction of robot-assisted laparoscopic surgery in CRC treatment enhances precision and maneuverability beyond what conventional laparoscopic procedures offer. Our study observed an approximately 13% decreased risk of overall postoperative complications and 22% reduced risk of prolonged hospital stays in

TABLE 4. Stratified associations between surgery type on postoperative complications and prolonged LOS by age, tumor location, and hospital teaching status

			Any postoperative complication		*Prolonged LOS*[a,b]	
Variables	*n (%)*	*Surgery type*	*aOR*[c] *(95% CI)*	*p*	*aOR*[c] *(95% CI)*	*p*
Age, y						
75–79	1877 (45.8)	Robotic vs laparoscopic	0.87 (0.73–1.04)	0.136	0.75 (0.59–0.94)	**0.013**
80–84	1375 (33.5)	Robotic vs laparoscopic	0.89 (0.73–1.09)	0.272	0.81 (0.63–1.04)	0.094
≥85	844 (20.7)	Robotic vs laparoscopic	0.83 (0.65–1.06)	0.135	0.80 (0.60–1.06)	0.119
Tumor location						
Colon	2976 (72.8)	Robotic vs laparoscopic	0.86 (0.75–1.00)	**0.045**	0.74 (0.62–0.90)	**0.002**
Rectum	1120 (27.2)	Robotic vs laparoscopic	0.87 (0.70–1.09)	0.232	0.84 (0.67–1.06)	0.139
Hospital teaching status						
Teaching	1196 (29.2)	Robotic vs laparoscopic	0.89 (0.76–1.04)	0.138	0.79 (0.66–0.95)	**0.014**
Nonteaching	2900 (70.8)	Robotic vs laparoscopic	0.82 (0.66–1.03)	0.083	0.73 (0.55–0.96)	**0.024**

P values <0.05 are shown in bold.
aOR = adjusted OR; LOS = length of hospital stay.
[a]Excluding patients who died in the hospital.
[b]LOS of >75th percentile (7 d).
[c]Adjusted by related variables in Table 1 after propensity score matching with $p < 0.05$, including smoking, hypertension, dyslipidemia, obesity, chronic kidney disease, and hospital region.

patients undergoing robot-assisted procedures compared to those receiving pure laparoscopic surgery. This is generally consistent with prior research in the medical literature. A single-center study by Cuellar-Gomez et al[26] that included 76 patients aged 75 years and older also suggested that with a good operative safety profile and an acceptable disease-specific survival rate, robotic CRC surgery is viable for patients with advanced age. Hancock et al[27] compared outcomes of colon resection between robotic and laparoscopic approaches, without a specific focus on the elderly population, and found that the outcomes of both techniques were comparable. There are limited comparative studies specifically focusing on robotic versus laparoscopic resections in elderly patients, with most reports being single-hospital experiences involving small patient cohorts. However, it should be noted that some previous studies have reported better outcomes with robotic surgery compared to laparoscopic surgery for CRC. Crippa et al[28] found that robotic surgery for rectal cancer was strongly associated with improved short-term outcomes compared to laparoscopic surgery. Also, a study by Palomba et al,[29] published in 2022, reported that robotic colorectal surgery in older patients led to better recovery and shorter hospital stays compared to conventional laparoscopic surgery. A study by de'Angelis et al[30] retrospectively analyzed 86 patients and found that, in those aged 70 years or older, robotic colorectal surgery yielded surgical and oncological outcomes comparable with laparoscopic surgeries, despite having a longer procedure time. Our population-level study offers more robust evidence, extending beyond the findings of the previously cited studies.

Our study did not assess the conversion rate from minimally invasive procedures to open surgery because it was difficult to define this conversion using the ICD code system in the NIS database. However, it is worth noting that several studies have reported on conversion rates, although they did not specifically focus on the age group of 75 years and older. A systematic review encompassing 334 robotic and 337 laparoscopic cases of rectal cancer surgery indicated that robot-assisted surgery was associated with a lower rate of conversion to open surgery compared to conventional laparoscopic procedures despite having significantly longer operative times.[31] A study using the ACS-NSQIP database, which included patients of various ages, reported that the mean conversion rate to open surgery for robotic procedures was lower than that for laparoscopy (4.3% vs 9.2%) in the treatment of CRC.[32] These findings collectively highlight the need for further confirmation and research.

In our stratified analysis, it was found that robotic surgery was linked to a lower risk of postoperative complications and prolonged hospital stay in patients with colon cancer compared to laparoscopic surgery, but these associations were not observed in patients with rectal cancer. This finding might be attributed to several factors, such as anatomical and technical differences between colon and rectal surgeries, the complexity of rectal procedures, and variations in the surgeons' expertise with robotic technology. Specifically, rectal cancer surgery is generally considered more challenging than colon resection.[33] The skill level of surgeons in robotic procedures can differ, with the learning curve for robotic rectal surgery potentially being distinct from that of colon surgery. A recent randomized controlled trial found that in patients with middle or low rectal cancer, robotic-assisted surgery did not significantly enhance the quality of total mesorectal excision compared to conventional laparoscopic surgery.[33] This finding highlights the need for more specific research, especially regarding rectal cancer, to better understand and optimize the use of robotic surgery in CRC treatment.

When stratified by age, it was observed that robotic surgery reduces prolonged hospital stay in patients aged 75 to 79 years, but this effect is not seen in older patients. This could be because of the relatively greater physiological resilience of the 75 to 79 age group, enabling them to better capitalize on the benefits of robotic surgery, such as reduced trauma and quicker recovery, compared to their older counterparts. In addition, patients older than 80 years might have different postoperative care and rehabilitation needs, which could prolong their hospital stay irrespective of the surgical technique used. Nonetheless, these identified differences emphasize the significance of making tailored decisions in selecting surgical approaches based on individual patient characteristics.

Finally, although robot-assisted surgery showcases several superior inpatient outcomes, the augmented total hospital costs associated with this technology demand careful consideration. The economic implications of adopting robotic technology in colorectal surgery need to be judiciously weighed against the observed clinical benefits. The increased financial burden poses a challenge to health care systems, necessitating a comprehensive evaluation of the cost-effectiveness of robot-assisted surgery compared to conventional laparoscopic approaches in the future.

In summary, this study is novel and important for using a very large national cohort, showing the real-world utility and outcomes after robot-assisted surgery in the context of CRC surgery among elderly patients aged 75 years and older. It acts as a catalyst for ongoing research into the risks and benefits of robot-assisted surgery, especially for older patients, and recognizes the evolving nature of robotic surgery and the need for continuous investigation.

Limitations

The study is inherently limited by its retrospective design and observational nature. There is the possibility of coding errors, as in other studies that used ICD code systems. Intraoperative parameters, such as operative time, laboratory data, type of anastomosis, and information regarding surgeon experience, are not included in the NIS database and thus could not be evaluated. Although conversion rate is important when comparing the robotic approach to the laparoscopic approach, it was difficult to accurately define conversion in the NIS, hindering its analysis. In addition, the details of hospital costs (eg, costs from an operation, pharmacy, laboratory tests, imaging) were not provided by the data set and thus could not be evaluated. This study also lacks long-term follow-up data, and thus long-term oncological outcomes cannot be evaluated.

CONCLUSIONS

In US patients with CRC aged 75 years and older who require surgery, compared to conventional laparoscopic surgery, robot-assisted surgery is associated with better inpatient outcomes in terms of complication rate and risk of prolonged LOS, especially in patients with colon cancer. However, robotic surgery is associated with higher total hospital costs. These results may help clinicians improve risk stratification for these patients. Future randomized controlled studies are warranted to confirm the present findings.

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