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ORIGINAL SCIENTIFIC REPORT

Minimally Invasive Proctectomy for Rectal Cancer: A National Perspective on Short-term Outcomes and Morbidity

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Abstract

Background Prior randomized trials showed comparable short-term outcomes between open and minimally invasive proctectomy (MIP) for rectal cancer. We hypothesize that short-term outcomes for MIP have improved as surgeons have become more experienced with this technique.

Methods Rectal cancer patients who underwent elective abdominoperineal resection (APR) or low anterior resection (LAR) were included from the American College of Surgeons National Surgical Quality Improvement Program database (2016–2018). Patients were stratified based on intent-to-treat protocol: open (O-APR/LAR), laparoscopic (L-APR/LAR), robotic (R-APR/LAR), and hybrid (H-APR/LAR). Multivariable logistic regression analysis was used to assess the impact of operative approach on 30-day morbidity.

Results A total of 4471 procedures were performed (43.41% APR and 36.59% LAR); O-APR 42.72%, L-APR 20.99%, R-APR 16.79%, and H-APR 19.51%; O-LAR 31.48%, L-LAR 26.34%, R-LAR 17.48%, and H-LAR 24.69%. Robotic APR and LAR were associated with shortest length of stay and significantly lower conversion rate. After adjusting for other factors, lap, robotic and hybrid APR and LAR were associated with decreased risk of overall morbidity when compared to open approach. R-APR and H-APR were associated with decreased risk of serious morbidity. No difference in the risk of serious morbidity was observed between the four LAR groups.

Conclusion Appropriate selection of patients for MIP can result in better short-term outcomes, and consideration for MIP surgery should be made.

Introduction

In 1982, Bill Heald performed the first total mesorectal excision (TME) for rectal cancer [1]. Since then, it has become the gold standard surgical technique for rectal cancer resection. It is a technically challenging procedure as surgeons operate in a narrow confined space with limited visual exposure [2].

In 1988, laparoscopic surgery was first introduced and has progressively gained popularity and is being performed extensively in colon and rectal surgery [3]. The laparoscopic approach has several advantages when compared to open approach for rectal cancer surgery. It results in faster recovery of bowel function, less blood loss, and shorter

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length of stay (LOS) [4, 5]. However, laparoscopic surgery is associated with several drawbacks including loss of 3-dimensional vision, requirement of inflexible straight devices, uncomfortable ergonomic position, and the fulcrum effect [6]. The laparoscopic approach for rectal cancer is technically demanding and is associated with a steep learning curve and high conversion rates (10–46.2%) [7–9].

In 1997, Guy-Bernard Cadiere introduced robotic surgery [10], and in 2000, Food and Drug Administration approved "Da Vinci" Robotic System (Intuitive Surgical Inc., Sunnyvale, CA, USA) for intrabdominal surgery. In 2001, the first robotic-assisted colectomy was performed by Philip Weber [11], and the first robotic-assisted TME was performed by Pigazzi in 2006 [12]. Since then, the use of robotic-assisted TME has been slowly increasing as it seems to have potentials to overcome some of the limitations of the laparoscopic approach. Robotic proctectomies may provide several technical advantages when compared to laparoscopic surgery including 3-dimensional view, stable endoscopic platform, improved instrument articulation, superior ergonomics, and enhanced dexterity and motion scaling [6].

Several studies have shown the oncological safety and feasibility of minimally invasive colorectal surgery [13–16]. However, evidence for minimally invasive approach for rectal cancer is mixed. Some studies have shown no significant differences in postoperative short-term outcomes and LOS between laparoscopic and robotic rectal surgery [17–19]. In contrast, other studies have shown that robotic rectal surgery was associated with fewer postoperative complications and shorter LOS when compared to laparoscopic approach [20–22]. The oncological safety of laparoscopic and robotic rectal surgery has been documented in multiple studies [5, 23–26]. With growing experience of both laparoscopic and robotic approaches for rectal cancer, we aim to examine the short-term outcomes after surgery for rectal cancer among these two surgical approaches.

Methods

Data source

This was a retrospective cohort study of the 2016–2018 American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) Procedure Targeted Participant Use Data File (PUF) merged with the main 2016–2018 ACS-NSQIP PUF using the unique case identification variable. The procedure-targeted file contains 28 proctectomy-specific variables collected from 159 participating sites [27]. Patients' preoperative risk factors, intraoperative variables, and 30-day morbidity and mortality were obtained from the main ACS-NSQIP file. Briefly, ACS-NSQIP was designed for the purpose of developing outcomes-based initiatives to improve surgical quality of care [28]. The data are captured from clinical records by certified surgical clinical reviewers and undergo inter-rater reliability audits to assess the quality of the data collected. This study was reviewed and approved by the Institutional Review Board of the Johns Hopkins University School of Medicine.

Patient selection

Adult patients diagnosed with rectal cancer (International Classification of Diseases 9th and 10th revision [ICD-9/10] codes of 154.1 and C20) who underwent an elective abdominoperineal or low anterior resection (APR or LAR) (CPT codes of 45110, 45395, 45126 [APR] or 45397, 45111, 45119, 45112, 45120, 45123, 45114, 44156 [LAR]) between January 1, 2016, and December 31, 2018, were included. Emergency cases were excluded. Initially, patients were stratified into five groups using NSQIP-defined operative approach variable: 1) open APR (O-APR) or LAR (O-LAR); 2) minimally invasive APR or LAR (MI-APR or MI-LAR) (laparoscopic APR or LAR [L-APR or L-LAR], robotic APR or LAR [R-APR or R-LAR]); 3) MI-APR/LAR with unplanned conversion to open; 4) hybrid APR or LAR (H-APR or H-LAR); and 5) hybrid with unplanned conversion to open. Since an intent-to-treat protocol was of interest in this study, the two unplanned conversions to open groups 3) and 5) were collapsed with groups 2) and 4), respectively, forming the following four final groups: 1) O-APR or O-LAR; 2) L-APR or L-LAR; 3) R-APR or R-LAR; 4) H-APR or H-LAR. Consequently, the hybrid group consisted of hybrid, laparoscopic, or robotic APR or LAR with planned open assistance and hybrid APR or LAR with unplanned conversion to an open procedure. Hybrid refers to the hand-assisted technique of resection. APR and LAR were analyzed separately, as they are different techniques and carry different patterns of complications. Patients with missing or other than the aforementioned operative approaches were excluded (1.15%).

Baseline characteristics

Patient demographics included age (categorized as: < 50, 50–64, 64–74 and ≥ 75 years), sex, and race (white, black, other [American Indian/Alaskan Native, Native Hawaiian/Pacific Islander, Asian], unknown or not reported). Clinical characteristics included the American Society of Anesthesiologists (ASA) Physical Status Classification (categorized as "I–II," no or mild disturbance; "III," severe

disturbance; and "IV–V," life-threatening and moribund), obesity (Body Mass Index [BMI] $\geq$ 30 kg/m^2), and preoperative comorbidities (current smoker, diabetes, history of chronic obstructive pulmonary disease [COPD], hypertension requiring medication, dyspnea, steroid use, and bleeding disorder). Finally, oncological characteristics consisted of clinical stages (T, N, and M), tumor location (lower third, middle third, upper third, and unknown), and chemotherapy or radiation therapy within 90 days of proctectomy.

Outcomes

The primary outcome was overall morbidity defined as an occurrence of one or more of the following adverse events within 30 days of surgery: wound infection, pneumonia, urinary tract infection (UTI), venous thromboembolic event (VTE), cardiac complication, shock/sepsis, unplanned intubation, bleeding requiring transfusion, renal complication, ventilator usage $>$ 48 h, organ/space surgical site infection (SSI), or anastomotic leak. Anastomotic leak is defined by NSQIP as a leak of endoluminal contents through an anastomosis; this could include air, fluid, gastrointestinal contents, or contrast material. The secondary outcomes included Clavien–Dindo (C–D) III–IV serious surgical complications [29], readmission, mortality, reoperation, LOS measured as days from operation to discharge, and operative time. The C–D classification was applied to the NSQIP-defined complications in the following manner: III—cardiac and renal complications, organ space SSI or reoperation; and IV—shock/sepsis, unplanned intubation, or being on ventilator $>$ 48 h. Readmission is defined by NSQIP as admission to the same or another hospital for any reason.

Statistical analysis

Categorical variables were presented as counts and proportions, and continuous variables were presented as means ($\pm$ standard deviation). Patient baseline characteristics and outcomes were compared between operative approaches using Pearson's X^2 test or Fisher's exact test for categorical variables and Student's t test for continuous variables. Four multivariable logistic regression models were designed to assess the impact of operative approaches on overall morbidity and C–D serious complications and included variables with $p < 0.25$ from univariate analysis as recommended by Hosmer and Lemeshow [30]. As a result, first model (overall morbidity for APR) was adjusted for race, ASA, smoking, diabetes, COPD, hypertension, dyspnea, bleeding disorder, stage T, chemotherapy, and radiation therapy. Second model (serious morbidity for APR) was adjusted for sex, race, ASA, obesity, smoking, diabetes, COPD, hypertension, dyspnea, bleeding disorder, chemotherapy, and radiation therapy. The third model (overall morbidity for LAR) was adjusted for race, ASA, obesity, smoking, diabetes, COPD, hypertension, bleeding disorder, stage T, chemotherapy, and radiation therapy. Lastly, the fourth model (serious morbidity for LAR) was adjusted for sex, race, ASA, obesity, smoking, diabetes, hypertension, tumor location, and chemotherapy. Stage M was not considered for adjusted analysis due to high percentage of missing data. Odds ratios (OR) and 95% confidence intervals (CI) were reported. Hosmer–Lemeshow tests were used to assess the goodness-of-fit of the four multivariable models. All statistical analyses were performed using Stata/MP version 14.1 (StataCorp LP, College Station, TX).

Results

Study population

Between 2016 and 2018, a total of 4471 rectal cancer patients underwent APR or LAR and met the inclusion criteria. The distribution of APR approaches was the following: 1211 (42.72%) O-APR, 595 (20.99%) L-APR, 476 (16.79%) R-APR, and 553 (19.51%) H-APR. Among LAR, 515 (31.48%) patients underwent O-LAR, 431 (26.34%) L-LAR, 286 (17.48%) R-LAR, and 404 (24.69%) H-LAR.

Patients, who underwent APR, were comparable between the four operative approaches with respect to age, sex, obesity, and several other comorbidities (Table 1). In comparison to patients who underwent O-APR, patients who underwent either MI-APR or H-APR tended to have lower ASA classification, tumors located in the lower or middle third part of the rectum, and undergo chemotherapy and/or radiation more frequently.

Differences in patients who underwent LAR were observed in age, sex, race, ASA classification, COPD, steroid use, stage T/M, tumor location, chemotherapy and radiation therapy between the four operative approaches (Table 2). LAR patients were comparable with respect to stage N, obesity, and several other comorbidities. In addition, there were no differences observed in terms of sex, ASA classification, chemotherapy, and radiation therapy between MI-LAR and O-LAR groups.

Unadjusted outcomes

In comparison to O-APR; L-APR, R-APR, and H-APR patients had significantly lower rates of overall morbidity (41.29% O-APR vs. 26.39% L-APR vs. 24.37% R-APR vs. 23.33% H-APR), C–D serious complications (17.92% vs. 13.78% vs. 11.76% vs. 11.93%, respectively), bleeding

Table 1 Demographic, Clinical, and Oncological Characteristics of Rectal Cancer Patients Who Underwent APR Stratified by Operative Approach

Characteristic, n (%)	O-APR 1211 (42.72)	L-APR 595 (20.99)	R-APR 476 (16.79)	H-APR 553 (19.51)	*p*
Age group, years					0.077
< 55	292 (24.11)	129 (21.68)	112 (23.53)	132 (23.87)	
55–64	351 (28.98)	156 (26.22)	141 (29.62)	172 (31.10)	
65–74	331 (27.33)	184 (30.92)	124 (26.05)	120 (21.70)	
≥ 75	237 (19.57)	126 (21.18)	99 (20.80)	129 (23.33)	
Age, mean ± SD	63.13 ± 12.47	64.07 ± 12.31	63.28 ± 12.55	63.06 ± 13.22	0.454
Male	743 (61.35)	367 (61.68)	317 (66.60)	363 (65.64)	0.105
Race					<0.001
White	816 (67.38)	349 (58.66)	367 (77.10)	393 (71.07)	
Black	74 (6.11)	23 (3.87)	28 (5.88)	38 (6.87)	
Other	51 (4.21)	32 (5.38)	42 (8.82)	30 (5.42)	
Unknown	270 (22.30)	191 (32.10)	39 (8.19)	92 (16.64)	
ASA classification					<0.001
I–II	322 (26.63)	200 (33.61)	150 (31.51)	214 (38.70)	
III	804 (66.50)	369 (62.02)	306 (64.29)	320 (57.87)	
IV–V	83 (6.87)	26 (4.37)	20 (4.20)	19 (3.44)	
BMI ≥ 30 kg/m^2	375 (31.12)	193 (32.71)	151 (31.72)	188 (34.06)	0.652
Current smoker	244 (20.15)	113 (18.99)	80 (16.81)	103 (18.63)	0.463
Diabetes	204 (16.85)	103 (17.31)	86 (18.07)	92 (16.64)	0.925
History of COPD	65 (5.37)	24 (4.03)	16 (3.36)	20 (3.62)	0.179
Hypertension	534 (44.10)	289 (48.57)	229 (48.11)	237 (42.86)	0.107
Dyspnea	95 (7.84)	33 (5.55)	30 (6.30)	23 (4.16)	0.022
Steroid use	33 (2.73)	12 (2.02)	14 (2.94)	19 (3.44)	0.525
Bleeding disorder	26 (2.15)	13 (2.18)	11 (2.31)	17 (3.07)	0.672
Clinical stage T					<0.001
T0–T2	161 (13.32)	124 (20.88)	80 (16.81)	92 (16.64)	
T3–T4	709 (58.64)	361 (60.77)	317 (66.60)	354 (64.01)	
Unknown	339 (28.04)	109 (18.35)	79 (16.60)	107 (19.35)	
Clinical stage N					<0.001
N0	454 (37.49)	252 (42.35)	208 (43.70)	242 (43.76)	
N1	272 (22.46)	165 (27.73)	135 (28.36)	130 (23.51)	
N2	135 (11.15)	61 (10.25)	49 (10.29)	62 (11.21)	
Unknown	350 (28.90)	117 (19.66)	84 (17.65)	119 (21.52)	
Clinical stage M					<0.001
M0/MX	630 (52.02)	366 (61.51)	299 (62.82)	325 (58.77)	
M1	56 (4.62)	19 (3.19)	14 (2.94)	23 (4.16)	
Unknown	525 (43.35)	210 (35.29)	163 (34.24)	205 (37.07)	
Tumor location					<0.001
Lower third	671 (55.41)	353 (59.33)	304 (63.87)	332 (60.04)	
Middle third	231 (19.08)	129 (21.68)	95 (19.96)	128 (23.15)	
Upper third	66 (5.45)	40 (6.72)	22 (4.62)	27 (4.88)	
Unknown	243 (20.07)	73 (12.27)	55 (11.55)	66 (11.93)	
Chemotherapy within 90 days	672 (56.19)	367 (62.31)	289 (61.92)	349 (64.04)	0.005
Radiation within 90 days	619 (51.76)	356 (60.65)	285 (60.64)	331 (60.85)	<0.001

O-APR, Open Abdominoperineal Resection; L-APR, Laparoscopic Abdominoperineal Resection; R-APR, Robotic Abdominoperineal Resection; H-APR, Hybrid Abdominoperineal Resection; SD, Standard Deviation; ASA, American Society of Anesthesiology; BMI, Body Mass Index; COPD, Chronic Obstructive Pulmonary Disease

Table 2 Demographic, Clinical, and Oncological Characteristics of Rectal Cancer Patients Who Underwent LAR Stratified by Operative Approach

Characteristic, n (%)	O-LAR 515 (31.48)	L-LAR 431 (26.34)	R-LAR 286 (17.48)	H-LAR 404 (24.69)	*p*
Age group, years					0.008
< 55	161 (31.26)	143 (33.18)	126 (44.06)	152 (37.62)	
55–64	139 (26.99)	134 (31.09)	82 (28.67)	109 (26.98)	
65–74	146 (28.35)	106 (24.59)	55 (19.23)	9 (24.01)	
≥ 75	69 (13.40)	48 (11.14)	23 (8.04)	46 (11.39)	
Age, mean ± SD	60.95 ± 12.09	59.96 ± 12.11	58.01 ± 11.35	59.05 ± 13.13	0.007
Male	317 (61.55)	272 (63.11)	194 (67.83)	230 (56.93)	0.032
Race					<0.001
White	326 (63.30)	212 (49.19)	214 (74.83)	266 (65.84)	
Black	33 (6.41)	28 (6.50)	25 (8.74)	18 (4.46)	
Other	30 (5.83)	39 (9.05)	32 (11.19)	30 (7.43)	
Unknown	126 (24.47)	152 (35.27)	15 (5.24)	90 (22.28)	
ASA classification					<0.001
I–II	177 (34.37)	157 (36.43)	118 (41.26)	219 (54.34)	
III	312 (60.58)	260 (60.32)	159 (55.59)	176 (43.67)	
IV–V	26 (5.05)	14 (3.25)	9 (3.15)	8 (1.99)	
BMI ≥ 30 kg/m^2	168 (32.68)	136 (32.00)	93 (32.63)	113 (28.04)	0.427
Current smoker	97 (18.83)	70 (16.24)	39 (13.64)	52 (12.87)	0.064
Diabetes	71 (13.79)	62 (14.39)	45 (15.73)	45 (11.14)	0.331
History of COPD	21 (4.08)	10 (2.32)	3 (1.05)	5 (1.24)	0.013
Hypertension	195 (37.86)	170 (39.44)	116 (40.56)	145 (35.89)	0.596
Dyspnea	28 (5.44)	22 (5.10)	10 (3.50)	11 (2.72)	0.162
Steroid use	15 (2.91)	3 (0.70)	3 (1.05)	16 (3.96)	0.005
Bleeding disorder	11 (2.14)	8 (1.86)	2 (0.70)	15 (3.71)	0.057
Clinical stage T					<0.001
T0–T2	77 (14.98)	75 (17.40)	56 (19.58)	106 (26.24)	
T3–T4	303 (58.95)	278 (64.50)	170 (59.44)	233 (57.67)	
Unknown	134 (26.07)	78 (18.10)	60 (20.98)	65 (16.09)	
Clinical stage N					0.657
N0	208 (40.39)	178 (41.30)	127 (44.41)	186 (46.04)	
N1	139 (26.99)	114 (26.45)	77 (26.92)	102 (25.25)	
N2	48 (9.32)	31 (7.19)	25 (8.74)	34 (8.42)	
Unknown	120 (23.30)	108 (25.06)	57 (19.93)	82 (20.30)	
Clinical stage M					0.002
M0/MX	291 (56.50)	279 (64.73)	182 (63.64)	264 (65.35)	
M1	33 (6.41)	10 (2.32)	9 (3.15)	9 (2.23)	
Unknown	191 (37.09)	142 (32.95)	95 (33.22)	131 (32.43)	
Tumor location					<0.001
Lower third	124 (24.08)	116 (26.91)	91 (31.82)	118 (29.21)	
Middle third	214 (41.55)	197 (45.71)	139 (48.60)	191 (47.28)	
Upper third	93 (18.06)	93 (21.58)	37 (12.94)	74 (18.32)	
Unknown	84 (16.31)	25 (5.80)	19 (6.64)	21 (5.20)	
Chemotherapy within 90 days	315 (61.64)	250 (58.41)	183 (64.21)	209 (52.25)	0.007
Radiation within 90 days	307 (60.20)	247 (57.58)	175 (61.62)	207 (51.62)	0.027

O-LAR, Open Low Anterior Resection; L-LAR, Laparoscopic Low Anterior Resection; R-LAR, Robotic Low Anterior Resection; H-LAR, Hybrid Low Anterior Resection; SD, Standard Deviation; ASA, American Society of Anesthesiology; BMI, Body Mass Index; COPD, Chronic Obstructive Pulmonary Disease

required transfusion (24.61% vs. 9.24% vs. 8.19% vs. 7.23%), and positive radial margins (13.21% vs. 9.28% vs. 9.07% vs. 8.88%) (Table 3). R-APR was associated with significantly lower rate of unplanned conversion to open procedure (20.67% L-APR vs. 5.88% R-APR, $p < 0.001$) and shortest LOS (7.79 vs. 6.18 vs. 5.51 vs. 6.59 days). There was no difference between the four operative approaches with respect to anastomotic leak, readmission, and mortality. Reoperation rates were comparable between the groups with the exception of O-APR vs. L-APR (7.68% vs. 5.04%, $p = 0.037$). Operative time was the longest for the O-APR group, but similar to the R-APR (334.37 vs. 322.42 min, $p = 0.133$). No differences in outcomes were observed between L-APR and H-APR groups, and LOS is the only outcome that differed between R-APR and H-APR.

In comparison to O-LAR; L-LAR, R-LAR, and H-LAR patients had significantly lower rates of overall morbidity (28.74% O-LAR vs. 21.58% L-LAR vs. 14.34% R-LAR vs. 19.55% H-LAR $p < 0.001$), wound infection (6.99% vs. 3.25% vs. 2.45% vs. 3.22%), and bleeding required transfusion (12.04% vs. 6.03% vs. 2.80% vs. 4.70%) (Table 4). There were no differences between the four operative approaches with respect to serious morbidity, anastomotic leak, radial margin positivity, readmission, mortality, and reoperation. LOS was comparable between O-LAR and H-LAR (7.16 vs. 6.40, $p = 0.121$) groups, and significantly lower in L-LAR and R-LAR groups (5.88 vs. 4.69 days). O-LAR was associated with the shortest operative time (271.61 vs. 314.36 vs. 293.05 vs. 300.41 min). In the L-ARP vs. R-APR group comparison, R-APR was associated with lower conversion rate (4.90% vs. 22.04%, $p < 0.001$), lower rates of overall morbidity (14.34% vs. 21.58%, $p = 0.015$) and bleeding requiring transfusion (2.80% vs. 6.03%, $p = 0.046$), and shorter operative time (293.05 vs. 314.36 min, $p = 0.033$). No differences in outcomes were observed between L-LAR and H-LAR groups, and LOS is the only outcome that differed between R-LAR and H-LAR.

Adjusted analysis

After adjusting for other factors, L-APR, R-APR, and H-APR were associated with decreased risk of overall morbidity when compared to O-APR (OR 0.53, 95% CI 0.42–0.67, $p < 0.001$; OR 0.52, 95% CI 0.40–0.66, $p < 0.001$; OR 0.50, 95% CI 0.39–0.63, $p < 0.001$, respectively) (Table 5). In addition, R-APR and H-APR

Table 3 Unadjusted Rates of 30-Day APR Outcomes Stratified by Operative Approach

Outcome, n (%)	O-APR 1211 (42.72)	L-APR 595 (20.99)	*p* O vs. L	R-APR 476 (16.79)	*p* O vs. R	H-APR 553 (19.51)	*p* O vs. H
Overall morbidity[a]	500 (41.29)	157 (26.39)	<0.001	116 (24.37)	<0.001	129 (23.33)	<0.001
Serious morbidity[b]	217 (17.92)	82 (13.78)	0.026	56 (11.76)	0.002	66 (11.93)	0.001
Wound infection[c]	151 (12.47)	52 (8.74)	0.018	44 (9.24)	0.062	48 (8.68)	0.020
Bleeding[d]	298 (24.61)	55 (9.24)	<0.001	39 (8.19)	<0.001	40 (7.23)	<0.001
Anastomotic leak	22 (1.82)	7 (1.18)	0.309	8 (1.68)	0.849	9 (1.63)	0.779
Unplanned conversion	–	123 (20.67)	–	28 (5.88)*	–	–	–
Positive margins—radial	138/1045 (13.21)	49/528 (9.28)	0.023	38/419 (9.07)	0.028	43/484 (8.88)	0.015
Readmission	193 (15.94)	93 (15.63)	0.867	71 (14.92)	0.603	71 (12.84)	0.091
Mortality	8 (0.66)	3 (0.50)	0.999	0 (0.00)	0.115	0 (0.00)	0.288
Reoperation	93 (7.68)	30 (5.04)	0.037	25 (5.25)	0.079	29 (5.24)	0.061
Length of stay, days, mean ± SD	7.79 ± 21.05	6.18 ± 10.61	0.078	5.51 ± 8.31	0.022	6.59 ± 7.26	0.191
Operative time, min, mean ± SD	334.37 ± 153.52	306.51 ± 120.13	<0.001	322.42 ± 128.46*	0.133	312.35 ± 126.71	0.003

SD, Standard Deviation. O-APR, Open Abdominoperineal Resection; L-APR, Laparoscopic Abdominoperineal Resection; R-APR, Robotic Abdominoperineal Resection; H-APR, Hybrid Abdominoperineal Resection

*$p < 0.05$ (L-APR = reference group)

[a]Overall morbidity: Wound infection, pneumonia, urinary tract infection, VTE, cardiac complication, shock/sepsis, unplanned intubation, bleeding requiring transfusion, renal complication, on ventilator > 48 h, organ space surgical site infection, and anastomotic leak

[b]CD III–V complications: III—cardiac complication, renal complication, organ space surgical site infection, reoperation; IV—shock/sepsis, unplanned intubation, on ventilator > 48 h

[c]Wound infection: superficial SSI, deep incisional SSI, or wound disruption

[d]Bleeding requiring transfusion

Table 4 Unadjusted Rates of 30-Day LAR Outcomes Stratified by Operative Approach

Outcome, n (%)	O-LAR 515 (31.48)	L-LAR 431 (26.34)	*p* O vs. L	R-LAR 286 (17.48)	*p* O vs. R	H-LAR 404 (24.69)	*p* O vs. H
Overall morbidity[a]	148 (28.74)	93 (21.58)	0.012	41 (14.34)*	<0.001	79 (19.55)	0.001
Serious morbidity[b]	69 (13.40)	61 (14.15)	0.737	27 (9.44)	0.098	47 (11.63)	0.424
Wound infection[c]	36 (6.99)	14 (3.25)	0.010	7 (2.45)	0.006	13 (3.22)	0.012
Bleeding[d]	62 (12.04)	26 (6.03)	0.002	8 (2.80)*	<0.001	19 (4.70)	<0.001
Anastomotic leak	24 (4.66)	22 (5.10)	0.752	9 (3.15)	0.302	18 (4.46)	0.883
Unplanned conversion		95 (22.04)	–	14 (4.90)*	–	–	–
Positive margins—radial	23/435 (5.29)	12/381 (3.15)	0.133	9/239 (3.77)	0.374	13/365 (3.56)	0.241
Positive margins—distal	15/429 (2.91)	7/381 (1.62)	0.147	4/244 (1.64)	0.162	4/369 (1.08)	0.026
Readmission	66 (12.82)	60 (13.92)	0.618	43 (15.03)	0.380	66 (16.34)	0.131
Mortality	1 (0.19)	5 (1.16)	0.098	1 (0.35)	0.999	1 (0.25)	0.999
Reoperation	19 (3.69)	28 (6.50)	0.048	11 (3.85)	0.911	19 (4.70)	0.444
Length of stay, days, mean ± SD	7.16 ± 8.78	5.88 ± 9.15	0.028	4.69 ± 9.86	<0.001	6.40 ± 5.19	0.121
Operative time, min, mean ± SD	271.61 ± 111.44	314.36 ± 132.20	<0.001	293.05 ± 129.36*	0.014	300.41 ± 115.27	<0.001

SD, Standard Deviation. O-LAR, Open Low Anterior Resection; L-LAR, Laparoscopic Low Anterior Resection; R-LAR, Robotic Low Anterior Resection; H-LAR, Hybrid Low Anterior Resection

*$p < 0.05$ (L-LAR = reference group)

[a]Overall morbidity: Wound infection, pneumonia, urinary tract infection, VTE, cardiac complication, shock/sepsis, unplanned intubation, bleeding requiring transfusion, renal complication, on ventilator > 48 h, organ space surgical site infection, and anastomotic leak

[b]CD III–V complications: III—cardiac complication, renal complication, organ space surgical site infection, reoperation; IV—shock/sepsis, unplanned intubation, on ventilator > 48 h

[c]Wound infection: superficial SSI, deep incisional SSI, or wound disruption

[d]Bleeding requiring transfusion

had significantly reduced risk of serious complications when compared to O-APR (OR 0.66, 95% 0.48–0.92, $p = 0.015$; OR 0.71, 95% CI 0.53–0.97, $p = 0.031$). L-APR showed a trend toward decreased risk of serious morbidity ($p = 0.067$). There were no significant differences in the risk of either overall or serious morbidity for L-ARP vs. R-APR, L-APR vs. H-APR, and R-APR vs. H-ARR. L-LAR, R-LAR, and H-LAR were associated with decreased risk of overall morbidity when compared to O-LAR (OR 0.64, 95% CI 0.47–0.88, $p = 0.005$; OR 0.49, 95% CI 0.33–0.72, $p < 0.001$; OR 0.70, 95% CI 0.50–0.97, $p = 0.033$, respectively); however, there was no difference in the risk of serious morbidity in any of the comparison groups (Table 6).

Discussion

Minimally invasive surgery (MIS) is associated with reduced tissue trauma and has been shown to result in better short-term outcomes including reduced postoperative pain, reduced postoperative complications, early ambulation, and shorter LOS [31]. Over the past decade, laparoscopic proctectomy (LP) has gained popularity in the treatment of rectal cancer [32]. However, the use of robotic proctectomy (RP) remains less established. Due to the technical challenges associated with rectal and pelvic surgery, there is a debate around the best MIS approach for rectal cancer [31]. In this study, we observed that a large proportion of proctectomies were performed using a MIS approach, which may continue to increase as technical proficiency and technology continue to improve.

Clear radial margins were seen more commonly with minimally invasive approaches to APR; however, this was not observed within the LAR group. This goes against the findings of the COREAN trial, which showed no difference in circumferential margin positivity between laparoscopic and open groups for mid and low rectal cancers [25]. A meta-analysis by Wang et al. indicated that the risk of positive circumferential resection margin in the robotic TME group was lower than laparoscopic TME group (OR 0.44, 95% CI 0.20–0.96, $p < 0.05$); however, this finding was not replicated in our study [33].

The COLOR II trial showed that patients in the LP group had less blood loss, longer operative time, faster return of bowel function, and shorter LOS when compared

Table 5 Logistic Regression Analyses: Impact of APR Operative Approach on Overall and Serious Morbidity

Outcome	Unadjusted OR (95% CI)	*p*	Adjusted OR (95% CI)	*p*
Overall Morbidity				
L-APR vs. O-APR	0.51 (0.41–0.63)	<0.001	0.53 (0.42–0.67)[a]	<0.001
R-APR vs. O-APR	0.46 (0.36–0.58)	<0.001	0.52 (0.40–0.66)[a]	<0.001
H-APR vs. O-APR	0.43 (0.34–0.54)	<0.001	0.50 (0.39–0.63)[a]	<0.001
L-APR vs. R-APR	1.11 (0.84–1.47)	0.452	1.03 (0.77–1.38)[a]	0.844
L-APR vs. H-APR	1.18 (0.90–1.54)	0.231	1.07 (0.81–1.42)[a]	0.635
R-APR vs. H-APR	1.06 (0.79–1.41)	0.695	1.04 (0.77–1.40)[a]	0.800
Serious Morbidity				
L-APR vs. O-APR	0.73 (0.56–0.96)	0.027	0.76 (0.57–1.02)[b]	0.067
R-APR vs. O-APR	0.61 (0.45–0.84)	0.002	0.66 (0.48–0.92)[b]	0.015
H-APR vs. O-APR	0.62 (0.46–0.83)	0.002	0.71 (0.53–0.97)[b]	0.031
L-APR vs. R-APR	1.20 (0.83–1.72)	0.328	1.15 (0.79–1.69)[b]	0.471
L-APR vs. H-APR	1.18 (0.83–1.67)	0.351	1.07 (0.75–1.53)[b]	0.712
R-APR vs. H-APR	0.98 (0.67–1.44)	0.933	0.93 (0.63–1.37)[b]	0.714

OR, Odds Ratio; CI, Confidence Interval; O-APR, Open Abdominoperineal Resection; L-APR, Laparoscopic Abdominoperineal Resection; R-APR, Robotic Abdominoperineal Resection; H-APR, Hybrid Abdominoperineal Resection

[a]Adjusted for all variables with $p < 0.250$ from univariate analysis: race, ASA, smoking, diabetes, COPD, hypertension, dyspnea, bleeding disorder, stage T, chemotherapy, radiation therapy

[b]Adjusted for all variables with $p < 0.250$ from univariate analysis: male, race, ASA, BMI $\geq$ 30, smoking, diabetes, COPD, hypertension, dyspnea, bleeding disorder, chemotherapy, radiation therapy

Table 6 Logistic Regression Analyses: Impact of LAR Operative Approach on Overall and Serious Morbidity

Outcome	Unadjusted OR (95% CI)	*p*	Adjusted OR (95% CI)	*P*
Overall Morbidity				
L-LAR vs. O-LAR	0.68 (0.51–0.92)	0.012	0.64 (0.47–0.88)[a]	0.005
R-LAR vs. O-LAR	0.42 (0.28–0.61)	<0.001	0.49 (0.33–0.72)[a]	<0.001
H-LAR vs. O-LAR	0.60 (0.44–0.82)	0.001	0.70 (0.50–0.97)[a]	0.033
L-LAR vs. R-LAR	1.64 (1.10–2.46)	0.015	1.31 (0.86–2.00)[a]	0.211
L-LAR vs. H-LAR	1.13 (0.81–1.58)	0.470	0.91 (0.64–1.30)[a]	0.617
R-LAR vs. H-LAR	0.69 (0.46–1.04)	0.076	0.70 (0.45–1.07)[a]	0.099
Serious Morbidity				
L-LAR vs. O-LAR	1.07 (0.74–1.54)	0.737	1.06 (0.72–1.57)[b]	0.755
R-LAR vs. O-LAR	0.67 (0.42–1.08)	0.100	0.78 (0.48–1.27)[b]	0.319
H-LAR vs. O-LAR	0.85 (0.57–1.26)	0.424	1.01 (0.67–1.53)[b]	0.965
L-LAR vs. R-LAR	1.58 (0.98–2.56)	0.061	1.37 (0.82–2.27)[b]	0.228
L-LAR vs. H-LAR	1.25 (0.83–1.88)	0.279	1.05 (0.69–1.61)[b]	0.807
R-LAR vs. H-LAR	0.79 (0.48–1.30)	0.360	0.77 (0.46–1.30)[b]	0.328

OR, Odds Ratio; CI, Confidence Interval; O-LAR, Open Low Anterior Resection; L-LAR, Laparoscopic Low Anterior Resection; R-LAR, Robotic Low Anterior Resection; H-LAR, Hybrid Low Anterior Resection

[a]Adjusted for all variables with $p < 0.250$ from univariate analysis: race, ASA, BMI $\geq$ 30, smoking, diabetes, COPD, hypertension, bleeding disorder, stage T, chemotherapy, radiation therapy

[b]Adjusted for all variables with $p < 0.250$ from univariate analysis: male, race, ASA, BMI $\geq$ 30, smoking, diabetes, hypertension, tumor location, chemotherapy

to open proctectomy (OP) (all $p < 0.001$). However, the morbidity was similar between the two groups (40% vs. 37%, $p = 0.424$) [5]. Similar findings were seen in the COREAN trial which showed that LP was associated with earlier return of bowel function, less pain, and less blood loss, while the rates of overall complications in LP and OP were similar [25]. In this present study, all minimally invasive and hybrid approaches for both APR and LAR had significantly lower rates of overall morbidity when compared to the open group, while O-APR had higher risk of C–D III–V serious complications when compared to L-, R-, and H-APR. LOS was shorter for L- and R-LAR procedures when compared to O-LAR, and shorter for R-APR when compared to O-APR. Bleeding rates were significantly lower in all minimally invasive approaches for both APR and LAR when compared to the open group, and wound infection rates were lower for every group with the exception of R-APR, which trended toward significant ($p = 0.062$).

When directly comparing the laparoscopic to the robotic approach, our analysis showed that R-APR was associated with lower rate of conversion to open when compared to L-APR (5.88% vs. 20.67%). With regard to LAR, the conversion rates were again lower for the robotic approach (4.90% for R-LAR and 22.04% for L-LAR). This is consistent with the results from a National Cancer Database study which included 956 patients who underwent RP and 5447 patients who underwent LP and found lower rate of conversion in RP (9.5% vs. 17.4%, $p < 0.001$) [32]. A similar finding was seen in another study by Sun et al. with a conversion rate of (8% vs. 16%, $p < 0.001$) for RP vs LP, respectively [34]. The lower conversion rates of RP seen in our study and other studies could be attributed to the benefits of RP on overcoming the technical challenges associated with LP, which result from the anatomical nature of the pelvis and the demanding nature of TME [25, 34].

R-APR was found to have an increased operative time compared to L-APR, while R-LAR was found to have lower overall morbidity, bleeding requiring transfusion, and operative time compared to L-LAR. Consistent with our results, Baik et el reported in a single center randomized trial, lower serious complication rate in RP compared to LP (5.4% vs. 19.3%), shorter LOS in the RP group, and higher conversion rate for LP group [35]. In contrast, several other studies and systematic reviews showed no difference in morbidity between LP and RP. A study of Nationwide Inpatient Sample Database found that the overall morbidity of OP, LP, and RP were 39.7%, 32.5%, and 26.9%, respectively ($p < 0.01$). Both LP and RP had lower risk of morbidity compared with OP (adjusted OR 0.77, 95% CI 0.65–0.92, 0.57, 95% CI 0.40–0.80, $p < 0.01$). However, there was no difference in morbidity between LP and RP (adjusted OR 0.79, 95% CI 0.55–1.14, $p = 0.21$) [36]. One important consideration when comparing the increased morbidity related to OP is that these lesions may have been of a more advanced stage and not amenable to a minimally invasive approach. However, due to the lack of complete staging data in NSQIP, it is difficult to firmly draw this conclusion.

A systematic review that compared short-term outcomes between LP and RP reported no difference in postoperative morbidity (OR 0.92, 95% CI 0.75–01.12, $p = 0.40$), postoperative mortality (OR 0.67, 95% CI 0.28–1.62, $p = 0.38$), and rate of reoperation (OR 0.76, 95% CI 0.50–1.16, $p = 0.20$). It concluded that RP is safe and feasible, but it failed to demonstrate superiority over LP except for early return of bowel function, lower rate of conversion, and shorter LOS [37]. A pooled analysis of robotic vs laparoscopic surgery for TME showed lower conversion rate in robotic group (OR 0.23, 95% CI 0.10–0.52, $p < 0.01$), again consistent with our findings. However, there was no difference in postoperative complications between the two groups (OR 0.95, 95% CI 0.73–1.25, $p > 0.05$) [33]. With mixed results in the literature of equivalent or better short-term outcomes of RP, we think that the observed better outcomes and reduced serious morbidity of both R-LAR and R-APR in this study can be attributed to surgeons' experience, improved robotic technology over the time, and appropriate case selection.

Our analysis showed better short-term outcomes with MIP; however, consideration for MIP should be based on the clinical and oncological outcomes. While multiple studies have shown equivalent oncological outcomes between MIP and OP, there are a conflicting data on short-term oncological outcomes associated with MIP approach. The AlaCaRT trial could not establish noninferiority of LP compared to OP, and the authors concluded that their results do not provide sufficient evidence for the routine use of LP [38]. In addition, results from the recently published Australasian Laparoscopic Cancer of the Rectum Randomized Clinical Trial showed that the 2-year recurrence, disease free survival, and overall survival did not differ significantly between LP and OP. However, the authors concluded that the direction of pathology differences is in favor of the open technique and that their results cannot confirm or refute that LP is inferior to OP [39]. Multiple studies including the present study showed that MIP is associated with less short-term morbidity; however, oncological outcomes associated with each surgical approach must be taken in consideration when considering MIP for rectal cancer. Caution is still needed when recommending MIP as multiple randomized trials could not advocate for its routine use based on the oncological outcomes.

There are several limitations to our study including the inherent bias associated with a retrospective review of an administrative database. In addition, ACS-NSQIP database relies on coding accuracy, which may not always be precise. There may be confounding variables not recorded in this database that could be associated with the choice of surgical approach such as surgeon specialty or volume performed by each surgeon or institution. The design of the ACS-NSQIP data extraction protocol limited our ability to determine the level of specialty training for operating surgeons, and surgeon-specific decision-making regarding surgical approach could not be evaluated. A further limitation is the lack of data on cost related to OP compared to MIP within NSQIP. However, studies have identified that a minimally invasive approach can be associated with lower facility and professional cost [40]. Despite these limitations, using the ACS-NSQIP database provides a large sample from a diverse hospitals throughout the USA, which gives the ability to adjust for a number of confounding factors and draw reasonable conclusions regarding the short-term outcomes of different surgical approaches.

In conclusion, a minimally invasive or hybrid approach appears to be associated with lower overall morbidity than OP. This benefit is observed regardless as to whether the case is a LAR or an APR. Appropriate selection of patients for MIP can therefore result in better short-term outcomes. Further study is needed to determine long term oncological outcomes for MIP before truly concluding on the optimum surgical approach for rectal cancer.

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Compliance with ethical standards

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