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Evolution of minimally invasive surgery for rectal cancer: update from the national cancer database

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Abstract

Background As the use of minimally invasive techniques in colorectal surgery has become increasingly prevalent, concerns remain about the oncologic effectiveness and long-term outcomes of minimally invasive low anterior resection (MI-LAR) for the treatment of rectal cancer.

Study design The 2010–2015 National Cancer Database (NCDB) Participant Data Use File was queried for patients undergoing elective open LAR (OLAR) or MI-LAR for rectal adenocarcinoma. A 1:1 propensity match was performed on the basis of demographics, comorbidity, and tumor characteristics. Outcomes were compared between groups and Cox proportional hazard modeling was performed to identify independent predictors of mortality. A subset analysis was performed on high-volume academic centers.

Results 35,809 patients undergoing LAR were identified of whom 18,265 (51.0%) underwent MI-LAR. After propensity matching, patients receiving MI-LAR were less likely to have a positive circumferential radial margin (CRM) (5.5% vs. 6.6%, $p=0.0094$) or a positive distal margin (3.6% vs. 4.6%, $p=0.0022$) and had decreased 90-day all-cause mortality (2.0% vs. 2.6%, $p=0.0238$). MI-LAR resulted in decreased hospital length of stay (5 vs. 6 days, $p<0.0001$) but a greater rate of 30-day readmission (7.6% vs. 6.5%, $p=0.0054$). Long-term overall survival was improved with MI-LAR (79% vs. 76%, $p<0.0001$). Cox proportional hazard modeling demonstrated a decreased risk of mortality with MI-LAR (HR 0.859, 95% CI 0.788–0.937).

Conclusion MI-LAR is associated with improvement in CRM clearance and long-term survival. In the hands of experienced surgeons with advanced laparoscopy skills, MI-LAR appears safe and effective technique for the management of rectal cancer.

Keywords Rectal cancer · Minimally invasive surgery · Low anterior resection

Colorectal cancer, the third most common cancer worldwide, remains a major cause of morbidity and mortality. It is estimated that colorectal cancer is responsible for 50,000 deaths per year in the United States [1]. Coordination of multidisciplinary care and advancements in chemotherapy and radiation therapy have significantly improved outcomes in the past 40 years, however, surgical resection of the primary tumor remains the cornerstone of curative treatment. In recent years, the use of minimally invasive surgical (MIS) approaches, including both laparoscopic and robotic techniques, has gained traction for the management of colon cancer due to accumulating evidence demonstrating improved short-term outcomes and oncologic equivalency [2, 3]. In comparison, the adoption of laparoscopic approaches in the management of rectal cancer has occurred at a slower pace due to concerns for the increased difficulty of pelvic

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

These data were presented as a poster by Kristen Rhodin at the Association of Women Surgeons Resident and Medical Student Research Forum in Boston, MA in October 2018.

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dissection and thus the ability to perform a total mesorectal excision (TME) equivalent to open procedures [4, 5].

The ACOSOG Z6051 trial raised concerns about the oncologic efficacy of laparoscopic proctectomy for patients with stage II/III rectal cancer as laparoscopic rectal resection failed to demonstrate non-inferiority compared to open proctectomy [6]. Z6051 utilized a composite pathologic endpoint and, although these findings raised concerns about long-term survival the trial did not report survival data. Several additional studies have compared minimally invasive (defined as either laparoscopic or robotic) low anterior resection (MI-LAR) and open LAR (OLAR), however, concerns over oncologic efficacy and long-term outcomes between these two approaches remain incompletely understood [6–10].

As colorectal surgeons continue to fine tune their laparoscopic and robotic skillsets, it can be reasonably expected that they will become increasingly facile with more complicated operations, including MI-LAR, resulting in improved outcomes. The goal of this study was to utilize a large, contemporary national database to expand on previous analyses, conducting the largest study to date and using the most recent data to examine differences in both oncologic outcomes and long-term follow-up between MI-LAR and OLAR.

Methods

Data source

The National Cancer Data Base (NCDB) is prospectively maintained by the American College of Surgeons' Commission on Cancer (CoC) and the American Cancer Society [11]. The NCDB gathers data from more than 1500 CoC-accredited centers and is estimated to capture approximately 70% of all newly diagnosed cases of cancer in the United States and Puerto Rico. It now contains upwards of 30 million patient records.

Study design

The Duke University Institutional Review Board granted approval for this retrospective analysis. The NCDB was queried for all adult patients diagnosed with rectal adenocarcinoma from 2010 to 2015 who underwent LAR. Patients undergoing LAR were selected using Surgery Procedure of the Primary Site codes 30 and 40, as designated by the Facility Oncology Registry Data Standards criteria. Any patients with non-malignant pathology or preoperatively identified metastatic disease were excluded. Patients who underwent conversion to an open procedure were included in the MI-LAR cohort. The primary endpoint was overall survival. Secondary endpoints included: adequacy of lymph node harvest (defined as greater 12 or more lymph nodes harvested in the dataset), hospital length of stay (LOS), distal margin positivity, circumferential radial margin (CRM) positivity, 30-day readmission, and 90-day mortality.

Statistical analysis

Patients were stratified by surgical approach as MI-LAR, which includes both laparoscopic and robotic approaches, or open LAR (OLAR). Baseline characteristics and unadjusted outcomes were compared using the Kruskal–Wallis test for continuous variables and Pearson χ^2 test for categorical variables. After stratification by surgical approach a 1:1 propensity match was performed using a nearest neighbor algorithm. For long-term survival a multivariable Cox proportional hazards model was constructed adjusting for patient age, gender, race, insurance status, comorbidities, clinical tumor stage, hospital type and volume, use of neoadjuvant therapy, and use of adjuvant therapy.

Sensitivity analysis

MI-LAR is more likely to be performed at academic and high-volume centers. This could potentially result in overestimation of outcomes from MI-LAR. Thus, a subset analysis of matched patients treated at high-volume academic medical centers was performed. High-volume hospitals were defined as those in the top tertile of annual hospital case volume. Designation of academic hospital was provided in the dataset. Surgical and oncologic outcomes were compared between MI-LAR and OLAR. Overall survival was examined using the Kaplan Meier method and Cox Proportional Hazards modeling.

Subset analyses

The risk of several outcomes in this study, including margin positivity or nodal spread, is low in patients with T0 or Tis tumors. We performed a subset analysis excluding patients with T0 and Tis tumors (by either clinical or pathological staging) to provide a more representative sample of patients.

Although robotic and laparoscopic approaches are both considered to be minimally invasive approaches these require distinct skillsets, different advanced training, and different patient selection. In order to define the difference between these two approaches to MI-LAR a subset analysis was performed comparing individuals who underwent Robotic LAR (R-LAR) and Laparoscopic LAR (L-LAR).

Model diagnostics were assessed. A p value of less than 0.05 was considered statistically significant. Statistical analysis was performed using SAS 9.4 (SAS Institute, Cary, North Carolina).

Results

A total of 35,809 patients were included in this study, of whom 18,265 (51%) underwent MI-LAR. Baseline demographics and unadjusted outcomes are presented in Table 1. Patients who underwent MI-LAR were younger (61 vs. 63 years, $p < 0.0001$), less likely to be black (7.0% vs. 8.7%, $p < 0.0001$), and more likely to have private insurance (53.0% vs. 44.6%), and more often from a higher annual income area (63.3% vs. 55.7%, $p < 0.0001$) and/or higher education (60.0% vs. 53.6%, $p < 0.0001$). Patients undergoing MI-LAR were less comorbid (76.2% with Charlson–Deyo score of 0 vs. 73.8%, $p < 0.0001$), more likely to be treated in high-volume (38.9% vs. 27.4%, $p < 0.0001$) or academic (37.3% vs. 33.2%, $p < 0.0001$) medical centers, and more likely to be treated in the northeast or west compared with the south ($p < 0.0001$). Use of MI-LAR increased throughout the study period (10.8% in 2010 vs. 22.5% in 2015). MI-LAR less frequently resulted in an inadequate lymph node harvest (21.2% vs. 24.9%, $p < 0.0001$), positive distal margin (3.9% vs. 5.8%, $p < 0.0001$), positive CRM (5.6% vs. 7.7%, $p < 0.0001$), and increased rates of R0 resection (97.6% vs. 96.7%, $p < 0.0001$). Patients undergoing MI-LAR had a shorter duration of hospital stay (5 vs. 6 days, $p < 0.0001$) with no difference in 30-day readmission rates (7.0% vs. 6.8%, $p = 0.3685$), and decreased 90-day mortality (2.0% vs. 3.1%, $p < 0.0001$).

Propensity-matched analysis

Following propensity matching a total of 16,708 patients were available for analysis. Matched demographics and outcomes are presented in Table 2. Matched groups demonstrated no difference in demographics or tumor characteristics, with the exception of year of diagnosis, and the use of MI-LAR increasing over the study period. Patients who underwent MI-LAR were less likely to have positive distal margins (3.6% vs. 4.6%, $p = 0.0022$) or CRM (5.5% vs. 6.6%, $p = 0.0094$). MI-LAR was associated with decreased length of hospital stay (5 vs. 6 days, $p < 0.0001$) and reduced 90-day mortality (2.0% vs. 2.6%, $p = 0.0238$), but increased 30-day readmission (7.6% vs. 6.5%, $p = 0.0054$).

Matched survival analysis

Median follow-up time was 53 months (range 1–156 months). MI-LAR was associated with improved long-term overall survival over OLAR (Fig. 1). At 5-years, overall survival was 79% among patients undergoing MI-LAR vs. 76% among patients undergoing OLAR. After adjustment, MI-LAR was associated with a decreased risk of long-term mortality (HR 0.859, 95% CI 0.788–0.937, $p = 0.0006$) (Table 3).

Subgroup analysis of matched patients treated at high-volume academic hospitals

The first subgroup analysis included 4028 matched patients treated in high-volume academic centers. There were no clinically significant differences in baseline demographics, with the exception being year of diagnosis (Table 4). MI-LAR was associated with shorter length of hospital stay (5 vs. 6 days, $p < 0.0001$) but there were no statistically significant differences in other outcomes, including rates of positive margins, adequacy of lymph node harvest, and 90-day mortality. After adjustment, use of MI-LAR was not associated with any difference in long-term survival (HR 0.849, 95% CI 0.678–1.063, $p = 0.154$) (Table 5).

Subgroup analysis of matched patients excluding T0 and Tis tumors

The second subgroup analysis included 17,094 matched patients excluding patients with either clinical or pathological T0 and Tis tumors. There were no clinically significant differences in baseline demographics, with the exceptions of year of diagnosis and attainment of higher education in patients undergoing MI-LAR (Table 6). MI-LAR was associated with decreased rates of positive distal margin (4.2% vs 5.3%, $p = 0.0006$), CRM (6.0% vs 7.0%, $p = 0.0118$), and shorter length of hospital stay (5 vs. 6 days, $p < 0.0001$). MI-LAR was also associated with improved 90-day mortality (2.0% vs 2.6%, $p = 0{,}0376$) and 5-year survival (78% vs 74%, $p < 0.0001$).

Subgroup analysis of matched patients treated at high-volume academic hospitals

The final subgroup analysis stratified 16.006 patients by either laparoscopic ($n = 11{,}583$) or robotic approach ($n = 4.423$). Patients undergoing Robotic LAR (R-LAR) were more likely to be male, younger than 65, have private insurance, fewer comorbidities, treated at academic medical centers, treated at centers with higher volumes, and diagnosed more recently. R-LAR was also associated with higher clinical but not pathological disease stage and with neoadjuvant treatment (Table 7). Fewer patients undergoing R-LAR required conversion to an open procedure (8.0% vs. 14.6%, $p < 0.0001$), however, there were no differences in inadequate lymph node harvest (19.0% vs. 20.4%, $p = 0.0537$), positive distal margin (4.0% vs. 4.4%, $p = 0.2390$) or positive

Table 1 Baseline demographics and unadjusted outcomes between minimally invasive low anterior resection (MI-LAR) and open LAR (OLAR)

	MI-LAR ($N=18,265$)	OLAR ($N=17,544$)	All patients ($N=35,809$)	p value
Patient age (years)	61 (52, 70)	63 (53, 72)	62 (53, 71)	
Patient age group (years)				< 0.0001
< 65	11,038 (62.0%)	9664 (56.8%)	20,702 (59.5%)	
65–80	5429 (30.5%)	5671 (33.3%)	11,100 (31.9%)	
> 80	1329 (7.5%)	1674 (9.8%)	3003 (8.6%)	
Male gender	10,998 (60.2%)	10,568 (60.2%)	21,566 (60.2%)	0.9655
Race				< 0.0001
Black	1278 (7.0%)	1518 (8.7%)	2796 (7.8%)	
Other	1182 (6.5%)	935 (5.3%)	2117 (5.9%)	
Insurance status				< 0.0001
Private	9589 (53.0%)	7722 (44.6%)	17,311 (48.9%)	
Medicaid	1033 (5.7%)	1158 (6.7%)	2191 (6.2%)	
Medicare	6800 (37.6%)	7507 (43.3%)	14,307 (40.4%)	
None	456 (2.5%)	761 (4.4%)	1217 (3.4%)	
Annual income ≥ $48,000	11,526 (63.3%)	9752 (55.7%)	14,436 (40.4%)	< 0.0001
Higher education	10,944 (60.0%)	9388 (53.6%)	20,332 (56.9%)	< 0.0001
Charlson–Deyo score				< 0.0001
0	13,915 (76.2%)	12,953 (73.8%)	26,868 (75.0%)	
1	3394 (18.6%)	3513 (20.0%)	6907 (19.3%)	
≥ 2	956 (5.2%)	1078 (6.1%)	2034 (5.7%)	
Hospital location				< 0.0001
South	6017 (34.3%)	6983 (41.1%)	13,000 (37.6%)	
Midwest	4620 (26.3%)	4723 (27.8%)	9343 (27.1%)	
Northeast	3898 (22.2%)	3017 (17.8%)	6915 (20.0%)	
West	3016 (17.2%)	2256 (13.3%)	5272 (15.3%)	
Hospital type				< 0.0001
Academic	6549 (37.3%)	5645 (33.2%)	12,194 (35.3%)	
Comprehensive community	10,086 (57.5%)	9662 (56.9%)	19,748 (57.2%)	
Community	916 (5.2%)	1672 (9.8%)	2588 (7.5%)	
Annual hospital volume (cases)				< 0.0001
Median	12	10	11	
Q1, Q3	7.0, 20.0	5.0, 17.0	6.0, 18.0	
Hospital volume				< 0.0001
High-volume	7111 (38.9%)	4810 (27.4%)	11,921 (33.3%)	
Medium-volume	5926 (32.4%)	5392 (30.7%)	11,318 (31.6%)	
Low-volume	5228 (28.6%)	7342 (41.8%)	12,570 (35.1%)	
Year of diagnosis				< 0.0001
2010	1971 (10.8%)	3684 (21.0%)	5655 (15.8%)	
2011	2406 (13.2%)	3250 (18.5%)	5656 (15.8%)	
2012	2700 (14.8%)	3061 (17.4%)	5761 (16.1%)	
2013	3222 (17.6%)	2781 (15.9%)	6003 (16.8%)	
2014	3859 (21.1%)	2491 (14.2%)	6350 (17.7%)	
2015	4107 (22.5%)	2277 (13.0%)	6384 (17.8%)	
Tumor size (mm)	35 (21, 50)	36 (23, 50)	35 (22, 50)	< 0.0001
Clinical T stage				< 0.0001
T0/Is	239 (1.7%)	227 (1.7%)	466 (1.7%)	
T1	2303 (16.0%)	1907 (14.2%)	4210 (15.2%)	
T2	2660 (18.5%)	2304 (17.2%)	4964 (17.9%)	
T3	8731 (60.7%)	8272 (61.8%)	17,003 (61.2%)	
T4	445 (3.1%)	682 (5.1%)	1127 (4.1%)	

Table 1 (continued)

	MI-LAR ($N=18,265$)	OLAR ($N=17,544$)	All patients ($N=35,809$)	p value
Clinical N stage				0.0307
N0	11,368 (66.6%)	10,885 (67.7%)	22,253 (67.1%)	
N1	4640 (27.2%)	4299 (26.7%)	8939 (27.0%)	
N2	1056 (6.2%)	900 (5.6%)	1956 (5.9%)	
High-grade tumor	1749 (10.8%)	1735 (11.0%)	3484 (10.9%)	0.5298
Clinical stage				< 0.0001
1	4395 (30.5%)	3732 (27.8%)	8127 (29.2%)	
2	4412 (30.6%)	4592 (34.3%)	9004 (32.4%)	
3	5591 (38.8%)	5080 (37.9%)	10,671 (38.4%)	
Pathologic T stage				< 0.0001
T0	2095 (12.1%)	1622 (9.9%)	3717 (11.0%)	
T1	3306 (19.0%)	2415 (14.7%)	5721 (16.9%)	
T2	5041 (29.0%)	4644 (28.2%)	9685 (28.6%)	
T3	6523 (37.6%)	7016 (42.7%)	13,539 (40.0%)	
T4	403 (2.3%)	753 (4.6%)	1156 (3.4%)	
Pathologic N stage				0.0001
N0	12,114 (70.7%)	11,197 (68.8%)	23,311 (69.7%)	
N1	3709 (21.6%)	3651 (22.4%)	7360 (22.0%)	
N2	1319 (7.7%)	1431 (8.8%)	2750 (8.2%)	
Pathologic M1	16 (0.1%)	22 (0.1%)	38 (0.1%)	0.3304
Pathologic stage				< 0.0001
1	7007 (45.3%)	5785 (39.1%)	12,792 (42.3%)	
2	3598 (23.2%)	4050 (27.4%)	7648 (25.3%)	
3	4862 (31.4%)	4938 (33.4%)	9800 (32.4%)	
4	16 (0.1%)	20 (0.1%)	36 (0.1%)	
Neoadjuvant therapy	9076 (49.8%)	8889 (50.8%)	17,965 (50.3%)	0.0568
Surgical approach				
Laparoscopic	13,112 (71.8%)	0 (0.0%)	13,112 (71.8%)	
Robotic	5153 (28.2%)	0 (0.0%)	5153 (28.2%)	
Conversion to open	2290 (12.5%)	0 (0.0%)	2290 (12.5%)	
Adjuvant therapy	1499 (8.2%)	1610 (9.2%)	3109 (8.7%)	0.0011
Inadequate LN harvest	3589 (21.2%)	4012 (24.9%)	7601 (23.0%)	< 0.0001
Positive distal margin	704 (3.9%)	1008 (5.8%)	1712 (4.8%)	< 0.0001
Positive CRM	882 (5.6%)	1162 (7.7%)	2044 (6.6%)	< 0.0001
Completeness of resection				< 0.0001
R0	17,433 (97.6%)	16,407 (96.7%)	33,840 (97.2%)	
R1	398 (2.2%)	499 (2.9%)	897 (2.6%)	
R2	23 (0.1%)	63 (0.4%)	86 (0.2%)	
Hospital length of stay (days)	5 (4, 7)	6 (5, 9)	6 (4, 8)	< 0.0001
30-day readmission	1275 (7.0%)	1181 (6.8%)	2456 (6.9%)	0.3685
Follow-up (months)	35.1 (23.7, 50.8)	40.0 (25.2, 56.6)	37.4 (24.4, 54.1)	< 0.0001

Data are presented as median (Q1, Q3) or percent (number)

LN lymph node, *CRM* circumferential radial margin

CRM (5.8% vs. 6.1%, $p=0.4979$). R-LAR was associated with decreased use of adjuvant treatment (7.1% vs. 9.7%, $p<0.0001$) but improved 30-day (0.8% vs. 1.2%, $p=0.0499$) and 90-day mortality (1.5% vs. 2.3%, $p=0.0055$) and, however, by 5 years the mortality of each approach was 78%.

Discussion

This national analysis of more than 35,000 patients is the largest study to date to examine the differences between surgical approaches in the management of rectal cancer. We

Table 2 Propensity-matched demographics and outcomes between minimally invasive low anterior resection (MI-LAR) and open LAR (OLAR)

	MI-LAR ($N=8354$)	Open LAR ($N=8354$)	All patients ($N=16,708$)	p value
Patient age group (years)				0.5641
< 65	4944 (59.2%)	4878 (58.4%)	9822 (58.8%)	
65–80	2729 (32.7%)	2773 (33.2%)	5502 (32.9%)	
> 80	681 (8.2%)	703 (8.4%)	1384 (8.3%)	
Male gender	5106 (61.1%)	5084 (60.9%)	10,190 (61.0%)	0.7391
Race				0.0821
White	7275 (87.1%)	7188 (86.0%)	14,463 (86.6%)	
Black	613 (7.3%)	688 (8.2%)	1301 (7.8%)	
Other	466 (5.6%)	478 (5.7%)	944 (5.6%)	
Insurance status				0.8917
No	252 (3.0%)	248 (3.0%)	500 (3.0%)	
Yes	8102 (97.0%)	8106 (97.0%)	16,208 (97.0%)	
Insurance type				0.9404
Private	4203 (50.3%)	4156 (49.7%)	8359 (50.0%)	
Medicaid	515 (6.2%)	533 (6.4%)	1048 (6.3%)	
Medicare	3295 (39.4%)	3329 (39.8%)	6624 (39.6%)	
Other	89 (1.1%)	88 (1.1%)	177 (1.1%)	
None	252 (3.0%)	248 (3.0%)	500 (3.0%)	
Annual income ≥ $48,000	5051 (60.5%)	5019 (60.1%)	10,070 (60.3%)	0.6241
Higher education	4933 (59.0%)	4802 (57.5%)	9735 (58.3%)	0.0414
Charlson–Deyo score				0.1954
0	6297 (75.4%)	6203 (74.3%)	12,500 (74.8%)	
1	1595 (19.1%)	1649 (19.7%)	3244 (19.4%)	
≥ 2	462 (5.5%)	502 (6.0%)	964 (5.8%)	
Hospital location				0.8998
South	3000 (35.9%)	3010 (36.0%)	6010 (36.0%)	
Midwest	2461 (29.5%)	2420 (29.0%)	4881 (29.2%)	
Northeast	1610 (19.3%)	1618 (19.4%)	3228 (19.3%)	
West	1283 (15.4%)	1306 (15.6%)	2589 (15.5%)	
Hospital type				0.8029
Academic	3116 (37.3%)	3142 (37.6%)	6258 (37.5%)	
Comprehensive community	4748 (56.8%)	4709 (56.4%)	9457 (56.6%)	
Community	490 (5.9%)	503 (6.0%)	993 (5.9%)	
Annual hospital volume (cases)	11 (6, 18)	11 (6, 19)	11 (6. 18)	0.3273
Hospital volume				0.844
High-volume	2682 (32.1%)	2671 (32.0%)	5353 (32.0%)	
Medium-volume	2835 (33.9%)	2811 (33.6%)	5646 (33.8%)	
Low-volume	2837 (34.0%)	2872 (34.4%)	5709 (34.2%)	
Year of diagnosis				< 0.0001
2010	978 (11.7%)	1607 (19.2%)	2585 (15.5%)	
2011	1133 (13.6%)	1506 (18.0%)	2639 (15.8%)	
2012	1238 (14.8%)	1507 (18.0%)	2745 (16.4%)	
2013	1497 (17.9%)	1378 (16.5%)	2875 (17.2%)	
2014	1738 (20.8%)	1240 (14.8%)	2978 (17.8%)	
2015	1770 (21.2%)	1116 (13.4%)	2886 (17.3%)	
Tumor size (mm, median, IQR)	35 (22, 50)	35 (22, 50)	35 (22, 50)	0.9995
Clinical T stage				0.8969
T0/Is	129 (1.5%)	144 (1.7%)	273 (1.6%)	
T1	1194 (14.3%)	1170 (14.0%)	2364 (14.1%)	
T2	1607 (19.2%)	1614 (19.3%)	3221 (19.3%)	

Table 2 (continued)

	MI-LAR ($N=8354$)	Open LAR ($N=8354$)	All patients ($N=16,708$)	p value
T3	5123 (61.3%)	5125 (61.3%)	10,248 (61.3%)	
T4	301 (3.6%)	301 (3.6%)	602 (3.6%)	
Clinical N stage				0.9636
N0	5247 (62.8%)	5252 (62.9%)	10,499 (62.8%)	
N1	2545 (30.5%)	2533 (30.3%)	5078 (30.4%)	
N2	562 (6.7%)	569 (6.8%)	1131 (6.8%)	
High-grade tumor	808 (10.7%)	795 (10.5%)	1603 (10.6%)	0.6346
Clinical stage				0.7277
1	2484 (29.9%)	2458 (29.6%)	4942 (29.7%)	
2	2712 (32.6%)	2760 (33.2%)	5472 (32.9%)	
3	3115 (37.5%)	3093 (37.2%)	6208 (37.3%)	
Pathologic T stage				0.9433
T0	876 (10.5%)	846 (10.1%)	1722 (10.3%)	
T1	1246 (14.9%)	1238 (14.8%)	2484 (14.9%)	
T2	2586 (31.0%)	2591 (31.0%)	5177 (31.0%)	
T3	3452 (41.3%)	3488 (41.8%)	6940 (41.5%)	
T4	194 (2.3%)	191 (2.3%)	385 (2.3%)	
Pathologic N stage				0.4515
N0	5649 (69.6%)	5649 (69.6%)	11,298 (69.6%)	
N1	1834 (22.6%)	1798 (22.2%)	3632 (22.4%)	
N2	628 (7.7%)	668 (8.2%)	1296 (8.0%)	
Pathologic M1	8 (0.1%)	7 (0.1%)	15 (0.1%)	1.0000
Pathologic stage				0.946
1	3162 (42.1%)	3128 (41.8%)	6290 (42.0%)	
2	1938 (25.8%)	1911 (25.6%)	3849 (25.7%)	
3	2411 (32.1%)	2433 (32.5%)	4844 (32.3%)	
4	5 (0.1%)	5 (0.1%)	10 (0.1%)	
Neoadjuvant therapy	4695 (56.2%)	4661 (55.8%)	9356 (56.0%)	0.607
Surgical approach				
Lap	5883 (70.4%)	0 (0.0%)	5883 (70.4%)	
Robotic	2471 (29.6%)	0 (0.0%)	2471 (29.6%)	
Conversion to open	1115 (13.3%)	0 (0.0%)	1115 (13.3%)	
Adjuvant therapy	678 (8.1%)	675 (8.1%)	1353 (8.1%)	0.9548
Inadequate LN harvest	1732 (22.1%)	1818 (23.3%)	3550 (22.7%)	0.0893
Positive distal margin	300 (3.6%)	379 (4.6%)	679 (4.1%)	0.0022
Positive CRM	410 (5.5%)	478 (6.6%)	888 (6.0%)	0.0094
Completeness of resection				0.3106
R0	8017 (97.9%)	7938 (97.6%)	15,955 (97.7%)	
R1	159 (1.9%)	186 (2.3%)	345 (2.1%)	
R2	12 (0.1%)	12 (0.1%)	24 (0.1%)	
Hospital length of stay (days)	5 (4, 7)	6 (5, 8)	6 (4, 8)	<0.0001
30-day readmission	634 (7.6%)	541 (6.5%)	1175 (7.1%)	0.0054
90-day mortality	133 (2.0%)	189 (2.6%)	322 (2.4%)	0.0238
Follow-up (months)	35.8 (23.9, 51.8)	40.2 (25.9, 56.2)	37.9 (24.9, 54.3)	35.8 (23.9, 51.8)

Data are presented as median (Q1, Q3) or percent (number)

LN lymph node, *CRM* circumferential radial margin

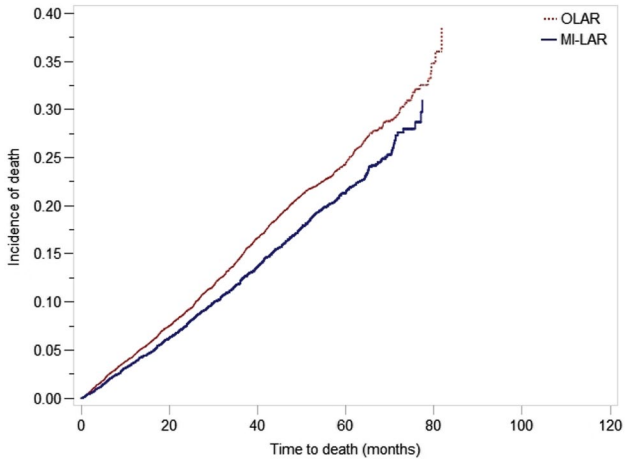

Fig. 1 Cumulative incidence plot for death in propensity-matched patients treated with minimally invasive low anterior resection (MI-LAR) or open LAR (OLAR)

Table 3 Cox proportional hazard model of predictors of overall mortality

Parameter	Hazard ratio	95% confidence interval	*p* value	
MI-LAR	0.859	0.788	0.937	0.0006
Female sex	1.352	1.236	1.479	< 0.0001
Insured	1.401	1.099	1.786	0.0064
Charlson–Deyo Score 1	1.343	1.215	1.485	< 0.0001
Charlson–Deyo Score 2	1.852	1.605	2.137	< 0.0001
Neoadjuvant therapy	1.217	1.107	1.337	< 0.0001
Adjuvant therapy	1.861	1.564	2.214	< 0.0001

found that MI-LAR was associated with clinically and statistically significant improvements in short-term oncologic outcomes including adequacy of lymph node harvest and rates of negative circumferential radial and distal margins even when excluding patients with low-stage tumors. This study also provides long-term follow-up which demonstrates that MI-LAR was associated with improved survival. Importantly, we were able to demonstrate these improved outcomes despite including patients who required conversion to open procedures, which would be expected to blunt the size of these effects.

Although the role of MIS approaches to proctectomy has been an area of investigation for two decades, the existing evidence is limited and the influence of approach on long-term mortality remains unclear. The United Kingdom Medical Research Council's CLASICC trial (1996–2002) was the first prospective multi-center randomized control trial to evaluate the use of laparoscopy in the treatment of rectal cancer. Of the 794 patients with either colon or rectal cancer randomized to receive laparoscopic or open surgery, only 246 patients underwent LAR for rectal cancer and 31% of MI-LAR cases required conversion to open leaving only 112 cases in the MI-LAR cohort. Within this limited cohort, a twofold increase in the incidence of a positive CRM (12% vs. 6%) was observed in patients undergoing MI-LAR, this was not statistically significant and, on long-term follow-up there has been no difference in disease-free or overall survival between treatment groups for patients with rectal cancer [12–14]. Subsequently the COREAN (2006–2009) and COLOR II (2004–2010) trials detected no significant differences between surgical approaches in the rates of CRM positivity, locoregional recurrence, disease-free survival, or overall survival at 3 years [8, 9, 15].

The similar outcomes between approaches seen in these early trials left the decision of MI-LAR or OLAR to the discretion of individual surgeons. However, two subsequent non-inferiority trials failed to demonstrate non-inferiority of laparoscopic proctectomy. In the ALaCaRT trial, a total of 475 patients underwent either laparoscopic or open rectal resection [10]. The rate of positive CRM was 7% in the laparoscopic group compared to 3% in the open surgical group. Similarly, the ACOSOG Z6051, a North American trial of 462 individuals undergoing either laparoscopic or open rectal resection between 2008 and 2013, failed to demonstrate non-inferiority utilizing a composite endpoint of distal margin positivity, circumferential margin positivity, and completeness of TME [6]. Although these trials found similar short-term outcomes between surgical approaches, these pathological findings raised concerns about the oncologic equivalency between groups; however, neither trial examined long-term outcomes which substantially limits the clinical significance of their findings. The use of a composite endpoint for oncologic adequacy in Z6051 further limits the interpretation and application of these findings.

Despite the evidence provided by these RCTs, the impact of surgical approach on long-term survival remains extremely limited. Moreover, concerns persist about the external validity of these highly selective studies which may not reflect contemporary practice, particularly during a two decade period of significant change in the use of minimally invasive approaches. Unfortunately beyond these international RCTs, the majority of the literature comparing surgical approaches to proctectomy consists of single institution studies which demonstrate similar outcomes, with shorter hospital length of stay and reduced infection rates in patients receiving laparoscopic procedures [16, 17]. Small studies investigating oncologic outcomes specifically, including CRM negativity, have found similar or improved outcomes with MI-LAR with other studies suggesting a specific role for MI-LAR in facilitating simultaneous resection of liver metastases and management of bulky

Table 4 Propensity-matched demographics and outcomes between minimally invasive low anterior resection (MI-LAR) and open LAR (OLAR) at high-volume academic centers

	MI-LAR ($N=2014$)	Open LAR ($N=2014$)	All patients ($N=4028$)	p value
Patient age group (years)				0.9582
< 65	1245 (61.8%)	1237 (61.4%)	2482 (61.6%)	
65–80	660 (32.8%)	665 (33.0%)	1325 (32.9%)	
> 80	109 (5.4%)	112 (5.6%)	221 (5.5%)	
Male gender	1260 (62.6%)	1252 (62.2%)	2512 (62.4%)	0.8199
Race				0.5771
White	1739 (86.3%)	1716 (85.2%)	3455 (85.8%)	
Black	154 (7.6%)	165 (8.2%)	319 (7.9%)	
Other	121 (6.0%)	133 (6.6%)	254 (6.3%)	
Insurance status				0.5982
No	43 (2.1%)	49 (2.4%)	92 (2.3%)	
Yes	1971 (97.9%)	1965 (97.6%)	3936 (97.7%)	
Insurance type				0.7373
Private	1070 (53.1%)	1077 (53.5%)	2147 (53.3%)	
Medicare	731 (36.3%)	730 (36.2%)	1461 (36.3%)	
Medicaid	150 (7.4%)	133 (6.6%)	283 (7.0%)	
Other	20 (1.0%)	25 (1.2%)	45 (1.1%)	
None	43 (2.1%)	49 (2.4%)	92 (2.3%)	
Annual income ≥ $48,000	1267 (63.0%)	1243 (61.8%)	2510 (62.4%)	0.4348
Higher education	1218 (60.6%)	1219 (60.6%)	2437 (60.6%)	1.0000
Charlson–Deyo score				0.0709
0	1558 (77.4%)	1497 (74.3%)	3055 (75.8%)	
1	352 (17.5%)	392 (19.5%)	744 (18.5%)	
≥ 2	104 (5.2%)	125 (6.2%)	229 (5.7%)	
Hospital location				0.7608
South	635 (31.5%)	608 (30.2%)	1243 (30.9%)	
Midwest	685 (34.0%)	713 (35.4%)	1398 (34.7%)	
Northeast	526 (26.1%)	523 (26.0%)	1049 (26.0%)	
West	168 (8.3%)	170 (8.4%)	338 (8.4%)	
Annual hospital volume (cases)	23 (17, 29)	23 (18, 32)	24 (18, 30)	< 0.0001
Year of diagnosis				< 0.0001
2010	115 (5.7%)	218 (10.8%)	333 (8.3%)	
2011	148 (7.3%)	279 (13.9%)	427 (10.6%)	
2012	290 (14.4%)	380 (18.9%)	670 (16.6%)	
2013	378 (18.8%)	380 (18.9%)	758 (18.8%)	
2014	533 (26.5%)	359 (17.8%)	892 (22.1%)	
2015	550 (27.3%)	398 (19.8%)	948 (23.5%)	
Tumor size (mm)	35 (22, 50)	37 (23, 50)	35 (23, 50)	0.0701
Clinical T stage				0.9398
T0/Is	21 (1.0%)	26 (1.3%)	47 (1.2%)	
T1	259 (12.9%)	268 (13.3%)	527 (13.1%)	
T2	345 (17.1%)	347 (17.2%)	692 (17.2%)	
T3	1304 (64.7%)	1288 (64.0%)	2592 (64.3%)	
T4	85 (4.2%)	85 (4.2%)	170 (4.2%)	
Clinical N stage				0.9665
N0	1110 (55.8%)	1109 (55.8%)	2219 (55.8%)	
N1	681 (34.2%)	684 (34.4%)	1365 (34.3%)	
N2	200 (10.0%)	195 (9.8%)	395 (9.9%)	
High-grade tumor	203 (11.6%)	196 (11.0%)	399 (11.3%)	0.6326
Clinical stage				0.9274

Table 4 (continued)

	MI-LAR ($N=2014$)	Open LAR ($N=2014$)	All patients ($N=4028$)	p value
1	494 (24.8%)	498 (25.0%)	992 (24.9%)	
2	609 (30.5%)	616 (30.9%)	1225 (30.7%)	
3	891 (44.7%)	878 (44.1%)	1769 (44.4%)	
Pathologic T stage				0.8128
T0	296 (14.7%)	300 (14.9%)	596 (14.8%)	
T1	299 (14.8%)	301 (14.9%)	600 (14.9%)	
T2	630 (31.3%)	603 (29.9%)	1233 (30.6%)	
T3	755 (37.5%)	768 (38.1%)	1523 (37.8%)	
T4	34 (1.7%)	42 (2.1%)	76 (1.9%)	
Pathologic N stage				0.9783
N0	1389 (71.2%)	1389 (71.2%)	2778 (71.2%)	
N1	427 (21.9%)	430 (22.0%)	857 (22.0%)	
N2	136 (7.0%)	133 (6.8%)	269 (6.9%)	
Pathologic M1	3 (0.1%)	1 (0.0%)	4 (0.1%)	0.6248
Pathologic stage				0.8192
1	811 (45.9%)	778 (44.3%)	1589 (45.1%)	
2	407 (23.0%)	421 (24.0%)	828 (23.5%)	
3	547 (31.0%)	554 (31.6%)	1101 (31.3%)	
4	2 (0.1%)	2 (0.1%)	4 (0.1%)	
Neoadjuvant therapy	1251 (62.2%)	1286 (63.9%)	2537 (63.0%)	0.2814
Adjuvant therapy	100 (5.0%)	102 (5.1%)	202 (5.0%)	0.9425
Surgical approach				
Laparoscopic	1304 (64.7%)	0 (0.0%)	1304 (64.7%)	
Robotic	710 (35.3%)	0 (0.0%)	710 (35.3%)	
Conversion to open	222 (11.0%)	0 (0.0%)	222 (11.0%)	
Inadequate LN harvest	344 (18.2%)	313 (16.6%)	657 (17.4%)	0.2132
Positive distal margin	73 (3.6%)	85 (4.2%)	158 (3.9%)	0.3721
Positive CRM	102 (5.8%)	105 (6.1%)	207 (5.9%)	0.7202
Hospital length of stay (days)	5 (4, 8)	6 (5, 9)	6 (4, 8)	<0.0001
30-day readmission	155 (7.8%)	139 (7.0%)	294 (7.4%)	0.3635
90-day mortality	15 (1.0%)	26 (1.6%)	41 (1.4%)	0.2074
Long-term survival				<0.0001
2 year	92%	91%		
3 year	88%	85%		
5 year	79%	76%		
Follow-up (months)	32.3 (23.1, 45.0)	37.0 (25.0, 51.8)	34.6 (24.1, 48.6)	<0.0001

Data are presented as median (Q1, Q3) or percent (number)

LN lymph node, *CRM* circumferential radial margin

T4 tumors [18–22]. Previous studies utilizing administrative databases to compare surgical approaches to proctectomy have consistently demonstrated improvements in hospital length of stay and perioperative morbidity with laparoscopic approaches [23, 24]. Comparisons between laparoscopic and robotic approaches, including work by Speicher et al., in 2015, have demonstrated similar operative and oncologic outcomes between approaches [25, 26]. These findings are redemonstrated here, with robotic approaches demonstrating improvements in operative and short-term outcomes, although long-term survival does not differ between approaches and these cohorts differed significantly in several important demographics and comorbidities. Although some studies have demonstrated improved CRM clearance, lymph node harvest, and rates of R0 resection with minimally invasive approaches, the impact of surgical procedure on long-term mortality has been inconsistent [24, 27, 28]. Sujatha-Bhaskar et al., in a similar NCDB national analysis, demonstrate superior rates of CRM negativity and improved survival in patients receiving laparoscopic proctectomy

Table 5 Cox proportional hazard model of predictors of overall mortality amongst patients treated at high-volume academic centers

Parameter	Hazard ratio	95% Confidence interval		*p* value
MI-LAR	0.849	0.678	1.063	0.154
Female sex	1.555	1.223	1.976	0.0003
Insured	0.931	0.459	1.888	0.8423
Charlson–Deyo Score 1	1.587	1.233	2.043	0.0003
Charlson–Deyo Score 2	1.723	1.165	2.547	0.0064
Pathological Stage 2	0.059	0.008	0.427	0.0051
Neoadjuvant therapy	0.946	0.734	1.221	0.6706
Adjuvant therapy	1.794	0.995	3.234	0.0519

although the inclusion criteria of this analysis selected for locally advanced disease, with all patients receiving neoadjuvant chemoradiation, surgical resection, and adjuvant therapy. The result of this is a limited population of 6,313 patients and heterogeneity of the specific surgical resection received.

When considering only patients treated at high-volume academic centers, which we considered to be a proxy for high-volume surgeons with skills in advanced laparoscopy or fellowship training, we found that surgical approach did not impact oncologic outcomes or perioperative morbidity and mortality in these centers (Tables 4, 5) [29, 30]. This suggests that improved outcomes may be due to a combination of surgeon volume, patient selection, and the multidisciplinary approach offered at high-volume centers. Taken together, these findings suggest that although MI-LAR is a safe and effective choice of treatment for rectal cancer, these procedures should be done by experienced surgeons on appropriately selected patients and approached in a multidisciplinary fashion at high-volume centers.

Although our findings suggest that MI-LAR is associated with improved oncologic outcomes and survival overall, laparoscopic approaches to advanced cases could be considered a proxy to surgical care in high-volume academic centers with highly trained experts [30]. Our subgroup analysis, considering only operations performed in academic medical centers in the highest tertile of operative volume, found no clinically or statistically significant differences in oncologic outcomes or survival between MI-LAR and OLAR. This highlights that although MI-LAR is safe and effective, with similar outcomes to OLAR, it should be performed on appropriately selected patients by surgeons experienced with advanced laparoscopy in high-volume centers with a robust multidisciplinary approach to cancer care.

Although the NCDB is the single largest clinical cancer database in the nation, and is widely accepted to capture contemporary practice patterns, it is susceptible to miscoding as are all administrative datasets. Additionally, although the NCDB provides several tumor-specific variables not included in other databases its granularity is ultimately more limited than institutional data and as such our ability to assess clinically important variables is limited. These include the specific agents used for neoadjuvant and adjuvant therapy and the completion of that therapy. Additionally, we were unable to determine disease-specific survival using the available data, limiting our ability to discriminate differences in this important outcome. Lastly, it is difficult to directly compare this analysis to RCTs as this is a retrospective and non-randomized analysis and as such is vulnerable to selection bias and unmeasured confounders influencing the surgical approach chosen for a given patient. Despite these limitations our study is the largest to date comparing MI-LAR and OLAR for rectal cancer in terms of pathologic oncologic outcomes and long-term survival. Our findings of improved CRM clearance with MI-LAR strengthen the conclusions drawn from prior RCTs, single institution studies, and smaller database studies and support the continued expansion of MI-LAR.

Conclusions

This study is the largest to date comparing the oncologic efficacy of MI-LAR and OLAR for the treatment of rectal cancer and provides important data on long-term survival with these approaches. MI-LAR is associated with improved short-term outcomes, oncologic outcomes including circumferential radial margin, and long-term survival compared to OLAR. Importantly, until long-term follow-up from ongoing RCTs is available this provides important evidence for the use of MI-LAR due to both pathologic surrogates for oncologic efficacy and improvements in long-term survival. Nonetheless, the decision to perform MI-LAR is dependent upon the skillset of individual surgeons and the characteristics of individual medical centers and should be performed by experienced surgeons in high-volume academic centers.

Table 6 Propensity-matched demographics and outcomes between minimally invasive low anterior resection (MI-LAR) and open LAR (OLAR) excluding T0 and Tis tumors

	MI-LAR ($N=8547$)	Open LAR ($N=8547$)	All patients ($N=17{,}094$)	p value
Patient age group (years)				0.6081
< 65	5060 (59.2%)	4998 (58.5%)	10,058 (58.8%)	
65–80	2796 (32.7%)	2837 (33.2%)	5633 (33.0%)	
> 80	691 (8.1%)	712 (8.3%)	1403 (8.2%)	
Male gender	5280 (61.8%)	5252 (61.4%)	10,532 (61.6%)	0.6711
Race				0.3670
White	7413 (86.7%)	7378 (86.3%)	14,791 (86.5%)	
Black	634 (7.4%)	682 (8.0%)	1316 (7.7%)	
Other	500 (5.9%)	487 (5.7%)	987 (5.8%)	
Insurance status				0.2909
No	254 (3.0%)	279 (3.3%)	533 (3.1%)	
Yes	8293 (97.0%)	8268 (96.7%)	16,561 (96.9%)	
Insurance type				0.4173
Private	4346 (50.8%)	4229 (49.5%)	8575 (50.2%)	
Medicare	3344 (39.1%)	3425 (40.1%)	6769 (39.6%)	
Medicaid	519 (6.1%)	525 (6.1%)	1044 (6.1%)	
Other	84 (1.0%)	89 (1.0%)	173 (1.0%)	
None	254 (3.0%)	279 (3.3%)	533 (3.1%)	
Annual income ≥ $48,000	5169 (60.5%)	5112 (59.8%)	10,281 (60.1%)	0.3817
Higher education	5021 (58.7%)	4892 (57.2%)	9913 (58.0%)	0.0473
Charlson–Deyo score				0.2110
0	6428 (75.2%)	6368 (74.5%)	12,796 (74.9%)	
1	1664 (19.5%)	1672 (19.6%)	3336 (19.5%)	
≥ 2	455 (5.3%)	507 (5.9%)	962 (5.6%)	
Hospital location				0.4299
South	3123 (36.5%)	3142 (36.8%)	6265 (36.7%)	
Midwest	2499 (29.2%)	2406 (28.2%)	4905 (28.7%)	
Northeast	1656 (19.4%)	1693 (19.8%)	3349 (19.6%)	
West	1269 (14.8%)	1306 (8.3%)	2575 (15.1%)	
Hospital type				0.9490
Academic	3178 (37.2%)	3178 (37.2%)	6373 (37.3%)	
Comprehensive community	4866 (56.9%)	4856 (56.8%)	9722 (56.9%)	
Community	503 (5.9%)	496 (5.8%)	999 (5.8%)	
Annual hospital volume (cases)	11 (6, 18)	11 (6, 19)	11 (6, 18)	0.0725
Year of diagnosis				< 0.0001
2010	1027 (12.0%)	1729 (20.2%)	2756 (16.1%)	
2011	1178 (13.8%)	1586 (18.6%)	2764 (16.2%)	
2012	1286 (15.0%)	1511 (17.7%)	2797 (16.4%)	
2013	1513 (17.7%)	1400 (16.4%)	2913 (17.0%)	
2014	1758 (20.6%)	1218 (14.3%)	2976 (17.4%)	
2015	1785 (20.9%)	1103 (12.9%)	2888 (16.9%)	
Tumor size (mm)	35 (21, 50)	35 (22, 50)	35 (22, 50)	0.0727
Clinical T stage				0.5928
T1	1389 (16.3%)	1344 (15.7%)	2733 (16.0%)	
T2	1615 (18.9%)	1673 (19.6%)	3288 (19.2%)	
T3	5216 (61.0%)	5195 (60.8%)	10,411 (60.9%)	
T4	327 (3.8%)	335 (3.9%)	662 (3.9%)	
Clinical N stage				0.1394
N0	5271 (62.6%)	5347 (63.7%)	10,618 (63.2%)	
N1	2542 (30.2%)	2505 (29.8%)	5047 (30.0%)	

Table 6 (continued)

	MI-LAR ($N=8547$)	Open LAR ($N=8547$)	All patients ($N=17{,}094$)	p value
N2	601 (7.1%)	541 (6.4%)	1142 (6.8%)	
High-grade tumor	827 (10.7%)	845 (10.8%)	1672 (10.7%)	0.7561
Clinical stage				0.1644
1	2555 (30.2%)	2561 (30.3%)	5116 (30.3%)	
2	2731 (32.3%)	2831 (33.5%)	5562 (32.9%)	
3	3164 (37.4%)	3058 (36.2%)	6222 (36.8%)	
Pathologic T stage				0.9778
T1	1518 (17.8%)	1513 (17.7%)	3031 (17.7%)	
T2	2926 (34.2%)	2928 (34.3%)	5854 (34.2%)	
T3	3889 (45.4%)	3883 (45.4%)	7772 (45.5%)	
T4	214 (2.5%)	223 (2.6%)	437 (2.6%)	
Pathologic N stage				0.7119
N0	5593 (67.5%)	5654 (68.1%)	11,247 (67.2%)	
N1	1971 (23.8%)	1937 (23.3%)	3908 (23.6%)	
N2	716 (8.6%)	706 (8.5%)	1422 (8.6%)	
Pathologic M1	8 (0.1%)	7 (0.1%)	15 (0.1%)	0.6248
Pathologic stage				0.7884
1	3443 (41.6%)	3393 (41.3%)	6836 (41.4%)	
2	2174 (26.2%)	2193 (26.7%)	4367 (26.5%)	
3	2658 (32.1%)	2631 (32.0%)	5289 (32.0%)	
4	8 (0.1%)	5 (0.1%)	13 (0.1%)	
Neoadjuvant therapy	4748 (55.6%)	4759 (55.7%)	9507 (55.6%)	0.8777
Adjuvant therapy	712 (8.3%)	688 (8.0%)	1400 (8.2%)	0.5212
Surgical approach				
Laparoscopic	6112 (71.5%)	0 (0.0%)	6112 (71.5%)	
Robotic	2435 (28.5%)	0 (0.0%)	2435 (28.5%)	
Conversion to open	1144 (13.4%)	0 (0.0%)	1144 (13.4%)	
Inadequate LN harvest	1747 (21.8%)	1834 (23.0%)	3581 (22.4%)	0.0630
Positive distal margin	354 (4.2%)	449 (5.3%)	803 (4.7%)	0.0006
Positive CRM	453 (6.0%)	521 (7.0%)	974 (6.5%)	0.0118
Hospital length of stay (days)	5 (4, 7)	6 (5, 8)	6 (4, 8)	<0.0001
30-day readmission	610 (7.2%)	560 (6.6%)	1170 (6.9%)	0.1378
90-day mortality	136 (2.0%)	189 (2.6%)	325 (2.3%)	0.0376
Long-term survival				<0.0001
2 year	92%	91%		
3 year	88%	85%		
5 year	78%	74%		
Follow-up (months)	35.7 (24.0, 51.8)	40.4 (26.3, 56.7)	38.0 (25.0, 54.4)	<0.0001

Data are presented as median (Q1, Q3) or percent (number)

LN lymph node, *CRM* circumferential radial margin

Table 7 Demographics and outcomes between laparoscopic low anterior resection (L-LAR) and robotic LAR (R-LAR)

	L-LAR ($N=11,583$)	R-LAR ($N=4423$)	All patients ($N=16,006$)	p value
Patient age group (years)				< 0.0001
< 65	6770 (60.1%)	2793 (64.8%)	9563(61.4%)	
65–80	3499 (31.1%)	1275 (29.6%)	4774 (30.6%)	
> 80	998 (8.9%)	243 (5.6%)	1241 (8.0%)	
Male gender	6922 (59.8%)	2744 (62.0%)	9666 (60.4%)	0.0083
Race				0.7500
White	10,006 (86.4%)	3840 (86.3%)	13,846 (86.5%)	
Black	829 (7.2%)	303 (6.9%)	1132 (7.1%)	
Other	748 (6.5%)	280 (6.3%)	1028 (6.4%)	
Insurance status				0.0080
No	315 (2.7%)	88 (2.0%)	403 (2.5%)	
Yes	11,154 (97.3%)	4287 (98.0%)	15,411 (97.95%)	
Insurance type				< 0.0001
Private	5880 (51.3%)	2414 (55.2%)	8294 (52.3%)	
Medicare	4516 (39.4%)	1538 (35.2%)	6054 (38.2%)	
Medicaid	629 (5.5%)	285 (6.5%)	914 (5.8%)	
Other	129 (110%)	50 (1.1%)	179 (1.1%)	
None	315 (2.7%)	88 (2.0%)	403 (2.5%)	
Annual income ≥ $48,000	7290 (63.1%)	2721 (61.7%)	10,011 (62.7%)	0.0959
Higher education	6913 (59.8%)	2613 (59.2%)	9526 (59.6%)	0.4933
Charlson–Deyo score				0.0009
0	8711 (75.2%)	3427 (77.5%)	12,138 (75.8%)	
1	2213 (19.1%)	802 (18.1%)	3015 (18.8%)	
≥ 2	659 (5.7%)	194 (4.4%)	853 (5.3%)	
Hospital location				< 0.0001
South	3920 (35.2%)	1425 (33.5%)	5345 (34.7%)	
Midwest	2779 (24.9%)	1224 (28.2%)	4003 (26.0%)	
Northeast	2477 (22.2%)	905 (21.3%)	3382 (22.0%)	
West	1975 (17.7%)	695 (16.4%)	2670 (17.3%)	
Hospital type				< 0.0001
Academic	3800 (34.1%)	1840 (43.3%)	5640 (36.6%)	
Comprehensive community	6649 (59.6%)	2277 (53.6%)	8926 (58.0%)	
Community	702 (6.3%)	132 (3.1%)	834 (5.4%)	
Annual hospital volume (cases)	11 (6, 19)	14 (7, 22)	12 (6, 20)	< 0.0001
Year of diagnosis				< 0.0001
2010	1507 (13.0%)	261 (5.9%)	1768 (11.0%)	
2011	1688 (14.6%)	433 (9.8%)	2121 (13.3%)	
2012	1792 (15.5%)	580 (13.1%)	2372 (14.8%)	
2013	2080 (18.0%)	756 (17.1%)	2836 (17.7%)	
2014	2266 (19.6%)	1077 (24.3%)	3343 (20.9%)	
2015	2250 (19.4%)	1316 (29.8%)	3566 (22.3%)	
Tumor size (mm)	34 (20, 50)	35 (22, 50)	35 (20, 50)	0.0128
Clinical T stage				< 0.0001
T1	1672 (19.4%)	454 (12.5%)	2126 (17.3%)	
T2	1757 (20.4%)	653 (18.0%)	2410 (19.7%)	
T3	4926 (57.1%)	2396 (66.0%)	7322 (59.7%)	
T4	275 (3.2%)	129 (3.6%)	404 (3.3%)	
Clinical N stage				< 0.0001
N0	7556 (70.5%)	2555 (61.6%)	10,111 (68.0%)	
N1	2584 (24.1%)	1284 (31.0%)	3868 (26.0%)	

Table 7 (continued)

	L-LAR ($N=11,583$)	R-LAR ($N=4423$)	All patients ($N=16,006$)	p value
N2	585 (5.5%)	308 (7.4%)	893 (6.0%)	
High-grade tumor	1185 (11.2%)	422 (10.87)	1607 (11.1%)	0.3571
Clinical stage				< 0.0001
1	3013 (34.7%)	906 (25.0%)	3919 (31.8%)	
2	2574 (29.6%)	1155 (31.9%)	3729 (30.3%)	
3	3105 (35.7906%)	1557 (43.2%)	4662 (37.9%)	
Pathologic T stage				< 0.0001
T1	2448 (22.4%)	781 (18.7%)	3229 (21.4%)	
T2	3526 (32.2%)	1473 (35.3%)	4999 (33.1%)	
T3	4653 (42.5%)	1840 (44.1%)	6493 (42.9%)	
T4	319 (2.9%)	78 (1.9%)	397 (2.6%)	
Pathologic N stage				0.4303
N0	7273 (67.7%)	2869 (67.7%)	10,142 (67.7%)	
N1	2521 (23.5%)	1019 (24.1%)	3540 (23.6%)	
N2	949 (8.8%)	349 (8.2%)	1298 (8.9%)	
Pathologic M1	12 (0.1%)	4 (0.1%)	16 (0.1%)	1.0000
Pathologic stage				0.5527
1	4615 (43.6%)	1744 (42.4%)	6359 (43.3%)	
2	2566 (24.2%)	1003 (24.4%)	3569 (24.3%)	
3	3391 (32.0%)	1361 (33.1%)	4752 (32.3%)	
4	12 (0.1%)	4 (0.1%)	16 (0.1%)	
Neoadjuvant therapy	4930 (42.7%)	2495 (59.5%)	7425 (46.5%)	< 0.0001
Adjuvant therapy	1119 (9.37)	312 (7.1%)	1431 (9.0%)	< 0.0001
Conversion to open	1696 (14.6%)	355 (8.0%)	2051 (12.8%)	< 0.0001
Inadequate LN harvest	2175 (20.4%)	805 (19.0%)	2980 (20.0%)	0.0537
Positive distal margin	510 (4.4%)	176 (4.0%)	686 (4.3%)	0.2390
Positive CRM	616 (6.1%)	222 (5.8%)	838 (6.0%)	0.4979
Hospital length of stay (days)	5 (4, 7)	5 (4, 7)	5 (4, 7)	< 0.0001
30-day readmission	115 (1.2%)	25 (0.8%)	1120 (7.0%)	0.1764
90-day mortality	212 (2.3%)	45 (1.5%)	257 (2.1%)	0.0055
Long-term survival				< 0.0001
2 year	91%	94%		
3 year	87%	86%		
5 year	78%	78%		
Follow-up (months)	36.1 (23.8, 52.1)	32.4 (22.9, 46.5)	35.1 (23.5, 50.7)	< 0.0001

Data are presented as median (Q1, Q3) or percent (number)

LN lymph Node, *CRM* circumferential radial margin

Compliance with ethical standards

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