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Trends in utilization, conversion rates, and outcomes for minimally invasive approaches to non-metastatic rectal cancer: a national cancer database analysis

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Abstract

Background This study examined utilization and conversion rates for robotic and laparoscopic approaches to non-metastatic rectal cancer. Secondary aims were to examine short- and long-term outcomes of patients who underwent conversion to laparotomy from each approach.

Methods The National Cancer Database (NCDB) was reviewed for all cases of non-metastatic adenocarcinoma of the rectum or rectosigmoid junction who underwent surgical resection from 2010 to 2016. Utilization rates of robotic, laparoscopic, and open approaches were examined. Patients were split into cohorts by approach. Subgroup analyses were performed by primary tumor site and surgical procedure. Multivariable analysis was performed by multivariable logistic regression for binary outcomes and multivariable general linear models for continuous outcomes. Survival analysis was performed by Kaplan–Meier and multivariable cox-proportional hazards regression.

Results From 2010 to 2016, there was a statistically significant increase in utilization of the robotic and laparoscopic approaches over the study period and a statistically significant decrease in utilization of the open approach. The conversion rates for robotic and laparoscopic cohorts were 7.0% and 15.7%, $p < 0.0001$. Subgroup analysis revealed statistically lower conversion rates between robotic and laparoscopic approaches for rectosigmoid and rectal tumors and for LAR and APR. Converted cohorts had statistically significant higher odds of short term mortality than the non-converted cohorts ($p < 0.05$). Laparoscopic conversion had statistically higher odds of positive margins ($p < 0.0001$) and 30-day unplanned readmission ($p < 0.0001$) than the laparoscopic non-conversion. Increased adjusted mortality hazard was seen for converted laparoscopy relative to non-converted laparoscopy ($p = 0.0019$).

Conclusion From 2010 to 2016, there was a significant increase in utilization of minimally invasive approaches to surgical management of non-metastatic rectal cancer. A robotic approach demonstrated decreased conversion rates than a laparoscopic approach at the rectosigmoid junction and rectum and for LAR and APR. Improved outcomes were seen in the minimally invasive cohorts compared to those that converted to laparotomy.

The management of rectal adenocarcinoma is highly individualized, involving various sequences of chemoradiotherapy based both on the initial clinical stage and final pathologic diagnosis [1]. Despite advances in neoadjuvant and adjuvant therapies, curative surgical resection remains the cornerstone of treatment. While the principles of a total mesorectal excision have not changed, evolving minimally invasive

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techniques represent a paradigm shift in the management of this disease.

With regard to such post-operative metrics as analgesia use, length of stay, and return of bowel function, laparoscopic approaches to rectal cancer have clear advantages over traditional laparotomy [2]. However, the technical demands of a laparoscopic pelvic dissection for rectal cancer have been attributed with increased risk of conversion to open [3]. Additionally, technical limitations of limited range of motion, loss of dexterity, and two-dimensional instrument articulations have led to scrutiny of the appropriateness of laparoscopy for the management of rectal cancer in several trials [2, 4–6].

Robot-assisted proctectomy was developed to overcome the technical shortcomings of laparoscopy, while maintaining the benefits of a minimally invasive approach. Benefits offered by the robotic platform include improved ergonomics, three dimensional, high resolution imaging, and fully articulating instruments. Published in 2017, the Robotic Versus Laparoscopic Resection for Rectal Cancer (ROLARR) trial sought to examine the difference in conversion rate between a robotic and a laparoscopic rectal cancer resection [4]. Their study revealed conversion to open rates from robotic and laparoscopic approaches of 8.1% vs 12.2%, respectively [4]. This difference in conversion rates, the authors concluded, was not significant enough to justify its use over laparoscopy in rectal cancer surgery [4].

Despite various conclusions in the literature, the utilization of minimally invasive techniques has continued to increase, and robotic surgery has eclipsed laparoscopy in certain centers [7]. Rate of conversion to laparotomy is often cited as a surrogate for proficiency and open conversions have been shown to have both short and long oncologic implications [8–10]. However, to date no large population study has analyzed how conversion rates have changed as utilization of minimally invasive techniques continue to increase. Moreover, no large population studies have examined short-and long-term oncologic consequences of conversion from a minimally invasive approach to laparotomy. Thus, the primary aim of this study was to examine trends in minimally invasive technique utilization and rates of conversion to open in non-metastatic rectal cancer. Furthermore, this study aimed to investigate potential oncologic consequences in patients who undergo conversion to laparotomy from a robotic or laparoscopic approach.

Materials and methods

This was a retrospective cohort study of clinical data from The National Cancer Database NCDB registry from 2010 to 2016. The NCDB is a clinical oncology database, sourced from hospital registry data collected from over 1500 Commission on Cancer accredited facilities across the United States. The NCDB contains de-identified data, and therefore this study was deemed exempt by our institutional review board. No written consent was required. The NCDB Rectum Participant User File (PUF) was reviewed for patients diagnosed with invasive adenocarcinoma, identified using histology ICDO-3 code 8140/3, who underwent partial or total proctectomy (Procedural Codes 30 and 50, respectively), which included low anterior resection and abdominoperineal resection. The database began collecting data for surgical approach in 2010, and thus diagnoses prior to 2010 and those with an open or missing surgical approach data were excluded. Patients with Stage IV disease were excluded as were cases without valid staging, treatment, or follow-up data (Fig. 1).

Baseline demographics and clinicopathologic characteristics included age, sex, Charlson score, year of diagnosis, insurance, high school degree %, median income, facility type, clinical stage, systemic chemotherapy surgery sequence, and systemic radiation therapy surgery sequence. Outcomes assessed in univariate and multivariate analyses were number of regional nodes examined, positive margins, negative circumferential margin, 30-day unplanned readmission, 30-and 90-day mortality, and days to receipt of chemotherapy in those who received adjuvant chemotherapy. Baseline demographics, clinicopathologic characteristics, and unadjusted outcomes were compared by way of Chi-square or Fisher's exact test for adequate cell count categorical variables and low cell count categorical variables ($>25\%$ of expected cell counts <5), respectively. Independent samples *t*-test was used for parametric continuous variable comparisons and Mann–Whitney U test was used for nonparametric continuous variable comparisons. Variables with corresponding univariate p value <0.2 were entered into multivariable models and adjusted for as potential confounding covariates following a backward stepwise selection procedure with stay criteria $\alpha=0.1$. Covariates for adjustment included age, sex, race, primary site, procedure, Charlson score, insurance, facility type, clinical stage, systemic chemotherapy surgery sequence, and systemic radiation therapy surgery sequence. Multivariable logistic regression was used for categorical outcomes and natural logarithm (ln) transformed multivariable general linear models were used for positively skewed continuous outcomes. Survival analysis was performed using Kaplan–Meier estimation with corresponding Log-Rank at the univariate level, followed by multivariable Cox-proportional hazards regression. Analysis of multicollinearity in multivariable models was performed by way of a variance inflation factor analysis (VIF) with VIF <2 considered acceptable.

All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC) and two-sided p value less than 0.05 was considered statistically significant. The NCDB

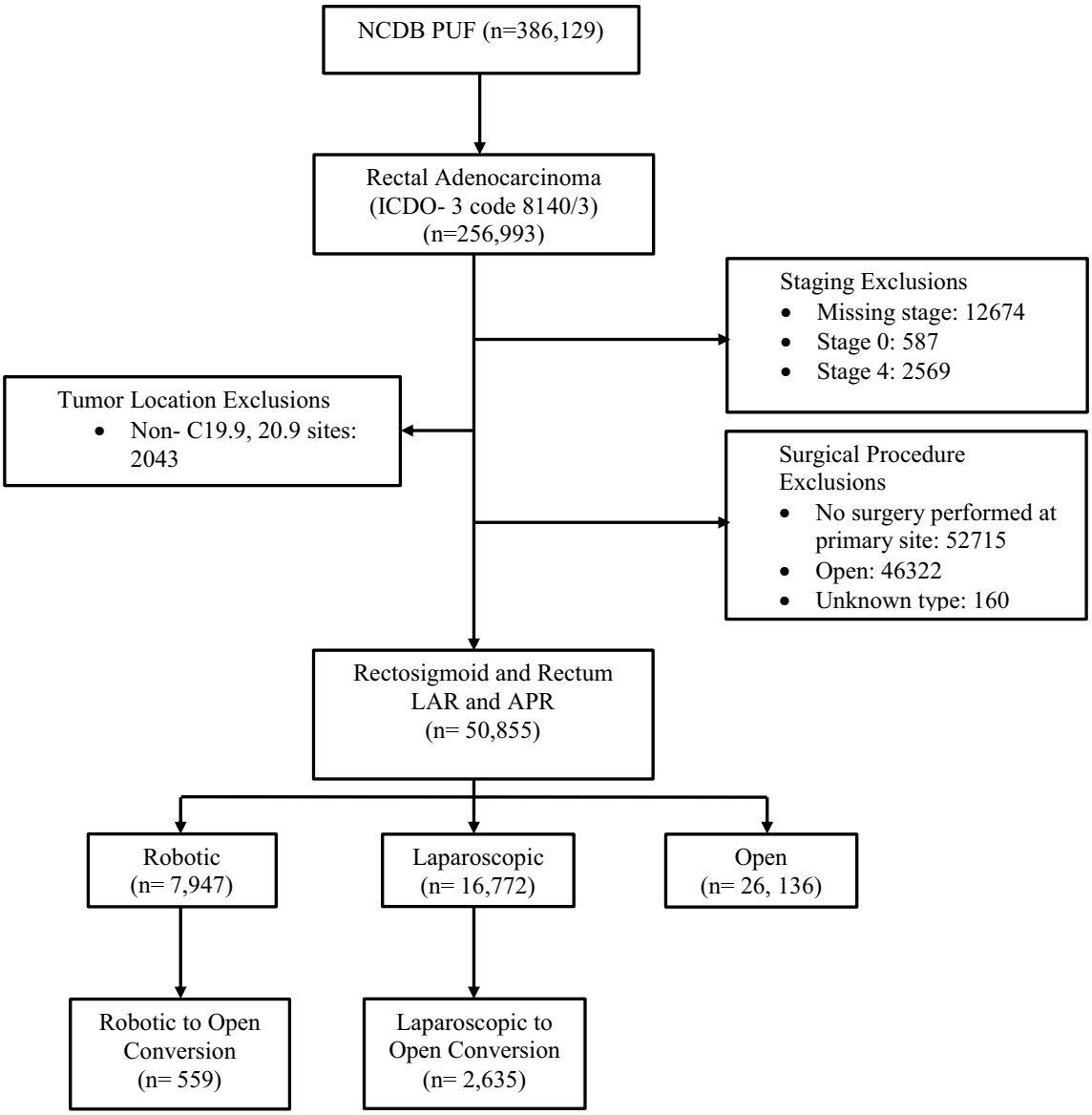

Fig. 1 Patient flow diagram

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 were 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 authors.

Results

For patients diagnosed with rectal adenocarcinoma between 2010 and 2016, 7947 patients underwent a robotic approach, 16,772 patients underwent a laparoscopic approach, and 26,136 patients underwent an open approach. The utilization of robotic and laparoscopic approaches significantly increased while the utilization of an open approach significantly decreased over the duration of the study ($p < 0.0001$; Fig. 2). Among the patients who underwent a minimally invasive approach, no statistically significant staging differences existed between the robotic and laparoscopic cohort, nor were there any differences in income or education. Relative to laparoscopic approach, robotic approach was significantly associated with a lower proportion of females, black patients, lower Charlson scores, and a higher proportion of private insurance, academic facility type, receipt of radiation therapy and chemotherapy (all respective $p < 0.05$; Table 1).

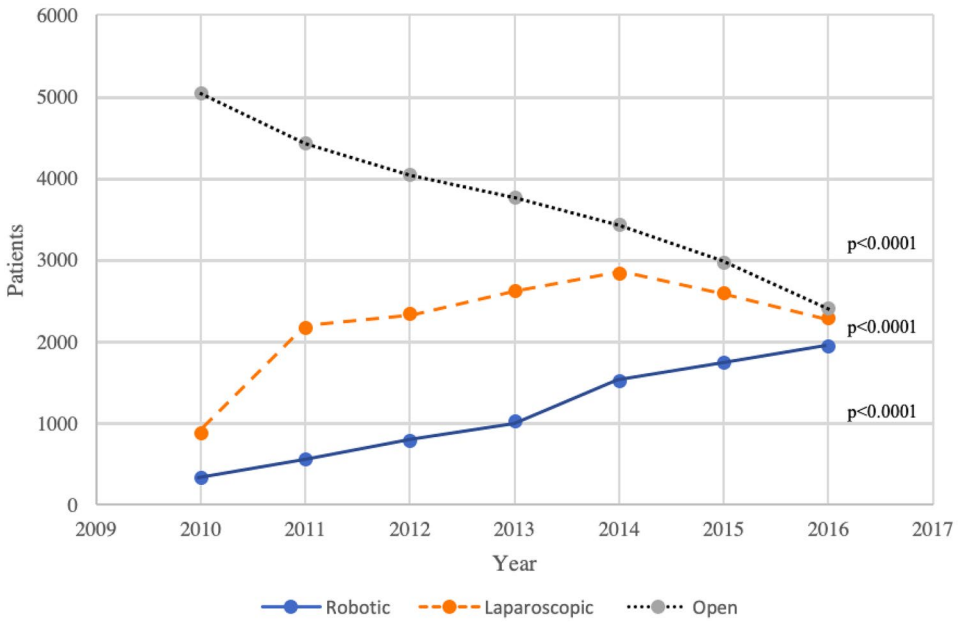

Fig. 2 Utilization of surgical procedure in rectal adenocarcinoma from 2010 to 2016

In the majority of patients in the robotic and laparoscopic groups, primary tumor site was classified C20.9 ("rectum"). Primary tumor site was less frequently classified as C19.9 ("rectosigmoid") in the robotic cohort than the laparoscopic cohort (14.2% vs 25.2%, $p < 0.0001$). In both groups, the procedure was classified as NCDB Procedure Code 30 (partial proctectomy, low anterior resection [LAR]) more frequently than Procedure Code 50 (total proctectomy, abdominal perineal resection [APR]). The approach was more frequently classified as APR in the robotic group than the laparoscopic group (22.0% vs 16.8%, $p < 0.0001$) (Table 1).

The difference in rates of conversion to laparotomy between robotic and laparoscopic approaches was statistically significant (7.0% vs 15.7%, $p < 0.0001$; Fig. 4). The trends in conversion rates for each approach are seen in Fig. 3. The robotic conversion to open rate did not significantly change over time ($p = 0.4599$), however, the laparoscopic conversion to open rate throughout the years significantly decreased ($p < 0.0001$).

Separate conversion subgroup analyses were performed for each approach with regard to primary tumor site and procedure. There were fewer conversions from a robotic approach than a laparoscopic approach at the rectosigmoid (6.2% vs 13.2%, $p < 0.0001$) and at the rectum (6.1% vs 12.7%, $p < 0.0001$; Fig. 4). Additionally, there were fewer conversions from a robotic approach than a laparoscopic approach for LAR (7.2% vs 14.9%, $p < 0.0001$) and APR (6.3% vs 17.0%, $p < 0.0001$; Fig. 4).

Univariate analysis for binary outcomes between robotic, robotic converted, laparoscopic, and laparoscopic converted approaches prior to adjusting for potential confounding covariates is seen in Table 2. Subsequent multivariable analysis showed that robotic conversion was significantly associated with increased adjusted odds of 30-day mortality ($p = 0.0288$) and 90-day mortality ($p = 0.0046$) compared to the non-converted robotic group. No difference was seen in regional nodes examined, positive margins, negative circumferential resection margins, or unplanned readmission between the robotic conversion and robotic cohorts (Table 3). In those who received adjuvant chemotherapy, no difference was seen in days from surgery to receipt of chemotherapy between the non-converted robotic and converted robotic cohort ($p = 0.1337$; Tables 4, 5).

Relative to the non-converted laparoscopic group, laparoscopic conversion was significantly associated with increased adjusted odds of 12 or more regional lymph nodes examined ($p = 0.0013$), positive margins ($p < 0.0001$), 30-day unplanned readmission ($p < 0.0001$), and 90-day mortality ($p < 0.0222$; Table 3). Increased adjusted odds of 30-day mortality trended towards significance ($p = 0.0582$) and no difference was detected in negative circumferential resection margins ($p = 0.5096$). In those who received adjuvant chemotherapy, those who received laparoscopic conversion had $6.0\% \pm 2.7\%$ longer time from surgery to chemotherapy relative to those who received non-converted laparoscopy (reverse transformed mean $\pm$ standard error; $p = 0.0306$; Tables 4, 5).

No significant differences in adjusted odds of 12 or more nodes examined, negative circumferential margin, 30-day unplanned readmission, 30-day mortality, or 90-day mortality were detected between the converted robotic and converted laparoscopic cohorts. A trend-level significant observation with a clinically relevant effect size was observed to show decreased adjusted odds of positive margin status in

Table 1 Demographics and clinicopathologic characteristics of the minimally invasive surgical approaches to rectal adenocarcinoma from 2010 to 2016

Variable	Robotic ($n=7947$)	Laparoscopic ($n=16,772$)	p value
Age	60.3 ± 12.4	61.6 ± 12.9	< 0.0001
Sex (Female)	2907 (36.6%)	6757 (40.3%)	< 0.0001
Clinical stage			0.2453
I	2501 (31.5%)	5452 (32.5%)	
II	2404 (30.3%)	5034 (30.0%)	
III	3042 (38.3%)	6286 (37.5%)	
Race			0.0362
White	6843 (86.1%)	14,330 (85.4%)	
Black	541 (6.8%)	1311 (7.8%)	
Other	503 (6.3%)	1009 (6.0%)	
Unknown	60 (0.8%)	122 (0.7%)	
Charlson score			0.0008
0	6147 (77.4%)	12,596 (75.1%)	
1	1371 (17.3%)	3134 (18.7%)	
2	295 (3.7%)	744 (4.4%)	
3+	134 (1.7%)	298 (1.8%)	
Radiation (yes)	6008 (75.6%)	10,483 (62.5%)	< 0.0001
Chemotherapy (yes)	6476 (81.5%)	11,927 (71.1%)	< 0.0001
Primary site			< 0.0001
Rectosigmoid	1129 (14.2%)	4233 (25.2%)	
Rectum	6818 (85.8%)	12,539 (74.8%)	
Procedure			< 0.0001
LAR	5369 (78.0%)	11,918 (84.2%)	
APR	1513 (22.0%)	2236 (16.8%)	
Year of diagnosis			< 0.0001
2010	344 (4.3%)	1889 (11.3%)	
2011	565 (7.1%)	2172 (13.0%)	
2012	789 (9.9%)	2350 (14.0%)	
2013	1028 (12.9%)	2629 (15.7%)	
2014	1522 (19.2%)	2840 (16.9%)	
2015	1755 (22.1%)	2598 (15.5%)	
2016	1944 (24.5%)	2294 (13.7%)	
Insurance			< 0.0001
Not insured	173 (2.2%)	578 (3.5%)	
Private	4289 (54.0%)	8310 (49.6%)	
Medicaid	571 (7.2%)	1107 (6.6%)	
Medicare	2741 (34.5%)	6410 (38.2%)	
Other government	86 (1.1%)	195 (1.2%)	
Unknown	87 (1.1%)	172 (1.0%)	
Median income ($)			0.6545
< 38 k	1218 (15.3%)	2519 (15.0%)	
38–48 k	1776 (22.4%)	3807 (22.7%)	
48–63 k	2108 (26.5%)	4412 (26.3%)	
63 k+	2824 (35.5%)	6003 (35.8%)	
Unknown	21 (0.3%)	31 (0.2%)	
% no HS degree			0.1036
21% or more	1197 (15.1%)	2739 (16.3%)	
13–21%	2002 (25.2%)	4129 (24.6%)	
7–13%	2612 (32.9%)	5535 (33.0%)	
< 7%	2123 (26.7%)	4345 (25.9%)	
Unknown	13 (0.2%)	24 (0.1%)	

Table 1 (continued)

Variable	Robotic ($n=7947$)	Laparoscopic ($n=16,772$)	p value
Facility type			<0.0001
CCP	241 (3.0%)	945 (5.6%)	
Comprehensive CCP	2933 (36.9%)	7100 (42.3%)	
Academic program	3157 (39.7%)	5798 (34.6%)	
Integrated network	1279 (16.1%)	2258 (13.5%)	
Unknown	337 (4.2%)	671 (4.0%)	
Systemic surgery sequence			<0.0001
None	1448 (18.2%)	4741 (28.3%)	
Before	3607 (45.4%)	5770 (34.4%)	
After	802 (10.1%)	2714 (16.2%)	
Before and after	2061 (25.9%)	3435 (20.5%)	
Intraoperative	7 (0.1%)	5 (<0.1%)	
Unknown	22 (0.3%)	107 (0.6%)	
Radiology surgery sequence			<0.0001
None	1914 (24.1%)	6205 (37.0%)	
Before	5531 (69.6%)	9068 (54.1%)	
After	448 (5.6%)	1357 (8.1%)	
Before and after	27 (0.3%)	52 (0.3%)	
Intraoperative	2 (<0.1%)	6 (<0.1%)	
Unknown	25 (0.3%)	84 (0.5%)	

Reported as *n* (%)

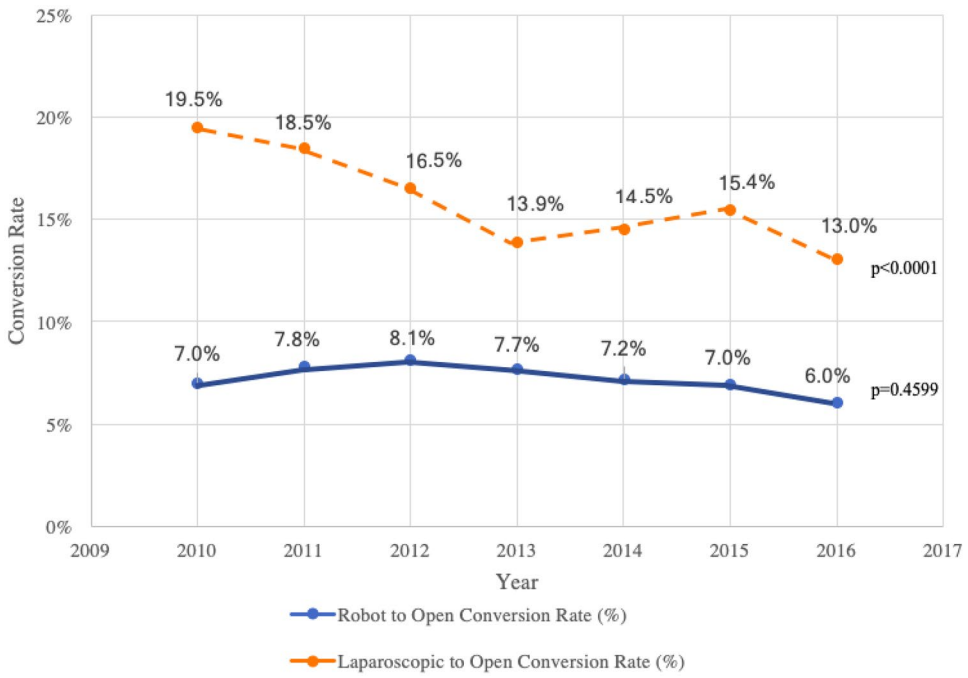

Fig. 3 Rates of conversion to open by surgical procedure from 2010 to 2016

those who underwent robotic conversion relative to those who underwent laparoscopic conversion ($p<0.1$; Table 3).

Kaplan Meier estimation illustrates survival in Fig. 5. Five-year overall survival for the non-converted robotic, converted robotic, non-converted laparoscopic, converted laparoscopic, and open cohorts were 74.1%, 67.7%, 73.6%, 69.7%, and 67.4%, respectively. Multivariable Cox-proportional hazards regression further elucidated increased adjusted mortality hazard for converted laparoscopy relative to non-converted laparoscopy ($p=0.0019$). No difference in

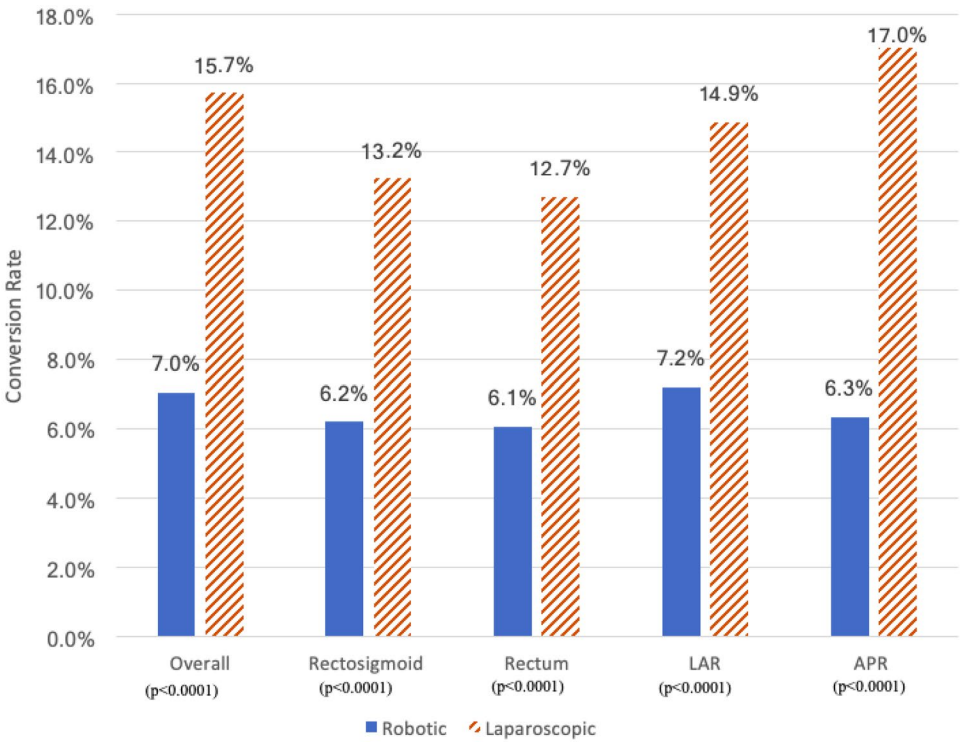

Fig. 4 Conversion rates: overall, tumor site, and procedure

Table 2 Univariable outcome summary statistics by treatment approach

Variable	Robotic not converted ($n=7388$)	Robotic conversion to open ($n=559$)	Laparoscopic not converted ($n=14{,}137$)	Laparoscopic conversion to open ($n=2635$)
12 + regional nodes examined	5629 (76.2%)	424 (75.9%)	10,408 (73.6%)	2018 (76.6%)
Positive margins	312 (4.2%)	29 (5.2%)	664 (4.7%)	191 (7.3%)
Negative circumferential resection margin	6119 (82.8%)	456 (81.6%)	1151 (81.7%)	2141 (81.3%)
30-day unplanned readmission	533 (7.2%)	51 (9.1%)	872 (6.2%)	233 (8.8%)
30-day mortality	36 (0.5%)	7 (1.3%)	126 (0.9%)	37 (1.4%)
90-day mortality	72 (1.0%)	13 (2.3%)	250 (1.8%)	69 (2.6%)

Reported as *n* (%)

adjusted mortality hazard was detected between converted and non-converted robotic cohorts or converted laparoscopy and converted robotic cohorts (Table 6).

Discussion

To date, ROLARR represents the largest randomized controlled trial on robotic surgery, and is therefore considered the strongest available evidence on the platform. Despite the authors' conclusions, many surgeons feel that a robotic approach for rectal cancer is oncologically safe and subsequent analyses have found lower conversion rates than seen in ROLARR [11]. The present study found both a lower rate of robotic to open conversions and higher rate laparoscopic to open conversions than in ROLARR. Likewise, Crippa et al. conducted a retrospective analysis of 600 patients undergoing laparoscopic and robotic rectal cancer surgery and found that robotic surgery was associated with a statistically significant reduction risk of conversion (5.0% vs 13.8%) [12]. A recent systematic review and meta-analysis of 681 patients across 12 countries demonstrated a significant difference in risk of intraoperative conversion to open surgery between robotic and laparoscopic surgery, with the risk begin lower in the robotic cohort [11]. These results were unchanged after removing the study of lowest quality in the sensitivity analysis.

Several explanations exist as to why these subsequent analyses have generated conclusions counter to ROLARR. Among the limitations stated by the authors of ROLAAR,

Table 3 Multivariable analysis: outcomes by treatment approach

Outcome	Robotic conversion to open vs robotic aOR (95% CI)	*p* value	Laparoscopic conversion to open vs laparoscopic aOR (95% CI)	*p* value	Robotic conversion to open vs lap. conversion to open aOR (95% CI)	*p* value
12 + regional nodes examined	1.02 (0.83–1.26)	0.8306	1.18 (1.07–1.30)	0.0013	1.08 (0.86–1.35)	0.5035
Positive margins	1.20 (0.81–1.78)	0.3752	1.52 (1.29–1.80)	< 0.0001	0.71 (0.47–1.07)	0.0997
Negative circumferential resection margin	0.90 (0.72–1.12)	0.3372	0.96 (0.87–1.07)	0.5096	1.02 (0.80–1.30)	0.8797
30-day unplanned readmission	1.25 (0.92–1.69)	0.1524	1.45 (1.25–1.69)	< 0.0001	1.03 (0.75–1.42)	0.8360
30-day mortality	2.53 (1.10–5.82)	0.0288	1.45 (0.99–2.11)	0.0582	1.27 (0.55–2.94)	0.5816
90-day mortality	2.43 (1.32–4.50)	0.0046	1.39 (1.05–1.84)	0.0222	1.18 (0.63–2.22)	0.6034

aOR adjusted odds ratio, *CI* confidence interval, *Lap* laparoscopic

Table 4 Days from surgery to receipt of adjuvant chemotherapy

Days from surgery to chemotherapy	Robotic not converted ($n = 586$)	Robotic conversion to open ($n = 64$)	Laparoscopic not converted ($n = 1997$)	Laparoscopic conversion to open ($n = 404$)
Median (range)	47 (0, 498)	49 (18, 631)	46 (0, 1024)	48 (6, 221)

is that "operations in that trial were performed, on average, by a surgeon considered to be an expert in conventional laparoscopic surgery and who may still have been in their learning phase for robotic surgery" [4], potentially producing falsely lower laparoscopic conversion rates and falsely higher robotic conversion rates than are seen among the surgical population as a whole. While their sensitivity analysis does address this discrepancy, a trial that included 40 surgeons considered expert in laparoscopy raises the question of generalizability of their results.

This analysis observed a significant increase in utilization of the laparoscopic approach over time and that the laparoscopic conversion rate statistically decreased over the from 2010 to 2016 (19.5% vs 13%, $p < 0.0001$) (Fig. 3). This has been observed in the literature as well. In the 2005 landmark CLASICC trial, the conversion rate was noted to be 34% [3] much higher than in the subsequent ROLARR trial (12.2%) [4], and this analysis (15.7%). A unique strength of this analysis is that we observed this trend within a single study, which has yet to be described. These findings contribute to the existing literature by suggesting that, as utilization of laparoscopy increases during residency and fellowship training and independent practice, improvement in skill and experience with these approaches are potentially translating to a decreasing laparoscopic conversion rates over time.

While the utilization of robotics also significantly increased and the conversion rate was lower in 2016 than 2010 (7.0% vs. 6.0%), the observable change was not statistically significant. Like the surgeons in ROLAAR, those who contributed to NCDB may have also still been in the learning phase for robotic surgery from 2011 to 2014. However, in the subsequent years, the conversion rate appeared to plateau, despite rapidly rising robotic utilization. Two explanations may account for the discrepancy between conversion trends between the laparoscopic and robotic approaches. The first is the different learning curves associated with these two approaches for rectal cancer resections. Jiménez-Rodríguez et al. conducted a systematic review of the literature and sought to investigate the learning curve in robotic rectal cancer resections compared to laparoscopy [13]. Their analysis found that most published studies observe a shorter learning curve for robotic resections versus laparoscopic resections, citing studies which determined the learning curve for robotics to be 15–35 cases, significantly lower than the 30–70 surgeries cited for a laparoscopic approach [14–18]. Thus,

Table 5 Days from surgery to receipt of adjuvant chemotherapy (multivariable/adjusted)

Days from surgery to chemotherapy	Adjusted ln[β (SE)]	*p* value
Robotic conversion to open vs robotic	0.1054 (0.0703)	0.1337
Laparoscopic conversion to open vs laparoscopic	0.0580 (0.0268)	0.0306
Robotic conversion vs laparoscopic conversion	0.0721 (0.0635)	0.2567

Ln natural logarithm transformed, *β* parameter estimate, *SE* standard error

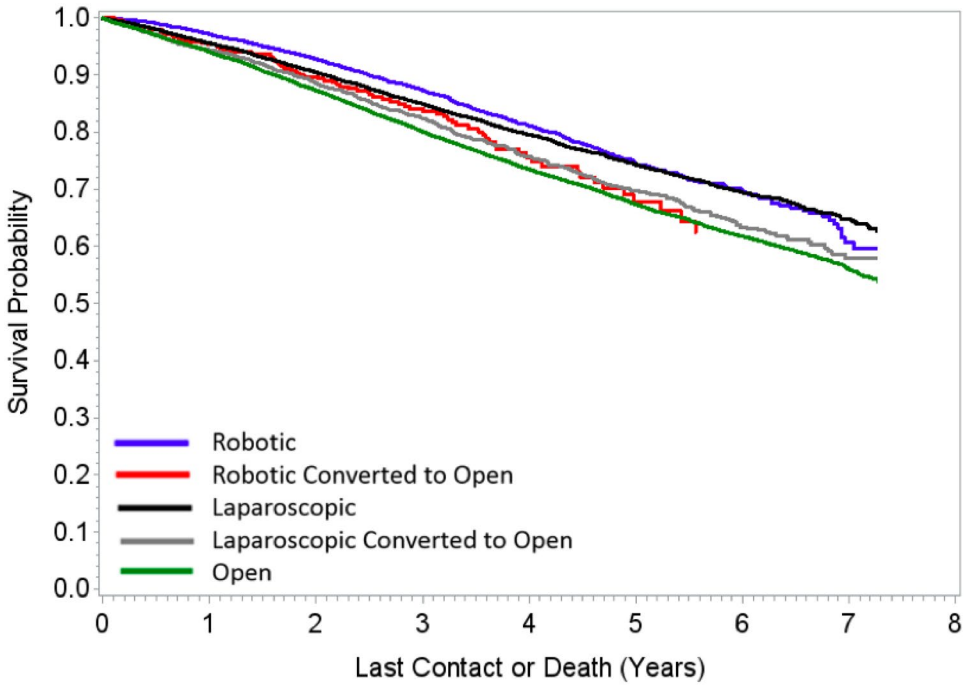

Fig. 5 Kaplan–Meier survival analysis

Table 6 Multivariable survival analysis: adjusted cox-proportional hazards regression

Approach	aHR (95% CI)	*p* value
Laparoscopic conversion to open vs laparoscopic	1.16 (1.06–1.27)	0.0019
Robotic conversion to open vs robotic	1.21 (0.96–1.52)	0.1086
Laparoscopic conversion to open vs robotic conversion to open	0.99 (0.78–1.25)	0.9087

aHR adjusted hazards ratio, *CI* confidence interval

the shorter learning curve seen in robotics may translate to lower conversion rates early in the learning phase which subsequently remain stable over time [19]. Another explanation is simply that, as the conversion rate started low (7%), there may not reasonably be more room for significant improvement below this rate.

While conversion in NCDB is a binary variable, the circumstances behind conversion are often multifactorial and can involve patient, surgeon, and tumor-related factors. One limitation to the NCDB is the lack of details on the reason for and timing of conversion to laparotomy. In their series, Crippa et al. noted that poor vision, adhesions, and intra-abdominal obesity were the main reasons for conversion from laparoscopy, but not from robotic [12]. Additionally, they concluded that the reduction in risk of conversion between robotic and laparoscopic approaches was conserved in both obese and non-obese patients [12]. However, the authors did note that bleeding complications accounted for a quarter of the robotic conversions. Factors such as working on a distant console and a time-consuming undocking process likely affected these surgeons' decision to convert from a robotic approach to laparotomy [12]. Similarly, Bhama et al. found that risk factors for laparoscopic colorectal resection included obesity, moderate adhesions, and severe adhesions [20]. Of these three risk factors, only severe adhesions were a risk factor for conversion with the robotic approach [20]. Thus, while our data demonstrates that overall conversion rates differ between approaches, published literature highlights unique challenges with regard to the decision to convert to laparotomy from either a robotic or laparoscopic approach.

The secondary objective of this analysis was to examine the consequences of conversion to open both in terms of short-term oncologic measures and in survival. Though our analysis showed that a robotic converted to open approach was significantly associated with increased adjusted odds of 30-day mortality ($p = 0.0288$) and 90-day mortality ($p = 0.0046$) compared to the robotic non-converted group, this did not translate to statistically significant differences in 5-year survival between the two groups (aHR [95% CI] 1.21 [0.96–1.52], 0.1086). However, significant differences in both short- and long-term outcomes were seen between the laparoscopic and laparoscopic converted groups. While laparoscopic conversion to open was significantly associated

with increased adjusted odds of 12 or more regional lymph nodes examine ($p=0.0013$), conversion was associated with increased odds of positive margins ($p<0.0001$), 30-day unplanned readmission ($p<0.0001$), and 90-day mortality ($p<0.0222$). In those who received adjuvant chemotherapy, days from surgery to receipt of adjuvant chemotherapy also statistically different in multivariable analysis ($p=0.0306$). Furthermore, multivariable cox-proportional hazards regression revealed increased adjusted mortality hazard for converted laparoscopy relative to non-converted laparoscopy ($p=0.0019$) but not for converted robotic relative to non-converted robotic ($p=0.1086$).

Allaix et al. conducted a MEDLINE search of currently available evidence on the impact of conversion in rectal cancer on both short-term outcomes and long-term survival. They found that the results after conversion from laparoscopy were less favorable than those achieved by than in the laparoscopic non-converted patients, observing both lower OS and DFS in the case of conversion in laparoscopic rectal cancer [21]. In our analysis, we observed significant differences in number of lymph nodes examined and positive margins between the laparoscopic converted and non-converted groups, but not between the robotic converted and non-converted groups, potentially impacting OS and DFS. Majbar et al. observed that conversion to laparotomy in patients undergoing rectal resection was associated with higher rates of postoperative complications, anastomotic leaks, and reoperations. Conversion was also an independent predictive factor to postoperative morbidity in their multivariate analysis.[22]. Thus, the long-term effects of conversion in these patients are likely multifactorial, related to tumor status, postoperative complication rate, and potentially the inflammatory response incited by conversion to laparotomy [23].

Kim et al. conducted an analysis to evaluate how the timing of open conversion influences short-term and oncologic outcomes after minimally invasive surgery for colorectal cancer. In their study, patients were classified into early (within 60 min of procedure start) or late (after 60 min) conversion groups. Between the early conversion and non-conversion groups, mean operative time was longer in the early conversion group, but rates of 30-day postoperative complications, time to soft diet, and hospital stay were not different statistically different. However, between the late conversion and non-converted groups, rates of 30-day postoperative complications, intensive care unit care and transfusion were significantly higher in the late conversion group. Additionally, time to soft diet and hospital stay were longer in the late conversion group compared to non-converted. Ultimately, recurrence-free and cancer-specific survival rates did not differ among the early, late conversion, and non-converted groups [24]. While our analysis could not examine the timing of conversion, this would have been helpful in identifying risks associated with post-operative outcomes in these patients, as data suggests that open conversion within 60 min of the beginning of surgery may not worsen short-term and oncologic outcomes.

Numerous limitations exist in this study. Common to all retrospective reviews, this study is prone to selection bias, with surgeons' potential selection patients with more favorable BMI, tumor characteristics, or less extensive history of abdominal surgery, ultimately affecting the decision of surgical approach and threshold for conversion. While the NCDB offers the Charlson score, which is comparable to the American Society of Anesthesiologists (ASA) score, it offers no data with regard to BMI, prior abdominal surgeries, nutritional markers, specific tumor height etc. Mentioned earlier, the NCDB does not offer details on reason or timing for conversion, which as discussed, have major implications on the reason for conversion and potentially differences in outcomes between groups. Wide variation in surgeon experience with the various approaches likely existed, with no means in NCDB to control for years of experience or duration from residency or fellowship training. While this adds skill level heterogeneity to each sample, lack of descriptors prevented us from performing a skill-based sensitivity analysis between groups. Regarding the analysis of time to adjuvant chemotherapy, only those who were coded as receiving adjuvant therapy were included in this specific analysis, regardless of tumor status, node status, or post-operative mortality. Thus, those who qualified for adjuvant therapy but experienced complications that may have resulted in forgoing therapy were excluded in the analysis, introducing some error in this metric.

Additionally, the issue of power must be discussed as the low rates of robotic and laparoscopic conversion significantly reduce our sample sizes, and in turn our power, when we analyze conversions. This lends itself to increased probability of type II error, or false non-inferiority. For example, the trend-level significant ($p<0.1$) difference between positive margins between converted robotic and converted laparoscopic cases would require sample sizes of 1311 robotic conversions and 6185 laparoscopic conversions to detect our observed effect size as statistically significant at $p<0.05$ ($\alpha=0.05$) with minimum adequate power of 80%. This is roughly 2.5 times the conversion cases that our sample provides us. We have additionally weighed the observed adjusted effect sizes (aORs, aHRs, etc.) with our observed conclusions of statistical significance. Although, per the example, every comparison in our study is not adequately powered, we are observing clinically negligible effect sizes associated with non-significant p values for all comparisons other than trend-level significant findings. Because of this, once more years of data accrue, similar comparisons with higher power are warranted for triangulation of conclusions. Finally, certain outcomes such as disease-free survival and

recurrence rates are absent from NCDB which could aid in the overall oncologic assessment of these patients.

This analysis of a large, national oncology database demonstrated that the utilization of minimally invasive approaches to rectal adenocarcinoma are increasing while rates open approach utilization and rates of conversion to laparotomy are decreasing. Additionally, a robotic approach was associated with significantly less conversions at the rectosigmoid junction and rectum and for LAR and APR. Moreover, we identified a statistically significant mortality hazard associated with laparoscopic conversion that was not seen in the robotic group. Ultimately, these factors should be considered when deciding on a minimally invasive strategy for resection of rectal adenocarcinoma.

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Compliance with ethical standards

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