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ORIGINAL RESEARCH

# Impact of BMI on Adverse Events After Laparoscopic and Open Surgery for Rectal Cancer

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## Abstract

**Purpose** The impact of body mass index (BMI) on outcomes after open or laparoscopic surgery for rectal cancer remains unclear. The objective of this retrospective cohort study was to examine the interaction of body mass index and surgical modality (i.e., laparoscopy versus open) with respect to short-term clinical outcomes in patients with rectal cancer.

**Methods** The ACS-NSQIP database (2012–2016) was reviewed for patients undergoing open or laparoscopic surgery for rectal cancer. The primary outcome was 30-day all-cause morbidity. Logistic regression and Cox proportional hazard models were used for analysis.

**Results** A total of 16,145 patients were grouped into open ($N = 6759$, 42%) and laparoscopic ($N = 9386$, 58%) cohorts. Patients with higher BMI ($p < 0.001$) and those undergoing open surgery ($p < 0.001$) were at increased risk of all-cause morbidity. There was no significant change in the odds ratio of experiencing all-cause morbidity between open and laparoscopic surgery with increasing BMI ($p = 0.572$). Median length of stay was significantly shorter in the laparoscopy group (4 days vs. 6 days; $p < 0.001$), at the cost of increased operative time (239 min vs. 210 min, $p < 0.001$). The difference in operative time between laparoscopy and open surgery did not increase with rising BMI (i.e., Δ37 min vs. Δ39 min at BMI 25 kg/m$^2$ vs 50 kg/m$^2$, respectively, $p = 0.491$).

**Conclusion** BMI may not be a strong modifier for surgical approach with respect to short-term clinical outcomes in patients with obesity and rectal cancer. Laparoscopic surgery was associated with improved short-term clinical outcomes, without much change in the absolute difference in operative time compared with open surgery, even at higher BMIs.


**Keywords** Adverse events · Body mass index · Laparoscopy · Laparotomy · Rectal cancer

## Introduction

Colorectal cancer (CRC) is the third most common malignancy in the world [1]. Carcinomas of the rectosigmoid colon and rectum comprise of approximately 40–45% of all CRC cases [1]. These cancers pose a unique challenge to the surgeon, in part due to their location in the bony confines of the pelvis—an even greater predicament in patients with significant intra-abdominal obesity [2]. Worldwide obesity has tripled in the last four decades [3]. This trend in the prevalence of obesity, a known risk factor for CRC, demands greater study of the interaction of body mass index (BMI) and surgical modality.

Obesity increases the complexity of both open and laparoscopic surgery, and has been associated with increased conversion rates, length of stay (LOS) and overall morbidity including wound infections, respiratory complications, and anastomotic leaks [4]. Additionally, there are several studies comparing open and laparoscopic resections for rectal cancer [5–10]. Recent evidence favors laparoscopy with respect to short-term post-operative outcomes including wound infections, blood loss, time to return of bowel function, time to resumption of oral diet, opioid use, and LOS [5–9]. A recent systematic review and

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meta-analysis of five prospective randomized studies also found comparable pathologic outcomes including complete mesorectal excision, nodal harvest, and distal margin distance between open and laparoscopic rectal resections [10]. While the authors did not identify any significant differences in intra-operative blood loss, LOS, or complication rates, these data were not highlighted in their manuscript in keeping with their primary objective of examining pathologic outcomes of rectal cancer surgery [10]. Both laparoscopy and open surgery are currently thought to offer similar rates of locoregional recurrence and disease-free and overall survival in patients with rectal cancer [6–9]. Despite the abovementioned studies, there is a lack of robust evidence on the interaction between BMI and surgical modality; it is unclear whether body mass index modifies the effect of surgical modality on post-operative outcomes in patients with rectal cancer.

We aimed to assess the interaction of BMI and surgical modality (i.e., open versus laparoscopic surgery) with respect to short-term clinical outcomes in patients with rectal cancer. We hypothesized that BMI does not impact the relative reduction of all-cause morbidity in laparoscopic surgery for rectal cancer compared to open surgery.

## Methods

### Data Source

A multi-institutional retrospective cohort analysis was conducted using the American College of Surgeons' (ACS) National Surgical Quality Improvement Program (NSQIP) Participant Use File (PUF) and colectomy-targeted dataset between 2012 and 2016 (4-year period during which the proctectomy targeted dataset was not published). The NSQIP PUF reports on surgical outcomes from 680 participating hospitals across North America. The dataset provides de-identified data on demographic characteristics, perioperative variables, and post-operative 30-day outcomes for patients undergoing major surgery at participating institutions. Clinical and investigative parameters were prepared in consistency with the STROBE statement [11].

### Patient Selection

All adult (> 18 years) patients undergoing surgical resection of malignant neoplasms of the rectosigmoid or rectum were included based on the following International Classification of Diseases (ICD) codes 154.0, 154.1, 154.8, C19, and C20. Further selection was based on the principal operation performed via the following Current Procedural Terminology (CPT) codes 45395, 44207, 44208, 45110, 44145, and 44146. The study population was then stratified into two cohorts: patients that underwent a laparoscopic resection and patients that underwent an open resection. Patients undergoing a concurrent procedure were excluded with the exception of procedures considered to be routine aspects of colorectal surgery including intraoperative endoscopy, lysis of adhesions, stoma formation, colonic lavage, splenic flexure mobilization, frozen section, cystoscopy with stent insertion, and exam under anesthesia. Patients with the following characteristics—pregnancy, prior operation within 30 days, emergency surgery, disseminated cancer, comatose, pre-operative sepsis, and ASA class V—were excluded from analysis.

### Study Measures and Outcomes

The NSQIP dataset was queried for baseline demographic characteristics including age, sex, BMI, and American Society of Anesthesiologists (ASA) classification. Laparoscopic and open cohorts were compared with respect to short-term clinical outcomes. Our primary outcome was all-cause 30-day morbidity, comprising of wound complications (i.e., incisional surgical site infections [SSIs] and organ space SSIs) and non-wound complications (i.e., urinary tract infection [UTI], pneumonia, sepsis, septic shock, bleed, deep vein thrombosis [DVT], pulmonary embolism [PE], myocardial infarction [MI], cardiac arrest, and cerebrovascular accident [CVA]). Secondary outcomes included stratified 30-day morbidity based on each of the abovementioned factors. Thirty-day mortality and resource outcomes including length of stay (LOS, in days), total operative time (in minutes), and 30-day re-admission and re-operation rates were also compared between groups.

### Data Analysis

Continuous variables were described by quartiles and categorical variables by counts and proportions. Associations between adverse events and predictors including BMI and surgical approach were modeled using multivariable binary logistic regression, ordinal logistic regression, ordinary least squares, and Cox proportional hazards models for binary, ordinal (surgical time), continuous (length of stay), and time-to-event outcomes, respectively. The theoretical framework for the regression model accounted for the following clinically relevant covariates: age, sex, BMI, comorbidities, ASA class, and operative approach. As surgical approach and BMI (included as a flexible restricted cubic spline term) were of primary interest, these variables were included in all models along with their interaction. The interaction between approach and BMI allows the effect of approach to vary as a function of BMI, and for the detection of regions of BMI in which a certain approach might be associated with better or worse outcomes. Odds or hazard ratios comparing risk of adverse event between surgical approaches as a function of BMI (at various thresholds ranging from 20 to 50 kg/m$^2$), adjusted for other comorbidities, were plotted along with point-wise 95% confidence intervals. The importance of BMI and surgical approach was tested by using joint multiple degrees-of-freedom Wald tests of whether or not all terms in the model involving each variable were different from zero. Single imputation was used to handle missing data. Statistical significance was set at $p < 0.05$ for all comparisons. All analyses were done using R statistical software (version 3.4.3, Vienna, Austria).

## Results

A total of 16,145 patients were grouped in to laparoscopic ($N = 9386$) and open ($N = 6759$) cohorts. Baseline demographic characteristics of the patient cohorts are listed in Table 1.

**Table 1** Baseline characteristics of the patient cohort

| | Laparoscopic cohort | Open cohort |
|---|---|---|
| *N* (%) | 9386 (58) | 6759 (42) |
| Median age, years (IQR) | 61 (52–70) | 63 (55–72) |
| Sex, n (%) | | |
| Male | 5666 (60.4) | 4309 (63.8) |
| Female | 3720 (39.6) | 2450 (36.2) |
| Median BMI, kg/m$^2$(IQR) | 27 (24–31) | 28 (24–32) |
| Comorbidities, n (%) | | |
| Smoking history (within 1 year) | 1483 (16) | 1177 (17) |
| Diabetes | 1435 (15) | 1228 (18) |
| COPD | 301 (3) | 329 (5) |
| Hypertension | 4092 (44) | 3389 (50) |
| Congestive Heart Failure | 31 (0.3) | 24 (1) |
| Renal Failure | 4 (0) | 7 (0) |
| Steroid Use | 175 (2) | 160 (2) |
| Bleeding Disorder | 193 (2) | 162 (2) |
| ASA[a] class, *n* (%) | | |
| Mild | 4383 (46.7) | 2598 (38.4) |
| Moderate | 4499 (47.9) | 3769 (55.8) |
| Severe | 257 (2.7) | 274 (4.1) |
| Procedure, *n* (%) | | |
| Colectomy, partial, with anastomosis, with coloproctostomy | 6292 (67) | 3435 (51) |
| Colectomy, partial, with anastomosis, with coloproctostomy, with colostomy | 1192 (13) | 950 (14) |
| Proctectomy, complete, combined abdominoperineal, with colostomy | 1902 (20) | 2374 (35) |

[a]American Society of Anesthesiologists (ASA) Class

Table 2 compares short-term clinical outcomes between laparoscopic and open surgery. Open surgery ($p < 0.001$) and BMI ($p < 0.001$) are both associated with an increasing risk of all-cause morbidity (Fig. 1a). Table 3 provides a snapshot of the odds of experiencing adverse events for each surgical approach as a function of specific BMI values, adjusted for all clinically relevant covariates. The risk of all-cause morbidity increases with increasing BMI in both open and laparoscopic surgery (Fig. 1). This trend was not significantly different as a function of operative technique with increasing BMI (Fig. 1b, Table 3). BMI, therefore, does not appear to be a strong modifier for surgical approach with respect to all-cause morbidity. In other words, the odds of experiencing morbidity (expressed as a ratio of open surgery vs. laparoscopic surgery) at a BMI of 25 kg/m$^2$ (OR 1.76, 95% CI 1.60–1.93) were comparable with the odds of experiencing morbidity at a BMI of 50 kg/m$^2$ (OR 2.05, 95% CI 1.42–2.96, $p = 0.572$; Table 3).

When stratified by complication type, patients in the laparoscopy group had a significantly lower incidence of all wound complications including incisional SSIs ($p < 0.001$; Table 2), and organ space SSIs ($p = 0.039$; Table 2, Fig. 2a). Laparoscopy was also associated with a lower rate of non-wound complications ($p < 0.0001$; Table 2), including pneumonia ($p < 0.001$), sepsis ($p = 0.031$), and post-operative bleed ($p < 0.001$; Table 2). The risk difference between open and laparoscopic surgery of the abovementioned complications, however, did not rise significantly with increases in BMI (Table 3, Fig. 2b). Notably, the event rates for DVT, PE, MI, and cardiac arrest were too low (< 1%) to fit a model with all the covariates (Table 2).

There were no group differences with respect to 30-day mortality ($p = 0.102$; Table 2). Open surgery was associated with greater adjusted odds of having a longer LOS compared with laparoscopic surgery ($p < 0.001$, OR 2.96, 95% CI 2.71–3.24 at BMI of 30; Table 2; Fig. 3a). These odds ratios did not increase significantly with rising BMI ($p = 0.277$, Table 3, Fig. 3b). Finally, laparoscopy was associated with having a longer median operative time in comparison with open surgery (time difference of 38 min at BMI of 30 kg/m$^2$, $p < 0.0001$; Table 2; Fig. 4a). The absolute time difference between open and laparoscopic surgery, however, did not increase significantly with increasing BMI ($p = 0.491$, Table 3; Fig. 4b). Laparoscopy resulted in approximately 40 min of added operative time compared with open surgery for rectal cancer, irrespective of a patient's BMI. Re-admission ($p = 0.807$; Table 2) and re-operation rates ($p = 0.881$; Table 2) were comparable between the open and laparoscopic cohorts.

## Discussion

This retrospective study, using the multi-institutional ACS-NSQIP 2012–2016 dataset, demonstrates that laparoscopy is associated with improved 30-day morbidity in comparison

**Table 2** Summary of short-term clinical outcomes stratified by operative technique

| | Laparoscopic cohort | Open cohort | $p$ |
|---|---|---|---|
| All-cause morbidity, $n$ (%) | 1640 (17.5) | 2038 (30.8) | < 0.0001* |
| Stratified morbidity, $n$ (%) | | | |
| Wound complications | | | |
| Incisional SSI[a] | 403 (4.3) | 665 (9.8) | < 0.0001* |
| Organ space SSI | 495 (5.3) | 425 (6.3) | 0.039* |
| Non-wound complications | 1188 (12.7) | 1761 (26.1) | < 0.0001* |
| Infectious complications | | | |
| UTI[b] | 237 (2.5) | 262 (3.9) | 0.071 |
| Pneumonia | 102 (1.1) | 173 (2.6) | < 0.0001* |
| Sepsis | 216 (2.3) | 224 (3.3) | 0.031* |
| Septic shock | 69 (0.7) | 90 (1.3) | 0.168 |
| Cardiovascular complications | | | |
| MI[c] | 39 (0.4) | 56 (0.8) | 0.030* |
| Cardiac arrest | 24 (0.3) | 30 (0.4) | 0.234 |
| DVT[d] | 43 (0.5) | 48 (0.7) | 0.175 |
| PE[e] | 391 (4.2) | 805 (11.9) | < 0.0001* |
| 30-day mortality, $n$ (%) | 44 (0.5) | 59 (0.9) | 0.102 |
| Median length of stay (days) (IQR) | 4 (3–6) | 6 (5–9) | < 0.0001* |
| Median operative time, (min) (IQR) | 239 (181–312) | 210 (154–282) | < 0.0001* |
| 30-day re-operation, $n$ (%) | 507 (5.4) | 411 (6.1) | 0.881 |
| 30-day re-admission, $n$ (%) | 1154 (12.3) | 938 (13.9) | 0.807 |

[a]Incisional SSI: consists of superficial and deep surgical site infections

[b]*UTI* urinary tract infection

[c]*MI* myocardial infarction

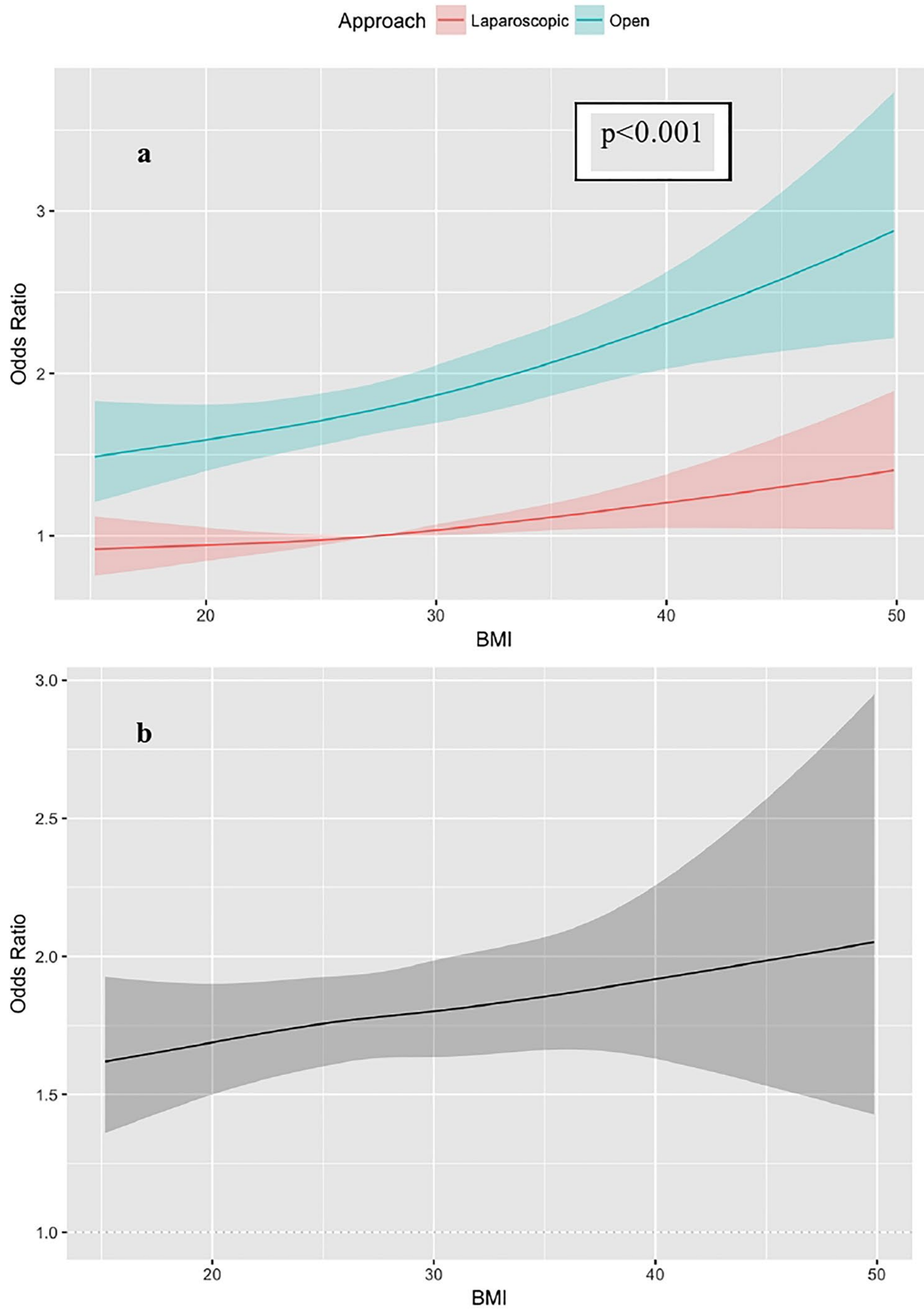
[d]*DVT* deep vein thrombosis

[e]*PE* pulmonary embolism

with open surgery in patients with obesity and rectal cancer. To our knowledge, this is among the first studies to also examine the interaction between BMI and surgical modality in this patient population. There seems to be a trade-off between improved short-term outcomes such as wound infections and LOS with laparoscopy and increased operative time. However, there is no strong evidence that the protective effect of laparoscopy and difference in operative time changes as a function of BMI.

The benefits of laparoscopy with respect to wound complications, blood loss, and LOS are well documented in the surgical literature [5–9], [12]. In a Cochrane Review of 17 trials, wound infections were observed in only 4.6% of patients undergoing laparoscopic colorectal surgery, in comparison with conventional surgery (8.7%, RR 0.56, $p = 0.002$). Despite variability in the data, blood loss, intensity of post-operative pain, and duration of ileus were all significantly lower in the laparoscopic group [12]. The multi-institutional COREAN trial of laparoscopic versus open surgery for mid or low rectal cancer also demonstrated a lower rate of superficial SSIs in patients undergoing laparoscopic surgery ($p = 0.02$). While estimated blood loss was significantly lower in this subset of patients ($p = 0.006$), the difference in hospital LOS failed to achieve statistical significance ($p = 0.06$) [5]. Our findings also in keeping with the results of a large multi-center propensity matched cohort study demonstrating significantly lower blood loss and complications (but comparable 3-year overall survival and recurrence-free survival) with laparoscopic surgery for rectal cancer [13]. It is important to note that the higher short-term morbidity after open surgery in this study may, in part, be explained by a higher rate of abdominoperineal resections in this group of patients. Further, laparoscopy for rectal cancer has been consistently associated with prolonged operative time compared with open surgery [5–10], [13]. This coincides with our findings of a relatively constant time difference of approximately 40 min between laparoscopic and open cases, irrespective of body mass index. The learning curve for laparoscopic rectal surgery may account for this finding. It is also important to note that differences in operative time between the two approaches maybe smaller in higher volume centers [14]; however, this was difficult to disentangle within the limits of a large administrative dataset such as NSQIP.

**Fig. 1** **a** Odds ratios, comparing against the reference group, of all-cause morbidity as a function of surgical approach and BMI, with other predictors held fixed at their reference levels. **b** Odds of all-cause morbidity between open and laparoscopic procedures, with pointwise 95% confidence interval, across various BMIs




BMI has also been shown to be an independent predictor of adverse outcomes after colorectal surgery, regardless of operative approach [4, 15]. A recent meta-analysis on this topic reported a significantly higher rate of conversion in obese patients than in non-obese patients [4]. Likewise, Bell et al.'s review of 1464 laparoscopic colorectal resections demonstrated that conversion was 4.1 times more likely in obese patients than their non-obese counterparts. Obesity was also associated with a significantly lower likelihood of attempting laparoscopy [16]. With respect to post-operative outcomes, obese patients with CRC are also at an increased risk of wound infections, pulmonary events, and anastomotic leaks. [4, 15] It is important to note that obesity has not been shown to adversely affect oncologic outcomes in CRC, including number of lymph nodes harvested, the presence of positive margins, and disease-free and overall survival [4, 17]. Of note, post-operative wound complications have been shown to contribute to significant patient morbidity as well as increased LOS and cost [18]. The heavy bacterial load associated with colorectal surgery combined with a large incision

**Table 3** Odds ratios (95% CI) for short-term clinical outcomes stratified by operative technique (laparoscopy as reference) as a function of various body mass indices[a]

| BMI (kg/m$^2$) | All-cause morbidity | Incisional SSI[b] | Organ space SSI[b] |
|---|---|---|---|
| 25 | 1.49 (1.34–1.66) | 1.75 (1.39–2.21) | 1.32 (1.06–1.64) |
| 30 | 1.56 (1.40–1.74) | 1.93 (1.61–2.30) | 1.18 (0.97–1.42) |
| 35 | 1.64 (1.46–1.85) | 2.07 (1.66–2.59) | 1.07 (0.84–1.35) |
| 40 | 1.73 (1.44–2.08) | 2.10 (1.66–2.65) | 1.00 (0.72–1.37) |
| 45 | 1.82 (1.36–2.43) | 2.10 (1.48–2.98) | 0.93 (0.54–1.61) |
| 50 | 1.91(1.28–2.86) | 2.10 (1.25–2.50) | 0.88 (0.40–1.95) |
| BMI (kg/m$^2$) | Non-wound morbidity | Mortality | Length of stay[c] |
| 25 | 1.87 (1.68–2.08) | 1.80 (0.96–0.36) | 3.08 (2.80–3.39) |
| 30 | 1.91 (1.70–2.14) | 1.87 (0.99–3.53) | 2.96 (2.71–3.24) |
| 35 | 1.95 (1.71–2.22) | 1.86 (0.83–4.16) | 2.76 (2.45–3.11) |
| 40 | 2.00 (1.63–2.45) | 1.86 (0.79–4.37) | 2.69 (2.36–3.06) |
| 45 | 2.05 (1.49–2.82) | 1.85 (0.53–6.44) | 2.64 (2.14–3.26) |
| 50 | 2.11 (1.34–3.30) | 1.85 (0.31–11.09) | 2.59 (1.88–3.57) |
| BMI (kg/m$^2$) | Operative time[c] | Re-admission | Re-operation |
| 25 | 37 (33–41) | 1.07 (0.96–1.19) | 1.04 (0.90–1.21) |
| 30 | 38 (34–42) | 1.09 (0.97–1.22) | 1.10 (0.94–1.28) |
| 35 | 38 (33–43) | 1.08 (0.95–1.23) | 1.12 (0.94–1.34) |
| 40 | 38 (31–45) | 1.03 (0.85–1.25) | 1.10 (0.84–1.45) |
| 45 | 39 (27–50) | 0.99 (0.73–1.34) | 1.08 (0.7–1.67) |
| 50 | 39 (22–56) | 0.94 (0.61–1.46) | 1.06 (0.57–1.96) |

[a]P value for all trends did not achieve statistical significance (> 0.05)

[b]SSI surgical site infection

[c]Time difference (minutes) between laparoscopic and open surgery

in a patient with significant intra-abdominal adiposity can magnify the risk of post-operative wound morbidity. Data from patients with stage III colon adenocarcinoma suggests that laparoscopy is associated with less delay to initiation of adjuvant system therapy and improved overall survival. The leading theory relates to the lower incidence of complications, such as wound related morbidity, and improved LOS with laparoscopic colectomies [19]. Likewise, patients with transmural or node positive rectal cancer often require adjuvant therapy 6 weeks after surgery. Post-operative wound or infectious complications may therefore delay the time to definitive treatment and have a detrimental impact on recurrence and overall survival in this vulnerable patient population. While there is a paucity of data on the topic of time to adjuvant therapy in rectal cancer, it is possible that the short-term advantages of laparoscopy demonstrated in this study may extend to the delayed post-operative period. The results of a recent large population-based study using propensity score matching of laparoscopic and open surgery for rectal cancer demonstrated a lower incidence of locoregional relapse and long-term mortality with minimally invasive techniques, despite similarity in early pathologic outcomes between groups. The authors attributed this finding to an amalgamation of factors including a heightened inflammatory response after open surgery that facilitates the growth and survival of residual tumor cells, and possibly a selection bias favoring low risk patients for laparoscopic surgery [20].

To our knowledge, ours is the first study to delineate how short-term outcomes, based on the surgical approach to rectal cancer, change as a function of BMI. While BMI is thought to increase the complexity of laparoscopy and increase the risk of conversion, we suggest that the favorable association of laparoscopy with short-term outcomes (i.e., less wound-related morbidity, pulmonary complications, blood loss, and LOS) persists in patients with high BMIs. This includes patients with BMI > 30 kg/m$^2$, a cutoff at which 50% of rectal cancer patients have been reported to undergo conversion to open surgery [16]. However, this is likely the very patient population, which could reap the benefits of laparoscopy on short-term outcomes and LOS. While this may come at a cost of increased operative time, our findings suggest that the difference in time between laparoscopy and open surgery does not necessarily increase with BMI. Laparoscopy takes on average only 40 min longer than open surgery—an important factor to consider when considering conversion to open in patients

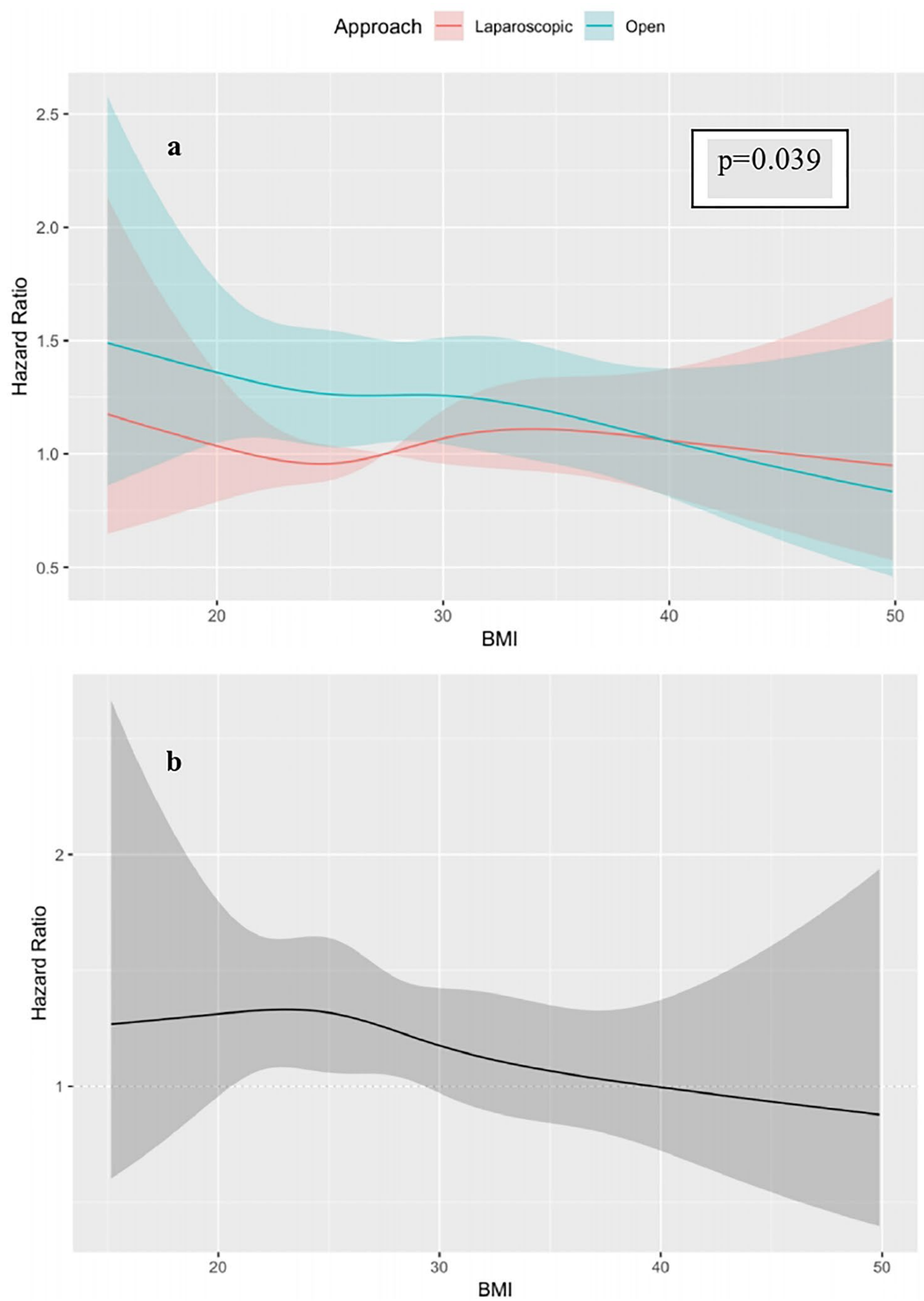



**Fig. 2** **a** Odds ratios, comparing against the reference group, of organ space SSIs as a function of surgical approach and BMI, with other predictors held fixed at their reference levels. **b** Odds of organ space SSIs between open and laparoscopic procedures, with pointwise 95% confidence interval, across various BMIs

with a challenging body habitus. It has also been theorized that patients with high BMI can be operated on successfully as most of the adiposity is limited to the extra-abdominal compartment [21]. Our findings also justify the increased adoption of laparoscopy for rectal cancer in the last decade. In a recent analysis of the ACS-NSQIP dataset, nearly 53% of resections for rectal cancer in 2016 were performed laparoscopically compared with only 9.8% in 2005 [22].

The limitations of this study include those that are inherent to the administrative NSQIP dataset. This includes the presence of unmeasured confounders and selection bias, due to voluntary enrollment of hospitals across North America. NSQIP hospitals account for approximately 12% of US hospitals, and have been shown to be larger, more well-resourced, and academic-affiliated compared with non-participating hospitals [23]. The general NSQIP dataset sampling frame also changes every year and lacks information on oncologic metrics (including receipt of neoadjuvant chemoradiation, location of tumor from anal verge, CRM status, and quality of the mesorectal resection) and long-term clinical outcomes.

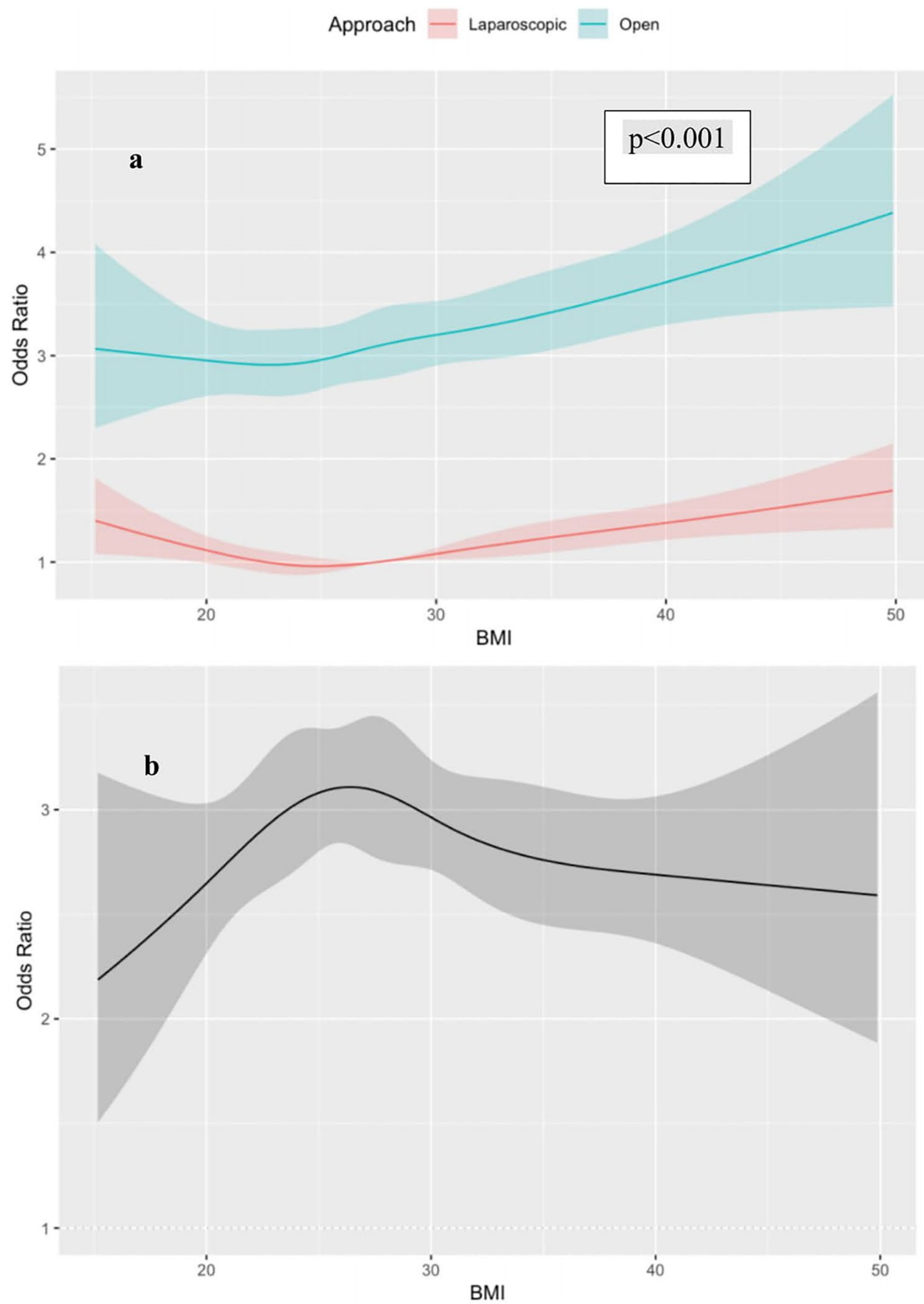



**Fig. 3** **a** Odds ratios, comparing against the reference group, of increased length of stay as a function of surgical approach and BMI, with other predictors held fixed at their reference levels. **b** Odds of increased length of stay between open and laparoscopic procedures, with pointwise 95% confidence interval, across various BMIs

The findings are also affected by limited case ascertainment due to coding changes and lack of granularity with respect to several important variables including why certain patients were offered laparoscopic versus open surgery and vice versa. Missing data on the use of bowel preparation, type of anastomosis performed (i.e., stapled vs. hand-sewn), use of wound protectors, conversion rates, surgeon experience, and volume also contribute to the selection bias inherent to use of large datasets such as NSQIP. Finally, although BMI is a simple and objective measure of obesity, it can be an inaccurate marker of body adipose tissue. The presence of visceral fat obscures tissue planes and makes it difficult to access the root of the mesentery. Therefore, the abdominal fat ratio would have been a more reliable marker of intra-abdominal obesity in this population [24, 25]. We also did not study emerging minimally invasive approaches such as robotic rectal surgery and trans-anal total mesorectal excision (TaTME), which may offer additional advantages for patients with obesity and rectal cancer. Nonetheless, the multi-institutional nature of this study, coupled with the large sample size, supports the added

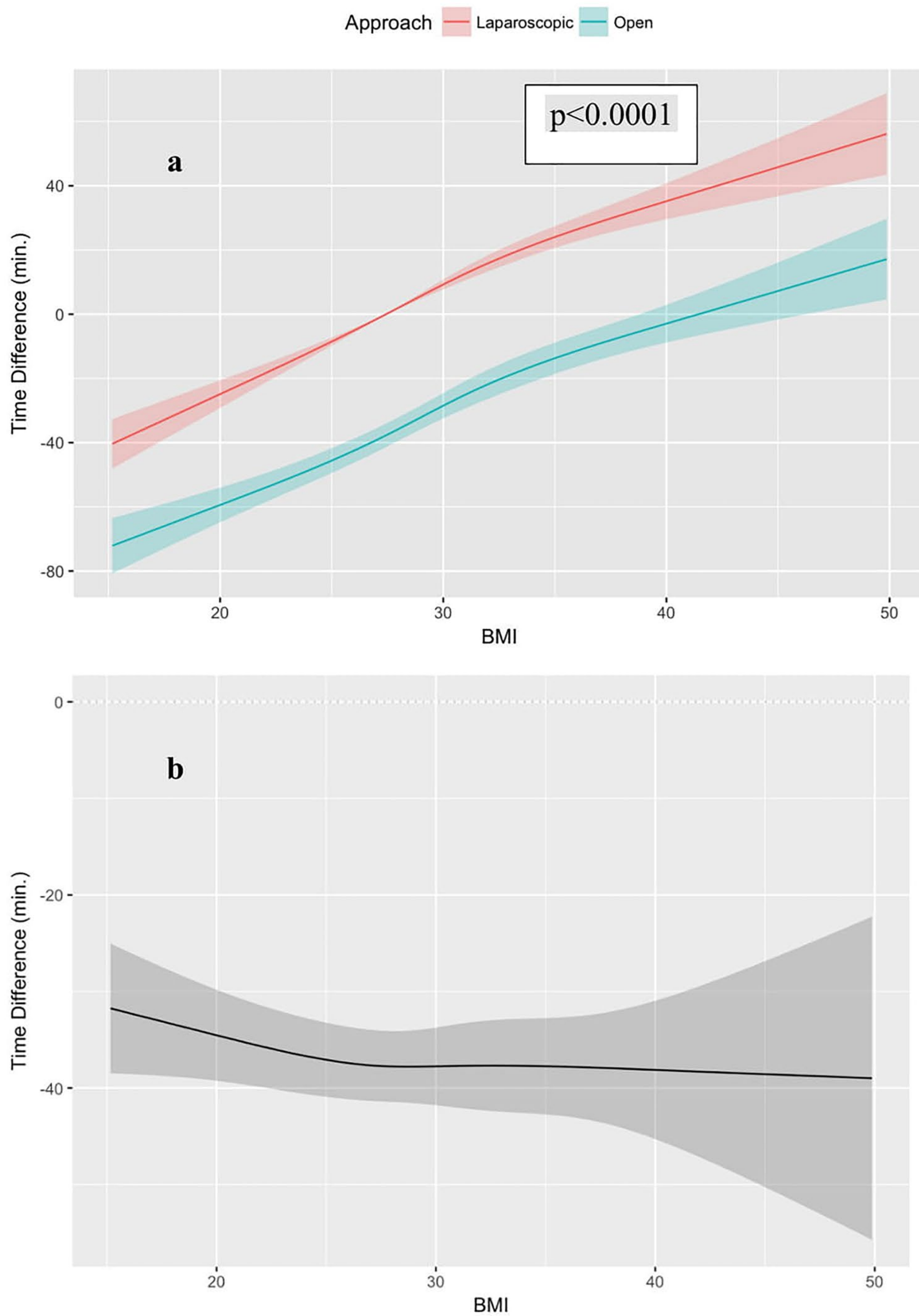



**Fig. 4** **a** Odds ratios, comparing against the reference group, of increased operative time as a function of surgical approach and BMI, with other predictors held fixed at their reference levels. **b** Time difference between open and laparoscopic procedures, with pointwise 95% confidence interval, across various BMIs

value of our findings to the current body of literature on body mass index and surgical modality in rectal cancer.

## Conclusions

This study demonstrates an association between minimally invasive surgery and favorable short-term outcomes in patients with obesity and rectal cancer; BMI however, was not observed to be an effect modifier for modality in the surgical management of rectal cancer. Early conversion to open surgery due to body habitus may not necessarily amount to increased savings with respect to operative time and may confer added morbidity and length of stay in the immediate post-operative period.

**Author Contributions** Conceptualization: all authors. Methodology: Dhruvin Hirpara, Colin O'Rourke, and Sami Chadi. Formal analysis and investigation: Dhruvin Hirpara and Colin O'Rourke. Writing—original draft

preparation: Dhruvin Hirpara, Colin O'Rourke, and Arash Azin. Writing—review and editing: all authors. Funding acquisition: not applicable. Resources: Sami Chadi. Supervision: Steven Wexner and Sami Chadi.

**Availability of Data and Material** All raw data is available in the form of participant use files from the ACS-NSQIP website (https://www.facs.org/quality-programs/acs-nsqip/participant-use).

## Declarations

**Conflict of Interest** Dr. Wexner—consulting: Intuitive Surgical, Karl Storz, Stryker, Medtronic, Takeda, Regentys, and OstomyCure; stock options: Regentys, LifeBond, Pragma, and Renew Medical; royalties: Medtronic, Intuitive Surgical, Karl Storz, and Unique Surgical Innovations.

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