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Respiratory complications after colonic procedures in chronic obstructive pulmonary disease: does laparoscopy offer a benefit?

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Abstract
Background Patients with severe chronic obstructive pulmonary disease (COPD) are at a higher risk for postoperative respiratory complications. Despite the benefits of a minimally invasive approach, laparoscopic pneumoperitoneum can substantially reduce functional residual capacity and raise alveolar dead space, potentially increasing the risk of respiratory failure which may be poorly tolerated by COPD patients. This raises controversy as to whether open techniques should be preferentially employed in this population.

Methods The American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database from 2011 to 2014 was used to examine the clinical data from patients with COPD who electively underwent laparoscopic and open colectomy. Patients defined as having COPD demonstrated either functional disability, chronic use of bronchodilators, prior COPD-related hospitalization, or reduced forced expiratory reserve volumes on lung testing (FEV1 \75%). Demographic data and preoperative characteristics were compared. Linear and logistic regressions were utilized to perform multivariate analysis and determine risk-adjusted outcomes.

Results Of the 4397 patients with COPD, 53.8% underwent laparoscopic colectomy (LC) while 46.2% underwent open colectomy (OC). The LC and OC groups were similar with respect to demographic data and preoperative comorbidities. Equivalent frequencies of exertional dyspnea (LC 35.4 vs OC 37.7%, P = 0.11) were noted. After multivariate risk adjustment, OC demonstrated an increased rate of overall respiratory complications including pneumonia, reintubation, and prolonged ventilator dependency when compared to LC (OR 1.60, 95% CI 1.30–1.98, P\0.01). OC was associated with longer length of stay (10 ± 8 vs. 6.7 ± 7 days, P\0.01) and higher readmission (OR 1.36, 95% CI 1.09–1.68, P\0.01) compared to LC.

Conclusion Despite the potential risks of laparoscopic pneumoperitoneum in the susceptible COPD population, a minimally invasive approach was associated with lower risk of postoperative respiratory complications, shorter length of stay, and decrease in postoperative morbidity.

Keywords COPD • Colorectal disease • Colectomy Laparoscopy

In colorectal operations, laparoscopy has proven to favorably impact postoperative outcomes, yielding shorter length of stay, reduced surgical site infection, lower rates of anastomotic leak, and early mobilization and recovery compared to an open approach. [1–3] Nonetheless, it remains uncertain if pre-existing pulmonary disease should preclude laparoscopic intervention in favor of an open approach.

Chronic obstructive pulmonary disease (COPD) has been identified as an independent risk factor for postoperative pulmonary complications following open and laparoscopic abdominal surgery [4, 5]. Physiologic changes that accompany COPD during pneumoperitoneum include reduction in dynamic compliance and reduction in functional residual capacity,

increasing risk of atelectasis, hypoxemia, and subsequent respiratory failure [6, 7]. Thus, diminished pulmonary status has been perceived as a relative contraindication to minimally invasive surgery due to the belief that this patient subset will not tolerate pneumoperitoneum and be predisposed to higher rates of postoperative respiratory complications.

Small retrospective cohort studies have examined the role of abdominal laparoscopy for patients with COPD and have demonstrated no difference in pulmonary complications compared to open technique [8]. To date, no large cohort studies have examined the utility of minimally invasive techniques in colonic operations for patients with pulmonary disease. Therefore, in this study, we intend to use a large national database to examine the utilization of laparoscopy in patients diagnosed with severe COPD and to determine the impact of laparoscopy on postoperative complication rates.

Methods

A retrospective review of the National Surgical Quality Improvement Program (NSQIP) from 2011 to 2014 was performed to identify patients with COPD who underwent elective colonic operations. ACS NSQIP is a nationally validated, risk-adjusted, outcome-based database that records detailed perioperative clinical data from surgical patients [9]. Approval for the use of this patient database was obtained from the Institutional Review Board at the University of California, Irvine Medical Center, and from ACS.

NSQIP reviewers identify COPD as an established historical and current diagnosis in the patient's medical record. Furthermore, prior to the defined surgical procedure, patients identified with COPD have demonstrated one of the following criteria: a functional disability such as dyspnea from COPD, requirement of chronic bronchodilator therapy or COPD-specific oral/inhaled medication, hospitalization for treatment of COPD, or a forced expiratory reserve volume over the first second of exhalation (FEV1) \75% of predicted. Alternative pulmonary processes such as asthma and interstitial lung disease are not included in this variable designation.

CPT codes were used to stratify by open and laparoscopic cohorts. Patients less than 18 and those with incomplete data were excluded. Open colectomy was defined by CPT including the following: 44140, 44141,
44143-7, 44150-1, 44,155-58, 44160. Laparoscopic colectomy was defined by the following CPT codes: 44204-8,
44210-12. Laparoscopic cases converted to open colectomy were identified and an intent-to-treat model was applied, as these cases were included in the laparoscopic subset.

Demographic and comorbidity data were examined with univariate analysis through Pearson Chi Square Testing and Student's T-testing. Our study featured a risk-adjusted multivariate analysis in order to acquire adjusted odds ratios for key endpoints. To ensure a comprehensive analytic model, two primary groups of NSQIP variables were employed as covariates in our analysis—patient demographic variables and patient comorbidity variables. Empiric inclusion of these demographic and comorbidity covariates allowed for a highly accurate and comprehensive multivariate analysis featuring linear and logistic regression. Patient demographic variables included age, gender, ethnicity, mean BMI, and American Society of Anesthesiologists (ASA) class. Patient comorbidity variables that were included as covariates in our analytic model were classified by organ system. Neurologic variables included prior history

of cerebrovascular accident (CVA). Cardiac variables included congestive heart failure, hypertension, history of myocardial infarction (MI), history of angina, and history of peripheral vascular disease (PVD). Pulmonary variables included exertional dyspnea and preoperative tobacco use. Renal variables included preoperative dialysis and acute renal failure (ARF). Metabolic variables included history of diabetes mellitus. Hematologic variables included preoperative bleeding disorders. Independent and partially dependent functional statuses as defined by NSQIP were included as covariates. Finally, preoperative weight loss (10% weight loss in last six months) and preoperative steroid use were included in our analysis as well.

Multivariate analysis was performed using linear and logistic regression implemented for the following key endpoints: 30-day mortality, respiratory complications, overall morbidity, reoperation, and readmission. Respiratory complications were defined as the occurrence of at least one of the following respiratory-related postoperative complications: pneumonia, unplanned reintubation, and mechanical ventilation for longer than 48 h.

Additional individual endpoints assessed through multivariate analysis included rates of pneumonia, unplanned reintubation, ventilator requirement for[48 h, acute renal failure, pulmonary embolism, deep venous thrombosis, sepsis, septic shock, superficial surgical site infection (SSI), deep SSI, and organ space SSI. Adjusted odds ratios with 95% confidence intervals were calculated with implementation of robust standard errors to guard against model misspecification. All statistical analyses were performed utilizing IBM_ SPSS Statistics, Version 23.0.0.0 (Armonk, NY). Statistical significance was assigned by a P value<0.05.

Results

From 2011 to 2014, 4397 patients underwent elective colectomy for patients defined with COPD. Of this overall cohort, 2364 (53.8%) patients underwent laparoscopic colectomy while 2033 (46.2%) underwent open colectomy. Mean age was statistically equivalent at 69 ± 10 years in the open cohort and 68 ± 10 years in the laparoscopic cohort (Table 1). Cohorts were similar with respect to gender and BMI distribution. Males composed 46.4% of the open cohort and 49.4% of the laparoscopic cohort. Mean BMI (Kg/m2) was 29 ± 8 for the open subset and 28 ± 7.5 for the laparoscopic subset. Rates of ASA Class II were lower in the open subset at 10.9% compared to 15.7% in the laparoscopic group, P\0.01. Rates of ASA Class III were higher in the open subset at 73.2% against 69.2% in the laparoscopic cohort, P\0.01. Rates of ASA Class IV were statistically equivalent at 15.6% in the open cohort and 14.8% in the laparoscopic subset. Patient comorbidity rates were reviewed (Table 2). Rate of exertional dyspnea was equivalent in both the open and laparoscopic cohorts at 37.7% and 35.4%, respectively, P = 0.11. Current tobacco use was present in 37.9% of the open group and 35.4% of the laparoscopic group, P = 0.09. Comparing the open and laparoscopic groups, rates of Diabetes Mellitus (24.2 vs 22.5%), preoperative weight loss (4.8 vs 4.4%), congestive heart failure (3 vs 2.2%), and hypertension (69.2 vs 69.7%) were statistically similar. Preoperative steroid use was higher in the open subset at 9.7% against 7.6% in the laparoscopic group, P\0.01. Partially dependent functional status was higher in the open cohort at 6% compared to 3.4% in the laparoscopic cohort, P\0.01. In terms of operative technique, partial colectomy was most commonly performed in 50.2% of the open cohort and 47.9% of the laparoscopic cohort, Table 3. Colonic malignancy was the most common operative indication in the open (47.3%) and laparoscopic (45.5%) groups, P = 0.25. Mean operative duration was equivalent at 167 ± 100 min and 167 ± 85 min in open and laparoscopic groups, respectively, P = 0.89. Mean length of stay was longer in the open colectomy group at 10 ± 8 days against 6.7 ± 7 days, P<0.01.

Table 1 Patient demographic characteristics

	Open $N = 2033$	Laparoscopic $N = 2364$	P value
Mean age (years)	69 ± 10	68 ± 10	0.99
Gender			
Male	944 (46.4%)	1167 (49.4%)	0.056
Female	1089 (53.6%)	1197 (50.6%)	0.056
Ethnicity			
White	1696 (90.5%)	1973 (90.5%)	0.37
Black	152 (8.1%)	158 (7.2%)	0.37
Asian	18 (1%)	32 (1.5%)	0.07
Mean BMI (Kg/m^2)	29 ± 8	28 ± 7.5	0.99
ASA			
Class II	221 (10.9%)	371 (15.7%)	<0.01
Class III	1488 (73.2%)	1637 (69.2%)	<0.01
Class IV	318 (15.6%)	350 (14.8%)	0.45

BMI Body Mass Index (Kg/m^2), *ASA* American Society of Anesthesiologists

Discussion

With respect to the management of patients with COPD, our study is the first to date that examines the utilization of minimally invasive colorectal operations on a national scale. After multivariate risk reduction, the benefits of laparoscopy were conveyed over multiple notable postoperative variables including length of stay, and rates of respiratory complications such as postoperative pneumonia, unplanned reintubation, and mechanical ventilation for longer than 48 h. Improvement in risk-adjusted rates of overall respiratory complications, postoperative morbidity, and 30-day mortality were demonstrated in the laparoscopic cohort.

It has been widely perceived that laparoscopy poses increased perioperative pulmonary risk due to the effects of pneumoperitoneum. Abdominal insufflation may lead to carbon dioxide retention and subsequent hypercarbia [10]. A rapid and statistically significant rise in carbon dioxide levels has been detected on end-tidal monitoring after insufflation [11]. The effect may additionally induce pulmonary vasoconstriction and dysrhythmia. Given intrinsic physiological changes in COPD, management of hypercarbia can be especially troublesome in emphysematous disease given limited effectiveness of intraoperative and postoperative adjunctive respiratory strategies [12]. These findings have warranted closer intraoperative monitoring in patients with

high-risk respiratory status as well as the belief that pre-existing cardiopulmonary compromise is a relative contraindication to laparoscopy.

Table 2 Key patient comorbidity univariate analysis

	Open $N = 2033$	Laparoscopic $N = 2364$	P value
Neuro			
History of CVA	10 (0.5%)	9 (0.4%)	0.20
Cardiac			
Congestive heart failure	60 (3%)	53 (2.2%)	0.17
Hypertension	1406 (69.2%)	1648 (69.7%)	0.72
History of MI	3 (0.1%)	2 (0.1%)	0.80
History of angina	2 (0.1%)	8 (0.3%)	0.20
History of PVD	21 (0.1%)	12 (0.5%)	0.28
Pulmonary			
Exertional dyspnea	767 (37.7%)	836 (35.4%)	0.11
Preoperative tobacco use	770 (37.9%)	836 (35.4%)	0.09
Renal: preoperative dialysis	16 (0.8%)	15 (0.6%)	0.67
Preoperative ARF	8 (0.4%)	3 (0.1%)	0.11
Metabolic: diabetes mellitus	493 (24.2%)	532 (22.5%)	0.18
Hematologic: preoperative bleeding disorder	127 (6.2%)	118 (5%)	0.05
Preoperative weight loss	98 (4.8%)	104 (4.4%)	0.55
Preoperative steroid use	197 (9.7%)	176 (7.6%)	<0.01
Functional status: independent	1904 (94%)	2274 (96.6%)	<0.01
Partially dependent	121 (6%)	81 (3.4%)	<0.01

CVA cerebrovascular accident, *MI* myocardial infarction, *PVD* peripheral vascular disease, *ARF* acute renal failure

Table 3 Univariate analysis of operative factors

	Open $N = 2033$	Laparoscopic $N = 2064$	P value
Operative technique			
Partial colectomy	1020 (50.2%)	1132 (47.9%)	0.13
Right colectomy (ileocolostomy)	433 (21.3%)	473 (22.9%)	0.22
Left colectomy (coloproctostomy)	401 (19.7%)	466 (19.7%)	0.99
Diagnosis			
Colonic malignancy	962 (47.3%)	1075 (45.5%)	0.25
Diverticulitis	270 (13.3%)	322 (15.6%)	0.03
Benign neoplasm	242 (11.9%)	494 (20.9%)	<0.01
Mean operative duration (min)	167 ± 100	167 ± 85	0.89
Mean length of hospital stay (days)	10 ± 8	6.7 ± 7	<0.01

Table 4 Multivariate analysis of key postoperative outcomes

	Open $N = 2033$	Laparoscopic $N = 2364$	MD/OR	95% CI	P value
Thirty-day mortality	68 (3.3%)	38 (1.6%)	1.94	1.28–2.94	<0.01
Respiratory complications	240 (11.8%)	173 (7.3%)	1.6	1.30–1.98	<0.01
Overall morbidity	846 (41.6%)	621 (26.3%)	1.94	1.71–2.22	<0.01
Thirty-day reoperation	101 (5%)	85 (3.6%)	1.4	1.04–1.89	0.02
Thirty-day readmission	203 (10%)	175 (7.4%)	1.36	1.09–1.68	<0.01

Table 5 Multivariate analysis of individual postoperative outcomes

	Open $N = 2033$	Laparoscopic $N = 2364$	OR	95% CI	P value
Pneumonia	158 (7.8%)	94 (4%)	1.9	1.49–2.54	<0.01
Unplanned reintubation	125 (6.1%)	90 (3.8%)	1.56	1.17–2.07	<0.01
Ventilator requirement > 48 h	104 (5.1%)	61 (2.6%)	1.95	1.40–2.71	<0.01
Acute renal failure	27 (1.3%)	25 (1.1%)	1.26	1.50–5.88	0.42
Pulmonary embolism	26 (1.3%)	22 (0.9%)	1.38	0.76–2.49	0.28
Deep venous thrombosis	36 (1.8%)	19 (0.8%)	2.18	1.24–3.80	<0.01
Sepsis	108 (5.3%)	70 (3%)	1.7	1.24–2.33	<0.01
Septic shock	67 (3.3%)	50 (2.1%)	1.44	0.98–2.11	0.06
Superficial SSI	231 (11.4%)	147 (6.2%)	1.94	1.55–2.42	<0.01
Deep SSI	49 (2.4%)	30 (1.3%)	1.77	1.11–2.83	0.02
Organ space SSI	110 (5.4%)	73 (3.1%)	1.72	1.26–2.34	<0.01

Despite the potentially negative physiologic changes associated with pneumoperitoneum, laparoscopy appears to offer substantial postoperative respiratory benefits in terms of clinical outcomes. As revealed in our analysis, high-risk severe COPD patients experienced substantial reductions in postoperative pneumonia and unplanned reintubation. In a prior randomized control trial by Schwent et al. that examined pulmonary function after laparoscopic and open colorectal resections in patients with normal pulmonary function, the cohort randomized to laparoscopic intervention demonstrated higher postoperative-forced vital capacity and FEV1 after conventional open operation. Moreover, lower arterial oxygen levels were detected following laparotomy compared to laparoscopy. [13] Nonetheless, no substantial difference in clinical pneumonia rates was identified despite this finding. In a retrospective cohort study by Inokuchi et al. that examined laparoscopic gastrectomy in patients with COPD, no difference in incidence of postoperative pulmonary complications was noted when comparing laparoscopic and open gastrectomy subsets. Our findings contrast this as lower risk-adjusted rates of pneumonia, unplanned reintubation, and prolonged mechanical ventilation were demonstrated in our laparoscopic cohort.

To challenge the presumption that pre-existing pulmonary compromise may be a contraindication to minimally invasive resection, Marks et al. examined laparoscopic colorectal operations in a high-risk patient subset. Despite an elevated rate of multiple preoperative pulmonary comorbidities as well as 75% incidence of ASA Class III and IV, patients undergoing laparoscopy revealed shorter hospitalization and reduced postoperative morbidity and mortality compared to an open approach. [14].

The respiratory benefits of laparoscopy in severe COPD patients illustrated in our study corroborate findings from other studies suggesting that minimally invasive techniques should in fact be preferentially employed in a higher risk, older patient subset with multiple medical comorbidities. This was consistent with the advanced age, high ASA class distribution, and generally high comorbidity rates demonstrated in our overall cohort. These findings principally agree with Marks et al. in that cardiopulmonary disease should no longer be considered a contraindication to minimally invasive surgery. Moreover, multiple factors in our analysis may further explain reduction in rates of reintubation and pneumonia experienced after minimally invasive surgery. Most notably, a shorter length of hospital stay was demonstrated in the laparoscopic subset. This reduction in duration is likely associated with decreased postoperative pain, resulting in earlier mobilization that has been consistently associated with reduction in atelectasis and pneumonia [15, 16]. This effect may be further magnified in the COPD patient

subset, given their decreased pulmonary reserve. Additionally, reductions in postoperative pain and analgesia requirements following laparoscopy may play a role in adequate pulmonary toileting and minimization of atelectasis formation [17]. Finally, additional benefits associated with our laparoscopic cohort such as lower rates of postoperative surgical site infection and deep venous thrombosis bear a significant impact on frail COPD patients, as occurrence of these complications may be poorly tolerated and associated with substantial mortality.

Some limitations did exist in our study. Since the COPD variable available in the NSQIP database had a singular definition, analysis examining varying degrees of mild and moderate COPD could not be performed. Additionally, NSQIP variables do not characterize intraoperative ventilator tactics or the utilization of adjunctive postoperative oxygenation strategies such as continuous positive airway pressure and high flow nasal cannula, thereby preventing inclusion of these factors in our analysis. Furthermore, due to the limitations of NSQIP, an inherent surgeon selection bias with regard to technique selection is likely present that is difficult to adjust for. To date, no NSQIP variables can allow consideration of individual surgeon experience or volume. Finally, errors in NSQIP coding can occur.

Conclusion

Despite the perceived belief that advanced obstructive pulmonary disease is a contraindication to laparoscopy due to the risk of hypercarbic respiratory failure, COPD patients who underwent elective laparoscopic colonic operations demonstrated reduction in respiratory complications, postoperative morbidity, and thirty-day mortality. Thus, our study demonstrates that when a laparoscopic approach is employed by experienced minimally invasive surgeons on COPD patients, safe and beneficial postoperative outcomes can be achieved. Laparoscopic techniques should be considered when determining optimal therapy for this unique patient subset.

Compliance with ethical standards

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