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Research Paper

Association of severe obesity with risk of conversion to open in laparoscopic cholecystectomy for acute cholecystitis☆,☆☆

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A R T I C L E I N F O

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A B S T R A C T

Background: Obesity is a known risk factor for cholecystitis and is associated with technical complications during laparoscopic procedures. The present study seeks to assess the association between obesity class and conversion to open (CTO) during laparoscopic cholecystectomy (LC).
Methods: Adult acute cholecystitis patients with obesity undergoing non-elective LC were identified in the 2017–2020 Nationwide Readmissions Database. Patients were stratified by obesity class; class 1 (Body Mass Index [BMI] = 30.0–34.9), class 2 (BMI = 35.0–39.9), and class 3 (BMI ≥ 40.0). Multivariable regression models were developed to assess factors associated with CTO and its association with perioperative complications and resource utilization.
Results: Of 89,476 patients undergoing LC, 40.6 % had BMI ≥ 40.0. Before adjustment, class 3 obesity was associated with increased rates of CTO compared to class 1–2 (4.6 vs 3.8 %; $p < 0.001$). Following adjustment, class 3 remained associated with an increased likelihood of CTO (Adjusted Odds Ratio [AOR] 1.45, 95 % Confidence Interval [CI] 1.31–1.61; ref.: class 1–2). Patients undergoing CTO had increased risk of blood transfusion (AOR 3.27, 95 % CI 2.54–4.22) and respiratory complications (AOR 1.36, 95 % CI 1.01–1.85). Finally, CTO was associated with incremental increases in hospitalization costs (β + $719, 95 % CI 538–899) and length of stay (LOS; β +2.20 days, 95 % CI 2.05–2.34).
Conclusions: Class 3 obesity is a significant risk factor for CTO. Moreover, CTO is associated with increased hospitalization costs and LOS. As the prevalence of obesity grows, improved understanding of operative risk by approach is required to optimize clinical outcomes. Our findings are relevant to shared decision-making and informed consent.

Key message

Obesity is a known risk factor for cholecystitis and has been associated with increased technical complications during laparoscopic procedures. In a large cohort of patients with obesity undergoing laparoscopic cholecystectomy for acute cholecystitis the present study identified an association between severe obesity and conversion to open.

Introduction

Cholecystitis remains a leading gastrointestinal cause of hospitalizations in the United States, with attributable costs of nearly $6 billion, annually [1]. In recent years, there has been a rise in the incidence of gallstone disease among adolescents and young adults with obesity [2]. Specifically, obesity has been associated with hypercholesterolemia and decreased secretion of bile salts that subsequently precipitate to form gallstones [3]. Furthermore, class 3 obesity (Body Mass Index [BMI] ≥ 40.0) has been associated with greater operative challenges, including difficult port entry, hepatomegaly, and increased risk of conversion to open (CTO) [4,5]. Early studies have thus considered class 3 obesity to be a relative contraindication to laparoscopic cholecystectomy (LC) [6].

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However, there has been a near-ubiquitous adoption of laparoscopy over the past two decades, with LC becoming one of the most routinely performed operations [7]. Despite such an increase in the collective expertise of LC, contemporary outcomes among obese patients following these procedures remain understudied. Select reports from high-volume centers have found no association between obesity and in-hospital mortality, thereby suggesting LC to be safe in this cohort [8,9]. Nevertheless, the association between obesity and additional perioperative risks, including CTO, remains poorly described in the modern era [10]. Therefore, a present-day understanding of the clinical and financial outcomes of LC among patients with obesity is warranted.

Among a national cohort of patients with obesity undergoing laparoscopic cholecystectomy, we sought to evaluate the independent association of class 3 obesity with CTO, perioperative complications, and hospitalization costs. We hypothesized class 3 obesity to be associated with an increased risk of perioperative complications, including CTO, and higher inpatient costs. We further hypothesized high-volume centers to be associated with improved outcomes among patients with obesity, relative to low-volume hospitals.

Methods

Data source and study population

This was a retrospective cohort study of the 2017–2020 Nationwide Readmissions Database (NRD). The NRD, maintained as part of the Healthcare Cost and Utilization Project (HCUP), is the largest all-payer readmissions database in the United States. Using center-specific discharge weighting, approximately 60 % of all hospitalizations in the United States are represented within the NRD [11]. Every patient is assigned a unique linkage number, which allows tracking of readmissions within each state and calendar year.

Non-elective adult (≥ 18 years) hospitalizations for laparoscopic or open cholecystectomy among those with obesity with a primary diagnosis of acute cholecystitis were identified using previously validated methodology [12–14]. All diagnoses and procedures were ascertained using *International Classification of Diseases, Tenth Revision* (ICD-10) codes [15]. Records missing key demographic data, including age, sex, vital status, and insurance status, were excluded (1.6 %). Records corresponding to planned open procedures were excluded from the primary analysis (4.0 %; Fig. 1).

Variable definitions and study outcomes

Patient and hospital characteristics, including age, sex, primary payer, insurance coverage, and hospital teaching status, are reported as they appear in the NRD data dictionary. The van Walraven modification of the Elixhauser Comorbidity Index was utilized to evaluate the burden of chronic diseases [16]. Patients were stratified by obesity class using ICD-10 codes and World Health Organization classification, into *class 1* (BMI = 30.0–34.9), *class 2* (BMI = 35.0–39.9), and *class 3* (BMI ≥ 40.0) (Supplemental Table 1) [17,18]. To facilitate comparison, patients with class 3 obesity comprised the *Class 3* cohort, with all others classified as *Class 1–2*. A sensitivity analysis comparing all three classes was performed to validate the combination of these subgroups.

The primary endpoint of the study was CTO, defined using relevant ICD-10 codes [19]. Secondary outcomes consisted of perioperative complications, inpatient costs, postoperative length of stay (LOS), non-home discharge, and non-elective readmission within 30 days. Perioperative complications were ascertained using previously validated ICD-10 codes and included acute kidney injury, infection, intraoperative (accidental puncture, bile leak, hemorrhage), and respiratory derangements (pneumonia, pneumothorax, acute respiratory distress, respiratory failure, prolonged ventilation, bronchopleural fistula) using previously validated ICD-10 codes [20]. Non-home discharge was defined as disposition to a skilled nursing facility, intermediate care facility, or short-term hospital. Hospitalization costs were tabulated by applying the hospital-specific cost-to-charge ratios to overall charges, and adjusted for inflation to the 2020 Personal Health Index [21].

To evaluate center-level expertise, annual institutional LC volume was tabulated. Restricted cubic spline analysis was used to identify high-volume centers (HVC) for LC. The usage of splines allows for a non-linear estimation of the relationship between CTO and hospital LC volume [22,23]. Based upon this exploratory analysis, HVC were defined as hospitals performing >30 LC cases per year among the study cohort (Fig. 2). A subgroup analysis was conducted to evaluate study outcomes among only patients receiving care at HVC. Further, relevant study endpoints were compared among patients undergoing CTO vs laparoscopic without conversion (*LC*) and CTO vs planned open (*Open*) cholecystectomy.

Statistical analysis

Categorical variables are reported as proportions (%), while continuous variables are represented as median and interquartile range (IQR). The Mann-Whitney U and Pearson's χ^2 tests were utilized to examine the significance of intergroup differences for continuous and categorical variables, respectively. Elastic net regularization was used to guide covariate selection. This automated method utilizes regressive least squares methodology to enhance model generalizability while reducing both selection bias and collinearity [24]. Multivariable logistic and linear regression models were created to assess the independent association between obesity class and outcomes of interest. All models were optimized using Bayesian information criteria and receiver operating characteristic (C-statistic). These tests are commonly used to assess

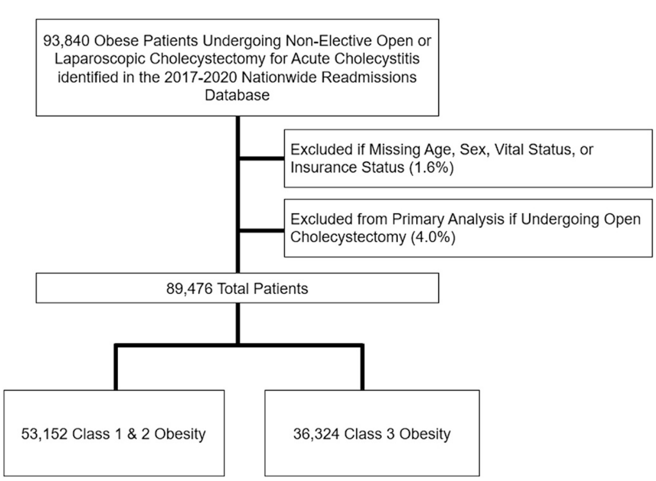

Fig. 1. Consort diagram.

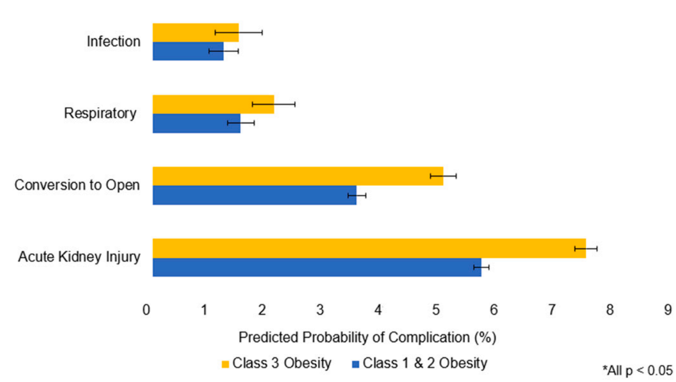

Fig. 2. Predicted probability of perioperative complications among patients undergoing laparoscopic cholecystectomy.

the generalizability and discrimination of models. Logistic regression outputs are reported as adjusted odds ratios (AOR), while beta coefficients (β) are reported for linear models, both with 95 % confidence intervals (CI).

All analyses were performed using Stata 16.1 (StataCorp, College Station, TX). Due to the deidentified nature of the NRD, this study was deemed exempt from full review by the Institutional Review Board at the University of California, Los Angeles.

Results

Demographic comparison

Of an estimated 89,476 patients with obesity undergoing non-elective laparoscopic cholecystectomy, 40.6 % were classified as *Class 3*. Compared to others, *Class 3* were younger (46 [34–58] vs 52 [39–65] years, $p < 0.001$), more commonly female (72.7 vs 61.6 %, $p < 0.001$), and more often privately insured (44.8 vs 41.5 %, $p < 0.001$). Additionally, *Class 3* were more likely to have diabetes (24.3 vs 23.5 %, $p = 0.04$) and liver disease (14.4 vs 13.0 %, $p < 0.001$), but less frequently had coronary artery disease (6.1 vs 9.5 %, $p < 0.001$; Table 1). Additionally, clinical characteristics were equivalent between patients with class 1 and class 2 obesity, as demonstrated in Supplemental Table 2.

Factors associated with conversion to open

On unadjusted analysis, *Class 3* was more likely to experience CTO compared to others (4.6 vs 3.8 %, $p < 0.001$).

After risk adjustment, *Class 3* was associated with increased odds of CTO (AOR 1.45, 95 % CI 1.31–1.61). Among patient and hospital characteristics, advanced age (AOR 1.03 [Per Year], 95 % CI 1.02–1.03) and lowest income quartile (AOR 1.30, 95 % CI 1.11–1.53; ref.: 76th–100th Quartile) were linked to an increased likelihood of CTO (Table 2). Conversely, female sex (AOR 0.56, 95 % CI 0.51–0.62) and treatment at metropolitan non-teaching hospitals (AOR 0.54, 95 % CI 0.44–0.67; ref.: Non-Metropolitan) were associated with decreased odds of CTO (Table 2).

Table 1
Patient demographics, comorbidities, and clinical characteristics stratified by obesity class among those undergoing laparoscopic cholecystectomy. Continuous variables are represented with median and interquartile range (IQR).

Parameter	Class 1–2 (*n* = 53,152)	Class 3 (*n* = 36,324)	*p*-Value
Age (years, median [IQR])	52 [39–65]	46 [34–58]	<0.001
Elixhauser index (median [IQR])	3 [2–4]	3 [2–4]	0.52
Female (%)	61.6	72.7	<0.001
Income (%)			<0.001
76th–100th quartile	18.4	14.5	
51st-75th quartile	25.1	24.0	
26th–50th quartile	28.2	29.3	
0–25th quartile	28.3	32.2	
Primary payer (%)			<0.001
Private	41.5	44.8	
Medicare	28.9	21.3	
Medicaid	19.1	22.5	
Other	10.6	11.4	
Hospital teaching status (%)			<0.001
Non-metropolitan	7.0	8.7	
Metropolitan non-teaching	26.3	25.0	
Metropolitan teaching	66.7	66.4	
Comorbidities (%)			
Diabetes	23.5	24.3	0.04
Hypertension	50.3	50.2	0.78
Congestive heart failure	5.2	5.9	0.001
Coronary artery disease	9.5	6.1	<0.001
Anemia	2.2	2.7	0.008
Liver disease	13.0	14.4	<0.001
Coagulopathy	2.3	1.8	<0.001
Cancer	1.1	0.9	0.07
Class 1 obesity (%)	52.8	–	
Converted to open (%)	3.8	4.6	<0.001

Table 2
Risk-adjusted odds of conversion to open (CTO) during laparoscopic cholecystectomy. CI, confidence interval.

Parameter	Adjusted odds of CTO	95 % CI	p-Value
Age (per year)	1.03	1.02–1.03	<0.001
Female	0.56	0.51–0.62	<0.001
Elixhauser index	1.19	1.13–1.31	<0.001
Income			
76th–100th quartile	(Ref)	–	–
51st–75th quartile	1.14	0.97–1.34	0.10
26th–50th quartile	1.21	1.03–1.42	0.018
0–25th quartile	1.30	1.11–1.53	0.001
Primary payer			
Private	(Ref)		
Medicare	0.91	0.79–1.04	0.17
Medicaid	0.97	0.84–1.12	0.68
Other	0.93	0.78–1.11	0.42
Hospital teaching status			
Non-metropolitan	(Ref)	–	–
Metropolitan non-teaching	0.54	0.44–0.67	<0.001
Metropolitan teaching	0.80	0.67–0.93	0.003
Class 3 obesity	1.45	1.31–1.61	<0.001

Secondary outcomes

Compared to *Class 1–2*, *Class 3* had greater adjusted odds of experiencing perioperative acute kidney injury (AOR 1.43, 95 % CI 1.30–1.56) in addition to respiratory (AOR 1.39, 95 % CI 1.19–1.62) and infectious (AOR 1.22, 95 % CI 1.03–1.44; Fig. 2) complications. *Class 3* also had an increased likelihood of in-hospital mortality (AOR 3.91, 95 % CI 1.94–7.87).

Additionally, *Class 3* was associated with an incremental increase in LOS (β +0.26 days, 95 % CI 0.21–0.30), higher hospitalization costs (β + $719, 95 % CI 538–899), and higher odds of non-home discharge (AOR 1.77, 95 % CI 1.54–2.03), compared to others. Conversely, *Class 3* was not associated with increased odds of non-elective 30-day readmission (AOR 1.04, 95 % 0.94–1.16).

Subgroup analysis of patients treated at HVC

An annual average of 184 hospitals was included in the analysis, with 38.1 % classified as HVC (Fig. 3). On adjusted analysis, HVC was

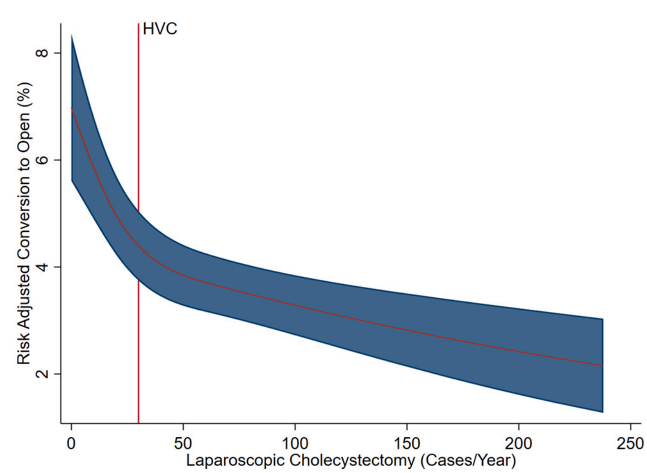

Fig. 3. Risk-adjusted association between hospital volume and conversion to open (CTO). High-volume centers were defined as 30 laparoscopic cholecystectomy cases per year and are denoted on the right as HVC.

associated with a decreased likelihood of conversion to open (AOR 0.80, 95 % CI 0.70–0.90).

On bivariate analysis of patients undergoing LC at HVC, *Class 3* was more likely to experience CTO (4.4 vs 3.3 %, $p < 0.001$), compared to *Class 1–2*. Upon adjustment, *Class 3* remained associated with increased odds of CTO (AOR 1.67, 95 % CI 1.42–1.97). Similarly, *Class 3* was associated with higher risk of experiencing perioperative acute kidney injury (AOR 1.42, 95 % CI 1.21–1.66), respiratory (AOR 1.41, 95 % CI 1.05–1.88), and infectious complications (AOR 1.65, 95 % CI 1.27–2.14). Lastly, *Class 3* remained associated with increased LOS (β +0.26 days, 95 % CI 0.20–0.33), hospitalization costs (β + $699, 95 % CI 480–918), and odds of non-home discharge (AOR 1.48, 95 % CI 1.15–1.90), relative to *Class 1–2*.

CTO vs LC perioperative complications and resource utilization

Compared to *LC*, *CTO* was associated with increased intraoperative (AOR 10.30, 95 % CI 7.96–13.3), blood transfusion (AOR 3.27, 95 % CI 2.54–4.22), and respiratory (AOR 1.36, 95 % CI 1.01–1.85) complications. Yet, *CTO* had similar odds of mortality (AOR 0.60, 95 % CI 0.09–3.88).

Those undergoing CTO had significantly increased risk-adjusted LOS (β +2.20 days, 95 % CI 2.05–2.34) and hospitalization costs (β + $6172, 95 % CI 454–814) compared to LC. Additionally, *CTO* had increased likelihood of non-home discharge (AOR 1.77, 95 % CI 2.17–3.33) and non-elective 30-day readmission (AOR 1.37, 95 % 1.10–1.67).

Additional comparison of planned open and CTO

Relative to *CTO*, *Open* patients were older (59 [47–69] vs 57 [46–67] years, $p = 0.008$), less commonly privately insured (31.8 vs 39.0 %, $p < 0.001$), and were less likely to undergo surgery at a teaching hospital (62.9 vs 69.6 %, $p = 0.002$). *Open* was comparable to *CTO* in obesity class (Class 3; 44.7 vs 45.0 %, $p = 0.16$), diabetes (35.1 vs 32.8 %, $p = 0.17$), and hypertension (62.1 vs 60.7 %, $p = 0.39$; Table 3).

Following adjustment, *Open* was associated with increased odds of acute kidney injury (AOR 1.56, 95 % CI 1.24–1.95), respiratory (AOR 1.62, 95 % CI 1.11–2.37) and infectious (AOR 1.96, 95 % CI 1.26–3.05) complications compared to *CTO*.

Table 3
Patient demographics, comorbidities, and clinical characteristics stratified by approach. Continuous variable presented as median and interquartile range (IQR). Conversion from laparoscopic to open cholecystectomy denoted as CTO. IQR, inter-quartile range.

Parameter	CTO ($n = 3669$)	Open ($n = 2900$)	p-Value
Age (years, median [IQR])	57 [46–67]	59 [47–69]	0.008
Elixhauser index (median [IQR])	3 [2–4]	3 [2–5]	<0.001
Female (%)	51.6	51.2	0.81
Income (%)			0.16
76th–100th quartile	14.5	13.1	
51st–75th quartile	23.8	21.4	
26th–50th quartile	29.3	31.8	
0–25th quartile	32.2	33.7	
Primary payer (%)			<0.001
Private	39.0	31.8	
Medicare	37.1	43.0	
Medicaid	15.0	14.2	
Other	8.9	11.0	
Hospital teaching status (%)			0.002
Non-metropolitan	11.7	14.0	
Metropolitan non-teaching	18.7	23.0	
Metropolitan teaching	69.6	62.9	
Comorbidities (%)			
Diabetes	32.8	35.1	0.17
Hypertension	60.7	62.1	0.39
Congestive heart failure	7.5	10.8	0.002
Coronary artery disease	9.6	12.2	0.02
Anemia	2.4	2.7	0.60
Liver disease	13.6	13.9	0.78
Coagulopathy	2.5	4.2	0.005
Cancer	1.5	2.5	0.05
Obesity class			0.16
1	28.3	31.0	
2	26.7	24.3	
3	45.0	44.7	

Discussion

With the rising prevalence of obesity, an increasing proportion of US adults are at risk of cholecystitis. In light of reports stating over 75 % of cholecystectomies are now performed laparoscopically, a contemporary understanding of LC outcomes among patients with obesity is needed [25]. Using a national cohort of LC patients with obesity, we observed class 3 obesity to be linked with greater risk of CTO and perioperative complications compared to classes 1 and 2. We additionally demonstrated CTO to be associated with increased costs, LOS, and risk of perioperative complications. With implications for the optimal management of acute cholecystitis in patients with obesity, these findings require further discussion.

The present study demonstrates class 3 obesity to be associated with increased risk of CTO and perioperative complications. Laparoscopic cholecystectomy may require an unplanned conversion to an open procedure, most commonly due to inflammation, adhesions, and anatomic difficulty [26]. Among these, anatomic difficulty is often cited as a reason for the link between obesity and increased operative risks in LC, and several conjectures have been made regarding this relationship. A 2015 meta-analysis by Yang et al. indicated visceral fat to be the primary contributor to increased technical difficulties during surgery [27]. In particular, increased visceral fat could limit the exposure of the surgical field and restrict the ability to maneuver instruments, thereby increasing the risk of CTO, operative times, and postoperative infections [27]. Although prior literature has demonstrated the relative safety of LC among patients with obesity, there is a higher risk among those with severely elevated BMI [28,29]. Taken together, our findings underscore the increased risks of perioperative complications following LC associated with severe obesity, even in the present era of greater collective expertise. Patients with obesity should, thus be appropriately counseled on increased perioperative risk of adverse events when engaging in shared decision-making about surgical treatments.

Although CTO is linked with greater risk of complications and death, planned open procedures demonstrated inferior outcomes compared to conversion. Prior studies regarding appendectomy and pancreatectomy have shown CTO confers an increased risk of perioperative bleeding compared to planned open procedures [30,31]. However, our findings support the growing idea that CTO is not a failure but rather a rescue maneuver [31]. CTO, thus, should not be considered as an indicator of poor-quality care [32]. Nevertheless, it remains necessary to identify patients at risk of having required unplanned conversion to open cholecystectomy. In conjunction with the pro-inflammatory state of obesity, the current analysis further identified increasing age and male sex to be associated with a higher likelihood of CTO [33]. While reasons for this are likely multifaceted, inflammation secondary to both age and male sex is a proposed factor [33]. Consequently, laparoscopic procedures should not be avoided solely due to the possibility of CTO. Instead, the constellation of risk factors of each patient should be considered when determining the optimal operative approach to maximize care value.

Although prior work has described improved outcomes at high-volume cholecystectomy centers, the present analysis demonstrated patients with class 3 obesity to experience inferior clinical outcomes regardless of center volume [34–36]. Volume-outcome relationships are postulated to arise from the streamlined perioperative care practices at centers with greater caseloads [37]. Indeed, while high-volume centers outperformed low-volume hospitals in the present analysis, the improvement in clinical outcomes observed was not sufficient to mitigate the independent risk associated with class 3 obesity. With a growing obese population, the characterization of factors influencing the quality of treatment for patients with obesity is increasingly warranted. Interestingly, a 2021 retrospective study suggested an association between increasing bariatric surgery facility volume and reduced complications following non-bariatric general surgery procedures among obese patients [38]. Our findings illustrate the relevance of such research, given that hospital volume of LC alone may not sufficiently mitigate poor outcomes for patients with obesity requiring cholecystectomy. Education regarding the specific challenges posed by obese anatomy may help address the unique health risks associated with class 3 obesity.

The present study is not without limitations. Given its utilization of an administrative database, the study is subjected to potential variation in coding practices across centers, coding errors, and missing values. The present work is also restricted to patients with obesity due to demonstrated significant under-coding among non-obese individuals [39]. More granular data, including specific lab values, perioperative imaging, decision-making related to operative approach, intraoperative findings, and exact BMI, could not be ascertained from the NRD. Lastly, the nature of retrospective cohort studies precludes any identification of causal relationships. Despite these limitations, the present work utilizes robust statistical methodology and a large contemporary dataset to identify important risk factors for CTO in cholecystectomy among patients with obesity.

In conclusion, the current study identified an increased risk of CTO among those with class 3 obesity. Additionally, planned open procedures were associated with increased perioperative complications relative to CTO. Moreover, traditional quality benchmarks, including center-level volume of LC, may not be sufficient to mitigate the risks associated with severe obesity. Novel preoperative assessments are needed to accurately quantify the perioperative risk among this unique population. The present study has important implications for the risk stratification and counseling of patients with obesity undergoing laparoscopic cholecystectomy.

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Ethical approval statement

Due to the deidentified nature of the NRD, this study was deemed exempt from full review by the Institutional Review Board at the University of California, Los Angeles.

CRediT authorship contribution statement

Troy N. Coaston: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Amulya Vadlakonda:** Conceptualization, Data curation, Formal analysis, Validation, Writing – original draft, Writing – review & editing. **Joanna Curry:** Conceptualization, Methodology, Writing – review & editing. **Saad Mallick:** Conceptualization, Methodology, Writing – review & editing. **Nguyen K. Le:** Conceptualization, Writing – review & editing. **Corynn Branche:** Conceptualization. **Nam Yong Cho:** Visualization. **Peyman Benharash:** Conceptualization, Data curation, Methodology, Resources, Software, Supervision, Visualization, Writing – review & editing.

Declaration of competing interest

Author PB received proctor fees from Atricure as a surgical proctor. All other others declare no financial or non-financial competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sopen.2024.05.005.

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