2016

# Impact of patient factors on operative duration during laparoscopic cholecystectomy: evaluation from the National Surgical Quality Improvement Program database

Bethany Rose Lowndes
*University of Nebraska-Lincoln*

Cornelius A. Thiels
*Mayo Clinic*

Elizabeth B. Habermann
*Mayo Clinic*

Juliane Bingener
*Mayo Clinic*

M. Susan Hallbeck
*Mayo Clinic*, hallbeck@unl.edu



*See next page for additional authors*



Lowndes, Bethany Rose; Thiels, Cornelius A.; Habermann, Elizabeth B.; Bingener, Juliane; Hallbeck, M. Susan; and Yu, Denny, "Impact of patient factors on operative duration during laparoscopic cholecystectomy: evaluation from the National Surgical Quality Improvement Program database" (2016). *Mechanical & Materials Engineering Faculty Publications*. 269.
http://digitalcommons.unl.edu/mechengfacpub/269

The American Journal of Surgery (2016) 212, 289-296

The American Journal of Surgery®

Clinical Science

# Impact of patient factors on operative duration during laparoscopic cholecystectomy: evaluation from the National Surgical Quality Improvement Program database

**Bethany Lowndes, Ph.D.[a,b], Cornelius A. Thiels, D.O.[a,c], Elizabeth B. Habermann, Ph.D.[a,c], Juliane Bingener, M.D.[a,c], Susan Hallbeck, Ph.D.[a,b,c,*], Denny Yu, Ph.D.[a]**

[a]*Mayo Clinic, Health Sciences Research, 200 First Street SW, Rochester, MN 55905, USA;* [b]*Department of Mechanical and Material Engineering, University of Nebraska-Lincoln, 1400 R Street, Lincoln, NE 68588, USA;* [c]*Mayo Clinic, Department of Surgery, 200 First Street SW, Rochester, MN 55905, USA*

**KEYWORDS:**
Laparoscopic cholecystectomy;
Patient factors;
Procedure duration;
Procedural difficulty;
NSQIP;
Science of health care delivery

**Abstract**

**BACKGROUND:** Patient factors impact laparoscopic cholecystectomy (LC) difficulty, specifically operative duration. This study quantifies the impact of patient factors on LC duration.

**METHODS:** The national surgery database (American College of Surgeons National Surgical Quality Improvement Program) was reviewed for all elective LC for biliary colic from 2005 to 2013. Multivariate general linear model and logistic regression were used to evaluate patient factors as predictors of operative duration greater than 60 minutes, adjusted for resident involvement and cholangiography.

**RESULTS:** A total of 24,099 LC met inclusion criteria. Regression analysis found procedure duration greater than 60 minutes was less likely for patients age greater than 40 and less than 30 ($P < .001$) and more likely for men ($P < .05$), body mass index (BMI) greater than 30 compared with BMI 18.5 to 24.9 ($P < .05$), abnormal liver function test (LFT) ($P < .05$), and higher ASA class ($P < .05$). Smoking, cardiovascular disease, chronic obstructive pulmonary disease, diabetes, and abnormal white blood cell count were not significant predictors.

**CONCLUSIONS:** Higher BMI, younger age, male gender, higher ASA, and abnormal LFTs are possible predictors of prolonged LC duration and can aid in operating room scheduling and utilization.


B.L. is supported through research grants from AHRQ and Stryker Endoscopy. C.A.T. and E.B.H. have nothing to disclose. S.H. has research funding from Stryker Endoscopy and Midwest Center for Occupational Health and Safety Education and Research Center. J.B. is supported through a research grant (NIDDK), specified research through Nestle and Stryker Endoscopy, has received travel support from Intuitive Surgical, and serves on the Surgeon Advisory Board for Titan Medical. D.Y. reports grants support from Stryker Endoscopy, Midwest Center for Occupational Health and Safety Education and Research Center, and AcademyHealth outside this submitted work.

* Corresponding author. Tel.: +1-507-284-0450; fax: +1-507-538-7957.

E-mail address: hallbeck.susan@mayo.edu

Manuscript received August 28, 2015; revised manuscript December 31, 2015


http://dx.doi.org/10.1016/j.amjsurg.2016.01.024

Patient factors including age, body mass index (BMI), and gender are known to impact the difficulty of laparoscopic cholecystectomy (LC) procedures and the risk for adverse patient outcomes.[1,2]

As procedure difficulty increases (eg, sicker patients and/or more complex cases), operative costs, operative duration, and surgeon workload may also increase.[3–7] Many studies have recognized the importance of integrating patient factors such as age and obesity into scoring systems that predict procedure difficulty and conversion-to-open risk for surgical planning and patient-risk consent.[3–7] These predictions may identify prolonged duration of cases to balance caseload and to maintain patient and surgeon satisfaction, as well as enhancing operating room (OR) utilization. However, existing scoring systems and models require intraoperative variables such as the presence of scarring and anatomic abnormalities that limit the application of these models across institutions and patient populations.

Predicting the duration of a surgical case is notoriously unreliable and difficult. Both overestimating and underestimating duration can have negative effects on quality of care, staffing, hospital efficiency, and surgeon efficiency. In addition, patient and surgeon satisfaction are negatively impacted when cases are delayed.[8] Current practice often involves computer algorithms that use historical durations for common Current Procedural Terminology (CPT) codes as a predictor for operative duration,[9,10] which is not sufficient. For example, one large nonprofit institution uses institutional experience for each CPT code and augments this with surgeon-specific experience using a computer-based platform. Similarly, other studies have noted improvements with models adjusted for complexity and/or allowing the surgeon to modify the predicted duration.[11–13] Although better than subjective predictions, these systems remain imperfect and result in high variability and lost efficiency.[14,15] Efforts are being made to improve these models; however, limited work has been published on using patient-specific factors to predict operative duration. Yet, it is known that patient factors are predictive of complications.[16] Therefore, improving the prediction of operative duration based on patient-specific factors has the potential to increase OR efficiency and utilization and reduce cost.

Patient-factor driven models for operative duration will be especially helpful in providing health systems a tool to better understand operative difficulty and workload. By predicting case difficulty, a flexible tool can be developed to allow health systems to better adapt to changing population demographics. The population in the United States is aging with individuals older than aged 65 years expected to exceed 19% by 2030.[17] In addition, the prevalence of obesity in the country has increased over the past 20 years with over 30% of Americans classified as obese.[18] As population demographics change,[17,18] their impact on surgical duration and difficulty will similarly be affected; however, demographic trends for LC patients are unknown, and the associated impact on procedural difficulty is not clear. Therefore, an analysis of a national database could help identify readily available patient factors that are more predictive of prolonged LC across geographic areas and between multiple institutions.

The purpose of this study is to identify patient factors that impact operative duration using a large, multicenter database. The specific aims of this study include: (1) defining a patient-factor based risk model for LC patients using the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database, (2) evaluating distributions of LC patient factors over time, and (3) applying the patient-factor model to the NSQIP data to determine the impact on surgical duration. We hypothesize that this information, in conjunction with future prospective studies, could help further understanding on procedural difficulty and aid in surgical planning through OR scheduling and utilization.

## Methods

### Data source

Data were queried from the ACS-NSQIP database. NSQIP collects data on 135 variables for patients undergoing surgical procedures. Currently, over 600 hospitals participate in the program. Specific details regarding data collection and outcome variable definitions are available on the NSQIP website (https://www.facs.org/quality-programs/acs-nsqip).

### Patient factors for model

Factors for inclusion in the model were identified from a review of previous works quantifying the relationship between patient factors and measures of procedure difficulty, eg, operative duration and probability of conversion to open, were identified (Table 1). From the 13 applicable articles,[3–5,7,19–26] the following demographics and preoperative patient factors were used in the model (predictor used in other models [statistically significant predictor in other models]): gender (11[3] of 13 articles), age (11[4] of 13), BMI (11[6] of 13), American Society of Anesthesiologists (ASA) class (3[1] of 13), diabetes mellitus (3[1] of 13), white blood cell count (WBC; 4[3] of 13), and LFT (3[2] of 13). Therefore, these 7 patient factors were included in our model along with chronic obstructive pulmonary disease (COPD) and smoking. Ultrasonography factors such as identified gallstones, contracted gallbladder, pericholecystic fluid collection, and impacted stone were additional patient factors that were potentially predictive of a difficult procedure.[3–7] In addition, other clinical measures including medical history (abdominal scarring and previous abdominal surgery) and physical examination (palpable gallbladder and abdominal tenderness) were potential patient factor predictors of a difficult procedure. However, the variables of ultrasonography and history of present illness are not available in NSQIP.

**Table 1** Summary of patient factors difficulty predictors from literature

| Author | Clinical factors | Ultrasonography factors | Intraoperative factors |
|---|---|---|---|
| Lal et al | | GB wall thickness,* contracted GB,* impacted gallstones,* and CBD stones* | |
| Randhawa J. S. | Age, sex, BMI,* hospitalization,* previous upper abdominal surgery, palpable GB* | Pericholecystic collection, impacted stone, impacted stone, GB wall thickening* | Abdominal scarring |
| Vivek M. A. K. M. et al 2014 | Age,* sex,* previous upper abdominal surgery,* BMI >30,* abnormal LFT,* previous attacks,* cirrhosis,* previous upper abdominal surgery* | Multiple stones,* distended GB* | Adhesions, anatomic abnormalities,* inflamed GB |
| Gupta N. | Age, sex, BMI, hospitalization,* palpable GB* | Thickened GB wall (≥4 mm),* impacted stone*, pericholecystic collection, impacted stone | |
| Prabhu R. Y. | Sex, BMI >30, history of acute cholecystitis | Wall thickness >3 mm, contracted GB, dilated CBD (>6 mm) | Adhesions |
| Rosen M. | Age,* BMI,* acute cholecystitis,* WBC,* bilirubin,* tender right upper quadrant,* ASA,* CVD, DM | GB wall thickness* | |
| Hussain A. | Age, sex, BMI >30, previous upper abdominal surgery, cirrhosis | GB wall thickening, CBD >6 mm, pericholecystic collection, impacted stone | Anatomic abnormalities |
| Kahn I. A. | Age, sex, WBC, timing of onset of symptoms | GB wall thickening | |
| Lee N. W. | Age,* sex,* BMI, DM* previous upper abdominal surgery* | Pericholecystic collection,* GB wall thickening* | GB inflammation |
| Kama N. A. | Age, sex,* BMI,* abdominal tenderness, previous abdominal surgery,* WBC,* LFT | GB wall thickening* | Adhesions |
| Dhanke P. S. | Age, sex, BMI >27.5,* palpable GB,* hospitalization* | Impacted stone,* pericholecystic collection,* GB wall thickening* | |
| Alpont et al. | Age, sex, BMI, ASA, LFT,* WBC,* previous abdominal surgery, right upper quadrant tenderness,* CVD, cirrhosis, DM | GB wall thickening* | Number of stones, size of stones |
| Abelson J. et al | Age,* sex, race, BMI* (>80 kg), ASA, LFT,* previous abdominal surgery* | | |

ASA = American Society of Anesthesiologists; BMI = body mass index; CBD = common bile duct; CVD = cardiovascular disease; DM = diabetes mellitus; GB = gallbladder; WBC = white blood cell count.

*Statistically significant at $P < .05$. Other variables were either not significant, or not tested in a statistical model for these studies.

## Design of the database sample

The ACS-NSQIP was reviewed for all laparoscopic cholecystectomies from 2005 to 2013. Patients with CPT codes for laparoscopic cholecystectomies (47,562 or 47,563) and with a diagnosis of calculus of the gallbladder without cholecystitis (termed biliary colic, International Classification of Disease (ICD)-9 diagnosis code 574.2) were included in the analysis.

## Exclusions

In an attempt to minimize ambiguity of diagnosis, patients with any of the following preoperative conditions were excluded: emergent operation (n = 1,308), only the resident performing the case (n = 12), ASA class 5 (n = 3), being ventilator dependent (n = 9), in severe sepsis or septic shock (n = 512), current pneumonia (n = 10), open wound or wound infection (n = 112), acute renal failure (n = 15), greater than 4 units red blood cells in prior 72 hours (n = 20), preoperative dialysis (n = 122), and disseminated cancer (n = 78). To reduce confounding and to create a sample population that best represents elective operations, we excluded all patients with concurrent operations except: exploratory laparotomy (proxy for conversion to open), intraoperative cholangiography, lysis of adhesions, or stone retrieval procedures (n = 1,943 excluded).

## Demographic characteristics

Patient demographic characteristics identified and categorized, included gender, age (<30, 30 to 39, 40 to 49, 50 to 59, 60 to 69, and 70+ years), year of operation, ASA class (1-no disturb, 2-mild disturb, 3-severe disturb, and 4-severe disturb with constant threat to life), COPD, diabetes mellitus, smoking, and BMI (<18.5, 18.5 to 24.9, 25.0 to 29.9, 30.0 to 34.9, 35.0 to 39.9, and 40+ kg/m$^2$). Abnormal preoperative bilirubin (defined as ≥1 mg/dL), alkaline phosphatase (defined as ≥150 IU/L), and AST (aspartate aminotransferase, abnormal defined as >40 U/L) were used as a proxy for liver function test (LFT) or liver disease. Preoperative WBC was also examined, and abnormal WBC was defined as ≥12. History of myocardial infarction 6 months before surgery, previous percutaneous coronary intervention, history of angina in the 1 month before surgery, or previous cardiac surgery was used as a proxy for cardiovascular disease (CVD).

### Outcome variables

The primary outcome considered in this study was operative duration greater than 60 minutes, a consistent measure of LC difficulty[1,4,5,20] that was available in the NSQIP database. Other previously published difficulty outcome measures for LC such as conversion to open and bile or stone spillage were not available in the NSQIP database.

### Statistical analysis

Multivariate general linear model-analysis of variance was completed to compare patient factors with the dependent variables age and BMI and the independent variables gender and year ($\alpha = .05$). Binary logistic regressions were used to analyze the relationship between the dependent factor of operative duration with 13 predictors at a threshold for significance of $\alpha = .05$.

ACS-NSQIP is well known for having missing data, particularly for laboratory values as they are not always ordered by the physician. Because of missing data, 3 separate analyses were conducted to understand the impact these missing data may have on the conclusions: (1) excluding patients with any missing data (final n = 11,217), (2) keeping all patients and creating a separate level for each predictor for missing factors (n = 23,986), and (3) multiple imputation (n = 22,799) as suggested for NSQIP by Parsons et al 2011.[27] The multiple imputation (MI) method estimates missing variables using variables with known values available for each patient. MI with 5 imputations was performed for predictors missing more than 1% of data, ie, BMI (2.4%), abnormal WBC (16.5%), abnormal LFT (21.7%), and attending supervision (34.5%). Imputation was not performed for variables missing less than 1%, ie, sex (.27%) and ASA (.14%), or the dependent variable. Logistic regression parameters from MI method were pooled to estimate the effect of each parameter.

## Results

### Patient factors distribution and operative duration

Between 2005 and 2013, a total of 24,099 cases of LC for biliary colic were identified. The gender distribution remained consistent with females making up at least three-fourths of the LC cases. The percent of patients that were male varied between 21.0% and 23.4% over these 8 years but no specific trend was noted.

Patient age differed statistically across the 8-year study period ($P = .048$). The percentage of NSQIP LC patients above aged 65 years ranged from 10.2% to 15.4% for women and between 22.2% and 29.1% for men over the course of the study with random variation year to year and no trend during this time period. Although patient BMI differed across the years with higher percentages of both females and males over 30 kg/m$^2$ in 2013 (52.2% and 45.2%, respectively) than in 2005 (51.6% and 31.5%, respectively), there was no statistical significance. In addition, over the entire 8 years, there were more women than men with a BMI above 30 ($P < .001$), and the patient age distribution varied between women and men ($P < .001$) with more men over 65 years of age. In Fig. 1, this is demonstrated by the separation between the two trends over the 8 years as the percentage of males with a high BMI grows faster than the percentage of women.

Between 2005 and 2013, operative duration for the LC procedures exceeded 60 minutes for 40% to 60% of cases with a mean ± standard deviation of 70.0 ± 39.8 minutes for men and 64.1 ± 34.4 minutes for women.

### Model for predicting procedure duration

Because of missing data in the database, the logistic regression was run with 3 different methods of handling missing data according to previously described methods.[27] The models excluding patients with missing data, imputing

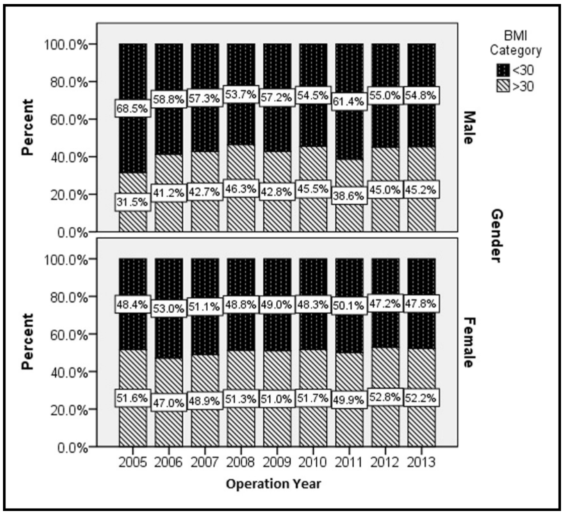


**Figure 1** ACS-NSQIP LC patient BMI distribution by gender and operation year (operyr) 2005 to 2013. Percentage of NSQIP LC patients with BMI greater than 30 kg/m$^2$ by gender This graph displays the percent of male and female LC patients who are obese (BMI over 30 kg/m$^2$) in the NSQIP database between 2005 and 2013. A higher percentage of females are in the obese category throughout the sampled years.

missing values, and creating separate variable categories for missing data resulted in areas under the curve of .71, .65, and .68, respectively. Due to few, minor differences in results, the method of including missing data as a separate category when necessary was selected.

Age, gender, BMI, ASA, and abnormal LFT were statistically significant factors in the logistic regression model for patient factors predicting prolonged procedure duration, defined as operative duration greater than 60 minutes (Table 2). The highest patient factor odds ratios for prolonged surgical duration was 1.96 times higher for patients with a BMI over 40 compared with a healthy BMI (18.5 to 24.9 kg/m$^2$; $P < .001$). The patient factors of smoking, COPD, diabetes, and abnormal WBC were not statistically significant.

Procedure duration was also influenced by nonpatient factors. Odds for longer procedures were 1.77 times higher for LC procedures with cholangiography (CPT code 47,563) vs no cholangiography (CPT code 47,562; $P < .001$). Patients were 4.55 times as likely to have a prolonged procedure when a resident was assisting the attending ($P < .001$).

**Table 2** Linear regression model for LC patient factors from ACS-NSQIP 2005 to 2013

| Predictors | N, total (n = 24,032) | % Of category with prolonged procedure time (>60 minutes) | Results: Odds ratio | Results: 95% confidence interval |
|---|---|---|---|---|
| CPT* | | | | |
| 47,563 | 4,995 | 58.3 | 1.77# | 1.66–1.90 |
| Attending† | | | | |
| Attending & resident in OR | 11,305 | 58.9 | 4.55# | 4.20–4.93 |
| Missing | 8,260 | 46.5 | 2.71# | 2.49–2.94 |
| Age, y‡ | | | | |
| 30–39 | 4,684 | 49.7 | 1.00 | .92–1.10 |
| 40–49 | 4,773 | 47.7 | .88# | .81–.96 |
| 50–59 | 4,450 | 49.7 | .96 | .87–1.05 |
| 60–69 | 3,272 | 45.6 | .77# | .70–.86 |
| 70+ | 2,528 | 45.3 | .75# | .66–.84 |
| Male | 5,462 | 53.0 | 1.35 | 1.27–1.45 |
| BMI§ | | | | |
| 18.5–24.9 | 4,565 | 43.5 | .96 | .74–1.25 |
| 25–29.9 | 7,077 | 45.4 | 1.08 | .99–1.16 |
| 30–34.9 | 5,509 | 47.8 | 1.20# | 1.10–1.30 |
| 35–39.9 | 3,174 | 51.2 | 1.35# | 1.23–1.49 |
| 40+ | 2,839 | 60.4 | 1.96# | 1.76–2.18 |
| Missing | 567 | 56.4 | 1.37# | 1.14–1.65 |
| ASA‖ | | | | |
| Class 2 | 14,978 | 47.4 | 1.07 | .98–1.16 |
| Class 3 | 5,286 | 53.2 | 1.25# | 1.13–1.39 |
| Class 4 | 280 | 58.2 | 1.57# | 1.19–2.06 |
| LFT | | | | |
| Abnormal | 3,403 | 56.3 | 1.22# | 1.12–1.32 |
| Missing | 5,218 | 41.8 | .79# | .73–.86 |
| Smoker | 4,381 | 49.7 | .99 | .92–1.06 |
| CVD | 96 | 43.8 | .64# | .42–.99 |
| COPD | 507 | 46.2 | .83 | .68–1.00 |
| Diabetes | 2,360 | 52.6 | .92 | .84–1.01 |
| WBC | | | | |
| Abnormal | 1,076 | 50.7 | .98 | .86–1.11 |
| Missing | 3,952 | 43.2 | .94 | .86–1.03 |
| No other CPT¶ | 23,131 | 47.9 | .54 | .47–.63 |
| Constant | | | .45# | |

ASA = American Society of Anesthesiologists; BMI = body mass index; CPT = Current Procedural Terminology; COPD = chronic obstructive pulmonary disease; CVD = cardiovascular disease; WBC = white blood cell count.

*Odds ratios compared with CPT code 47,562.

†Odds ratios compared with attending only.

‡Odds ratios compared with less than 30 years of age.

§Odds ratios compared with BMI less than 18.5.

‖Odds ratios compared with ASA class 1. ¶Odds ratios compared with an additional CPT code.

#$P < .05$.

The resulting regression model was statistically significant in predicting a prolonged LC procedure $\chi^2(27, n = 23,986) = 2451.42$, $P < .001$. Cases with observed operative duration less than 60 minutes were classified correctly 62% of the time, whereas cases with observed operative duration greater than 60 minutes were classified correctly 63.3% of the time. Fig. 2 displays the sensitivity of the model and the receiver operating characteristic curve for the regression model with an included area under the curve of .68.

## Comments

Age, gender, BMI, ASA, and abnormal LFT are significant predictors of difficult procedures, defined as operative duration over 60 minutes. Despite their inclusion in other available predictive models, COPD, diabetes, smoking, WBC, and cardiovascular disease were not statistically significant in this regression model as predictors of prolonged operative duration. Although some of these factors were included in some models, they were not significant factors in all studies as there was low agreement for these factors among studies as displayed in Table 1 (ie, 3 of 13 for diabetes). It is possible that other patient factors or patient independent factors not previously described may be more important in predicting prolonged operative duration and difficult operations.

The population in the United States is becoming older[17] and more obese,[18,28] and similar trends were found in patient factors for LC patients, which could increase the number of difficult cases which in turn decrease both patient satisfaction and provider health.[8,29,30] In the years analyzed in this study, the percent of patients with a BMI over 30 increased by nearly 12% for males and remained relatively constant females (Fig. 1). This trend may be a concern for the providers, as this change in the patient population could increase the chance of higher procedural difficulty. Although the trend is consistent with the increasing BMI in the US population overall, the magnitude of the increase in overweight LC patients is larger than what we would expect from the population data.[28] These more difficult procedures may impact the health care system by preventing the lowest procedure costs and increasing the patients' risks of complication.

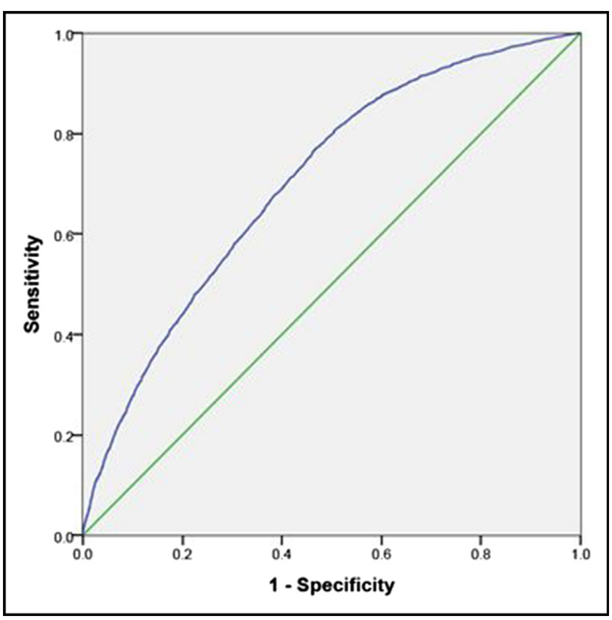


**Figure 2** ROC curve for linear regression model displaying the true positive (Sensitivity) and false positive (1-Specificity) rate for the model compared to the 45-degree diagonal line. This is the receiver operating characteristic curve for the linear regression model of the patient factors model applied to the LC NSQIP patients between the years from 2005 to 2013.

In addition to the impact of BMI, both gender and age were important patient factors for predicting difficult LC based on operative duration. For the impact of age on the difficulty of the LC procedures, it was expected that older age increased the odds of a difficult LC.[22,31] However, our analysis suggests that younger age is actually more predictive of a difficult procedure. We hypothesize that this could be because of other patient factors that may be associated with age as there appears to be some collinearity in the model (such as between age and ASA). In addition, younger patients may delay treatment because of covering up pain or holding out longer before the operation, leading to increased inflammation while older patients may recognize the symptoms and seek treatment sooner. Further research is needed to better understand if another factor is actually the cause of this relationship between age and extended operative duration and if age is just a confounding factor. There is controversy in the literature about using gender as a predictor of LC procedural difficulty with research both supporting[23,32,33] and refuting[4] its impact. It is hypothesized that the increased difficulty with male patients may be because of increased adhesions.[33] Because adhesions have been identified as possible predictors of a difficult procedure,[5,19,26] further studies are warranted to investigate potential interactions between adhesions and gender on procedural difficulty. This is critical as there was an observed imbalance in the gender distribution consistent with the literature with between 60% and 80% of LC patients being female.[3,6,34] However, if the age and BMI of patients undergoing LC continue to follow the same trends, the number of difficult procedures may also increase.

We propose that our model, which uses readily available presurgical patient factors, is an effective tool for predicting operative duration. In addition, this can be used to estimate procedural difficulty. Although the model does not contain ultrasonography[7] and intraoperative factors published in previous studies,[19,26] preoperative; these readily available factors like age, sex, BMI, ASA, and LFT may be valuable predictors of difficult LC procedures. An added benefit is that the factors used in this model can be readily obtained from national databases and or other institutional data sets. Despite the respectable ROC curve (.68), the model could potentially be improved by including more postsurgical patient factors and by including more descriptions of difficult procedures, such as conversion rate, which have been used in other models.[5,6,20,23] However, in this model, we were looking at prediction with data available before the surgery, not fitting retrospective data. We recommend that this model be validated with an institutional retrospective review and/or other national databases using the data available before surgery.

Although the LC procedure is a fairly routine procedure that is performed in high volumes, an increase in difficult procedures, as defined by operative duration over 60 minutes, will inherently expose the surgeons and hospitals to a higher workload.[29,30] The patient-factor-based model can provide a tool sensitive to operative duration and can be used to help address the significant challenge that the unexpected variations in operative duration pose to hospitals worldwide. The potential to improve efficiency in regard to surgical scheduling and OR utilization would have significant implications for the surgeon, the patients, and the health system. A better understanding of the patient factors that lead to LC procedural difficulty and how the resulting operative duration may lead to increased surgeon workload will aid in accurate caseload balancing systems and optimal patient safety practices. Surgical scheduling systems that use patient factors could potentially be used to maximize a surgeon's caseload with a significant impact given that even small improvements in utilization rates have the potential to greatly reduce cost and may even improve patient, surgeon, and staff satisfaction with better operative scheduling. Further research using institutional factors is needed to improve the predictive ability of the model at a particular institution before it can be applied to clinical practice; however, we feel this national database study provides important baseline data that will be useful when designing future studies and quality improvement projects.

## Limitations

This study was limited by the availability of patient factors in the NSQIP data including ultrasonography and intraoperative conditions, which other models have found to be highly predictive. Because of the coding system in NSQIP, single port and transvaginal procedures could not be identified. Although it is anticipated that the quantity of these procedures are small, the presence of these procedures in the data set may skew some of the results. In addition, our focus on LC was narrow and future studies looking at a variety of indications as well as concurrent procedures may be beneficial. Large databases such as the one used in this study often contain missing data which may potentially introduce bias. However, to reduce some of the bias, imputation, exclusion of missing data, and the inclusion of missing data as a separate category were all considered, resulting in 3 regression models with very similar findings. In addition, as NSQIP is a sample of LC procedures in the United States and the data are limited by the institutions that are included in this reporting process and their sampling strategy, international data, and data from nonparticipating institutions may impact the model. Using operative duration as the only measure of LC procedural difficulty is not the most accurate or inclusive definition of difficulty; however, it is what can be done with the NSQIP data base. An institutional study is needed to include other LC difficulty measures such as conversion to open, bile spillage, and stone spillage; which are postsurgery predictors of extended surgical duration and procedural difficulty as noted in Table 1. The inclusion of these measures may impact the predictive power of different patient factors and improve estimates of error or sensitivity for predicting procedural difficulty. At last, while beneficial for predicting LC duration, this model is not predictive for other operations. However, similar models looking at other common operations may be worth developing.

## Conclusions

Patient-specific factors including increased BMI, decreased age, male gender, increased ASA, and abnormal LFT are significant predictors of prolonged LC duration and may be indicators of increased procedural difficulty. As a regression model, when applied to NSQIP LC patients, the model is able to differentiate between operative duration above and below 60 minutes and therefore provide information for surgical planning and potentially improve both patient and provider satisfaction as well as OR utilization.

## Acknowledgments

This article was supported by The National Institute of Diabetes and Digestive and Kidney Diseases (K23 DK 93553) and Mayo Clinic's Department of Surgery Research. Also, this publication was made possible by funding from the Mayo Clinic Robert D. and Patricia E. Kern Center for the Science of Health Care Delivery.

## References

1. Sugrue M, Sahebally SM, Ansaloni L, et al. Grading operative findings at laparoscopic cholecystectomy- a new scoring system. World J Emerg Surg 2015;10:14.
2. Yang T, Guo L, Wang Q. Evaluation of preoperative risk factor for converting laparoscopic to open cholecystectomy: a meta-analysis. Hepatogastroenterology 2014;61:958–65.
3. Gupta N, Ranjan G, Arora MP, et al. Validation of a scoring system to predict difficult laparoscopic cholecystectomy. Int J Surg 2013;11:1002–6.
4. Dhanke PS, Ugane SP. Factors predicting difficult laparoscopic cholecystectomy: a single-institution experience. Int J Students Res 2014;4:5.
5. Randhawa JS, Pujahari AK. Preoperative prediction of difficult lap chole: a scoring method. Indian J Surg 2009;71:198–201.
6. Singh K, O A. Difficult laparoscopic cholecystecomy: a large series from north India. Indian J Surg 2006;68:205–8.
7. Rosen M, Brody F, Ponsky J. Predictive factors for conversion of laparoscopic cholecystectomy. Am J Surg 2002;184:254–8.

8. Richins S, Holmes M. Waiting for satisfaction. J Healthc Manag 1998;43:281–5.
9. Stepaniak PS, Heij C, Mannaerts GH, et al. Modeling procedure and surgical times for current procedural terminology-anesthesia-surgeon combinations and evaluation in terms of case-duration prediction and operating room efficiency: a multicenter study. Anesth Analg 2009;109:1232–45.
10. Strum DP, Sampson AR, May JH, et al. Surgeon and type of anesthesia predict variability in surgical procedure times. Anesthesiology 2000;92:1454–66.
11. Dexter F, Epstein RH, Lee JD, et al. Automatic updating of times remaining in surgical cases using bayesian analysis of historical case duration data and "instant messaging" updates from anesthesia providers. Anesth Analg 2009;108:929–40.
12. Balust J, Egger Halbeis CB, Macario A. Prevalence of anaesthesia information management systems in university-affiliated hospitals in Europe. Eur J Anaesthesiol 2010;27:202–8.
13. Egger Halbeis CB, Epstein RH, Macario A, et al. Adoption of anesthesia information management systems by academic departments in the United States. Anesth Analg 2008 Oct;107:1323–9.
14. Zhou J, Dexter F, Macario A, et al. Relying solely on historical surgical times to estimate accurately future surgical times is unlikely to reduce the average length of time cases finish late. J Clin Anesth 1999;11:601–5.
15. Wright IH, Kooperberg C, Bonar BA, et al. Statistical modeling to predict elective surgery time. Comparison with a computer scheduling system and surgeon-provided estimates. Anesthesiology 1996;85:1235–45.
16. Bilimoria KY, Liu Y, Paruch JL, et al. Development and evaluation of the universal ACS NSQIP surgical risk calculator: a decision aid and informed consent tool for patients and surgeons. J Am Coll Surg 2013;217:833–842.e1-3.
17. Prevention CfDCa. Mmwr series on public health and aging. MMWR Morb Mortal Wkly Rep 2003;52:6.
18. Yang L, Colditz GA. Prevalence of overweight and obesity in the United States, 2007-2012. JAMA Intern Med 2015;175:1412–3.
19. Vivek M, Augustine AJ, Rao R. A comprehensive predictive scoring method for difficult laparoscopic cholecystectomy. J Minim Access Surg 2014;10:62–7.
20. Lal P, Agarwal PN, Malik VK, et al. A difficult laparoscopic cholecystectomy that requires conversion to open procedure can be predicted by preoperative ultrasonography. JSLS 2002;6:59–63.
21. Prabhu RY, Irpatgire R, Naranje B, et al. Influence of timing on performance of laparoscopic cholecystectomy for acute biliary pancreatitis. Trop Gastroenterol 2009;30:113–5.
22. Hussain A. Difficult laparoscopic cholecystectomy: current evidence and strategies of management. Surg Laparosc Endosc percutaneous Tech 2011;21:211–7.
23. Kama N, Doganay M, Dolapci M, et al. Risk factors resulting in conversion of laparoscopic cholecystectomy to open surgery. Surg Endosc 2001;15:965–8.
24. Alponat A, Kum CK, Koh BC, et al. Predictive factors for conversion of laparoscopic cholecystectomy. World J Surg 1997;21:629–33.
25. Abelson JS, Afaneh C, Rich BS, et al. Advanced laparoscopic fellowship training decreases conversion rates during laparoscopic cholecystectomy for acute biliary diseases: a retrospective cohort study. Int J Surg 2015;13:221–6.
26. Lee NW, Collins J, Britt R, et al. Evaluation of preoperative risk factors for converting laparoscopic to open cholecystectomy. Am Surg 2012;78:831–3.
27. Parsons HM, Henderson WG, Ziegenfuss JY, et al. Missing data and interpretation of cancer surgery outcomes at the American College of Surgeons National Surgical Quality Improvement Program. J Am Coll Surg 2011;213:379–91.
28. Fryar CD, Carroll MD, Ogden CL. Prevalence of Overweight, Obesity, and Extreme Obesity Among Adults: United States, Trends 1960–1962 through 2009–2010. Hyattsville, MD: National Center for Health Statistics; 2012.
29. Park A, Lee G, Seagull FJ, et al. Patients benefit while surgeons suffer: an impending epidemic. J Am Coll Surg 2010 Mar;210:306–13.
30. Sari V, Nieboer TE, Vierhout ME, et al. The operation room as a hostile environment for surgeons: physical complaints during and after laparoscopy. Minim Invasive Ther Allied Technol 2010 Apr;19:105–9.
31. Lee SW, Lee JY, Kim KH, et al. Laparoendoscopic single-site surgery versus conventional laparoscopic varicocele ligation in men with palpable varicocele: a randomized, clinical study. Surg Endosc 2012;26:1056–62.
32. Zisman A, Gold-Deutch R, Zisman E, et al. Is male gender a risk factor for conversion of laparoscopic into open cholecystectomy? Surg Endosc 1996;10:892–4.
33. Lein HH, Huang CS. Male gender: risk factor for severe symptomatic cholelithiasis. World J Surg 2002;26:598–601.
34. Tiong L, Oh J. Safety and efficacy of a laparoscopic cholecystectomy in the morbid and super obese patients. HPB (Oxford) 2015;17:600–4.