Patient Safety in Surgery

RESEARCH

Open Access

Association between postoperative complications and hospital length of stay: a large-scale observational study of 4,495,582 patients in the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) registry

Garrett L. Healy[1*], Christina M. Stuart[1], Adam R. Dyas[1], Michael R. Bronsert[1,2], Robert A. Meguid[1,2], Tochi Anioke[1], Ahmad M. Hider[1], Richard D. Schulick[1] and William G. Henderson[1,3]

Abstract

Background Precise estimates of risk-adjusted increases in postoperative length of stay (LOS) associated with postoperative complications across a range of complications and operations are not available in the existing literature.

Methods Associations between preoperative characteristics, postoperative complications and postoperative LOS were tested using medians, interquartile ranges, and nonparametric rank sum tests in a retrospective cohort study using the 2005–2018 American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) dataset. A negative binomial model was used with postoperative LOS as the dependent variable and preoperative characteristics and postoperative complications as independent variables. The model was applied to estimate each patient's postoperative LOS with and without each postoperative complication to measure the association between each complication and risk-adjusted change in postoperative LOS.

Results A total of 4,495,582 patients were included. After risk-adjustment, occurrence of each postoperative complication was associated with significantly increased postoperative LOS (between + 3.9 and + 20.1 days, $p < 0.0001$). The longest risk-adjusted postoperative LOS increases were associated with prolonged ventilator use (+ 20.1 days), wound disruption (+ 19.4 days), and acute renal failure (+ 17.1 days).

Conclusion Occurrence of any postoperative complication was associated with increased risk-adjusted postoperative LOS. Degree of increase varied by complication. These data could be useful for patient counseling, allocation of resources, discharge planning, and quality improvement efforts.

Meeting Presentation Presented at the Western Surgical Association Annual Meeting, November 2023, Dana Point, CA and the American College of Surgeons Quality and Safety Conference, July 2024, Denver, CO

***Correspondence:**
Garrett L. Healy
Garrett.Healy@cuanschutz.edu
Full list of author information is available at the end of the article

Keywords Postoperative length of stay, LOS, Postoperative complications, Risk-adjusted, ACS-NSQIP

Background

Postoperative complications occur in 15% of nonemergent inpatient surgeries, with up to 6% of patients experiencing multiple complications [1]. Anecdotally, surgeons know that these complications impact postoperative length of stay (LOS) but lack precise estimates of the effect magnitude. In 2022, the average adjusted expense per inpatient hospital day in the United States was $3,025 [2], and delayed discharge leads to fewer open beds in acute care hospitals [3]. Targeted quality improvements to reduce this burden can significantly impact healthcare expenditures.

In a literature review of studies whose primary purpose was to examine the associations between postoperative complications and postoperative LOS, we identified 18 relevant articles (Supplemental Table 1) [4–21]. The majority (78%) of these studies were done for specific operations, such as lumbar spine surgery or lower extremity bypass, and 72% had small sample sizes of patients (≤7,500). Furthermore, complications were not uniformly defined and changes in LOS were variously measured. The literature lacked studies using broad surgical populations, large sample sizes, examining an array of specific complications, and incorporating risk adjustment for preoperative patient characteristics and other complications. Such a study would provide more precise estimates of risk-adjusted increases in postoperative LOS associated with postoperative complications across a range of complications and operations. These might inform clinical decision making, guide hospital resource allocation, and alleviate reliance on subjective and anecdotal evidence. This study could also provide implementable data for reference in programs for quality improvement and cost reduction, as LOS is often used as a proxy for value and quality of care for hospitals [3, 22].

The objective of this study was to estimate the unadjusted and risk-adjusted changes in postoperative LOS associated with specific types of postoperative complications in a broad inpatient surgical population. We hypothesized that each type of postoperative complication would be associated with significant changes in postoperative LOS, even after adjusting for preoperative risk and other complications, and that the changes in postoperative LOS would vary for the different types of complications.

Methods

Study design and data source

This was a retrospective cohort study using the prospectively collected 2005–2018 American College of Surgeons National Surgical Quality Improvement Program participant use file (ACS-NSQIP PUF). The ACS-NSQIP PUF contains surgical data from over 700 institutions primarily in the United States and Canada, across nine surgical subspecialties, including general, gynecology, neurosurgery, orthopedic, otolaryngology, plastic, thoracic, urology, and vascular surgery. Trained clinical nurses collect data from a systematic sample of operations within each participating institution. Data include patient demographic and preoperative medical characteristics and comorbidities, preoperative laboratory work, operative information, and 30-postoperative outcomes including mortality and 18 different complications [23]. In this study, laboratory variables were not used because we previously found that they did not add significantly to a patient's risk prediction beyond the non-laboratory preoperative variables collected in the ACS-NSQIP and they are often missing in a non-random fashion [24]. This study was reviewed by the Colorado Multiple Institutional Review Board and deemed exempt as it used deidentified and publicly available data.

Study sample

Because LOS is generally relevant only to inpatients, the study population was limited to inpatients in the ACS-NSQIP database. Patients were excluded if they had operations that were not in the nine designated subspecialties of the ACS-NSQIP Essentials Program or if they were missing data for key variables.

Dependent and independent variables

The primary dependent variable or outcome was patient postoperative LOS, defined as the number of days from the day of operation to the day of discharge from the hospital. The primary independent variable was each of the 18 ACS-NSQIP postoperative complications. Postoperative complications were counted only if they occurred prior to the patient's discharge from the hospitalization for the primary operation.

The independent variables for risk adjustment included 27 preoperative, non-laboratory ACS-NSQIP variables and Current Procedural Terminology (CPT)-specific median LOS calculated from the ACS-NSQIP database. The 27 preoperative variables of the patients included: age, sex, race/ethnicity, body mass index (BMI), functional health status (independent, partially dependent, totally dependent), transfer status (from home, acute care, or chronic care), surgeon specialty, emergency status, work relative value unit (wRVU) of the primary operation, and American Society of Anesthesiologists

physical status classification (ASA class, 1 to 5), and 17 different types of comorbidities.

Statistical analysis

The unadjusted associations between preoperative characteristics, postoperative complications, and LOS were examined by comparing median postoperative LOS for the categories of the categorical variables and tested for statistical significance using a Wilcoxon rank sum test for variables with two categories or a Kruskal–Wallis test for variables with > 2 categories. For continuous variables, a Pearson correlation coefficient was calculated between the continuous variable and postoperative LOS.

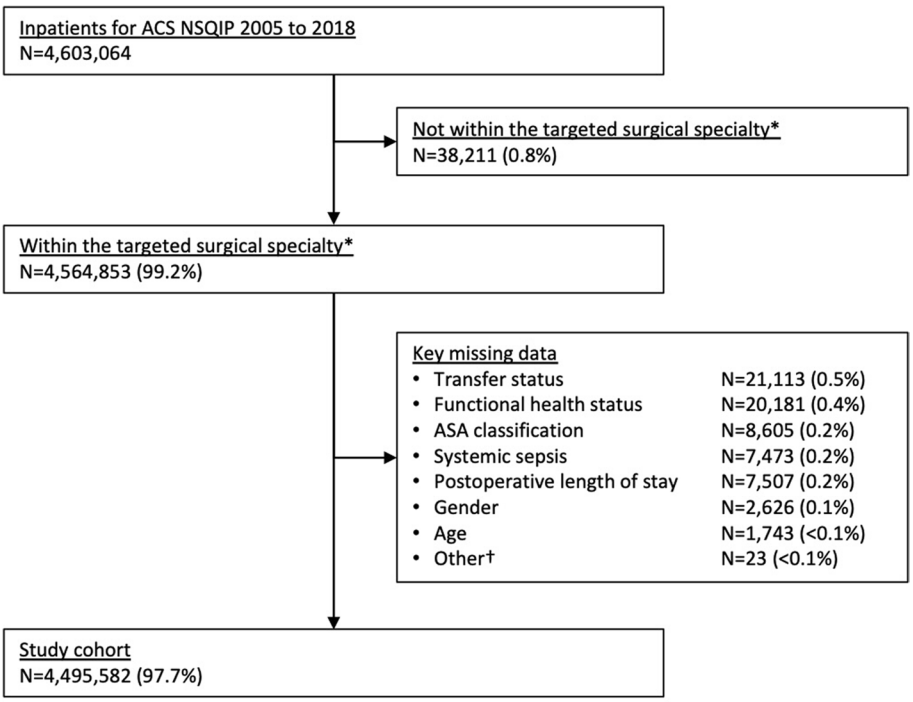
Risk-adjustment was accomplished using a negative binomial model with postoperative LOS as the dependent variable and the preoperative variables and postoperative complications as the independent variables. Once a negative binomial model was estimated, the model was applied to the patients to estimate the risk-adjusted postoperative LOS for patients with or without the preoperative characteristic or postoperative complication, and risk-adjusted median postoperative LOSs were compared and tested as above. Two-sided p-values ≤ 0.05 were considered statistically significant. All statistical analyses were performed using SAS version 9.4 (SAS Inc, Cary, NC).

Results

A total of 4,603,064 inpatients were included in the ACS-NSQIP PUF from 2005–2018. Of these, 38,211 patients (0.8%) were excluded for having operations in specialties other than the nine targeted surgical specialties; 69,271 patients (1.5%) were excluded for missing key data. This left a total of 4,495,582 patients (97.7%) in the analytic dataset (Fig. 1, Strength in Reporting of Observational Studies in Epidemiology (STROBE) diagram).

General preoperative characteristics of patients

The preoperative characteristics of this cohort and associations between characteristics and LOS are shown in Table 1, with unadjusted and risk-adjusted median postoperative LOS. The majority of patients were female (56.3%), white (67.2%), functionally independent (94.9%), admitted directly from home (94.0%), American Society of Anesthesiology Physical Status Classification (ASA class) II-III (86.4%), and underwent general or orthopedic surgery procedures (70.0%) and non-emergent



Abbreviation: ACS NSQIP, American College of Surgeons National Surgical Quality Improvement Program; ASA, American Society of Anesthesiologist.
*Surgery specialty included general surgery, Gynecology, Neurosurgery, Orthopedics, Otolaryngology, Plastics, Thoracic, Urology, and Vascular surgery.
†Emergency status, Dyspnea, chronic steroid use, cigarette smoker, and acute renal failure.

Fig. 1 STROBE DiagramSTROBE diagram of total initial patient cohort, those excluded for not undergoing operations within the targeted surgical subspecialties, those missing key data, and the final analyzed patient cohort

Table 1 General preoperative characteristics of patients and their associations with PLOS ($n = 4,495,582$)

Preoperative Characteristics	N (%)	Median LOS (IQR)*	Risk-Adjusted Median LOS (IQR)*^	Risk-Adjusted Change in LOS (days)
Sex				
Female	2,531,936 (56.3)	3 (1–5)	2.9 (2.3–4.3)	Reference
Male	1,963,646 (43.7)	3 (1–6)	3.2 (2.5–5.2)	+0.3
Race/Ethnicity				
American Indian or Alaska Native	24,340 (0.5)	3 (2–6)	2.3 (2.5–5.2)	-0.7
Asian or Pacific Islander	130,498 (2.9)	3 (1–5)	3.0 (2.3–4.8)	+0.0
Black, not of Hispanic origin	456,372 (10.2)	3 (2–6)	3.3 (2.5–5.6)	+0.3
Hispanic origin	230,670 (5.1)	2 (1–4)	2.7 (2.1–4.1)	-0.3
White, not of Hispanic origin	3,019,096 (67.2)	3 (2–5)	3.0 (2.3–4.6)	Reference
Null/unknown	634,606 (14.1)	3 (1–5)	3.1 (2.4–4.8)	+0.1
Smoking within one year				
No	3,655,837	3 (1–5)	3.0 (2.3–4.6)	Reference
Yes	839,745 (18.7)	3 (2–6)	3.3 (2.5–5.4)	+0.3
Functional health status prior to surgery				
Independent	4,266,622 (94.9)	3 (1–5)	2.9 (2.3–4.4)	Reference
Partially dependent	179,109 (4.0)	5 (3–10)	6.3 (4.3–10.2)	+3.4
Totally dependent	49,851 (1.1)	8 (4–16)	9.6 (6.1–17.6)	+6.7
Transferred status				
Admitted directly from home	4,227,105 (94.0)	3 (1–5)	2.9 (2.3–4.4)	Reference
Acute care hospital	201,539 (4.5)	5 (3–10)	5.8 (3.6–10.0)	+2.9
Chronic care facility	66,938 (1.5)	5 (3–10)	6.6 (4.5–10.2)	+3.7
Surgeon specialty				
General surgery	2,185,696 (48.6)	3 (2–6)	3.4 (2.4–5.7)	Reference
Gynecology	251,631 (5.6)	2 (1–3)	2.1 (1.8–2.4)	-1.3
Neurosurgery	255,275 (5.7)	3 (2–5)	3.3 (2.7–4.2)	-0.1
Orthopedics	963,743 (21.4)	3 (2–3)	2.9 (2.5–3.5)	-0.5
Otolaryngology	56,636 (1.3)	2 (1–4)	2.6 (2.2–3.3)	-0.8
Plastics	53,235 (1.2)	3 (1–5)	2.9 (2.3–4.3)	-0.5
Thoracic	77,900 (1.7)	4 (2–7)	4.5 (3.5–6.3)	+1.1
Urology	210,058 (4.7)	2 (1–4)	2.6 (2.2–3.4)	-0.8
Vascular	441,408 (9.8)	3 (1–6)	3.5 (2.5–5.8)	+0.1
Emergency status				
No	3,903,090 (86.8)	3 (1–5)	3.0 (2.4–4.4)	Reference
Yes	592,492 (13.2)	4 (1–8)	4.1 (2.4–8.0)	+1.1
ASA classification				
I	224,866 (5.0)	1 (1–3)	1.8 (1.6–2.1)	Reference
II	1,724,196 (38.4)	2 (1–4)	2.5 (2.1–3.4)	+0.7
III	2,158,858 (48.0)	3 (2–6)	3.5 (2.7–5.4)	+1.7
IV	373,838 (8.3)	6 (3–10)	6.3 (3.8–10.8)	+4.5
V	13,824 (0.3)	8 (2–17)	9.8 (5.9–18.1)	+8.0
Preoperative Characteristics	**Mean (SD)**	**Unadjusted Pearson Correlation Coefficient***		**Risk-Adjusted Pearson Correlation Coefficient^**
Age, years	59.4 (16.4)	0.125		-0.00025
Work relative value unit	19.8 (9.5)	0.194		-0.00056
CPT specific median length of stay	3.0 (2.3)	0.433		0.02242*

Abbreviations: IQR Interquartile range, *I* normal health patient, *II* patient with mild systemic disease, *III* Patient with severe systemic disease, *IV* patient with severe systemic disease that is a constant threat to life, *V* A moribund patient who is not expected to survive without the operation

^ Risk-adjustment was accomplished using a negative binomial model with PLOS as the dependent variable and the preoperative variables and postoperative complications as the independent variables

* All p values were < 0.0001

operations (86.8%). The average age was 59.4 (SD = 16.4); average wRVU was 19.8 (SD = 9.5).

The typical patient had an unadjusted median postoperative LOS of 3 days. Characteristics that increased median postoperative LOS included: partial (5 days) or total (8 days) functional dependence; transfer from acute or chronic care facility (5 days); or having an emergent or thoracic operation (4 days). A higher ASA class was monotonically related to a larger median LOS: ASA class I, 1 day; II, 2 days; III, 3 days; IV, 6 days; and V, 8 days. Increased age (r = 0.125) and complexity of the operation as measured by wRVU (r = 0.194) were moderately correlated with higher postoperative LOS. All *p*-values for testing the unadjusted association between patient characteristics and postoperative LOS were statistically significant at $p < 0.0001$.

After risk adjustment, these same general trends were true also for adjusted median postoperative LOS. In addition, males (3.2 days) had a longer adjusted median postoperative LOS than females (2.9 days), black patients had the highest adjusted median postoperative LOS (3.3 days) of all race/ethnicity groups, and smokers had a higher adjusted median postoperative LOS (3.3 days) compared to non-smokers (3.0 days). Patients undergoing thoracic (4.5 days), vascular (3.5 days), general (3.4 days), and neurosurgery (3.3 days) had the highest median postoperative LOS compared with other analyzed surgical specialties. All risk-adjusted comparisons were statistically significant at $p < 0.0001$ except for age and wRVU, which were not significantly correlated with postoperative LOS.

Preoperative comorbidities of patients

The 17 preoperative comorbidities for patients and their unadjusted and risk-adjusted associations with postoperative LOS are shown in Table 2. The most common comorbidities were hypertension (51.4%), obesity (42.8%), and diabetes mellitus (18.0%). Patients with each preoperative comorbidity, except for obesity, had higher median LOS compared to patients without the comorbidity. An underweight BMI, as opposed to obesity, was associated with higher median LOS. The largest differences in unadjusted medians were for ventilator dependence (+10 days), septic shock (+9 days), and ascites, acute renal failure, and preoperative transfusion (each + 4 days). These same trends held for the risk-adjusted median postoperative LOS. The largest increases in risk-adjusted median postoperative LOS between patients with vs. without the comorbidities were noted for prolonged ventilator dependence within 48 h of surgery (+12.4 days), septic shock (+11.3), acute renal failure (+6.1), ascites (+5.1), and prior transfusion (+5.0). All comparisons were statistically significant at $p < 0.0001$.

Postoperative complications

Table 3 presents the incidence of each of the 18 postoperative complications, and their unadjusted and risk-adjusted association with postoperative LOS. A total of 600,004 patients (13.4%) had at least one postoperative complication, with a subsequent increase in their median LOS of 6 days, from 2 (IQR 1–4) to 8 (4–14) days. The most common complications were the occurrence of bleeding requiring transfusion (7.4%), sepsis (1.9%), prolonged ventilator use (1.7%), pneumonia (1.6%), unplanned intubation (1.2%), septic shock (1.1%), and organ space surgical site infection (SSI) (1.0%). The other 11 complications had incidences of < 1.0%. Each complication resulted in an unadjusted increase in median LOS, with the largest differences occurring for wound disruption (+16 days), prolonged ventilator use (+15), organ space SSI (+14), unplanned intubation, septic shock, deep incisional SSI, deep veinous thrombosis (DVT), and acute renal failure (all + 12). All *p*-values were < 0.0001.

In risk-adjusted analyses, the trends were similar. Adjusted LOS increase was highest for prolonged ventilator use (+20.1 days), followed by wound disruption (+19.4), acute renal failure (+17.1), organ space SSI (+16.0), septic shock (+15.7), unplanned intubation (+14.3), DVT (+13.9), deep incisional SSI (+13.8), and pneumonia (+13.7). The lowest risk-adjusted LOS increase was for bleeding requiring transfusion (+3.9) (Table 3, Fig. 2).

Discussion

We conducted a comprehensive analysis of the associations between postoperative complications and postoperative length of stay in a broad surgical population. To our knowledge, this is the first study to publish precise estimates of risk-adjusted increases in postoperative LOS associated with postoperative complications across a broad range of complications and operations. While this has been suspected by surgeons, confirmatory data and precise estimates are lacking in the literature. All 18 postoperative complications collected by the ACS-NSQIP were significantly associated with increased postoperative LOS in unadjusted analysis and remained significant after adjusting for preoperative risk characteristics and concomitant complications. The increase in postoperative LOS varied by different complications, and prolonged ventilation use, wound disruption, and acute renal failure were associated with the greatest increases in LOS. These findings have implications in resource allocation in the 13.4% of patients who have postoperative complications. If the postoperative complication rates could be reduced by only a few percentage points, this could save many additional inpatient hospitals days.

Table 2 Unadjusted and risk-adjusted associations of patient preoperative comorbidities and PLOS ($n = 4,495,582$)

Patient Comorbidities	N (%)	Unadjusted Median LOS (IQR)*	Risk-Adjusted Median LOS (IQR)*^	Risk-Adjusted Change in LOS (days)
Ascites				
No	4,463,494 (99.3)	3 (1–5)	3.0 (2.4–4.7)	Reference
Yes	32,088 (0.7)	7 (4–13)	8.1 (4.6–15.2)	+5.1
Bleeding Disorder				
No	4,221,545 (93.9)	3 (1–5)	3.0 (2.3–4.5)	Reference
Yes	274,037 (6.1)	4 (2–8)	4.7 (3.1–7.8)	+1.7
Congestive Heart Failure				
No	4,442,958 (98.8)	3 (1–5)	3.0 (2.4–4.7)	Reference
Yes	52,624 (1.2)	6 (3–11)	6.8 (4.2–11.7)	+3.8
Chronic Obstructive Pulmonary Disease				
No	4,238,804 (94.3)	3 (1–5)	3.0 (2.3–4.6)	Reference
Yes	256,778 (5.7)	4 (2–8)	4.4 (3.1–7.3)	+1.4
Diabetes				
None	3,686,880 (82.0)	3 (1–5)	2.9 (2.3–4.5)	Reference
Oral	488,422 (10.9)	3 (2–5)	3.2 (2.6–5.0)	+0.3
Insulin	320,280 (7.1)	4 (2–7)	4.3 (3.0–7.3)	+1.4
Dialysis Within 2 Weeks				
No	4,419,883 (98.3)	3 (1–5)	3.0 (2.4–4.6)	Reference
Yes	75,699 (1.7)	5 (3–10)	6.5 (4.0–11.0)	+3.5
Disseminated Cancer				
No	4,346,644 (96.7)	3 (1–5)	3.0 (2.3–4.5)	Reference
Yes	148,938 (3.3)	5 (3–9)	5.8 (4.3–8.5)	+2.8
Dyspnea				
None	4,132,503 (91.9)	3 (1–5)	3.0 (2.3–4.6)	Reference
Moderate Exertion	324,162 (7.2)	3 (2–6)	3.5 (2.7–5.9)	+0.5
At Rest	38,917 (0.9)	6 (3–12)	6.8 (3.9–13.4)	+3.8
Hypertension				
No	2,185,001 (48.6)	2 (1–5)	2.7 (2.2–4.2)	Reference
Yes	2,310,581 (51.4)	3 (2–6)	3.3 (2.6–5.2)	+0.6
Acute Renal Failure				
No	4,470,065 (99.4)	3 (1–5)	3.0 (2.4–4.7)	Reference
Yes	25,517 (0.6)	7 (3–15)	9.1 (5.0–17.2)	+6.1
Body Mass Index				
Null/unknown	116,741 (2.6)	3 (1–7)	4.1 (2.6–7.1)	+0.6
Underweight (< 18.5)	93,640 (2.1)	5 (2–8)	5.3 (3.2–8.3)	+1.8
Normal weight (18.5–24.9)	1,046,902 (23.3)	3 (2–6)	3.5 (2.4–5.7)	Reference
Overweight (25.0–29.9)	1,316,392 (29.3)	3 (1–5)	3.0 (2.3–4.7)	-0.5
Obese Class I (30.0–34.9)	907,049 (20.2)	3 (1–5)	2.9 (2.3–4.2)	-0.6
Obese Class II (35.0–39.9)	495,640 (11.0)	3 (1–4)	2.8 (2.3–2.8)	-0.7
Obese Class III (≥ 40)	519,218 (11.6)	2 (1–4)	2.7 (2.4–3.3)	-0.8
Chronic Steroid Use				
No	4,296,364 (95.6)	3 (1–5)	3.0 (2.3–4.6)	Reference
Yes	199,218 (4.4)	4 (2–7)	4.3 (3.1–6.9)	+1.3
Transfusion of > 4 pRBC Within 72 Hours				
No	4,432,967 (98.6)	3 (1–5)	3.0 (2.4–4.6)	Reference
Yes	62,615 (1.4)	7 (4–13)	8.0 (5.1–13.7)	+5.0
Ventilator Dependent within 48 h				
No	4,464,439 (99.3)	3 (1–5)	3.0 (2.4–4.7)	Reference

Table 2 (continued)

Patient Comorbidities	N (%)	Unadjusted Median LOS (IQR)*	Risk-Adjusted Median LOS (IQR)*^	Risk-Adjusted Change in LOS (days)
Yes	31,143 (0.7)	13 (5–23)	15.4 (8.8–28.5)	+12.4
Open Wound With or Without Infection				
No	4,291,538 (95.5)	3 (1–5)	3.0 (2.3–4.4)	Reference
Yes	204,044 (4.5)	6 (3–10)	7.1 (4.9–10.8)	+4.1
Weight Loss > 10% Within 6 Months				
No	4,399,721 (97.9)	3 (1–5)	3.0 (2.3–4.6)	Reference
Yes	95,861 (2.1)	6 (4–10)	7.1 (4.7–11.0)	+4.1
Systemic Sepsis (Within 48 Hours)				
None	4,107,362 (91.4)	3 (1–5)	2.9 (2.3–4.4)	Reference
Systemic Inflammatory Response Syndrome	209,239 (4.7)	4 (2–8)	4.2 (2.5–7.9)	+1.3
Sepsis	144,660 (3.2)	6 (3–11)	7.4 (3.9–13.3)	+4.5
Septic Shock	34,321 (0.8)	12 (5–21)	14.2 (8.4–25.7)	+11.3

Abbreviation: *IQR* Interquartile range, *LOS* Length of stay, *pRBC* packed Red Blood Cells

^ Risk-adjustment was accomplished using a negative binomial model with PLOS as the dependent variable and the preoperative variables and postoperative complications as the independent variables

* All p values were < 0.0001

In addition to identification of postoperative complications that most affect postoperative LOS, this study provides evidence for preoperative characteristics and comorbidities that may modify LOS. While some risk factors for prolonged postoperative LOS are non-modifiable, others may be targeted for patient optimization prior to surgery. A potential target of optimization is underweight patients, who had a 2-day extended stay in the hospital postoperatively compared to normal weight patients. While many patients may be underweight due to systemic comorbidities such as cancer or severe illness, surgeons may counsel patients that improving their weight in a healthy manner may reduce the time they spend in the hospital after an operation by reduction of complications and improved recovery.

Our data are consistent with other smaller studies that have found associations between postoperative complications and length of stay in various subsets of surgeries and using different databases. Out of 18 studies in the literature that we reviewed [4–21], only two did not find a strong association between postoperative complications and increased LOS [4, 16]. In 2017, Mrdutt et al. analyzed 42,365 ACS-NSQIP patients undergoing elective laparoscopic colectomy and found that each postoperative complication increased the LOS [20]. In 2008, Boakye et al. examined the National Inpatient Sample and found that complications after laminectomy doubled postoperative LOS [6]. Additionally, in 2015 Damrauer et al. found similar results while investigating the effect of postoperative complications on postoperative LOS in 6,307 patients undergoing lower extremity bypass surgery using the California State Inpatient Database [7]. That study also found an independent association between postoperative LOS and patient readmission, indicating that finding avenues to reduce postoperative LOS could also have an effect on patient readmission, although further study is needed to determine if that is the case in a general surgical population. These findings suggest that the results of our study in a broad surgical population are in concordance with much of the research already done in individual operations.

There were two studies in our review that did not demonstrate a significant association between postoperative complications and postoperative LOS. In 2014, Krell et al. found that much of the variations in postoperative LOS were not attributable to either preoperative characteristics or postoperative complications in 22,664 patients undergoing inpatient colorectal resections [16]. Adogwa et al. reached the same conclusion in 23,102 patients after lumbar decompression and fusion procedure [4]. However, these studies used a different postoperative LOS outcome, whether patients had a LOS ≥ the 75th percentile of LOS. A binary cutoff could mask some of the effects of complications. This, plus a smaller sample size and more distinct patient populations, could explain the differences in the findings between these two studies and our study.

Our study is novel in that it has four important characteristics not currently found in the studies on postoperative complications and postoperative LOS in the

Table 3 Unadjusted and risk-adjusted association between in-hospital postoperative complications and PLOS ($n = 4,495,582$)

Postoperative Complication	N (%)	Unadjusted Median LOS, days (IQR)*	Unadjusted Change in LOS, days	Risk-Adjusted Median LOS, days (IQR)*^	Adjusted Change in LOS, days
Any Complication					
No	3,895,578 (86.7)	2 (1–4)	Reference	N/A	N/A
Yes	600,004 (13.4)	8 (4–14)	+6	N/A	N/A
Pneumonia					
No	4,424,945 (98.4)	3 (1–5)	Reference	3.0 (2.4–4.6)	Reference
Yes	70,637 (1.6)	14 (8–24)	+11	16.7 (9.1–32.7)	+13.7
Unplanned Intubation					
No	4,442,332 (98.8)	3 (1–5)	Reference	3.0 (2.4–4.6)	Reference
Yes	53,250 (1.2)	15 (8–26)	+12	17.3 (8.8–34.2)	+14.3
Prolonged Ventilator Use					
No	4,416,896 (98.3)	3 (1–5)	Reference	3.0 (2.3–4.6)	Reference
Yes	78,686 (1.7)	18 (11–29)	+15	23.1 (14.3–39.3)	+20.1
Septic Shock					
No	4,443,855 (98.9)	3 (1–5)	Reference	3.0 (2.4–4.6)	Reference
Yes	51,727 (1.1)	15 (8–26)	+12	18.7 (10.8–34.0)	+15.7
Sepsis					
No	4,409,471 (98.1)	3 (1–5)	Reference	3.0 (2.3–4.6)	Reference
Yes	86,111 (1.9)	11 (6–19)	+8	12.9 (7.3–22.9)	+9.9
Superficial SSI					
No	4,459,855 (99.2)	3 (1–5)	Reference	3.0 (2.4–4.6)	Reference
Yes	35,727 (0.8)	12 (8–19)	+9	13.2 (8.9–22.1)	+10.2
Deep Incisional SSI					
No	4,481,230 (99.7)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	14,352 (0.3)	15 (9–25)	+12	16.8 (10.2–31.3)	+13.8
Organ Space SSI					
No	4,448,271 (99.0)	3 (1–5)	Reference	3.0 (2.4–4.6)	Reference
Yes	47,311 (1.0)	17 (11–26)	+14	19.0 (11.2–34.1)	+16
Wound Disruption					
No	4,483,692 (99.7)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	11,890 (0.3)	19 (12–28)	+16	22.4 (11.7–44.9)	+19.4
Urinary Tract Infection					
No	4,455,101 (99.1)	3 (1–5)	Reference	3.0 (2.4–4.6)	Reference
Yes	40,481 (0.9)	11 (6–19)	+8	11.9 (7.4–22.3)	+8.9
Deep Venous Thrombosis/Thrombophlebitis					
No	4,473,129 (99.5)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	22,453 (0.5)	15 (9–24)	+12	15.9 (8.7–32.8)	+13.9
Pulmonary Embolism					
No	4,483,644 (99.7)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	11,938 (0.3)	11 (7–19)	+8	11.8 (6.7–24.6)	+8.8
Cardiac Arrest Requiring CPR					
No	4,476,856 (99.6)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	18,726 (0.4)	7 (2–15)	+4	8.6 (5.1–16.4)	+5.6
Myocardial Infarction					
No	4,476,254 (99.6)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	19,328 (0.4)	9 (6–16)	+6	10.4 (6.4–19.6)	+7.4
Bleeding Requiring Transfusion					
No	4,162,382 (92.6)	3 (1–5)	Reference	2.9 (2.3–4.3)	Reference
Yes	333,200 (7.4)	6 (4–10)	+3	6.8 (4.4–11.2)	+3.9

Table 3 (continued)

Postoperative Complication	N (%)	Unadjusted Median LOS, days (IQR)*	Unadjusted Change in LOS, days	Risk-Adjusted Median LOS, days (IQR)*^	Adjusted Change in LOS, days
Progressive Renal Insufficiency					
No	4,482,760 (99.7)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	12,822 (0.3)	13 (7–21)	+10	14.4 (7.9–29.8)	+11.4
Acute Renal Failure					
No	4,477,336 (99.6)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	18,246 (0.4)	16 (8–27)	+12	20.1 (10.8–37.6)	+17.1
Cardiovascular Accident/Stroke with Neurologic Defect					
No	4,485,535 (99.8)	3 (1–5)	Reference	3.0 (2.4–4.7)	Reference
Yes	10,047 (0.2)	10 (6–18)	+7	11.7 (6.5–25.3)	+8.7

Abbreviations: *IQR* interquartile range, *CPR* cardiopulmonary resuscitation, *LOS* postoperative length of stay, *SSI* surgical site infection

^ Risk-adjustment was accomplished using a negative binomial model with PLOS as the dependent variable and the preoperative variables and postoperative complications as the independent variables

* All *p* values were < 0.0001

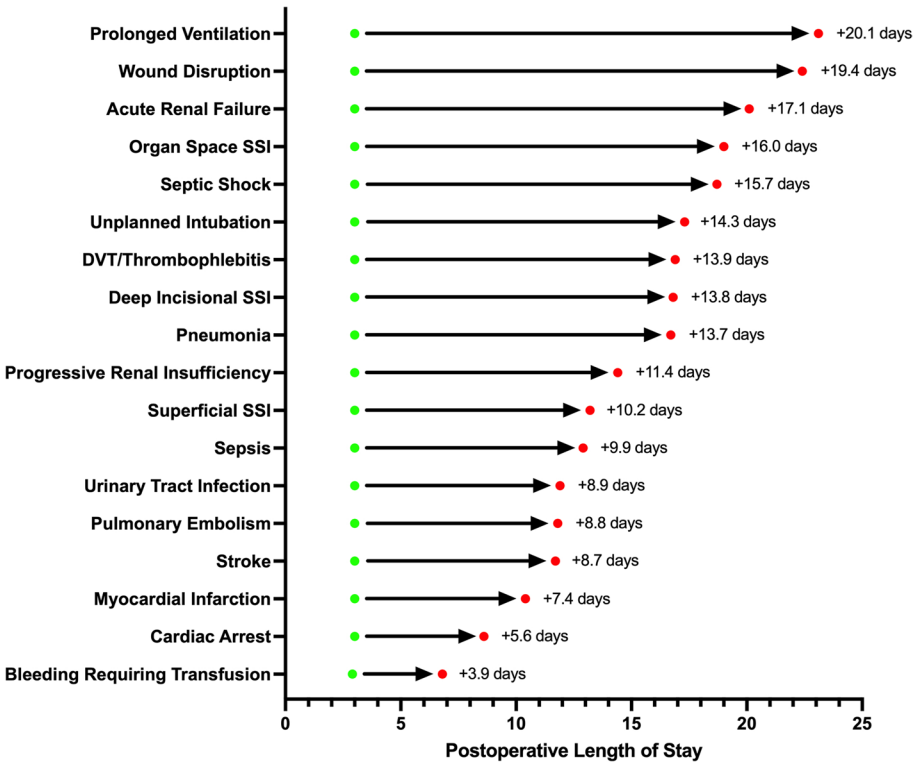


Fig. 2 Risk-adjusted Increase in Median Postoperative Length of Stay. The increase in postoperative length of stay associated with postoperative complications after risk-adjusting for preoperative characteristics and comorbidities and concomitant postoperative complications

literature: (1) analysis of a broad surgical population; (2) use of very large sample sizes; (3) inclusion of a wide array of postoperative complications; and (4) use of a straightforward analysis that provides average changes in LOS to be expected for each individual postoperative complication after adjusting for preoperative patient factors and other complications. Our data demonstrate that there is a strong association between postoperative complications and postoperative LOS, even when accounting for preoperative characteristics and concurrent complications. The results of this study provide concrete data for guiding decision making and resource

allocation, providing hospitals with data to improve quality at their institutions and target complications that can most severely impact patient postoperative LOS. In addition, it provides information that a surgeon can share with patients and their families to better understand the course of their hospital stay.

Strengths of this study include: (1) the use of a large, audited, comprehensive database capturing a representative sample of the national surgery volume; (2) consideration of postoperative complications across many surgical specialties; and (3) inclusion of data over 14 years. However, there are several important limitations of our study to consider. First, we analyzed a broad surgical population, and the associations may vary in more specific surgical subspecialties and operations. In addition, predictor variables and complications analyzed were limited to those measured in the ACS-NSQIP. In this analysis, we included patients who died in the 30-day window postoperatively, which may potentially artificially depress their postoperative LOS. There has also been concern that the "inpatient" variable in ACS-NSQIP may not be standardized between institutions, potentially complicating an inpatient-specific analysis [25]. Finally, while we were able to use a large dataset from the ACS-NSQIP, there may be bias in which institutions participate, favoring large academic centers, and therefore these data may not be applicable to all hospitals.

Our study demonstrates how postoperative complications significantly affect hospital resources, particularly by prolonging the length of stay. These findings stress the importance of careful perioperative management and prompt intervention when complications arise. The varying impact of different complications on length of stay highlights the need for tailored strategies to address specific postoperative challenges. For example, implementing enhanced protocols to prevent and manage prolonged ventilator use, wound disruptions, and acute renal failure could substantially reduce hospital stays and enhance patient outcomes. Furthermore, this study offers valuable data for developing predictive models for risk assessment, which can help healthcare providers allocate resources more efficiently and take proactive measures for high-risk patients [26–30]. Future research should focus on identifying the most effective interventions to lessen the impact of these complications and explore the potential benefits of personalized postoperative care plans.

Conclusions

In a broad surgical population, postoperative complications were significantly associated with increased postoperative LOS. The increase varied depending on the complication, and was greatest for prolonged ventilation, wound disruption, and acute renal failure. These data provide clinicians with additional information for counseling patients on the possible outcomes of surgery including postoperative LOS after complication, can allow administration to better allocate resources where they are needed, and can help guide clinicians on expected clinical course and discharge after a postoperative complication occurs.

Abbreviations

ACS-NSQIP PUF	American College of Surgeons National Surgical Quality Improvement Program Participant Use Data File
LOS	Length of Stay
ASA	American Society of Anesthesiologists
BMI	Body Mass Index

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13037-024-00409-9.

Supplementary Material 1.

Acknowledgements
The ACS-NSQIP and participating hospitals are the source of these data; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

Authors' contributions
RAM and WGH conceived of and designed the study. GLH contributed to study design and analysis and wrote the draft with input from all authors. MRB contributed to study design and conducted the data analysis. CMS, AD, TA, AMH, and RDS contributed to interpretation of results. All authors helped write, have read, and approved of the final version of the article.

Funding
This work was supported by an internal grant from the Department of Surgery, University of Colorado School of Medicine, and the University of Colorado School of Medicine Research Track. The funding organizations had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Availability of data and materials
The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. The raw data in this study was generated from the ACS-NSQIP PUF 2005-2018 and is publicly available upon request.

Declarations

Ethics approval and consent to participate
This study was reviewed by the Colorado Multiple Institutional Review Board and deemed exempt as it used deidentified and publicly available data.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Surgical Outcomes and Applied Research Program, Department of Surgery, University of Colorado School of Medicine, 12631 E 17 Ave #6117, Aurora, CO 80045, USA. [2]Adult and Child Center for Health Outcomes Research and Delivery Science, University of Colorado School of Medicine, 1890 N Revere Ct Third

Floor, Mail StopF443, Aurora, CO 80045, USA. [3]Department of Biostatistics and Informatics, Colorado School of Public Health, 13001 E 17 Pl B119, Aurora, CO 80045, USA.

Received: 12 July 2024 Accepted: 19 August 2024
Published online: 01 October 2024

References

1. Tevis SE, Cobian AG, Truong HP, et al. Implications of Multiple Complications on the Postoperative Recovery of General Surgery Patients. Ann Surg. 2016;263(6):1213–8. https://doi.org/10.1097/SLA.0000000000001390.
2. The Kaiser Family Foundation State Health Facts. Hospital Adjusted Expenses per Inpatient Day. Data Source: 1999–2022 AHA Annual Survey, Copyright 2022 by Health Forum, LLC, an affiliate of the American Hospital Association. Special data request, 2023. Available at https://www.kff.org/health-costs/state-indicator/expenses-per-inpatient-day/?currentTimeframe=0&sortModel=%7B%22colId%22:%22Location%22,%22sort%22:%22asc%22%7D#notes. Accessed March 24, 2024.
3. Tipton K, Leas BF, Mull NK, et al. Interventions To Decrease Hospital Length of Stay [Internet]. Rockville (MD): Agency for Healthcare Research and Quality (US); 2021. (Technical Brief, No. 40.). Available from: https://www.ncbi.nlm.nih.gov/books/NBK574435/.
4. Adogwa O, Lilly DT, Khalid S, et al. Extended Length of Stay After Lumbar Spine Surgery: Sick Patients, Postoperative Complications, or Practice Style Differences Among Hospitals and Physicians? World Neurosurg. 2019;123:e734–9. https://doi.org/10.1016/j.wneu.2018.12.016.
5. Almashrafi A, Vanderbloemen L. Quantifying the effect of complications on patient flow, costs and surgical throughputs. BMC Med Inform Decis Mak. 2016;16(1):136. https://doi.org/10.1186/s12911-016-0372-6.
6. Boakye M, Patil CG, Santarelli J, et al. Laminectomy and fusion after spinal cord injury: national inpatient complications and outcomes. J Neurotrauma. 2008;25(3):173–83. https://doi.org/10.1089/neu.2007.0395.
7. Damrauer SM, Gaffey AC, DeBord SA, et al. Comparison of risk factors for length of stay and readmission following lower extremity bypass surgery. J Vasc Surg. 2015;62(5):1192–1200.e1191. https://doi.org/10.1016/j.jvs.2015.06.213.
8. Finley CJ, Begum HA, Pearce K, et al. The Effect of Major and Minor Complications After Lung Surgery on Length of Stay and Readmission. J Patient Exp. 2022;9:23743735221077524. https://doi.org/10.1177/23743735221077524.
9. Fleischmann KE, Goldman L, Young B, et al. Association between cardiac and noncardiac complications in patients undergoing noncardiac surgery: outcomes and effects on length of stay. Am J Med. 2003;115(7):515–20. https://doi.org/10.1016/s0002-9343(03)00474-1.
10. Flynn DN, Speck RM, Mahmoud NN, et al. The impact of complications following open colectomy on hospital finances: a retrospective cohort study. Perioper Med (Lond). 2014;3(1):1. https://doi.org/10.1186/2047-0525-3-1.
11. Fukuda H, Morikane K, Kuroki M, et al. Impact of surgical site infections after open and laparoscopic colon and rectal surgeries on postoperative resource consumption. Infection. 2012;40(6):649–59. https://doi.org/10.1007/s15010-012-0317-7.
12. Gruskay JA, Fu M, Basques BA, et al. Factors Affecting Length of Stay and Complications After Elective Anterior Cervical Discectomy and Fusion: A Study of 2164 Patients From The American College of Surgeons National Surgical Quality Improvement Project Database (ACS NSQIP). Clin Spine Surg. 2016;29(1):E34–42. https://doi.org/10.1097/BSD.0000000000000080.
13. Gruskay JA, Fu M, Bohl DD, et al. Factors affecting length of stay after elective posterior lumbar spine surgery: a multivariate analysis. Spine J. 2015;15(6):1188–95. https://doi.org/10.1016/j.spinee.2013.10.022.
14. Hellsten EK, Hanbidge MA, Manos AN, et al. An economic evaluation of perioperative adverse events associated with spinal surgery. Spine J. 2013;13(1):44–53. https://doi.org/10.1016/j.spinee.2013.01.003.
15. Monge Jodra V, Sainz de Los Terreros Soler L, Diaz-Agero Perez C, et al. Excess length of stay attributable to surgical site infection following hip replacement: a nested case-control study. Infect Control Hosp Epidemiol. 2006;27(12):1299–1303. https://doi.org/10.1086/509828
16. Krell RW, Girotti ME, Dimick JB. Extended length of stay after surgery: complications, inefficient practice, or sick patients? JAMA Surg. 2014;149(8):815–20. https://doi.org/10.1001/jamasurg.2014.629.
17. Landais A, Morel M, Goldstein J, et al. Evaluation of financial burden following complications after major surgery in France: Potential return after perioperative goal-directed therapy. Anaesth Crit Care Pain Med. 2017;36(3):151–5. https://doi.org/10.1016/j.accpm.2016.11.006.
18. Mahmoud NN, Turpin RS, Yang G, et al. Impact of surgical site infections on length of stay and costs in selected colorectal procedures. Surg Infect (Larchmt). 2009;10(6):539–44. https://doi.org/10.1089/sur.2009.006.
19. McAleese P, Odling-Smee W. The effect of complications on length of stay. Ann Surg. 1994;220(6):740–4. https://doi.org/10.1097/00000658-199412000-00006.
20. Mrdutt MM, Isbell CL, Thomas JS, et al. Impact of complications on length of stay in elective laparoscopic colectomies. J Surg Res. 2017;219:180–7. https://doi.org/10.1016/j.jss.2017.05.113.
21. Pirson M, Dehanne F, Van den Bulcke J, et al. Evaluation of cost and length of stay, linked to complications associated with major surgical procedures. Acta Clin Belg. 2018;73(1):40–9. https://doi.org/10.1080/17843286.2017.1338850.
22. Wright CD, Gaissert HA, Grab JD, et al. Predictors of prolonged length of stay after lobectomy for lung cancer: a Society of Thoracic Surgeons General Thoracic Surgery Database risk-adjustment model. Ann Thorac Surg. 2008;85(6):1857–65. https://doi.org/10.1016/j.athoracsur.2008.03.024.
23. Hall BL, Hamilton BH, Richards K, et al. Does surgical quality improve in the American College of Surgeons National Surgical Quality Improvement Program: an evaluation of all participating hospitals. Ann Surg. 2009;250(3):363–76. https://doi.org/10.1097/SLA.0b013e3181b4148f.
24. Meguid RA, Bronsert MR, Juarez-Colunga E, et al. Surgical Risk Preoperative Assessment System (SURPAS): II. Parsimonious Risk Models for Postoperative Adverse Outcomes Addressing Need for Laboratory Variables and Surgeon Specialty-specific Models. Ann Surg. 2016;264(1):10–22. https://doi.org/10.1097/SLA.0000000000001677
25. Bovonratwet P, Webb ML, Ondeck NT, et al. Definitional Differences of "Outpatient" Versus "Inpatient" THA and TKA Can Affect Study Outcomes. Clin Orthop Relat Res. 2017;475(12):2917–25. https://doi.org/10.1007/s11999-017-5236-6.
26. Aasen DM, Bronsert MR, Rozeboom PD, et al. Relationships between predischarge and postdischarge infectious complications, length of stay, and unplanned readmissions in the ACS NSQIP database. Surgery. 2021;169(2):325–32. https://doi.org/10.1016/j.surg.2020.08.009.
27. Arora A, Lituiev D, Jain D, et al. Predictive Models for Length of Stay and Discharge Disposition in Elective Spine Surgery: Development, Validation, and Comparison to the ACS NSQIP Risk Calculator. Spine (Phila Pa 1976). 2023;48(1):E1-E13. https://doi.org/10.1097/BRS.0000000000004490
28. Dyas AR, Henderson WG, Madsen HJ, et al. Development and validation of a prediction model for conversion of outpatient to inpatient surgery. Surgery. 2022;172(1):249–56. https://doi.org/10.1016/j.surg.2022.01.025.
29. Madsen HJ, Henderson WG, Bronsert MR, et al. Associations Between Preoperative Risk, Postoperative Complications, and 30-Day Mortality. World J Surg. 2022;46(10):2365–76. https://doi.org/10.1007/s00268-022-06638-2.
30. Madsen HJ, Meguid RA, Bronsert MR, et al. Associations between preoperative risks of postoperative complications: Results of an analysis of 4.8 Million ACS-NSQIP patients. Am J Surg. 2022;223(6):1172–1178. https://doi.org/10.1016/j.amjsurg.2021.11.024

Publisher's Note