

# Development and Validation of Procedure-Specific Risk Score for Predicting Postoperative Pulmonary Complication: A NSQIP Analysis

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- BACKGROUND:** Postoperative pulmonary complications (PPCs; unplanned reintubation, postoperative pneumonia, and failure to liberate from mechanical ventilation within 48 hours), contribute significantly to increased rates of morbidity and mortality. Procedure type is an important factor that contributes risk in generalized PPC prediction models. The objective of this study was to develop and validate procedure-specific risk scores for the 6 procedures with the highest rates of PPCs.
- STUDY DESIGN:** American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) Participant Use File data (2005 to 2015) for patients undergoing pancreatectomy, hepatectomy, esophagectomy, abdominal aortic aneurysm repair, open aortoiliac repair, and lung resection were used for analysis. Multivariable logistic regression was used to develop pulmonary complications risk scores (PCRS) for each procedure. Youden indices were used to identify cutoff points within each PCRS and were further validated using a random selection of the original NSQIP dataset collected.
- RESULTS:** Twenty-one variables were included in the initial analysis, which yielded unique relative risk score models for each procedure. Within all the risk score models, long operative time (within the last quartile) was a strong predictor of PPCs. An increased rate of PPCs was associated with increasing PCRS values in both the training and validation samples for all procedures.
- CONCLUSIONS:** Important variables were identified for 6 common procedures that yield an increased risk of PPCs. These variables differed by procedure type, outlining the importance of procedure-specific risk scores. Each procedure-specific PCRS developed in this study can be used by health care professionals to better predict the risk of PPCs and to optimize patient outcomes. (J Am Coll Surg 2019;229:355–365. © 2019 by the American College of Surgeons. Published by Elsevier Inc. All rights reserved.)

Postoperative pulmonary complications (PPCs) are a major source of patient morbidity and mortality, as well as a financial burden on an already taxed health care system.<sup>1</sup>

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The incidence of PPCs after major surgery is as high as 23%, with up to 30% of these patients dying within the first 30 days after surgery.<sup>1</sup> Hospital length of stay is increased by 13 to 17 days for patients who experience a PPC, resulting in up to \$50,000 of unnecessary health care costs per case.<sup>1,2</sup> Numerous modifiable and nonmodifiable risk factors have been identified that contribute to PPCs, including surgery type and duration, patient age and comorbidities, use of general anesthesia, and preoperative infections and lab values.<sup>1</sup> Identification of high-risk patients and modifiable risk factors is imperative in order to improve mortality rates and ensure appropriate reimbursement from the Centers for Medicare and Medicaid Services, as postoperative respiratory failure has been

### Abbreviations and Acronyms

ACS	= American College of Surgeons National
NSQIP	Surgical Quality Improvement Project
PCRS	= pulmonary complications risk scores
PPC	= postoperative pulmonary complication

identified as an important quality metric by the Agency for Healthcare Research and Quality (AHRQ).<sup>2</sup>

The American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) collects patient-specific variables and 30-day postoperative outcomes via trained clinical reviewers at participating health care centers.<sup>2,3</sup> Multiple previous studies have used the ACS NSQIP database to develop risk scores to improve identification of high-risk patients and patient risk factors leading to PPCs. However, these risk scores are nonspecific to the procedure being performed.<sup>2,4-6</sup> Rates of PPCs vary widely by procedure type, with the following procedures identified as having a high incidence of PPCs: lung resection, open abdominal aortic aneurysm repair, pancreatectomy, hepatectomy, esophagectomy, and open aortoiliac repair.<sup>2,7,8</sup>

The ACS NSQIP online Surgical Risk Calculator is a reliable tool in predicting patient-specific post-surgical outcomes.<sup>9,10</sup> Developing a risk score that is specific both to PPCs and procedure type could further improve patient outcomes by identifying procedure-specific risk factors. This study aimed to examine risk factors specific to surgical procedures with the highest rates of PPCs and to develop and validate risk scores specific to these procedures. We hypothesized that risk factors for PPCs will vary by targeted procedure type, but that developing procedure-specific risk scores will help guide more targeted interventions to improve patient outcomes.

## METHODS

### Dataset and patient selection

Data were extracted from the 2005 to 2015 ACS NSQIP Participant Use Files (PUF). The sampling methodology of the ACS NSQIP database has been previously described.<sup>6-11</sup> Inclusion criteria included all patients undergoing the following surgical procedures: pancreatectomy, hepatectomy, esophagectomy, abdominal aortic aneurysm repair, open aortoiliac repair, and lung resection, all of which have been identified previously as having the highest rates of PPCs.<sup>2,7,8</sup> The Current Procedural Terminology (CPT) codes used in the analysis for each procedure are listed in eTable 1. Exclusion criteria included outpatient procedures, patients under 18 years of age, patients

with preoperative ventilator dependence, and patients who did not undergo general anesthesia. The training sample was formed by randomly selecting 80% of the dataset described. The remaining 20% of the dataset was used as the validation sample. This study was exempt from review by the University of Virginia Institutional Review Board because it used a publicly available dataset.

### Outcome and variable selection

The primary outcome was PPC within 30 days after the surgical procedure. Postoperative pulmonary complication was defined as unplanned reintubation, postoperative pneumonia, and failure to liberate from mechanical ventilation within 48 hours after intubation.<sup>12</sup> These are 3 major postoperative pulmonary complications cited in the literature that are also collected by the ACS NSQIP database.<sup>1,4,5,7,12</sup> This clinical aggregate is endorsed by the Agency for Healthcare Research and Quality (AHRQ) in evaluating pulmonary complications, and is modeled similarly to that by Johnson and colleagues in *Annals of Surgery*.<sup>2</sup> Although pulmonary embolism was also included as an outcome in the article by Johnson and coworkers,<sup>2</sup> other literature has not considered pulmonary embolism as a major pulmonary complication.<sup>4,7</sup> Therefore, this study chose the same collection of outcomes outlined by Hodari and associates<sup>12</sup> in the *Journal of Surgical Research* and omitted pulmonary embolism as an outcome.

Variable selection was based on extensive review of previous studies examining PPCs.<sup>1,2,4-8,13-16</sup> Those variables that were found to be statistically significant in previous studies or have a known association with PPCs and are collected in the ACS NSQIP database were included in the analysis (eTable 2). Year of operation was also included to control for changes and improvements in surgical procedures over time. Records with missing values within any of the selected variables were dropped from the sample.

A total of 21 variables (eTable 2) were included in the analysis, with discrete subcategories created for age, race, and total operation time (specific to each procedure). Given multiple unmeasured values within laboratory tests, including preoperative albumin level, creatinine level, and hematocrit level, only abnormal laboratory values were included in further analysis. Abnormal lab values were defined as preoperative creatinine > 1.2 mg/dL, preoperative albumin < 3.5 g/L, and preoperative hematocrit < 37% for males and < 35% for females.

### Risk model development and validation

Univariable analysis was performed within both the training and validation datasets of each procedure to

**Table 1.** Rates of Postoperative Pulmonary Complications in the Training and Validation Samples by Procedure

Procedure	Training sample		Validation sample		p Value
	n	%	n	%	
Pancreatectomy	2,774	7.57	712	7.83	0.3843
Hepatectomy	1,249	6.05	329	6.20	0.6892
Esophagectomy	1,477	23.74	346	22.39	0.2627
Abdominal aortic aneurysm repair	2,440	21.87	597	21.31	0.5222
Aortoiliac open operation	1,657	8.91	384	8.36	0.2380
Lung resection	1,551	7.61	395	7.62	0.9840

examine differences between patients with and without a PPC, as defined above, using ANOVA for continuous variables and chi-square test for categorical variables. All variables were included in further analysis regardless of statistical significance, given previously supported associations in the literature between these variables and PPCs. Within the training datasets of each procedure, stepwise regression with backward elimination was performed to determine  $\beta$ -coefficients and statistical significance of each variable, with  $p < 0.001$  as the criterion. Goodness of fit was determined by Hosmer-Lemeshow test and c-statistic.

Risk scores were developed by dividing each  $\beta$ -coefficient by the lowest  $\beta$ -coefficient created and multiplying by 10, rounding to the nearest integer. This created weighted numerical risks associated with each variable that could be summed to create a multivariable risk score for each individual patient, called the pulmonary complication risk score (PCRS). This risk score development method has been described in previous literature.<sup>2,4,17</sup> To determine risk score grouping end points, the Youden index was used to form 4 risk score categories.<sup>18,19</sup> This index combines sensitivity and specificity measures to assess the diagnostic efficacy of these end points in clinical practice.<sup>20</sup> Sensitivity and specificity of each end point were also calculated to examine the application of the risk score categories to clinical practice. Within the validation sample, risk scores were calculated for each observation and sorted into their appropriate risk score categories. Rates of PPCs between the validation and training samples within each risk score category were compared to evaluate the predictive value of the calculated risk score. Statistical analyses were performed with Stata SE 15.1 (StataCorp LLC).

## RESULTS

A total of 4,609,299 records were identified within the ACS NSQIP Participant Use Files between 2005 and 2015. The 6 previously mentioned procedures were included in the analysis based on Current Procedural

Terminology (CPT) codes, creating a total of 146,092 observations. After removing patients based on exclusion criteria and missing data, 142,122 patients remained within the final dataset. The total number of observations within each procedure group by operation year are shown in eTable 3. The training sample was created by randomly selecting approximately 80% of the final dataset, resulting in 113,642 observations in the training sample and 28,480 in the validation sample. Rates of PPCs between training and validation samples within each procedure are shown in Table 1. There was no statistically significant difference in PPC rates between training and validation samples.

The top 3 independent predictors of PPC after each procedure are indicated in Table 2. The specifics of each model are described below, with the complete risk score models shown in the accompanying Supplemental File. For all models, long operation time (within the last quartile) was a strong predictor of PPCs, with relative risk scores ranging from 56 to 114. Overall rates of PPC events varied by procedure type, ranging from 6.1% to 23.7% within the training samples. An increased rate of PPCs was associated with increasing PCRS values in both the training and validation samples for all procedures.

### Pancreatectomy risk model

There were a total of 2,774 PPC events within the training sample of the pancreatectomy group—a rate of 7.6%. The risk score model for pancreatectomy revealed the top 3 independent predictors of PPC after pancreatectomy procedure were emergent case, patient in a partially or totally dependent state, and long operation time (or total operation time within the last quartile  $\geq 403$  minutes), respectively. The relative risk values for each of these variables were 96, 89, and 88, respectively. The Hosmer–Lemeshow test revealed a statistically significant model ( $p = 0.0196$ ). An increasing PCRS was associated with an increased rate of PPCs, with rates ranging from 2.7% to 17.5% in the training sample and 3.1% to

**Table 2.** Top 3 Variables Most Predictive of Postoperative Pulmonary Complications by Procedure Based on the Pulmonary Complications Risk Score (PCRS)

Procedure	Emergency case		Partially or totally functionally dependent		Total operation time quartiles (specific to each procedure type, Q1–Q4)*		Age ≥ 80 y		History of severe COPD		Preoperative sepsis	
	Rank	RRV	Rank	RRV	Rank	RRV	Rank	RRV	Rank	RRV	Rank	RRV
Pancreatectomy	1	96	2	89	3	88 (Q4)	—	—	—	—	—	—
Hepatectomy	—	—	2	82	1	114	3	78	—	—	—	—
Esophagectomy	—	—	1	79	3	56 (Q4)	—	—	2	58	—	—
Abdominal aortic aneurysm repair	1	69	—	—	2	59 (Q4)	3	40	—	—	—	—
Aortoiliac open operation	3	37	—	—	1, 2 <sup>†</sup>	79 (Q4), 46 (Q3)	—	—	—	—	—	—
Lung resection	—	—	2	95	3	94 (Q4)	—	—	—	—	1	122

\*Total operation time quartiles were as follows for each procedure: pancreatectomy: Q1 <213 min, Q2 213–302 min, Q3 303–402 min, Q4 ≥403 min; hepatectomy: Q1 <156 min, Q2 156–220 min, Q3 221–305 min, Q4 ≥306 min; esophagectomy: Q1 <248 min, Q2 248–335 min, Q3 336–434 min, Q4 ≥435 min; abdominal aortic aneurysm repair: Q1 <168 min, Q2 168–218 min, Q3 219–287 min, Q4 ≥288min; aortoiliac open surgery: Q1 <144 min, Q2 144–202min, Q3 203–276 min, Q4 ≥277 min; lung resection: Q1 <90 min, Q2 90–139 min, Q3 140–202 min, Q4 ≥203 min.

<sup>†</sup>Q4 and Q3 were found to be the first and second variables most predictive of postoperative pulmonary complications, respectively, in this procedure group. RRV, relative risk value.

18.0% in the validation sample. The complete risk score model and a comparison of PPC rates after pancreatectomy between the training and validation samples within risk score groups are shown in Tables 3 and 4.

### Hepatectomy risk model

There were a total of 1,249 PPC events within the training sample of the hepatectomy group—a rate of 6.1%. The top 3 independent predictors of PPC after

**Table 3.** Pancreatectomy Pulmonary Complications Risk Score Model

Variable	Beta	Standard error	Wald	p Value	Odds ratio (95% CI)	Relative risk value
Age category						
60–69 y	0.089	0.089	1.649	0.099	1.093 (0.983–1.215)	10
70–79 y	0.271	0.271	4.793	< 0.001	1.311 (1.174–1.465)	30
≥80 y	0.462	0.462	5.990	< 0.001	1.587 (1.364–1.846)	52
Male sex	0.247	0.247	5.920	< 0.001	1.280 (1.179–1.389)	28
Preoperative albumin < 3.5 g/L	0.358	0.358	7.862	< 0.001	1.430 (1.308–1.564)	40
ASA Class III, IV, V	0.389	0.389	7.127	< 0.001	1.475 (1.326–1.642)	44
Emergency case	0.855	0.855	5.524	< 0.001	2.352 (1.736–3.185)	96
History of severe COPD	0.590	0.590	7.780	< 0.001	1.803 (1.554–2.092)	66
Current smoker within 1 y	0.307	0.307	6.141	< 0.001	1.360 (1.233–1.500)	35
Dyspnea at rest or moderate	0.477	0.477	7.423	< 0.001	1.612 (1.421–1.829)	54
Partially or totally functionally dependent	0.788	0.788	7.175	< 0.001	2.200 (1.774–2.729)	89
Disseminated cancer	0.431	0.431	5.269	< 0.001	1.539 (1.311–1.807)	49
Total operation time quartile, min						
213–302	0.195	0.195	2.985	0.003	1.216 (1.069–1.382)	22
303–402	0.374	0.374	5.908	< 0.001	1.453 (1.284–1.645)	42
≥403	0.783	0.783	13.073	< 0.001	2.189 (1.946–2.462)	88
Preoperative sepsis	0.743	0.743	6.884	< 0.001	2.102 (1.701–2.597)	84
Hypertension requiring medication	0.308	0.308	6.890	< 0.001	1.360 (1.246–1.485)	35
Preoperative creatinine > 1.2 mg/dL	0.347	0.347	5.743	< 0.001	1.414 (1.256–1.592)	39

Other variables in the initial regression included operation year, race/ethnicity, congestive heart failure (CHF) in 30 days before surgery, presence of ascites, history of renal failure, low hematocrit (<37% for male, <35% for female), low preoperative albumin (<3.5 g/L), and transfer from another acute care hospital.

ASA, American Society of Anesthesiologists.

**Table 4.** Pancreatectomy Pulmonary Complications Risk Score Groups

Risk group	Training sample					Validation sample				
	Patients, n	%	Event, n	%	Rate, %	Patients, n	%	Event, n	%	Rate, %
<97	9,656	26.4	260	9.4	2.7	2,410	26.6	74	10.4	3.1
97–158	11,534	31.5	619	22.3	5.4	2,801	30.9	158	22.2	5.6
159–225	10,386	28.4	1,011	36.4	9.7	2,609	28.7	254	35.7	9.7
>225	5,051	13.8	884	31.9	17.5	1,256	13.8	226	31.7	18.0
Total	36,627	100.0	2,774	100.0	7.6	9,076	100.0	712	100.0	7.8

Model c-statistic = 0.69

Cutoff points for risk score groupings within the Pulmonary Complications Risk Score were determined by the Youden index. Cutoff point of 96.5 had Youden index, sensitivity, and specificity of 0.167, 0.70, and 0.46, respectively. Cutoff point of 158.5 had Youden index, sensitivity, and specificity of 0.283, 0.68, and 0.60, respectively. Cutoff point of 225.5 had Youden index, sensitivity, and specificity of 0.159, 0.47, and 0.69, respectively.

hepatectomy procedure found by the risk score model were long operation time (or total operation time within the last quartile  $\geq 306$  minutes), patient in a partially or totally dependent state, and advanced age ( $\geq 80$  years), respectively. The relative risk values for each of these variables were 114, 82, and 78, respectively. The Hosmer–Lemeshow test did not reveal a statistically significant model ( $p = 0.3045$ ). An increasing PCRS was associated with an increased rate of PPCs, with rates ranging from 1.9% to 16.9% in the training sample and 1.9% to 17.2% in the validation sample. The complete risk score model and a comparison of PPC rates after hepatectomy between the training and validation samples within risk score groups are shown in Tables 5 and 6.

### Esophagectomy risk model

There were a total of 1,477 PPC events within the training sample of the esophagectomy group, a rate of 23.7%. The risk score model for esophagectomy showed the top 3 independent predictors of PPC after esophagectomy procedure were patients in a partially or totally dependent state, history of severe COPD, and long operation time (or total operation time within the last quartile  $\geq 435$  minutes), respectively. The relative risk values for each of these variables were 79, 58, and 56, respectively. The Hosmer–Lemeshow test did not reveal a statistically significant model ( $p = 0.1546$ ). An increasing PCRS was associated with an increased rate of PPCs, with rates ranging from 11.7% to 37.6% in the training sample and 10.8% to 37.2% in the validation sample. The

**Table 5.** Hepatectomy Pulmonary Complications Risk Score Model

Variable	Beta	Standard error	Wald	p Value	Odds ratio (95% CI)	Relative risk value
Age category						
60–69 y	0.240	0.240	3.176	0.001	1.272 (1.096–1.475)	21
70–79 y	0.508	0.508	6.120	< 0.001	1.661 (1.412–1.954)	44
$\geq 80$ y	0.897	0.897	6.877	< 0.001	2.451 (1.899–3.165)	78
Male sex	0.263	0.263	4.255	< 0.001	1.301 (1.152–1.468)	23
Total operation time quartile, min						
156–220	0.114	0.114	1.060	0.289	1.121 (0.907–1.386)	10
221–305	0.674	0.674	6.868	< 0.001	1.962 (1.619–2.378)	59
$\geq 306$	1.301	1.301	14.200	< 0.001	3.671 (3.068–4.393)	114
ASA Class III, IV, V	0.607	0.607	7.039	< 0.001	1.835 (1.550–2.173)	53
Preoperative sepsis	0.838	0.838	5.391	< 0.001	2.313 (1.705–3.137)	73
History of severe COPD	0.678	0.678	5.561	< 0.001	1.970 (1.551–2.502)	59
Current smoker within 1 year	0.488	0.488	6.409	< 0.001	1.628 (1.403–1.890)	43
Preoperative albumin < 3.5 g/L	0.572	0.572	7.759	< 0.001	1.772 (1.534–2.048)	50
Partially or totally functionally dependent	0.939	0.939	4.990	< 0.001	2.558 (1.769–3.700)	82
Hypertension requiring medication	0.290	0.290	4.483	< 0.001	1.336 (1.177–1.517)	25

Other variables in the initial regression included operation year, race/ethnicity, congestive heart failure (CHF) in 30 days before surgery, dyspnea at rest or moderate, disseminated cancer, presence of ascites, history of renal failure, low hematocrit (<37% for male, <35% for female), creatinine >1.2 mg/dL, emergency case, and transfer from another acute care hospital.

ASA, American Society of Anesthesiologists.

**Table 6.** Hepatectomy Pulmonary Complications Risk Score Groups

Risk group	Training sample					Validation sample				
	Patient, n	%	Event, n	%	Rate, %	Patient, n	%	Event, n	%	Rate, %
<117	8,062	39.1	150	12.0	1.9	2,084	39.3	40	12.2	1.9
117–161	4,888	23.7	239	19.1	4.9	1,219	23.0	54	16.4	4.4
162–228	4,981	24.1	402	32.2	8.1	1,314	24.8	116	35.3	8.8
>228	2,711	13.1	458	36.7	16.9	692	13.0	119	36.2	17.2
Total	20,642	100.0	1,249	100.0	6.1	5,309	100.0	329	100.0	6.2

Model c-statistic = 0.73

Cutoff points for risk score groupings within the pulmonary complications risk scores were determined by the Youden index. Cutoff point of 116.5 had a Youden index, sensitivity, and specificity of 0.244, 0.61, and 0.63, respectively. Cutoff point of 161.5 had a Youden index, sensitivity, and specificity of 0.336, 0.69, and 0.65, respectively. Cutoff point of 228.5 had a Youden index, sensitivity, and specificity of 0.203, 0.53, and 0.67, respectively.

complete risk score model and a comparison of PPC rates after esophagectomy between the training and validation samples within risk score groups are shown in Tables 7 and 8.

### Abdominal aortic aneurysm risk model

There were a total of 2,440 PPC events within the training sample of the abdominal aortic aneurysm repair group—a rate of 21.9%. For the abdominal aortic aneurysm repair model, the top 3 independent predictors of PPC after the procedure were emergency case, long operation time (or total operation time within the last quartile  $\geq 288$  minutes), and advanced age ( $\geq 80$  years), respectively. The relative risk values for each of these variables were 69, 59, and 40, respectively. The Hosmer–Lemeshow test revealed a statistically significant model ( $p = 0.0001$ ). An increasing PCRS was associated with an increased rate of PPCs, with rates ranging from 8.0% to 47.7% in the training sample and 8.7% to

49.2% in the validation sample. The complete risk score model and a comparison of PPC rates after abdominal aortic aneurysm repair between the training and validation samples within risk score groups are shown in Tables 9 and 10.

### Open aortoiliac repair risk model

There were a total of 1,657 PPC events within the training sample of the open aortoiliac repair group, a rate of 8.9%. The top 3 independent predictors of PPC after open aortoiliac repair found by the risk score model were total operation time within the last quartile ( $\geq 277$  minutes), total operation time within the third quartile (203 to 276 minutes), and emergency case, respectively. The relative risk values for each of these variables were 79, 46, and 37, respectively. The Hosmer–Lemeshow test revealed a statistically significant model ( $p = 0.0088$ ). An increasing PCRS was associated with an increased rate of PPCs, with rates ranging from

**Table 7.** Esophagectomy Pulmonary Complications Risk Score Model

Variable	Beta	Standard error	Wald	p Value	Odds ratio (95% CI)	Relative risk value
Age category						
60–69 y	0.120	0.120	1.580	0.114	1.127 (0.972–1.308)	10
70–79 y	0.447	0.447	5.298	< 0.001	1.564 (1.326–1.846)	37
$\geq 80$ y	0.589	0.589	4.105	< 0.001	1.802 (1.360–2.387)	49
Total operation time quartile, min						
248–335	0.241	0.241	2.649	0.008	1.272 (1.065–1.520)	20
336–434	0.316	0.316	3.496	< 0.001	1.372 (1.149–1.638)	26
$\geq 435$	0.675	0.675	7.696	< 0.001	1.963 (1.653–2.331)	56
Preoperative creatinine > 1.2 mg/dL	0.363	0.363	3.626	< 0.001	1.438 (1.182–1.751)	30
ASA Class III, IV, V	0.379	0.379	4.435	< 0.001	1.461 (1.236–1.728)	32
Partially or totally functionally dependent	0.942	0.942	4.445	< 0.001	2.565 (1.693–3.887)	79
History of severe COPD	0.699	0.699	6.642	< 0.001	2.012 (1.637–2.472)	58
Current smoker within 1 year	0.404	0.404	5.617	< 0.001	1.498 (1.301–1.726)	34
Dyspnea at rest or moderate	0.414	0.414	4.413	< 0.001	1.513 (1.259–1.819)	35

Other variables in the initial regression included operation year, race/ethnicity, male sex, congestive heart failure (CHF) in 30 days before surgery, preoperative sepsis, hypertension requiring medications, disseminated cancer, presence of ascites, history of renal failure, low hematocrit ( $<37\%$  for male,  $<35\%$  for female), low preoperative albumin ( $<3.5$  g/L), emergency case, and transfer from another acute care hospital.

ASA, American Society of Anesthesiologists.

**Table 8.** Esophagectomy Pulmonary Complications Risk Score Groups

Risk group	Training sample					Validation sample				
	Patient, n	%	Event, n	%	Rate, %	Patient, n	%	Event, n	%	Rate, %
<57	1,329	21.4	155	10.5	11.7	323	20.9	35	10.1	10.8
57–83	1,595	25.6	309	20.9	19.4	389	25.2	67	19.4	17.2
84–116	1,838	29.5	464	31.4	25.2	443	28.7	99	28.6	22.3
>116	1,460	23.5	549	37.2	37.6	390	25.2	145	41.9	37.2
Total	6,222	100.0	1,477	100.0	23.7	1,545	100.0	346	100.0	22.4

Model c-statistic = 0.65

Cutoff points for risk score groupings within the pulmonary complications risk scores were determined by the Youden index. Cutoff point of 56.5 had a Youden index, sensitivity, and specificity of 0.143, 0.67, and 0.48, respectively. Cutoff point of 83.5 had a Youden index, sensitivity, and specificity of 0.204, 0.69, and 0.52, respectively. Cutoff point of 116 had a Youden index, sensitivity, and specificity of 0.143, 0.54, and 0.60, respectively.

2.2% to 23.5% in the training sample and 1.4% to 20.5% in the validation sample. The complete risk score model and a comparison of PPC rates after open aortoiliac repair between the training and validation samples within risk score groups are shown in [Tables 11](#) and [12](#).

### Lung resection risk model

There were 1,551 PPC events within the training sample of the lung resection group—a rate of 7.6%. For the lung resection risk score model, the top 3 independent predictors of PPC after this procedure were preoperative sepsis, patient in a partially or totally dependent state, and long operation time (or total operation time within the last quartile  $\geq 203$  minutes). The relative risk values for each of these variables were 122, 95, and 94, respectively. The Hosmer-Lemeshow test revealed a statistically significant model ( $p = 0.0001$ ). An increasing PCRS was

associated with an increased rate of PPCs, with rates ranging from 1.5% to 17.8% in the training sample and 2.4% to 17.2% in the validation sample. The complete risk score model and a comparison of PPC rates after lung resection between the training and validation samples within risk score groups are shown in [Tables 13](#) and [14](#).

## DISCUSSION

This study developed unique risk scores for each of the 6 procedures with the highest rates of PPCs (pancreatectomy, hepatectomy, esophagectomy, abdominal aortic aneurysm repair, open aortoiliac repair, and lung resection). The risk scores can be used to help guide practitioners in optimizing patients undergoing these specific procedures to best prevent PPCs. For each procedure,

**Table 9.** Abdominal Aortic Aneurysm Repair Pulmonary Complications Risk Score Model

Variable	Beta	Standard error	Wald	p Value	Odds ratio (95% CI)	Relative risk value
Age category						
60–69 y	0.399	0.399	3.996	< 0.001	1.490 (1.225–1.813)	21
70–79 y	0.641	0.641	6.532	< 0.001	1.898 (1.566–2.301)	34
$\geq 80$ y	0.750	0.750	6.967	< 0.001	2.116 (1.714–2.613)	40
Emergency case	1.304	1.304	22.836	< 0.001	3.683 (3.293–4.119)	69
Preoperative creatinine > 1.2 mg/dL	0.362	0.362	6.944	< 0.001	1.436 (1.297–1.591)	19
Total operation time quartile, min						
168–218	0.467	0.467	6.173	< 0.001	1.595 (1.375–1.849)	25
219–287	0.686	0.686	9.241	< 0.001	1.985 (1.716–2.296)	36
$\geq 288$	1.118	1.118	15.439	< 0.001	3.058 (2.654–3.525)	59
Congestive heart failure in 30 d before operation	0.603	0.603	3.451	< 0.001	1.827 (1.298–2.573)	32
History of severe COPD	0.446	0.446	7.161	< 0.001	1.562 (1.383–1.765)	24
Current smoker within 1 y	0.189	0.189	3.560	< 0.001	1.207 (1.088–1.340)	10
Dyspnea at rest or moderate	0.293	0.293	4.594	< 0.001	1.340 (1.183–1.519)	16
Partially or totally functionally dependent	0.581	0.581	6.496	< 0.001	1.788 (1.501–2.131)	31
Preoperative hematocrit < 37% for male, <35% for female	0.216	0.216	3.878	< 0.001	1.241 (1.113–1.385)	11

Other variables in the initial regression included operation year, male sex, race/ethnicity, American Society of Anesthesiologists class III/IV/V, disseminated cancer, preoperative sepsis, hypertension requiring medications, presence of ascites, history of renal failure, low preoperative albumin (<3.5 g/L), and transfer from another acute care hospital.

**Table 10.** Abdominal Aortic Aneurysm Repair Pulmonary Complications Risk Score Groups

Risk group	Training sample					Validation sample				
	Patient, n	%	Event, n	%	Rate, %	Patient, n	%	Event, n	%	Rate, %
<75	3,957	35.5	315	12.9	8.0	1,075	38.4	93	15.6	8.7
75–101	2,858	25.6	518	21.2	18.1	673	24.0	115	19.3	17.1
102–138	2,408	21.6	685	28.1	28.4	610	21.8	171	28.6	28.0
>138	1,934	17.3	922	37.8	47.7	443	15.8	218	36.5	49.2
Total	11,157	100.0	2,440	100.0	21.9	2,801	100.0	597	100.0	21.3

Model c-statistic = 0.73

Cutoff points for risk score groupings within the pulmonary complications risk scores were determined by the Youden index. Cutoff point of 74.5 had a Youden index, sensitivity, and specificity of 0.231, 0.62, and 0.61, respectively. Cutoff point of 101.5 had a Youden index, sensitivity, and specificity of 0.345, 0.66, and 0.69, respectively. Cutoff point of 138.5 had a Youden index, sensitivity, and specificity of 0.204, 0.57, and 0.63, respectively.

multiple variables were identified, including both preoperative and intraoperative factors, which yield an increased risk of PPCs in surgical patients. Interestingly, these variables differed by procedure type, outlining the importance of procedure-specific risk scores when examining PPCs. The 1 variable that was consistent across all procedures in predicting PPCs was prolonged procedure time. Efforts to shorten operation time and therefore, time under general anesthesia, should be undertaken for all patients in order to prevent PPCs. Previous studies have identified multiple parameters that affect operating time including preoperative planning, equipment access, surgeon and operating room staff experience, and surgeon fatigue.<sup>21,22</sup> Preoperative planning and assuring adequate access to appropriate equipment, when possible, can be used to

improve procedure times. Continued advancements in procedure methods will also likely improve operation time and patient outcomes.

By using a large national database, this study allows the PCRS to be applied to a wide patient population. It also allows for multiple variables to be evaluated as risk factors for PPCs and be incorporated into the PCRS. For each procedure examined, an increasing PCRS is associated with an increased risk of PPCs in both the training and validation samples (Tables 4, 6, 8, 10, 12, 14). The PCRS can be calculated by examining the risk score model for the specific procedure type. Each preoperative risk factor included in the model has an associated relative risk value that can be summed to create a patient- and procedure-specific PCRS. This individualized PCRS can

**Table 11.** Open Aortoiliac Repair Pulmonary Complications Risk Score Model

Variable	Beta	Standard error	Wald	p Value	Odds ratio (95% CI)	Relative risk value
Age category						
60–69 y	0.277	0.277	4.033	< 0.001	1.319 (1.153–1.510)	13
70–79 y	0.398	0.398	5.244	< 0.001	1.489 (1.283–1.727)	19
≥80 y	0.267	0.267	2.542	0.011	1.306 (1.063–1.605)	13
Preoperative sepsis	0.670	0.670	7.612	< 0.001	1.955 (1.645–2.324)	32
Preoperative albumin < 3.5 g/L	0.372	0.372	5.598	< 0.001	1.450 (1.273–1.652)	18
ASA Class III, IV, V	0.595	0.595	3.360	< 0.001	1.814 (1.282–2.567)	28
Congestive heart failure in 30 d before operation	0.705	0.705	5.398	< 0.001	2.024 (1.567–2.614)	34
History of severe COPD	0.423	0.423	6.497	< 0.001	1.526 (1.343–1.734)	20
Current smoker within 1 y	0.209	0.209	3.547	< 0.001	1.233 (1.098–1.384)	10
Dyspnea at rest or moderate	0.278	0.278	4.136	< 0.001	1.320 (1.157–1.506)	13
Partially or totally functionally dependent	0.327	0.327	3.978	< 0.001	1.386 (1.180–1.628)	16
Emergency case	0.781	0.781	10.385	< 0.001	2.183 (1.884–2.530)	37
Total operation time quartile, min						
144–202	0.613	0.613	6.274	< 0.001	1.845 (1.524–2.234)	29
203–276	0.971	0.971	10.360	< 0.001	2.641 (2.198–3.174)	46
≥ 277	1.648	1.648	18.676	< 0.001	5.195 (4.370–6.175)	79

Other variables in the initial regression included operation year, male sex, race/ethnicity, hypertension requiring medications, disseminated cancer, presence of ascites, history of renal failure, low hematocrit (<37% for male, <35% for female), preoperative creatinine >1/2 mg/dL, and transfer from another acute care hospital.

ASA, American Society of Anesthesiologists.

**Table 12.** Open Aortoiliac Repair Pulmonary Complications Risk Score Groups

Risk group	Training sample					Validation sample				
	Patient, n	%	Event, n	%	Rate, %	Patient, n	%	Event, n	%	Rate, %
<72	4,963	26.6	110	6.6	2.2	1,256	27.3	18	4.7	1.4
72–107	6,491	34.9	413	24.9	6.4	1,605	34.9	107	27.9	6.7
108–139	4,766	25.6	568	34.3	11.9	1,167	25.4	143	37.2	12.3
>139	2,404	12.9	566	34.2	23.5	566	12.3	116	30.2	20.5
Total	18,624	100.0	1,657	100.0	8.9	4,594	100.0	384	100.0	8.4

Model c-statistic = 0.72

Cutoff points for risk score groupings within the pulmonary complications risk scores were determined by the Youden index. Cutoff point of 71.5 had a Youden index, sensitivity, and specificity of 0.232, 0.79, and 0.44, respectively. Cutoff point of 107.5 had a Youden index, sensitivity, and specificity of 0.328, 0.68, and 0.64, respectively. Cutoff point of 139.5 had a Youden index, sensitivity, and specificity of 0.195, 0.51, and 0.70, respectively.

then be compared to the risk score groups of that procedure to identify the expected rate of PPCs in this patient based on his or her preoperative risk factors before undergoing the procedure.

Mortality, morbidity, and health care costs are all increased in patients who suffer from PPCs.<sup>1</sup> For this reason, optimizing patients at high risk for PPCs is a necessity for practitioners. Using the PCRS outlined above, patients who are high risk for PPCs can be identified within each procedure type, and steps can be taken to improve patient status both preoperatively and intraoperatively. In addition, patients with a high risk of PPCs based on the PCRS can be more intensely monitored after surgery for complications. The PCRS can also be an important tool to be used in the informed consent process

by estimating the risk of PPCs in an individualized, patient-centered way.

One method of lowering PPC risk in patients intraoperatively is the use of lung-protective ventilation, including low tidal volumes (6 to 8 mL/kg) and higher levels of positive end-expiratory pressure (PEEP).<sup>7</sup> Other methods include pharmacologically optimizing patients with congestive heart failure and COPD, encouraging smoking cessation before the procedure, use of incentive spirometry immediately after surgery, improvement of preoperative anemia with dietary supplements, and postponement of elective surgery until lung function tests return to baseline after pulmonary infection.<sup>1,7,17</sup> Optimization of pain management to allow for coughing and full lung expansion, but without overuse of opioids, which

**Table 13.** Lung Resection Pulmonary Complications Risk Score Model

Variable	Beta	Standard error	Wald	p Value	Odds ratio (95% CI)	Relative risk value
Age category						
60–69 y	0.102	0.102	1.357	0.175	1.107 (0.956–1.283)	10
70–79 y	0.293	0.293	3.848	< 0.001	1.340 (1.154–1.555)	29
≥80 y	0.589	0.589	5.698	< 0.001	1.802 (1.472–2.207)	58
Male sex	0.267	0.267	4.809	< 0.001	1.306 (1.171–1.456)	26
Preoperative albumin < 3.5 g/L	0.627	0.627	7.404	< 0.001	1.872 (1.586–2.210)	62
ASA Class III, IV, V	0.555	0.555	6.060	< 0.001	1.741 (1.455–2.084)	54
Congestive heart failure in 30 d before operation	0.812	0.812	3.718	< 0.001	2.252 (1.468–3.455)	80
History of severe COPD	0.684	0.684	11.294	< 0.001	1.982 (1.760–2.232)	67
Current smoker within 1 y	0.425	0.425	7.190	< 0.001	1.530 (1.363–1.718)	42
Dyspnea at rest or moderate	0.240	0.240	3.945	< 0.001	1.271 (1.128–1.432)	24
Partially or totally functionally dependent	0.968	0.968	5.745	< 0.001	2.632 (1.892–3.661)	95
Preoperative hematocrit < 37% for male, <35% for female	0.385	0.385	5.856	< 0.001	1.470 (1.292–1.672)	38
Total operation time quartile, min						
90–139	0.370	0.370	4.048	< 0.001	1.448 (1.211–1.733)	36
140–202	0.567	0.567	6.416	< 0.001	1.763 (1.483–2.096)	56
≥203	0.955	0.955	11.337	< 0.001	2.598 (2.203–3.065)	94
Preoperative sepsis	1.241	1.241	9.062	< 0.001	3.460 (2.646–4.526)	122

Other variables in the initial regression included operation year, race/ethnicity, hypertension requiring medications, disseminated cancer, presence of ascites, history of renal failure, preoperative creatinine >1.2 mg/dL, emergency case, and transfer from another acute care hospital. ASA, American Society of Anesthesiologists.

**Table 14.** Lung Resection Pulmonary Complications Risk Score Groups

Risk group	Training sample					Validation sample				
	Patient, n	%	Event, n	%	Rate, %	Patient, n	%	Event, n	%	Rate, %
<111	5,078	24.9	76	4.9	1.5	1,271	24.5	30	7.6	2.4
111–172	5,911	29.0	260	16.8	4.4	1,585	30.6	77	19.5	4.9
173–231	5,268	25.9	482	31.1	9.1	1,334	25.7	117	29.6	8.8
>231	4,113	20.2	733	47.3	17.8	992	19.1	171	43.3	17.2
Total	20,370	100.0	1,551	100.0	7.6	5,182	100.0	395	100.0	7.6

Model c-statistic = 0.74

Cutoff points for risk score groupings within the pulmonary complications risk scores were determined by the Youden index. Cutoff point of 110.5 had a Youden index, sensitivity, and specificity of 0.243, 0.77, and 0.47, respectively. Cutoff point of 172.5 had a Youden index, sensitivity, and specificity of 0.349, 0.78, and 0.57, respectively. Cutoff point of 231.5 had a Youden index, sensitivity, and specificity of 0.189, 0.60, and 0.59, respectively.

may depress respiratory drive, may also improve PPCs in certain patients.<sup>17</sup> In addition, limiting operative time for patients with a very high risk of PPC should be valued in all procedure types by using preoperative planning.<sup>22</sup> Further studies investigating how these interventions may improve PPCs are needed. Procedure-specific techniques to decrease the incidence of PPCs include improving preoperative anemia for aortic aneurysm repair and pulmonary resection, preoperative antibiotics and stabilization in septic patients for pancreatotomy, hepatectomy, open aortoiliac repair, and lung resection, and optimization of preoperative albumin in pancreatotomy, hepatectomy, open aortoiliac repair, and lung resection.

Although previous studies have also identified risk factors for PPCs and developed risk scores for these complications, these risk scores have not been specific to certain procedures. Past studies have reported that the strongest predictor of PPCs is the surgical procedure type.<sup>5,17</sup> This study aimed to identify variables unique to these 6 procedures that have the highest rates of PPCs to further guide practitioners in a more specific manner. All risk factors included in this study were statistically significant in previous studies, but some of the risk factors included in the final PCRS for each procedure were different from those included in the final risk score created in other studies. These differences are likely due to calculations in this study being based on procedure type, not simply impact on PPCs. This study also included the year of operation in the analysis to control for changes and improvements in operative techniques over time. This may improve overall validity of the PCRS over previous risk scores that did not control for these changes. In addition, while the ACS NSQIP Risk Calculator is more specific to procedure type by delineating the specific current procedural terminology (CPT) code to be evaluated, it is not specific to pulmonary complications. The ACS NSQIP calculator includes

pneumonia as an outcome, but does not include prolonged intubation, and includes unplanned intubation as a “serious complication” grouped with many nonpulmonary complications. The PCRS developed by this study is the first of its kind to be both procedure- and complication-specific by focusing solely on PPCs.

This study has several limitations. Variables included in this study were limited to those variables collected by and included in the ACS NSQIP database. Several variables, such as preoperative pulmonary function test results and other lab values, were not collected in the ACS NSQIP database and therefore could not be included in the analysis. Laboratory reference ranges likely differed by institution, so our determination of abnormal was an estimate. In addition, the primary outcome of this study, PPCs, was limited in its definition to unplanned reintubation, postoperative pneumonia, and failure to liberate from mechanical ventilation within 48 hours after intubation. Other respiratory complications such as atelectasis, pleural effusion, pneumothorax, and bronchospasm, were not included in the analysis because they are not included in the ACS NSQIP database. The c-statistics of each PCRS showed moderate diagnostic accuracy, with the exception of esophagectomy, which had a lower c-statistic of 0.65. This is likely due to the low number of procedures included in the database within the timeframe examined. The c-statistic itself is limited in that it cannot provide information about the accuracy of the magnitude of predicted risk.<sup>23</sup> Finally, there is a limitation to the use of retrospective data and registry data, including missing and possibly inaccurate data. The ACS NSQIP database includes a comprehensive dataset of preoperative variables; however, some variables possibly related to PPCs are not collected, including pulmonary function tests and history of obstructive sleep apnea. Future studies may consider inclusion of these variables using a database with this information.

## CONCLUSIONS

Postoperative pulmonary complications affect up to 23% of surgical patients and contribute to increased patient morbidity and mortality, as well as increasing financial burdens on patients and the health care system.<sup>1</sup> In order to improve patient outcomes and limit PPCs, physicians must examine risk factors that may contribute to these poor outcomes. Although risk models have been developed in the past for PPCs, these scores have not been procedure-specific. The type of surgical procedure being performed is one of the largest risk factors of PPCs. This study developed procedure-specific risk scores to allow health care professionals to better predict the risk for PPCs in their surgical patients and improve patient outcomes.

## Author Contributions

Study conception and design: Foster, Charles, Turrentine

Acquisition of data: Charles, Turrentine, Sohn

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## Appendix.

**eTable 1.** Current Procedural Terminology (CPT) Codes Used in Analysis by Procedure

Procedure	CPT code
Lung resection	32440, 32442, 32445, 32480, 32482, 32484, 32486, 32488, 32491, 32503, 32504, 32505, 32506, 32507, 32663, 32666, 32667, 32668, 32669, 32670, 32671, 32672
Abdominal aortic aneurysm repair	34830, 34831, 34832, 35081, 35082, 35091, 35092, 35102, 35103
Open aortoiliac repair	35331, 35351, 35355, 35361, 35363, 35521, 35533, 35537, 35538, 35539, 35540, 35558, 35563, 35565, 35621, 35623, 35637, 35638, 35646, 35647, 35654, 35661, 35663, 35665
Esophagectomy	43101, 43107, 43108, 43112, 43113, 43116, 43117, 43118, 43121, 43122, 43123, 43124
Hepatectomy	47120, 47122, 47125, 47130
Pancreatectomy	48120, 48140, 48145, 48146, 48148, 48150, 48152, 48153, 48154, 48155, 48999

**eTable 2.** Variables of Known Significance in Postoperative Pulmonary Complications Included in the Logistic Regression

Variable	Source
Operation year	To account for changes in surgical procedure methods over time
Age category	Brueckmann et al, 2013 <sup>4</sup> ; Canet & Gallart, 2014 <sup>15</sup> ; Hua et al, 2012 <sup>6</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Pfeifer & Smetana, 2016 <sup>7</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Male sex	Canet & Gallart, 2014 <sup>15</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Race/ethnicity	Johnson et al, 2016 <sup>2</sup> ; Ramachandran et al, 2011 <sup>16</sup>
ASA Class III, IV, or V	Brueckmann et al, 2013 <sup>4</sup> ; Canet & Gallart, 2014 <sup>15</sup> ; Gupta et al, 2011 <sup>5</sup> ; Hua et al, 2012 <sup>6</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Pfeifer & Smetana, 2016 <sup>7</sup>
Congestive heart failure in 30 d before	Brueckmann et al, 2013 <sup>4</sup> ; Canet & Gallart, 2014 <sup>15</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Ramachandran et al, 2011 <sup>16</sup>
History of severe COPD	Brueckmann et al, 2013 <sup>4</sup> ; Canet & Gallart, 2014 <sup>15</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Pfeifer & Smetana, 2016 <sup>7</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Current smoker within 1 y	Canet & Gallart, 2014 <sup>15</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Dyspnea at rest or moderate	Canet & Gallart, 2014 <sup>15</sup> ; Hua et al, 2012 <sup>6</sup> ; Johnson et al, 2016 <sup>2</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Partially or totally functionally dependent	Canet & Gallart, 2014 <sup>15</sup> ; Canet et al, 2010 <sup>14</sup> ; Gupta et al, 2011 <sup>5</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup>
Disseminated cancer	Canet & Gallart, 2014 <sup>15</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Total operation time quartile (specific to each procedure type)	Canet et al, 2010 <sup>14</sup> ; Hua et al, 2012 <sup>6</sup> ; Miskovic & Lumb, 2017 <sup>1</sup>
Preoperative sepsis	Canet & Gallart, 2014 <sup>15</sup> ; Gupta et al, 2011 <sup>5</sup> ; Hua et al, 2012 <sup>6</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Hypertension requiring medication	Canet & Gallart, 2014 <sup>15</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Ascites	Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup>
Renal failure	Canet & Gallart, 2014 <sup>15</sup> ; Johnson et al, 2016 <sup>2</sup> ; Miskovic & Lumb, 2017 <sup>1</sup> ; Ramachandran et al, 2011 <sup>16</sup>
Preoperative hematocrit < 37% for male, <35% for female	Canet et al, 2010 <sup>14</sup> ; Miskovic & Lumb, 2017 <sup>1</sup>
Preoperative albumin < 3.5 g/L	Miskovic & Lumb, 2017 <sup>1</sup>
Preoperative creatinine > 1.2 mg/dL	Miskovic & Lumb, 2017 <sup>1</sup>
Transferred from another acute care hospital	Hua et al, 2012 <sup>6</sup>
Emergency case	Brueckmann et al, 2013 <sup>4</sup> ; Canet et al, 2010 <sup>14</sup> ; Gupta et al, 2011 <sup>5</sup> ; Hua et al, 2012 <sup>6</sup> ; Miskovic & Lumb, 2017 <sup>1</sup>

ASA, American Society of Anesthesiologists.

**eTable 3.** Total Number of Operations Performed within Each Procedure by Year of Operation

Year of operation	Pancreatectomy, n	Hepatectomy, n	Esophagectomy, n	Abdominal aortic aneurysm repair, n	Aortoiliac open operation, n	Lung resection, n	Total, n
2005	485	274	50	309	222	31	1,371
2006	1,548	756	212	897	843	121	4,377
2007	2,550	1,263	372	1,448	1,618	277	7,528
2008	3,013	1,622	401	1,492	1,915	596	9,039
2009	3,278	1,713	507	1,499	2,249	984	10,230
2010	3,504	1,904	546	1,408	2,339	1,178	10,879
2011	4,591	2,620	712	1,413	2,316	2,010	13,662
2012	5,334	2,905	954	1,412	2,397	4,307	17,309
2013	6,594	3,660	1,283	1,415	2,896	4,964	20,812
2014	7,044	4,223	1,306	1,341	3,084	5,452	22,450
2015	7,762	5,011	1,424	1,324	3,312	5,632	24,465
Total	45,703	25,951	7,767	13,958	23,191	25,552	142,122