Preoperative assessment of the risk for multiple complications after surgery

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Background. *The association between preoperative patient characteristics and the number of major postoperative complications after a major operation is not well defined.*
Methods. *In a retrospective, single-center cohort of 50,314 adult surgical patients, we used readily available preoperative clinical data to model the number of major postoperative complications from none to ≥3. We included acute kidney injury; prolonged stay (>48 hours) in an intensive care unit; need for prolonged (>48 hours) mechanical ventilation; severe sepsis; and cardiovascular, wound, and neurologic complications. Risk probability scores generated from the multinomial logistic models were used to develop an online calculator. We stratified patients based on their risk of having ≥3 postoperative complications.*
Results. *Patients older than 65 years (odds ratio 1.5, 95% confidence interval, 1.4–1.6), males (odds ratio 1.2, 95% confidence interval, 1.2–1.3), patients with a greater Charlson comorbidity index (odds ratio 3.9, 95% confidence interval, 3.6–4.2), patients requiring emergency operation (odds ratio 3.5, 95% confidence interval, 3.3.–3.7), and patients admitted on a weekend (odds ratio 1.4, 95% confidence interval, 1.3–1.5) were more likely to have ≥3 postoperative complications than they were to have none. Patients in the medium- and high-risk categories were 3.7 and 6.3 times more likely to have ≥3 postoperative complications, respectively. High-risk patients were 5.8 and 4.4 times more likely to die within 30 and 90 days of admission, respectively.*
Conclusion. *Readily available, preoperative clinical and sociodemographic factors are associated with a greater number of postoperative complications and adverse surgical outcomes. We developed an online calculator that predicts probability of developing each number of complications after a major operation. (Surgery 2016;160:463-72.)*

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More than 50 million inpatient surgical procedures are performed in the United States each year.[1] It is estimated that between 3% and 17% of all people undergoing surgical procedures develop postoperative complications, while almost 1% of surgical procedures result in death.[2-4] Postoperative complications are associated with greater risks of hospital mortality and hospital readmissions after discharge,[5-8] and the costs of health care associated with surgical procedures increase in proportion with the number of postoperative complications.[9-11]

Postoperative acute kidney injury (AKI) is a common and potentially devastating complication. When defined by consensus criteria, AKI affects as much as 30% of surgical patients and is associated with increased risk for other major complications, including sepsis, respiratory failure, cardiovascular complications, and prolonged stay in an intensive care unit (ICU). A combination of these major complications often occurs in the same patient,

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leading to a substantial increase in cost of care, development of chronic critical illness, and increased long-term mortality and disability.[6,11-29] The ability to determine preoperatively the overall risk for multiple major postoperative complications could be important for clinical decision-making. Appropriate risk-stratification of patients prior to operation may improve patient selection and promote the timely initiation of intraoperative preventive strategies to decrease the number and severity of complications.[30]

Previously reported predictive models assessing the preoperative risk for complications were often limited to specific types of operations or used statistical modeling for a single complication or complications grouped into binary categories rather than predicting the overall number of complications.[7,30-33] Developed to optimize predictive modeling when outcomes of interest have >2 categories, ordinal regression models have been underused in surgical studies, although such approaches may allow for better use of the clinical data with better predictive accuracy.[34] In a large, single-center cohort of adult patients undergoing any major inpatient operation by optimizing modeling approaches, we used readily available preoperative clinical data to develop preoperative risk scores for each number of major postoperative complications.

METHODS

Study cohort. Using the University of Florida Health Integrated Data Repository, we assembled a single-center cohort of perioperative patients by integrating multiple existing clinical and administrative databases at the University of Florida Health. We included all patients aged ≥18 years admitted to the hospital for >24 hours after any type of inpatient operative procedure between January 2000 and November 2010, as described previously.[14] The final cohort included 50,314 patients. The study was approved by the Institutional Review Board and Privacy Office of the University of Florida (eMethods online only version).

Covariates and outcome. The primary outcome was the exact number of postoperative complications of the 7 major complications we considered: AKI, mechanical ventilation required for >48 hours, ICU admission for >48 hours, severe sepsis, cardiovascular complications and/or the need for vasopressors for >24 hours, neurologic complications (including delirium), and wound complications (including mechanical wound complications and surgical infections). The number of complications ranged from none to ≥3 complications. We collapsed the last category to ≥3 due to a small number of patients with more than 3 complications. Postoperative AKI was defined using RIFLE (Risk, Injury, Failure, Loss, End-stage renal disease) criteria that corresponds to at least a 50% increase in serum creatinine after operation compared with a reference value, which was the minimum of the creatinine values available within 6 months of admission. For the definition of sepsis, we followed the selection criteria developed by the Agency for Healthcare Research and Quality for the patient safety indicators "Postoperative Sepsis," while severe sepsis was defined by the *International Classification of Diseases, Ninth Revision, Clinical Modification, Ninth Edition* (ICD-9-CM) codes for acute organ dysfunction due to the diagnosis of sepsis.[35-37] We determined the need for vasopressor therapy for >24 hours for each patient, using administration times and doses of any medication within the category of a vasopressor from the pharmacy database.[38] We defined neurologic complications (including delirium),[39] cardiovascular complications,[40,41] and wound complications (including mechanical wound complications and surgical site infections),[40,41] using previously described criteria based on ICD-9-CM codes as detailed in Supplementary Table I (online only version). The exact dates were used to calculate the duration of mechanical ventilation and the length of stay in an intensive care unit. Secondary outcomes were 30-day and 90-day mortality. Patient survival status was determined using hospital discharges and the Social Security Death Index.

The covariates used to develop predictive models were clinical variables available in routine preoperative assessment, including age (grouped as ≥65 years or <65 years), sex, African American ethnicity, primary insurance type, Charlson comorbidity index, and type of procedure, including cardiothoracic operation, noncardiac general and vascular operation, neurologic operation, specialty operations (including orthopedic, gynecologic, head and neck, urologic, and plastic surgery), and other operations (including burn, ophthalmology, transplantation, and trauma).

Statistical analysis. The analytic plan followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations for observational cohort studies.[42] We compared 5 ordinal regression modeling approaches (eMethods, online only version) to determine the method producing the best estimate of the risk for developing a specific number of complications (from none to ≥3).[43] To assess discrimination of the final model, we calculated the area under the receiver operating characteristics curve

(AUC) by averaging values obtained from all pairwise comparisons of the classes[44] and a confidence interval (CI) for the AUC from 100 bootstrap samples. Model fit for different approaches was compared using likelihood ratio tests and the Akaike information criterion. The multinomial logistic model, a baseline category logit model with maximal flexibility in the analysis of nominal responses, produced the best fit and was used to calculate the probabilistic risk score for each outcome category for an individual patient. The risk scores for each outcome ranged from 0 to 1 and corresponded to the probability for having that outcome given the preoperative characteristics of a patient.

Because patients with ≥3 complications had markedly increased mortality, we used a probabilistic risk score calculated with the multinomial logistic model for this outcome to develop 2 cut-offs that could be used to risk-stratify patients into low-, medium-, and high-risk for having ≥3 more major complications after operation. The cut-off points for the probabilistic risk score were determined using the maximum Youden index value and plateau of the accuracy curve (Supplementary Fig, online only version). Relative risks were used to show the association between risk categories and multiple complications, 30-day mortality, and 90-day mortality. The association between the number of complications and 30-day and 90-day mortality were tested using a multivariable logistic regression model. We performed sensitivity analyses by comparing the effect of the inclusion of patients with missing values for serum creatinine. Statistical analysis was performed with SAS (version 9.3, SAS Institute, Inc, Cary, NC) and R 3.0.2.

RESULTS

Baseline characteristics and resource utilization. Among 50,314 patients in the final cohort, 41% had no postoperative complications, while 26%, 12%, and 21% had 1, 2, and ≥3 complications, respectively. Increasing age and number of comorbidities, male sex, and emergent operation were more likely among patients with complications. Patients undergoing cardiothoracic operation were more likely to have ≥3 complications, while specialty operations had the greatest proportion of patients with no complications (Table I).

Among the 7 major complications we evaluated, postoperative AKI (39%, 19,644 out of 50,314) was the most common, followed by ICU admission >48 hours, cardiovascular complications and/or the need for vasopressors, and mechanical ventilation >48 hours (occurring in 32%, 23%, and 14% of the cohort, respectively). A majority of patients with ≥3 complications had some combination of prolonged ICU stay, mechanical ventilation, AKI, and cardiovascular complications, and/or the need for vasopressors. Length of hospital stay increased as the number of complications increased, ranging from 4 days among patients with no complications to 20 days among those with ≥3 complications ($P < .001$). Similarly, median length of stay in the ICU increased from 1 day in the no-complication group to 10 days among patients with ≥3 complications ($P < .001$). Patients with ≥3 complications had an almost 5-fold increase in median hospital cost of $70,000 compared with patients with no complications (median cost $13,000, $P < .0001$) and were less likely to be discharged home compared with patients with no complications (43% vs 85%, $P < .0001$; Table I).

Number of postoperative complications and mortality. Overall 30-day mortality and 90-day mortality were 3.5% and 6.6%, respectively. For patients with ≥3 complications, the 30-day mortality increased to 12.2% and 90-day mortality to 20.4%. A majority of deaths within 30 days and 90 days of hospitalization occurred in those patients with ≥3 complications (72%, 1,256 out of 1,749 and 63%, 2,098 out of 3,330, respectively; Supplementary Table II, online only version). An increasing number of complications were associated with increasing 30-day and 90-day mortality for all types of major operations. Patients who experienced no complications had very low 30-day mortality regardless of type of operation, ranging from 0.3% to 1.2%. Patients with only 1 complication still had a low 30-day mortality that remained <2.2% for all types of operations. Patients with 2 postoperative complications had as much as triple the risk for 30-day mortality regardless of the type of operation. Patients with ≥3 postoperative complications had up to a 20-fold increase in both 30-day and 90-day mortality. Thirty-day mortality for these patients ranged from 9% to 17%, while 90-day mortality was between 16% and 25% (Supplementary Table II, online only version). In multivariable regression analysis, the adjusted odds of 30-day and 90-day mortality for patients with ≥3 complications were about 16 and 9 times that for patients with no postoperative complications, even after adjusting for demographic and clinical preoperative variables (Table II).

Predictive models for number of major complications. Using the multinomial logistic model, with a discrimination AUC of 0.710 (95% CI, 0.707–0.713), we determined the strength of association between several preoperative factors and the risk

Table I. Clinical characteristics and resource utilization for all patients stratified by number of complications

Variables	Overall cohort (n = 50,314)	No. postoperative complications (n = 20,748)	1 postoperative complication (n = 13,200)	2 postoperative complications (n = 6,075)	≥3 postoperative complications (n = 10,291)
Age ≥65 y, n (%)	16,367 (32.5)	5,791 (27.9)	4,300 (32.6)*	2,237 (36.8)*	4,039 (39.3)*
Female sex, n (%)	24,668 (49.0)	11,275 (54.3)	6,396 (48.45)*	2,721 (44.8)*	4,276 (41.6)*
African American ethnicity, n (%)	6,182 (12.3)	2,423 (11.68)	1,706 (13.0)*	758 (12.5)	1,295 (12.6)
Primary insurance, n (%)					
Medicare	19,467 (38.7)	6,810 (32.8)	5,360 (40.6)*	2,690 (44.3)*	4,607 (44.8)*
Medicaid	6,517 (13.0)	2,680 (12.9)	1,551 (11.8)*	733 (12.1)	1,553 (15.1)*
Private	20,591 (40.9)	9,400 (45.3)	5,367 (40.7)*	2,264 (37.3)*	3,560 (34.6)*
No insurance	3,739 (7.4)	1,858 (9.0)	922 (7.0)*	388 (6.4)*	571 (5.6)*
Weekend admission, n (%)	6,881 (13.7)	2,105 (10.2)	1,713 (13.0)*	957 (15.8)*	2,106 (20.5)*
Emergency admission, n (%)	22,818 (45.4)	6,995 (33.7)	5,866 (44.4)*	3,128 (51.5)*	6,829 (66.4)*
Charlson-Deyo comorbidity score, n (%)					
0	18,490 (36.8)	9,996 (48.2)	4,692 (35.6)*	1,630 (26.8)*	2,172 (21.1)*
12	19,398 (38.5)	7,166 (34.5)	4,890 (37.1)*	2,554 (42.0)*	4,788 (46.5)*
≥3	12,426 (24.7)	3,586 (17.3)*	3,618 (27.4)*	1,891 (31.1)*	3,331 (32.4)*
Type of procedure, n (%)					
Cardiothoracic operation	6,755 (13.4)	912 (4.4)	1,297 (9.8)*	1,282 (21.1)*	3,264 (31.7)*
Neurologic operation	8,385 (16.7)	3,512 (16.9)	1,985 (15.0)*	899 (14.8)*	1,989 (19.3)*
Non-cardiac general operation	10,741 (21.3)	4,571 (22.0)	3,180 (24.1)*	1,349 (22.2)	1,641 (16.0)*
Specialty operations†	15,229 (30.3)	9,276 (44.7)	3,789 (28.7)*	1,095 (18.0)*	1,069 (10.4)*
Other operations‡	9,204 (18.3)	2,477 (11.9)	2,949 (22.3)*	1,450 (23.9)*	2,328 (22.6)*
Postoperative complications, n (%)					
Acute kidney injury	19,644 (39.0)	NA	6,417 (48.6)*	3,767 (62.0)*	9,460 (91.9)*
ICU admission for >48 h	16,244 (32.3)	NA	2,743 (20.8)*	3,674 (60.5)*	9,827 (95.5)*
Cardiovascular complications or need for vasopressors	11,786 (23.4)	NA	1,618 (12.3)*	2,215 (36.5)*	7,953 (77.3)*
Mechanical ventilation for >48 h	6,931 (13.8)	NA	35 (0.5)*	319 (4.6)*	6,577 (94.9)*
Mechanical wound complications and surgical infections	5,944 (11.8)	NA	1,589 (12.0)*	1,387 (22.8)*	2,968 (28.8)*
Neurologic and delirium complications	4,037 (8.0)	NA	796 (6.0)*	750 (12.4)*	2,491 (24.2)*
Severe sepsis	2,302 (4.6)	NA	2 (0.02)	38 (0.63)*	2,262 (22.0)*
Resource utilization					
Days in hospital, median (25th, 75th)	7 (4, 12)	4 (3, 6)	6 (4, 10)*	9 (6, 14)*	20 (12, 35)*
Hospital cost (1,000$), median (25th, 75th)	19 (12, 38)	13 (9, 18)	17 (12, 28)*	28 (19, 42)*	70 (42, 118)*
ICU admission, n (%)	26,433 (52.5)	4,454 (21.5)	6,637 (50.3)*	5,130 (84.4)*	10,212 (99.2)*
Days in ICU, median (25th, 75th)§	4 (2, 8)	1 (1, 2)	2 (1, 4)*	4 (2, 7)*	10 (5, 19)*
Mechanical ventilation, n (%)	12,873 (25.6)	879 (4.2)	1,640 (12.4)*	1,909 (31.4)*	8,445 (82.1)*
Days on mechanic ventilation, median (25th, 75th)§	3 (2, 11)	1 (1, 2)	2 (1, 2)	2 (1, 2)	7 (3, 18)*

(*continued*)

Table I. (*continued*)

Variables	Overall cohort (n = 50,314)	No. postoperative complications (n = 20,748)	1 postoperative complication (n = 13,200)	2 postoperative complications (n = 6,075)	≥3 postoperative complications (n = 10,291)
Discharge, *n* (%)					
Discharge to home	37,220 (76.9)	17,724 (85.4)	10,613 (80.4)*	4,493 (74.0)*	4,390 (42.7)*
Discharge to nursing home	3,971 (8.2)	929 (4.5)	888 (6.7)*	522 (8.6)*	1,632 (15.9)*
Discharge to other acute care facility/hospital	3,631 (7.5)	993 (4.8)	898 (6.8)*	491 (8.1)*	1,249 (12.1)*
Discharge to rehab facility	35,94 (7.4)	1,094 (5.3)	750 (5.7)	429 (7.1)*	1,321 (12.8)*

*P value < .05 for comparison with respect to no postoperative complications group using Bonferroni adjustment.
†Specialty operations include orthopedic, gynecologic, head and neck, urologic, and plastic surgery procedures.
‡Other operations include trauma, burn, and transplant procedures.
§Reported only for patients who were admitted to ICU and for patients who required mechanical ventilation, respectively.
ICU, Intensive care unit.

for each outcome category. Compared with younger patients, patients >65 years had 1.18 odds (95% CI, 1.07–1.29) of having 2 complications and 1.49 odds (95% CI, 1.37–1.62) of having ≥3 complications (Table III). Compared with females, males had greater odds of having >1 complication, with odds ratios (ORs) between 1.1 and 1.2. Patients with Medicare insurance had about 30–40% greater odds of having more postoperative complications than patients with private insurance. Compared with patients with no comorbidities, patients with comorbidities had greater odds of having a greater number of complications, ranging between 1.4 and 3.9. Patients undergoing cardiothoracic operation had much greater odds of having ≥3 postoperative complications versus no complications when compared with patients undergoing specialty operations (OR 23.64, 95% CI, 21.36–26.16). Compared with patients who underwent routine elective procedures and those admitted during the weekend, patients who had procedures that were performed under emergency circumstances were more likely to develop a greater number of complications (Table III).

Risk score for ≥3 postoperative complications. Because patients with ≥3 complications had markedly increased mortality, we used the probabilistic risk score calculated with the multinomial logistic model for this outcome to develop 2 cut-offs that could be used to risk-stratify patients into low, medium, and high risk for having ≥3 major postoperative complications. The probabilistic score of 0.2 was used to discriminate between low- and medium-risk groups, while a probabilistic score of 0.5 was used to discriminate between medium- and high-risk groups (Supplementary Fig, online only version and Fig 1, *A*). About 60%, 33%, and 7% of all patients were distributed in low-, medium-, and high-risk categories for developing ≥3 complications, respectively. We observed absolute risks of having at least 3 complications as 9.1%, 33.9%, and 57.5% in low-, medium-, and high-risk categories, respectively. Compared with patients with a low-risk score, patients with medium- and high-risk scores had relative risks of 3.7 (95% CI, 3.6–3.9) and 6.3 (95% CI, 6.0–6.6) for having ≥3 complications (Fig 1, *B*). Compared with patients with low-risk scores (Fig 1, *C* and *D*), relative risks of 30-day and 90-day mortality were 4.5 (95% CI, 4.0–5.0) and 3.5 (95% CI, 3.3–3.8) for patients with medium-risk scores and 5.8 (95% CI, 5.0–6.7) and 4.4 (95% CI, 4.0–4.9) for patients with high-risk scores, respectively. Thirty-day and 90-day mortality increased sharply among patients with >3 complications (Fig 2, *A*). The overall percentage for 30-day mortality was 1.4%, 6.3%, and 8.2% for low-, medium-, and high-risk categories, respectively, and for 90-day mortality, overall percentages were 3.2%, 11.3, and 14.3%, respectively. Percentages of 30-day and 90-day mortality for each risk category after stratification into groups based on number of complications are reported in Fig 2, *B* and *C*. Among patients with <3 complications, medium- and high-risk groups have significantly greater mortality rates than patients in the low-risk group.

DISCUSSION

In a large, single-center cohort of patients undergoing major operation, we have developed a simple preoperative risk model that predicts the number of major postoperative complications using a multinomial logistic regression approach. Our model uses readily available clinical and sociodemographic characteristics and can be applied to any

Table II. Unadjusted and adjusted association between number of postoperative complications and mortality

	No. postoperative complications	*1 postoperative complication*	*2 postoperative complications*	*≥3 postoperative complications*
30-day mortality				
Unadjusted OR (95% CI)	1 (Reference)	2.36 (1.86, 3)*	6.73 (5.34, 8.47)*	25.61 (21.08, 31.12)*
Adjusted OR (95% CI)†	1 (Reference)	1.83 (1.43, 2.33)*	4.69 (3.7, 5.94)*	16.12 (13.13, 19.78)*
90-day mortality				
Unadjusted OR (95% CI)	1 (Reference)	2.01 (1.75, 2.3)*	3.73 (3.22, 4.31)*	13.95 (12.46, 15.62)*
Adjusted OR (95% CI)†	1 (Reference)	1.48 (1.28, 1.7)*	2.49 (2.14, 2.9)*	9.03 (7.99, 10.21)*

*Denotes statistically significant findings at .05 significance level.
†Adjusted odds ratios were obtained adjusting for age group, sex, African American ethnicity, insurance type, comorbidity score, type of operation, emergency operation status, and weekend admission status.
OR, Odds ratio; *CI,* confidence interval.

Table III. Multivariable analysis of preoperative factors associated with the number of complications after operation

Variable	*1 vs no postoperative complications OR (95% CI)*	*2 vs no postoperative complications OR (95% CI)*	*≥3 vs no postoperative complications OR (95% CI)*
Age ≥ 65 (vs <65)	0.97 (0.91, 1.05)	1.18 (1.07, 1.29)*	1.49 (1.37, 1.62)*
Male (versus female)	1.11 (1.06, 1.17)*	1.17 (1.10, 1.24)*	1.23 (1.17, 1.30)*
Black (versus others)	1.12 (1.04, 1.20)*	1.07 (0.98, 1.18)	1.02 (0.94, 1.11)
Insurance type (versus private)			
Medicare	1.39 (1.29, 1.49)*	1.41 (1.28, 1.54)*	1.29 (1.18, 1.40)*
Medicaid	0.97 (0.90, 1.04)	1.06 (0.96, 1.17)	1.32 (1.22, 1.44)*
Uninsured	0.76 (0.69, 0.83)*	0.75 (0.66, 0.84)*	0.63 (0.56, 0.71)*
Charlson-Deyo comorbidity score (vs 0)			
1–2	1.42 (1.35, 1.50)*	1.97 (1.83, 2.13)*	2.56 (2.40, 2.74)*
≥3	2.07 (1.95, 2.20)*	3.00 (2.76, 3.26)*	3.89 (3.61, 4.20)*
Type of procedure (versus specialty operations†)			
Cardiothoracic operation	3.10 (2.82, 3.41)*	9.83 (8.82, 10.95)*	23.64 (21.36, 26.16)*
Neurologic operation	1.39 (1.30, 1.49)*	2.11 (1.91, 2.33)*	4.26 (3.89, 4.65)*
Noncardiac general and vascular surgery	1.64 (1.55, 1.75)*	2.38 (2.17, 2.60)*	2.96 (2.71, 3.24)*
Other operations‡	2.81 (2.62, 3.02)*	4.62 (4.19, 5.09)*	6.40 (5.84, 7.02)*
Emergency surgery (versus routine elective)	1.44 (1.36, 1.51)*	1.89 (1.76, 2.02)*	3.54 (3.33, 3.77)*
Weekend admission (versus weekday)	1.05 (0.98, 1.13)	1.19 (1.09, 1.30)*	1.36 (1.26, 1.47)*

*Denotes statistically significant findings at .05 significance level.
†Specialty operations include orthopedic, gynecologic, head and neck, urologic, and plastic surgery procedures.
‡Other operations include trauma, burn, and transplant procedures.
OR, Odds ratio; *CI,* confidence interval.

type of major surgical procedure. Using probabilistic methods, we developed 2 cut-offs that can be used to risk-stratify patients into low-, medium-, and high-risk groups for having ≥3 major postoperative complications. Compared with patients with a low-risk score, patients with medium- and high-risk scores had significantly increased risks of developing multiple complications and mortality within 30 and 90 days of admission. When based on readily available demographic and clinical data, the ability to determine the overall risk for multiple postoperative complications could be important in choosing optimal treatment options for patients with different preoperative risks, thus improving the quality of peri- and postoperative care. The ability to predict which patients are at increased risk for complications will allow surgeons to better judge a patient's fitness for a particular operation and will help the anesthesiologist to tailor intraoperative care to the patient. Our results corroborate existing evidence in the literature, demonstrating the association between postoperative complications and greater duration of hospital stay, greater health care costs, and a greater risk of mortality.[5-11,13] Patients

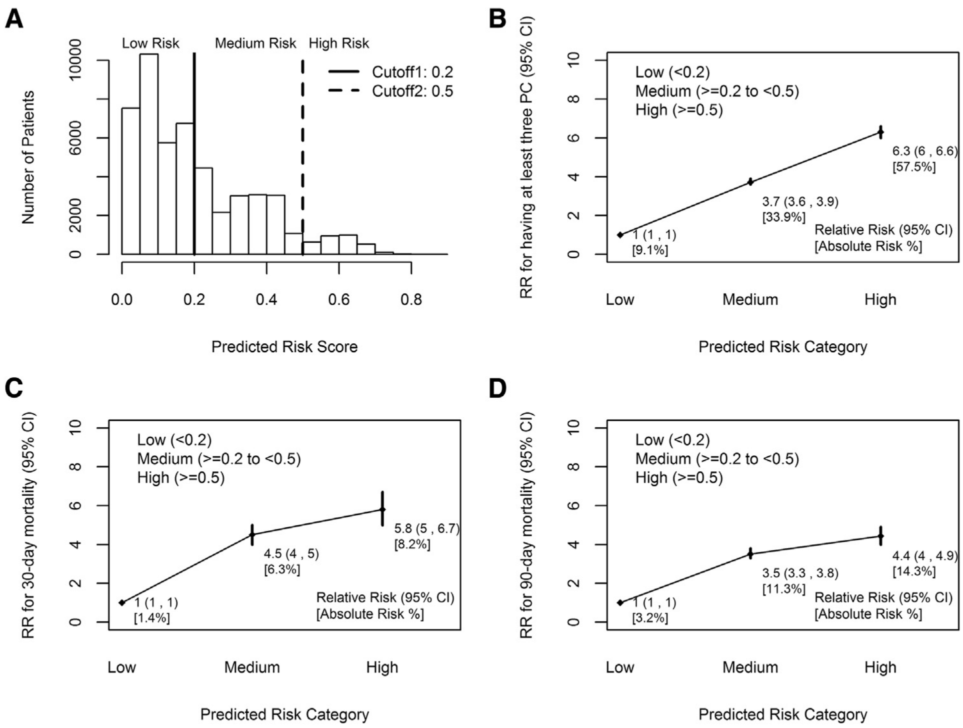

Fig 1. (*A*) Histogram of predicted risk scores with cut-offs to stratify patients into low-, medium-, and high-risk groups for having at least 3 PCs. (*B*) Relative risk (RR) and 95% CI for having at least 3 postoperative complications. (*C*) Relative risk and 95% CI for 30-day mortality. (*D*) Relative risk and 95% CI for 90-day mortality. Relative risks were obtained for the medium- and high-risk categories with respect to the low-risk group. $P < .05$ for comparison with respect to low-risk group. *PCs*, Postoperative complications; *RR*, relative risk; *CI*, confidence interval.

with ≥3 complications had markedly increased 30-day and 90-day mortality, as high as 20-fold, compared with patients who experienced no complications. The association between the increase in mortality and the number of complications was independent of other factors, including patients' age, sex, comorbidity burden on admission, and type of surgical procedure.

While multiple studies have shown that patient characteristics have an influence on the risk of developing postoperative complications, we are not aware of any previous studies that have modeled the number of complications.[30,33,35] Consistent with other studies, our study demonstrated that emergent operation, greater age, and greater number of comorbidities were associated with more postoperative complications.[31,32] One study demonstrated that preoperative functional status may help identify patients at greater risk of postoperative complications.[33] A strength of our study is that we were able to use only readily available preoperative demographic and clinical variables to ensure that a risk score could be calculated easily and quickly.

The statistical approach in previous studies mostly used dichotomized outcomes by categorizing patients into those who had no postoperative complications and those with ≥1 complication, rather than taking the number of complications as an ordinal variable. Calculations of asymptotic relative efficiency and results of simulations showed that simple logistic regression applied to dichotomized responses have decreased efficiency compared with ordinal regression models.[45] In addition, dichotomization can be arbitrary, especially when there are many ordered categories.[46] Instead of dichotomizing the outcome, we modeled the number of postoperative complications using several ordinal models, with multinomial logistic regression performing the best. By using a multinomial logistic regression, the model can be fit using any standard program, and the results can be interpreted easily. The multinomial model is appropriate when the effect of each predictor is different at every level of the outcome variable. Odds ratios in this study differed greatly across outcome levels for variables such as age and type of operation.

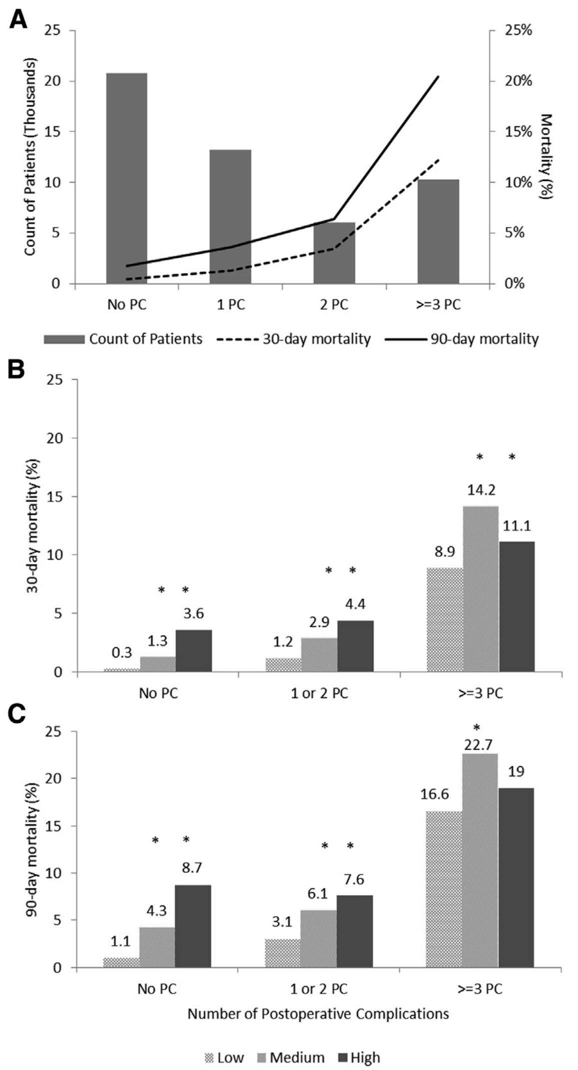

Fig 2. (*A*) The relationship between 30-day and 90-day mortality and the number of PCs. (*B*) Percentage of 30-day mortality for patients stratified by number of postoperative complications and risk categories obtained for having at least 3 complications. (*C*) Percentage of 90-day mortality for patients stratified by number of postoperative complications and risk categories obtained for having at least 3 complications. $*P < .05$ for comparison with respect to low-risk group. *PCs*, Postoperative complications.

This study does have some limitations. Due to the retrospective character of the study design, selection bias may be present. Our large sample size, however, minimizes the effect of any selection bias. Although we attempted to control for selection bias with multivariable statistical methods, we cannot exclude bias due to unmeasured factors, including intraoperative variables that may influence the number of complications. In addition, our data were taken from an administrative database, which presents the possibility for errors in reporting or coding for diagnoses, procedures, and cost-related measures. Previous analysis of this database has indicated that these errors would be minimal. The discrimination AUC of 0.71 for the strength of association between several preoperative factors and the risk for each outcome category was only fair, but the model was built on a small set of readily available variables for simplicity and accessibility. We have developed an online calculator to determine the probability for developing 0, 1, 2, or ≥3 complications and have made it accessible at http://www.prisma-p.org. Some of the definitions of the outcomes were arbitrary, particularly ICU stay >48 hours and length of mechanical ventilation >48 hours. In this study, the median ICU stay for patients with no complications was 1 day, which provides some justification for this choice. For many complicated procedures, such as open cardiac valve operation, liver transplantation, and open aortic operation, an ICU stay of >48 hours would not be considered a complication. While changing the definitions of the outcomes might change some of the odds ratios, it would not invalidate the use of the model.

In conclusion, this study showed that a selection of readily available demographic and clinical variables are associated strongly with several important postoperative outcomes, and we developed a single scoring system using multinomial logistic regression and a set of these variables, which can be used in clinical practice to risk-stratify patients. Given the association between a greater number of postoperative complications and increased adverse outcomes and costs, there is a critical need for strategies to better identify preoperatively those patients at risk for postoperative complications. We have developed an online calculator that calculates the risk for each number of complications after major operation. In describing this technique, we hope to provide a method for clinicians to stratify better patients preoperatively for operative procedures and to help clinicians to institute preventive measures early to decrease the number of complications and to improve outcomes.

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SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.surg.2016.04.013.

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