Multivariable Predictors of Postoperative Venous Thromboembolic Events after General and Vascular Surgery: Results from the Patient Safety in Surgery Study

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BACKGROUND: Venous thromboembolism (VTE) is a potentially preventable postoperative complication. Accurate risk prediction is an essential first step toward limiting serious, and sometimes fatal, postoperative VTE. We sought to develop and test a model to predict patients at high risk for postoperative VTE.

STUDY DESIGN: Data from the Patient Safety in Surgery (PSS) Study were used to develop and test a predictive model of VTE using multiple logistic regression analyses.

RESULTS: VTE occurred in 1,162 of 183,069 (0.63%) patients undergoing vascular and general surgical procedures. The 30-day mortality in patients who suffered a VTE was 11.19%. Fifteen variables independently associated with increased risk of VTE included patient factors (female gender, higher American Society of Anesthesiologists class, ventilator dependence, preoperative dyspnea, disseminated cancer, chemotherapy within 30 days, and $>$ 4 U packed red blood cell transfusion in the 72 hours before operation), preoperative laboratory values (albumin $<$ 3.5 mg/dL, bilirubin $>$ 1.0 mg/dL, sodium $>$ 145 mmol/L, and hematocrit $<$ 38%), and operative characteristics (type of surgical procedure, emergency operation, work relative value units, and infected/contaminated wounds). These variables were used to develop a predictive model for postoperative VTE (c-index = 0.7647) and a risk score that can be used in the preoperative assessment of patients undergoing major operations.

CONCLUSIONS: Venous thromboembolic events after noncardiac operations are relatively infrequent but highly lethal. Important multivariable risk factors for VTE in this setting were identified in the large PSS database. The risk-prediction scoring system, developed by using the logistic regression odds ratios, helps to identify patients at risk for postoperative VTE and to institute appropriate perioperative prophylactic measures. (J Am Coll Surg 2007;204:1211–1221. © 2007 by the American College of Surgeons)

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Venous thromboembolism (VTE) is a common cause of preventable morbidity and mortality in the postoperative period.[1] In the US, in 1998, 24,947 deaths were attributed to pulmonary embolism (PE), and the total number of deaths attributed to PE has been declining since 1979.[2] But the prevalence of pulmonary embolism at autopsy has not changed during the last 30 years.[3] These two facts suggest that the actual number of deaths from PE might be higher than recognized.

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Abbreviations and Acronyms

ASA = American Society of Anesthesiologists
DVT = deep vein thrombosis
NSQIP = National Surgical Quality Improvement Program
PE = pulmonary embolism
PSS = Patient Safety in Surgery Study
VA = Veterans Affairs
VTE = venous thromboembolism

Deep vein thrombosis (DVT) in the perioperative period can remain clinically silent. Located in proximal and distal deep veins, DVTs can lead to PE.[4] The incidence of VTE varies greatly, depending on the type of operation, patient comorbidities, and functional status. In surgical subpopulations, the risk of DVT varies from 0.4% to 80%, depending on the site of deep veins involved, nature of underlying operation, and patient comorbidities.[1]

Identifying patients at high risk for development of VTE is integral for instituting preventative measures targeted at high-risk groups. In other disease states, risk-assessment scores have been developed to predict the postoperative complications, such as mortality from the procedure itself, pneumonia, respiratory failure, and cardiac complications.[5-9] For example, the European system for cardiac risk assessment score (EuroSCORE) was developed to predict mortality in the cardiac surgery patient population.[5,6] As another example, multifactorial risk-factor indices were developed to identify the patients at risk for postoperative pneumonia and respiratory failure after major noncardiac operations using the National Surgical Quality Improvement Program (NSQIP) database.[7,8]

VTE has been targeted by the Centers for Medicare and Medicaid Services, the National Quality Forum, and others as an area for quality improvement. The key proposed process to accomplish this goal is appropriate VTE prophylaxis. We used data from the Patient Safety in Surgery (PSS) Study to develop and test a risk model for VTE. We then developed and validated a risk index with the intention of providing a method to assess preoperative risk of VTE in patients undergoing general and vascular operations.

METHODS

The PSS Study, which provided the data for this investigation, was conducted collaboratively by the American College of Surgeons and the Department of Veterans Affairs NSQIP with the objective of demonstrating the feasibility of implementing the Veterans Affairs (VA) NSQIP in private-sector hospitals.[10] A detailed description of the NSQIP and PSS Study methodologies has been reported previously and is summarized briefly here.[10-13] Patients from 128 VA medical centers and 14 private-sector hospitals who underwent major general or vascular procedures from fiscal years 2002 through 2004 were assessed as part of this study.

Data collection

Each hospital (VA and private sector) had a trained risk-assessment nurse who prospectively collected preoperative patient characteristics, including risk factors, intraoperative processes of care, and postoperative adverse occurrences after the operation on the first 36 (in the VA) or 40 (in the private sector) operations in each 8-day cycle. Entry of common procedures, such as breast biopsies and hernia repairs, were limited so that such cases would not overwhelm the database. Other data, such as laboratory values, were pulled into the data set from other computerized sources within the VA and were either pulled from computerized systems or entered by the nurses in the private-sector hospitals. The nurses completed in-depth training on all study definitions. Regular conference calls, annual meetings, and site visits were used to maintain data reliability.

The index operation was defined as the first operation during the hospitalization for the patient, as some patients had more than one operation during their hospital stay. On postoperative day 30, the nurse obtained outcome information through chart review, reports from morbidity and mortality conferences, and communication with each patient by letter or by telephone. Multiple operations within 30 days were not counted in the totals. Data were collected on the postoperative occurrence of DVT and PE.

Definition of DVT in PSS Study

DVT was defined as the identification of a new blood clot or thrombus within the venous system, which might be coupled with inflammation. Duplex, venogram, or CT scan confirmed this diagnosis. The patient had to be treated with anticoagulation therapy or placement of a vena cava filter, or both, or clipping of the vena cava.

Definition of PE in PSS Study

PE was defined as lodging of blood clot in the pulmonary artery with subsequent obstruction of blood supply to the lung parenchyma. A pulmonary embolism was considered to have occurred if the patient had a V-Q scan interpreted as high probability of pulmonary embolism, a positive pulmonary arteriogram, or positive CT angiogram.

Definition of VTE in PSS Study

A VTE event was considered to have occurred if either a pulmonary embolism or DVT as defined previously occurred as a postoperative complication in this study.

Statistical analysis

We used VTE as the primary dependent variable and used preoperative demographic and medical risk factors, preoperative laboratory values, and the work RVU of the operation itself as potential independent variables. Work RVU, as developed by the Centers for Medicare and Medicaid Services,[14] has been shown in the NSQIP to correlate well with the technical complexity of operations.[10] A category was added for "operation type" to capture the differential risks for VTE involved with operations on different areas of the body; these categories were entered as potential independent variables. Any pre- or perioperative variable that differed between those patients with and without a VTE with a p value of ≤ 0.20 in the bivariate analysis was considered a potential independent variable and was entered as such into the logistic regression analysis. Because operative time cannot be accurately predicted preoperatively, we decided a priori not to include it as a potential risk factor. We performed forward stepwise regression analysis and set the p value for selection as an independent variable at 0.05.

The data were complete with the exception of the preoperative laboratory values, where tests were often not ordered. For missing laboratory values, we used a statistical technique to impute the missing values.[11] These imputed values were used in the logistic regression modeling but not in the analyses comparing patient characteristics with and without VTE.

The data set was divided randomly into a development and a validation set, each consisting of half the total records. A logistic model was generated from the development set and run on the validation set to verify that the model was consistent when run on new data. For all regression analyses, the reference category was the one that conferred the least risk of VTE.

Development of a scoring system

Using a modification of the methods of Le Gall and colleagues[15] point values were assigned to each risk factor by rounding the odds ratio associated with each factor off to the nearest integer (eg, an odds ratio of 1.254 would add +1 to the final risk score). Adding these totals for each patient, point totals for each patient were calculated. The risk index values were then divided into discrete ranges. For each range, the mean predicted probability of VTE produced from the development model logistic regression equation was calculated. Multiplying these means by 100 produced the expected proportions of VTE. These proportions were then compared with the observed proportions of VTE in each range of the risk index using a chi-square goodness-of-fit test.

Evaluation of model performance

Discrimination and calibration of logistic regression models were determined using the c-statistic and Hosmer-Lemeshow goodness-of-fit tests in both development and validation data sets.

RESULTS

There were 184,120 patients assessed in the 128 VA and 14 private-sector academic medical centers in the general and peripheral vascular subspecialties during fiscal 2002, 2003, and 2004. Of these records, 1,051 cases not typically performed by general or vascular surgeons (current procedural terminology codes: 50000 to 59999: urinary, male genital, female genital systems and 61000 to 64999: nervous, eye, and auditory systems) were dropped from the study. Of the 183,069 patient records remaining in the study, an additional 286 were removed because of missing values in the response or explanatory variables, leaving 182,783 cases to determine the model parameters. A total of 183,069 cases were used in all tables, except for the tables related to the prediction models, for which 182,783 cases were used. The cases were grouped into 8 distinct categories based on the part of the body or system that was involved (Table 1). Operations on the gastrointestinal tract were the most common (71,568 of 183,069 [39%]), while hernia operations accounted for 24.6%, despite truncating the collection of this commonly performed operation.

Table 1. Operation Types

CPT range	Operations covered	No. of operations	% VTE
10000–29999	Integumentary and musculoskeletal system	22,020	0.45
30000–32999 38000–39999	Respiratory system, hemic and lymphatic systems, mediastinum, and diaphragm	2,880	1.46
33001–34900	Thoracoabdominal aneurysm, embolectomy/thrombectomy, venous reconstruction, and endovascular repair	2,867	1.15
35001–37799	Aneurysm, blood vessel repair, thromboendarterectomy, angioscopy, angioplasty and atherectomy, bypass and composite grafts, other artery, and vein	29,810	0.73
40000–43499	Mouth, palate, salivary glands, pharynx, adenoids, and esophagus	2,589	0.85
43500–49429 49650–49999	Stomach, intestines, appendix and mesentery, rectum and anus, liver, biliary tract, pancreas, abdomen, peritoneum, and omentum (nonhernia)	71,568	0.93
49491–49611	Hernioplasty, herniorrhaphy, herniotomy	44,970	0.15
60000–60999	Endocrine system	6,116	0.20
	CPT missing	249	1.20

CPT, current procedural terminology; VTE, venous thromboembolic event.

VTE occurred in 1,162 (0.63%) of the patients. A VTE event is defined in this case as either a pulmonary embolism or DVT complication. Patients with VTE had 11.19% 30-day mortality compared with only 2.54% for those without VTE. Thirty-one preoperative risk factors and 13 preoperative blood test results were associated with VTE in bivariate analyses (Table 2). Patients with VTE were considerably older, more likely to be women, and to have a higher American Society of Anesthesiologists (ASA) classification. They were more likely to have a history of congestive heart failure, impaired sensorium, and cerebral vascular accident. They were considerably more likely to have a dependent functional status, diabetes, disseminated cancer, steroid use, preoperative weight loss $>$ 10%, bleeding disorder, transfusion $>$ 4 U RBCs, undergone chemotherapy, ventilator dependence, COPD, acute renal failure, and undergone dialysis. They were also more likely to have low hematocrit, creatinine $>$ 1.5 mg/dL, and white blood cell counts $>$ 10,000/cumm.

In bivariate analyses, there were also differences in perioperative processes and postoperative complications (Table 3). Patients with VTE were more likely to have undergone emergency operation, have had a general anesthetic, and be an inpatient. Their operations were almost an hour longer than those without VTE and had a higher work RVU. Patients with VTE were also considerably more likely to have other complications, such as cardiac arrest, coma, cerebral vascular accident, sepsis, failure to wean from the ventilator, pneumonia, require reintubation, and acute renal failure.

The following potential preoperative independent variables did not differ significantly between those patients with and without a VTE ($p > 0.20$) and were removed from additional consideration: more than 2 alcoholic drinks per day, history of transient ischemic attacks, and central nervous system tumor. Race and pack-years smoked were also removed from additional statistical analysis because of a high number of missing values. All the risk factors that appeared statistically significant on the initial bivariate analysis (Table 2) were analyzed using multiple logistic regression analysis. On multiple logistic regression analysis, only 15 of these risk factors were found to be independently associated with risk of developing VTE (Table 4). Remaining variables or risk factors were not selected for development of the risk assessment model, because these risk factors or variables did not achieve statistical significance on multiple logistic regression analysis, even though they appeared to be significant risk factors on initial bivariate analysis.

Fifteen variables were found to be independently associated with VTE (Table 4). All 15 variables independently conferred increased risk of VTE, with odds ratios ranging from 1.167 (contaminated wound) to 9.369 (respiratory or hematologic system operation). The type of operation, specifically operation on the respiratory, hematologic and lymphatic systems; mediastinum; and diaphragm, conferred the highest risk. Patients who were ventilator-dependent, had higher ASA class, dis-

Table 2. Baseline Characteristics of Patient Population

Variable	No VTE	VTE	p Value
Sample size (n)	181,907	1,162	
30-d mortality rate	2.54	11.19	< 0.0001
Specialty code (%)			< 0.0001
General	78.74	73.92	
Peripheral vascular	21.26	26.08	
Race (%)			< 0.0001
Hispanic	4.39	3.96	
American Indian	0.28	0.17	
African American, not Hispanic	12.30	15.92	
Asian	0.79	0.52	
Caucasian, not Hispanic	64.71	68.16	
Unknown	9.25	6.45	
Missing	8.27	4.82	
Gender (%)			0.0203
Male	80.26	77.54	
Female	19.74	22.46	
Age (y), mean ± SD	60.31 ± 14.34	64.26 ± 13.65	< 0.0001
Cardiac (%)			
History of CHF	2.26	5.42	< 0.0001
Central nervous system (%)			
Impaired sensorium	1.54	5.68	< 0.0001
Coma	0.08	0.34	< 0.018
CVA with neurologic deficit	4.56	6.71	0.0005
CVA without neurologic deficit	2.96	4.13	0.0196
Hemiplegia	2.52	4.04	0.0010
History of TIA	3.93	3.27	0.2512
CNS tumor	0.16	0.26	0.4363
General (%)			
ASA class			< 0.0001
1−2	39.66	18.76	
3	50.02	56.88	
4−5	10.31	24.35	
DNR status (%)	0.87	1.46	0.0309
> 2 alcoholic drinks/d	7.67	8.64	0.2182
Dependent functional status	8.64	18.69	< 0.0001
Smoker	32.11	29.26	0.0379
Pack-years, mean ± SD	25.17 ± 33.86	27.38 ± 33.89	< 0.0001
Hepatobiliary (%)			
Ascites	1.18	3.70	< 0.0001
Laboratory (%)			
Albumin ≤ 3.5 mg/dL	31.97	54.67	< 0.0001
Alkaline phosphotase > 125 U/L	15.13	19.62	0.0003
Bilirubin > 1.0 mg/dL	14.16	19.79	< 0.0001
BUN > 60 mg/dL	1.50	2.95	< 0.0001
Creatinine > 1.5 mg/dL	13.54	19.10	< 0.0001
HCT ≤ 38%	33.81	54.76	< 0.0001
HCT > 45%	17.86	11.20	< 0.0001
Platelets ≤ 150,000/cumm	7.40	12.81	< 0.0001
Platelets > 400,000/cumm	7.27	12.99	< 0.0001

Table 2. Continued

Variable	No VTE	VTE	p Value
SGOT > 40 U/L	12.94	17.84	< 0.0001
Sodium < 135 mmol/L	15.23	22.29	< 0.0001
Sodium > 145 mmol/L	1.37	3.64	< 0.0001
WBC			< 0.0001
≤ 2.5^{th}/cumm	0.27	0.71	
> 10.0^{th}/cumm	21.34	32.83	
Nutritional/immune/other (%)			
Diabetes	18.80	22.89	0.0004
Disseminated cancer	2.40	7.66	< 0.0001
Wound infection	8.95	12.91	< 0.0001
Steroid use	3.07	8.43	< 0.0001
Weight loss > 10%	4.43	10.07	< 0.0001
Bleeding disorder	3.34	9.98	< 0.0001
Transfusion > 4 U RBCs	0.72	4.82	< 0.0001
Chemotherapy	1.30	4.22	< 0.0001
Radiotherapy	0.92	1.55	0.0249
Sepsis	2.59	9.32	< 0.0001
Pulmonary (%)			
Dyspnea (minimal or at rest)	14.45	26.10	< 0.0001
Ventilator dependent > 48 h	0.88	6.37	< 0.0001
Current pneumonia	0.82	3.36	< 0.0001
History of COPD	11.07	16.27	< 0.0001
Renal (%)			
Acute renal failure	0.88	2.15	< 0.0001
On dialysis	2.22	4.13	< 0.0001

ASA, American Society of Anesthesiologists; BUN, blood urea nitrogen; CHF, congestive heart failure; CNS, central nervous system; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DNR, do not resuscitate; HCT, hematocrit; RBC, red blood cell; SGOT, serum glutamic-oxalacetic transaminase; TIA, transient ischemic attack; VTE, venous thromboembolic event; WBC, white blood cell.

seminated cancer, and chemotherapy for malignancy in the last 30 days were at increased risk of VTE. Preoperative transfusions of > 4 U blood RBCs, preoperative serum sodium > 145 mmol/L, and preoperative hematocrit ≤ 38% were also independent predictors of VTE.

Risk index

VTE risk index can be calculated by adding the point values for each risk variable present in a patient (Table 5). For example, a 70-year-old male patient with ventilator dependence, ASA class 3, undergoing a thoracic operation, and a preoperative hematocrit of 35% has a VTE risk index score of 14 points (9 points for thoracic operation, 2 points for ASA class 3, 2 points for ventilator dependence, and 1 point for low hematocrit).

We divided the patients into discrete risk index score ranges based on the predicted rates of VTE (Table 6) using the development data set. We then tested these ranges of risk index scores with the validation data set (Table 6). The risk index score was divided into 3 discrete ranges based on the rate of VTE: low (risk score 1 to 6), medium (risk score 7 to 10), and high (risk score > 10). The model had a c-index (a measure of how well the index is able to predict the outcomes) of 0.7647, and the Hosmer-Lemeshow goodness-of-fit test produced a chi-square value of 9.8129 ($p = 0.2784$) indicating excellent discrimination and a good fit of the model.

The VTE complication rates for patients grouped by their risk indices are graphed in Figure 1. The estimated risk of VTE complication for the patient with risk index 14 is 2.1%. The graph shows logarithmic acceleration to the rate of VTE as risk indices increase with VTE rates.

DISCUSSION

With this large prospectively collected data set available from the VA and the private sector, we developed a model to predict VTE, which, although complex, is highly predictive. Tests of the regression model using

Table 3. Perioperative Processes of Care and Postoperative Complications

Perioperative variable	No VTE	VTE	P Value
Work RVU (%)			< 0.0001
< 10	30.51	34.11	
10–17	36.85	11.11	
> 17	32.65	54.78	
Emergency (%)	10.73	24.18	< 0.0001
Anesthesia (%)			< 0.0001
General	84.71	94.84	
Spinal	1.11	1.29	
Epidural	7.78	3.18	
Monitored	0.73	0.00	
Local	0.51	0.09	
Other	5.15	0.60	
Inpatient (%)	62.24	91.31	< 0.0001
Operation time (h), mean ± SD	2.15 ± 1.66	3.11 ± 2.18	< 0.0001
Wound class (%)			< 0.0001
Clean	60.89	38.98	
Clean/contaminated	29.47	43.80	
Contaminated	5.03	8.61	
Dirty/infected	4.61	8.61	
PGY (%)			< 0.0001
0	24.41	16.06	
1–2	16.92	8.49	
3	12.95	12.64	
4	10.09	13.45	
5	27.47	37.45	
≥ 6	8.16	11.91	
Cardiac complications (%)			
Cardiac arrest	0.80	6.02	< 0.0001
Myocardial infarction	0.54	2.15	< 0.0001
Central nervous system complications (%)			
Coma > 24 h	0.12	0.95	< 0.0001
Cerebral vascular accident	0.32	2.32	< 0.0001
Peripheral nerve injury	0.08	0.26	0.0778
Other surgical complications (%)			
Bleeding requiring > 4 U packed RBCs	0.56	2.84	< 0.0001
Graft/prosthesis failure	0.41	1.46	< 0.0001
Systemic sepsis	1.62	13.51	< 0.0001
Respiratory complications (%)			
Failure to wean	2.50	18.50	< 0.0001
Pneumonia	2.31	15.83	< 0.0001
Reintubation	1.88	14.81	< 0.0001
Urinary tract complications (%)			
Acute renal failure	0.57	3.70	< 0.0001
Renal insufficiency	0.55	3.27	< 0.0001
Urinary tract infection	2.21	11.79	< 0.0001
Wound complications (%)			
Dehiscence	1.13	3.01	< 0.0001
Superficial infection	3.25	7.31	< 0.0001
Deep wound infection	1.43	4.48	< 0.0001

PGY, post-graduate year of surgeon; RBC, red blood cell; RVU, relative value unit; VTE, venous thromboembolic event.

Table 4. Independent Predictors of Venous Thromboembolic Events (Development Set)

Step	Effect entered	Parameter estimate	Probability > chi-square	Odds ratio (95% Wald CI)
1	Work RVU 10–17 versus < 10	0.8058	< 0.0001	2.239 (1.635–3.066)
1	Work RVU > 17 versus < 10	1.0496	< 0.0001	2.857 (2.052–3.976)
2	Ventilator dependent	0.6184	0.0036	1.856 (1.223–2.816)
3	Preoperative albumin (≤ 3.5 versus > 3.5)	0.1936	0.0609	1.214 (0.991–1.486)
4	Integumentary versus endocrine	1.1779	0.0261	3.248 (1.151–9.167)
4	Respiratory and hemic versus endocrine	2.2375	< 0.0001	9.369 (3.225–7.219)
4	Thoracoabdominal versus endocrine	1.9209	0.0005	6.827 (2.318–10.111)
4	Aneurysm versus endocrine	1.3147	0.0111	3.724 (1.350–10.271)
4	Mouth, palate versus endocrine	1.3866	0.0209	4.001 (1.233–2.982)
4	Stomach, intestines versus endocrine	1.3898	0.0069	4.014 (1.463–11.009)
4	Hernia versus endocrine	0.6183	0.2603	1.856 (0.632–5.445)
5	Disseminated cancer	0.6275	< 0.0001	1.873 (1.370–2.561)
6	ASA class (2 versus 1)	0.2838	0.3948	1.328 (0.691–2.553)
6	ASA class (3 versus 1)	0.7522	0.0224	2.122 (1.112–4.047)
6	ASA class (4−5 versus 1)	0.8665	0.0122	2.378 (1.208–4.684)
7	Emergency	0.3784	0.0010	1.460 (1.165–1.830)
8	Preoperative hematocrit ≤ 38	0.2779	0.0044	1.320 (1.091–1.598)
9	Gender (female versus male)	0.315	0.0024	1.370 (1.118–1.680)
10	Chemotherapy for malignancy in last 30 d	0.6035	0.0049	1.829 (1.200–2.785)
11	Preoperative bilirubin > 1.0	0.2606	0.0155	1.298 (1.051–1.603)
12	Transfusion > 4 U packed RBCs in 72 h before operation	0.4757	0.0366	1.609 (1.030–2.513)
13	Wound class (clean/contaminated versus clean)	0.3372	0.0053	1.401 (1.105–1.776)
13	Wound class (contaminated versus clean)	0.1541	0.4106	1.167 (0.808–1.684)
13	Wound class (infected versus clean)	0.3237	0.0809	1.382 (0.961–1.988)
14	Preoperative serum sodium > 145 mmol/L	0.4793	0.0410	1.615 (1.020–2.558)
15	Dyspnea (yes versus no)	0.2015	0.0476	1.223 (1.002–1.493)

C-index = 0.7647; Hosmer-Lemeshow chi-square = 9.8129 (p = 0.2784); no. of records used = 91,403; p = 0.2784.
ASA, American Society of Anesthesiologists; RBC, red blood cell; RVU, relative value unit.

random samples for development and validation sets of the patient population suggest stable predictive ability of the model. The NSQIP has well-defined data definitions for each preoperative variable and postoperative complication, including VTE, making it an excellent platform on which to develop such a risk index model. This model helps surgeons identify high VTE−risk populations at the time of preoperative evaluation, thereby implementing appropriate prophylactic measures in a timely manner in patients at risk for VTE.

In this analysis of prospectively collected data, we found an incidence of 0.63% of VTE. This data analysis confirmed many previously described risk factors for VTE. In our study, patients with VTE were more likely to be older and women, and type of operation had an independent association with the risk of developing VTE. Endocrine operation was associated with the lowest risk of VTE and so was set as a reference in the risk modeling. Operations involving the respiratory system conferred the highest VTE risk (odds ratio = 9.369). This high VTE risk can be explained by postoperative respiratory failure, which is especially common after thoracic operations.[8] The consequent bedridden physical condition and limited mobility predisposes to VTE. Comorbidities such as disseminated malignancy, recent preoperative chemotherapy, and preoperative ventilator-dependence were clearly shown to be independently associated with development of postoperative VTE in this data analysis. These findings are clearly supported by numerous earlier studies that have shown that malignancy, associated chemotherapy, and ventilator dependence are risk factors for VTE.[1] Not surprisingly, patients with higher ASA class were found to have higher incidence of VTE in the postoperative period. Patients with VTE were also more likely to have low hematocrits in this data analysis. Transfusion of > 4 U packed RBC

Table 5. Venous Thromboembolic Event Complication Risk Index for General and Vascular Surgery Patients

Risk factor	Risk score points
Operation type other than endocrine	
Respiratory and hemic	9
Thoracoabdominal aneurysm, embolectomy/thrombectomy, venous reconstruction, and endovascular repair	7
Aneurysm	4
Mouth, palate	4
Stomach, intestines	4
Integument	3
Hernia	2
ASA physical status classification	
3, 4, or 5	2
2	1
Female gender	1
Work RVU	
> 17	3
10−17	2
Two points for each of these conditions	2
Disseminated cancer	
Chemotherapy for malignancy within 30 d of operation	
Preoperative serum sodium > 145 mmol/L	
Transfusion > 4 U packed RBCs in 72 h before operation	
Ventilator-dependent	
One point for each of these conditions	1
Wound class (clean/contaminated)	
Preoperative hematocrit ≤ 38%	
Preoperative bilirubin > 1.0 mg/dL	
Dyspnea	
Albumin ≤ 3.5 mg/dL	
Emergency	
Zero points for each of these conditions	0
ASA physical status class 1	
Work RVU < 10	
Male gender	

ASA, American Society of Anesthesiologists; RBC, red blood cell; RVU, relative value unit.

preoperatively was also independently associated with the development of VTE. A retrospective case-control study found that allogeneic blood transfusion was associated with increased risk of postoperative VTE.[16] Another retrospective case-control study found that intraoperative packed RBC and fresh frozen plasma transfusion were associated with increased VTE risk.[17]

Patients with preoperative infected and contaminated wounds have a higher incidence of VTE when compared with the rest of the patient population. A retrospective case-control study found wound infection to be a significant risk factor for VTE in burn patients with infected wounds.[18] Preoperative dyspnea was also associated with higher incidence of VTE. Again, this finding can be explained by immobility because of dyspnea.

We observed high 30-day postoperative mortality in patients with VTE when compared with patients without VTE (11.19% versus 2.54%). Given the mortality and morbidity associated with VTE, this is an important area for quality improvement, as it can substantially impact on the quality of care and outcomes of surgical patients.[19] Greater attention should be paid to appropriate VTE prophylaxis to prevent this complication. We have developed a simple preoperative assessment of likelihood of VTE so that we can target surgical patients for appropriate prophylaxis. Multimodality approaches using pharmacologic and mechanical VTE prophylaxis should be used in high-risk patients, as this approach has been shown to be effective.[20] As use of VTE prophylaxis electronic/computer alerts increased physicians' use of prophylactic measures and reduced rates of VTE, electronic alerts should be an essential part of an institution's approach in improving the quality of postoperative patient care.[21] In addition, Vaitkus and colleagues[22] have demonstrated that even asymptomatic DVT is associated with substantially increased mortality. Given

Table 6. Actual Versus Predicted Venous Thromboembolic Event Rates by Risk Index Levels in the Development and Validation Data Sets

		Development			Validation		
Risk level	Score range	n	Predicted VTEs (%)	Actual VTEs (%)	n	Predicted VTEs (%)	Actual VTEs (%)
Low	< 7	26,332	0.100	0.103	26,289	0.099	0.110
Medium	7–10	37,602	0.501	0.436	37,569	0.502	0.474
High	> 10	27,469	1.370	1.456	27,450	1.374	1.315

C-indices for the risk index were 0.7544 (development) and 0.7305 (validation). C-indices for the 3-level risk categories were 0.7201 (development) and 0.7033 (validation).
VTE, venous thromboembolic event.

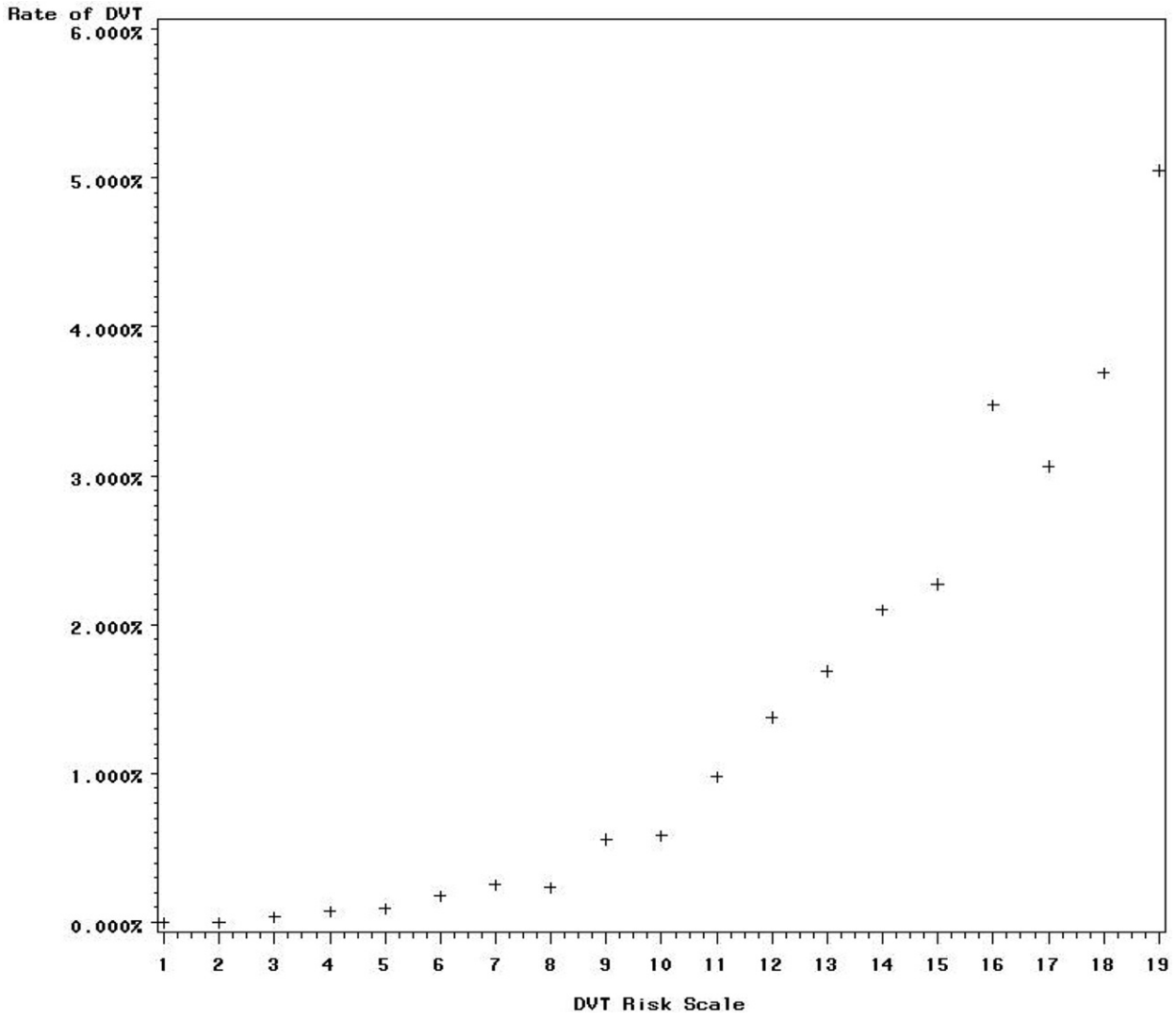

Figure 1. Relationship of deep vein thrombosis (DVT) risk scale to rate of DVT. The graph displays only data points for those scale levels with at least 50 patients (scale < 20).

that asymptomatic VTE is common, more aggressive surveillance might be warranted for those patients in the highest-risk groups.[4]

Even though high mortality was noted in patients with VTE, it is difficult to predict accurately whether this was a result of the occurrence of VTE alone or the underlying severity of the illness, which could be the reason behind both the mortality and VTE. Our models are limited in part by variables that are not part of the NSQIP database that might impact the rates of VTE, such as the period of bed immobilization. An additional limitation is that we do not have information about the process of VTE prophylaxis in this patient cohort to link the process and outcomes. As most perioperative DVTs are clinically silent and form spontaneously in proximal venous segments,[4] these silent VTEs might not have been recognized and included by the NSQIP methodology. In addition, PSS/NSQIP database included VTEs occurring within 30 postoperative days only. But the true impact of hospitalization on development of VTE can last longer than 30 days.[23] These two facts indicate that the NSQIP methodology can underestimate the true incidence of VTEs in the postoperative period and the impact of operations and hospitalization on development of postoperative VTE. Finally, considering that a large part of the data in this study was derived from VA medical centers, these data might not accurately reflect

the general population, as veterans are more likely to be male patients and have greater comorbidities.

Surgeons can use this newly developed VTE risk index to identify patients at highest risk for VTE at the time of preoperative evaluation and provide timely VTE prophylaxis and aggressive surveillance for those at highest risk.

Author Contributions

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