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Risk Stratification for the Development of Respiratory Adverse Events Following Vascular Surgery Using the Society of Vascular Surgery's Vascular Quality Initiative

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Abstract

Objective—Post-operative respiratory adverse events (RAEs) are associated with high rates of morbidity and mortality in general surgery, however little is known about these complications in the vascular surgery population, a frail subset with multiple comorbidities. The objective of this study was to describe the contemporary incidence of RAEs in vascular surgery patients, the risk factors for this complication and the overall impact of RAEs on patient outcomes.

Methods—The Vascular Quality Initiative was queried (2003–2014) for patients who underwent endovascular abdominal aortic repair, open abdominal aortic aneurysm (AAA) repair, thoracic endovascular aortic repair (TEVAR), suprainguinal bypass or infrainguinal bypass. A mixed-effects logistic regression model determined the independent risk factors for RAEs. Using a random 85% of the cohort, a risk prediction score for RAEs was created and the score was validated using the remaining 15% of the cohort, comparing the predicted to the actual incidence of RAE and determining the area under the receiver operating characteristic curve. The independent risk of in-hospital mortality and discharge to a nursing facility associated with RAEs was determined using a mixed-effects logistic regression to control for baseline patient characteristics, operative variables and other post-operative adverse events.

Results—The cohort consisted of 52,562 patients, with a 5.4% incidence of RAEs. The highest rates of RAEs were seen in current smokers (6.1%), recent acute myocardial infarction (10.1%), symptomatic congestive heart failure (CHF) (9.9%), chronic obstructive pulmonary disease (COPD) requiring oxygen therapy (11.0%), urgent and emergent procedures (6.4% and 25.9%, respectively), open AAA repairs (17.6%), in-situ suprainguinal bypasses (9.68%) and TEVARs

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(9.6%). The variables included in the risk prediction score were age, body mass index, smoking status, CHF severity, COPD severity, degree of renal insufficiency, ambulatory status, transfer status, urgency and operative type. The predicted compared to the actual RAE incidence were highly correlated, with a correlation coefficient of 0.943 (P<.0001) and a c-statistic=0.818. RAEs had a significantly higher rates of in-hospital mortality (25.4% vs. 1.2%, P<.0001, adjusted OR=5.85, P<.0001) and discharge to a nursing facility (57.8% vs. 19.0%, P<.0001, adjusted OR=3.14, P<.0001).

Conclusions—RAEs are frequent and one of the strongest risk factors for in-hospital mortality and inability to be discharged home. Our risk prediction score accurately stratifies patients based on key demographics, comorbidities, presentation, and operative type that can be used to guide patient counseling, preoperative optimization, and post-operative management. Furthermore, it may be useful in developing quality benchmarks for RAE following major vascular surgery.

Introduction

Vascular surgery patients have multiple baseline comorbidities, including coronary artery disease, congestive heart failure, chronic obstructive pulmonary disease and tobacco use, placing them at a high risk for post-operative complications.[1–3] The incidence of adverse events depends on patient characteristics and the surgical procedure, and it is well documented that major postoperative complications confer both short and long-term influences on patient outcomes and mortality.[4–9] In the general surgery literature, major respiratory adverse events are associated with some of the highest rates of mortality, specifically a 3–18 fold increased risk of in-hospital death.[10–14] Moreover, post-operative respiratory complications are reported to be the most expensive adverse event, far exceeding the costs of other major complications such as cardiovascular and infectious events.[4, 15]

While some studies have reported the incidence of respiratory complications in vascular surgery patients, this adverse event has generally been underappreciated in our surgical population as investigations have been limited to major thoracic and abdominal procedures.[4, 16–20] Previously published general surgery literature suggests that patients undergoing vascular procedures are at a particularly elevated risk of respiratory complcations.[8, 9, 11, 21, 22] However, there is a paucity of research into the risk factors for developing these clinically significant adverse event in the subset of vascular surgery patients, which can be a particularly frail group requiring complex surgical procedures. Therefore, our objective was to investigate the contemporary incidence of post-operative respiratory adverse events in patients undergoing vascular surgery utilizing a multi-centered, national database. Additionally, we sought to delineate the risk factors for developing respiratory complications and their impact on patient outcomes.

Methods

Patient Selection and Data Collection

Data was obtained from the Society of Vascular Surgery’s multi-centered (213 centers) database, the Vascular Quality Initiative (VQI). Patients included in the study were adults (≥18 years of age) who underwent any vascular procedure in the VQI where data on post-operative respiratory adverse events was collection, including endovascular aortic repair (EVAR), open abdominal aortic aneurysm (AAA) repair, thoracic endovascular aortic repair (TEVAR), suprainguinal bypass or an infrainguinal bypass from April 2003 through September 2014 (n=52,562). Procedures such as carotid endarterectomy or peripheral vascular interventions were not included as data on post-operative respiratory adverse events were not tracked for these procedures. This study received exempt status from the Institutional Review Board of the University of Pittsburgh; no study specific consent was required as the VQI data analysis activities fall under the protection of the SVS Patient Safety Organization, approved by Agency for Healthcare Research and Quality to analyze data for quality improvement purposes.

The main outcome of interest was post-operative respiratory adverse events (RAEs), which was consistently defined and captured across all of the above procedure types in VQI as pneumonia (lobar infiltrate on chest x-ray and pure growth of recognized pathogen or 4+ growth of recognized pathogen in presence of mixed growth) or re-intubation after initial extubation. Data was obtained on patient demographics (gender, race, body mass index [BMI], age, smoking status, transfer status, living status prior to admission, and ambulatory status), baseline comorbidities (hypertension, diabetes, coronary artery disease [CAD], congestive heart failure [CHF], chronic obstructive pulmonary disease [COPD], renal insufficiency, prior vascular procedures, stress test, and preoperative medications), operative information (American Society of Anesthesiologists [ASA] Class, urgency of the procedure, operation type, anesthesia, initial hemoglobin [g/dL], estimated blood loss, procedure time, and perioperative antibiotic use), other post-operative adverse events (number of units of packed red blood cells transfused, acute myocardial infarction [AMI], new cardiac dysrhythmia, CHF exacerbation, cerebrovascular events, acute renal failure, wound infection, distal embolization to the lower extremity, and return to the operating room), and patient outcomes (hospital length of stay, in-hospital mortality, and discharge to a rehabilitation or nursing facility). Variables were used in analyses if there was less than 20% missing data for the variable and if each category within a given variable had an incidence of at least 1% (>525 patients).

Determining Risk Factors for Respiratory Adverse Events

Univariable analysis was performed to determine the association of demographics, comorbidities, and operative variables with post-operative RAEs. Categorical variables were assessed using Pearson’s chi-square analysis, continuous variables that were normally distributed (pre-operative hemoglobin) were assessed with t-test, and continuous variables without a normal distribution (age, estimated blood loss) were assessed using a non-parametric analysis, the Mann-Whitney U-test, and subsequently converted into groups and analyzed as categorical variables. A mixed-effects logistic regression model was created to determine the adjusted odds ratios of risk factors for developing RAEs (demographics, comorbidities and operative variables) while also controlling for potential clustering of events at each hospital center as the random effect. Variables were entered into the model if on univariable analysis the p-value was < .2 and were not significantly correlated (Pearson’s correlation < .5, P<.05). All model variables were checked for significant interactions using a likelihood ratio test.

Development of the Preoperative Risk Prediction Score for Respiratory Adverse Events

A random 85% sample of the cohort was used to develop a preoperative risk prediction score for the development of post-operative RAEs. A mixed-effects logistic regression model predicting RAEs was created using only demographics (age, BMI, smoking status, ambulatory status), comorbidities (CHF, COPD, renal insufficiency), transfer status, urgency of the procedure, and operative type. Each variable coefficient was averaged over 10 bootstrapping replications of the model. The averaged coefficient was then adjusted by a scaling factor of 0.2 and rounded to the nearest whole number to obtain a point value for each variable.[23] The predicted probability of a respiratory event was calculated for each point total[23] and then point totals were clustered into 4 major risk groups: Low Risk (<5.0%), Intermediate-Low Risk (5–10%), Intermediate-High Risk (10–20%), and High Risk (>20%).

The prediction score was validated using the remaining 15% of the cohort. A point total was assigned to each patient based on his or her preoperative risk factors. The area under the Receiver Operator Characteristic (ROC) curve was calculated after the model was applied to this cohort. For each point total, the predicted incidence of RAEs and the actual incidence of RAEs in the 15% cohort were compared using Pearson correlation, excluding the most extreme 0.5% of patients in which there were less than 10 patients in each point total. Additionally, the incidence of RAEs for each risk group was calculated to determine if the actual incidence fell within the predicted risk range.

In conjunction with the Vascular Quality Initiative and the online and mobile device application Calculate by QxMD (Vancouver, Canada), this risk prediction tool was made available for iOS, Android and Windows 10 at http://qx.md/calculate or on the web at http://qxmd.com/resp-vqi, listed under "VQI: Respiratory Adverse Event Risk Post Vascular Surgery".

Impact of Respiratory Adverse Events on Patient Outcomes

The difference in the length of stay for those patients with and without a RAE was compared using a non-parametric Mann-Whitney U-test. The incidence of in-hospital mortality was calculated for those with and without a RAE and compared using chi-squared analysis. An adjusted odds ratio of in-hospital death associated with post-operative RAEs was determined by creating a mixed-effects logistic model (random effect=hospital center), controlling for demographics, baseline comorbidities, operative variables and other post-operative adverse events. Excluding patients with in-hospital mortality, the incidence of discharge to a facility (nursing or rehabilitation center) was calculated for patients with and without a RAE and compared using a chi-square analysis. Again, excluding those with in-hospital mortality, an adjusted odds ratio of discharge to a facility associated with post-operative RAEs was determined by creating a mixed-effects logistic model controlling for demographics, baseline comorbidities, operative variables and other post-operative adverse events.

Results

The study included 52,562 patients who underwent a major vascular surgery procedure from April 2003 through September 2014. Table I describes the baseline demographics, comorbidities and operative information of the cohort. The mean patient age was 69.9 ± 11.0 (18–89) years with a median age of 70 years. The majority of patients were male, Caucasian, and had hypertension. Baseline cardiac and pulmonary disease were common; nearly a third of patients had CAD or COPD, and 86% of patients were active or past smokers. The majority of patients underwent elective procedures and the most common procedure performed was an infra-inguinal bypass (38.7%), followed by EVAR (32.7%), open AAA repair (11.3%), extra-anatomic bypass (6.3%), in-situ suprainguinal bypass (6.2%) and TEVAR (4.8%).

The overall incidence of post-operative RAEs was 5.4% (n=2831); 773 patients had pneumonia (1.5%) and 2058 patients required re-intubatation (3.9%). As shown in Table II, RAEs were the 3rd most common post-operative adverse event, following a major transfusion (≥3units of packed red blood cell) (12.5% incidence) and any type of cardiac event (8.9% overall incidence, with 5.6% of patients developing a new dysrhythmia, 3.1% suffering an acute myocardial infarction, and 2.5% with a CHF exacerbation). Adverse events less frequent than RAEs were wound complications or infection, acute renal failure, and cerebrovascular events.

Risk Factors for the Development of Respiratory Adverse Events

Table III details the incidence of RAEs for each pre-operative and operative variable. Of note, RAEs occurred more frequently in females, underweight, older, and non-ambulatory patients. Compared to former or never smokers, current smokers had the highest incidence of RAEs at a rate of 6.1% (P<.0001); there was no significant difference between the rates of RAEs for never smokers and former smokers (cessation for ≥ 1 year) (5.2% and 4.8%, respectively, P=.192). Patients with the highest rates of RAEs were those with a recent AMI (within 6 months) or unstable angina (10.1%), symptomatic CHF (9.9%), COPD (7.8%) and COPD requiring oxygen therapy (11.0%). Additionally, patients with ASA Classifications IV and V had significantly higher rates of RAEs (9.4% and 36.6%, respectively). Operative variables highly associated with postoperative RAEs were urgent and emergent procedures (6.4% and 25.9%, respectively), open AAA repairs (17.6%), in-situ suprainguinal bypass (9.68%), and TEVARs (9.6%). Patients with RAEs had significantly longer operative lengths (median: 3.77 hours vs. 3.0 hours, P<.0001) and lower hemoglobin at presentation (mean 12.0 ± 2.48 g/dL vs. 13.0 ± 2.16 g/dL, P<.0001).

A mixed-effects, logistic regression model was performed to identify risk factors for developing post-operative RAEs while controlling for the effect of event clustering at each hospital center (detailed in Table IV). Underweight and morbidly obese patients, compared to normal weight patients, had a significantly increased risk of developing RAEs with an odds ratio (OR) of 1.51 (P<.0001) and 1.35 (P=.039), respectively. Conversely, obese patients had a decreased risk, with an odds ratio of 0.84 (P=.022). The risk of RAEs increased with older age, with those >80 years of age conferring the highest risk (OR=2.09 compared to <50 years of age, P<.0001). Current smokers had an OR of 1.26 compared to non-smokers (P=.011), while former smokers were not at a significantly higher risk. Increasing severity in COPD carried an increasing risk of RAEs, with those on medications alone having an OR of 1.74 (P<.0001) and those with an oxygen requirement having an OR of 2.33 (P<.0001), compared to patients without COPD. Symptomatic cardiac disease conferred an elevated risk of RAEs (recent AMI or unstable angina OR=1.50, P=.007 and symptomatic CHF OR=1.42, P=.001, compared to patients without cardiac disease). Clinical indicators of poorly optimized volume status, such as advanced renal insufficiency (Stage 4 OR=1.96, P<.0001 and Stage 5/dialysis OR=1.70, P<.0001) and patients with high intra-operative blood loss (≥2,000ml OR=2.31, P<.0001) had an independent increased risk of RAEs.

Bedbound or wheelchair confined patients were at an increased risk of respiratory events, likely as a marker of baseline deconditioning. As expected, markers of high acuity were significantly associated with RAEs, such as ASA class IV (OR=2.47, P<.0001), ASA Class V (OR=3.57, P<.0001) and emergent procedures (OR=4.16, P<.0001). Procedures that carried the highest risk of RAEs included in-situ suprainguinal bypasses (OR=4.89, P<.0001), open AAA repairs (OR=3.90, P<.0001), and TEVARs (OR=3.31, P<.0001), compared to an infrainguinal bypass, even while controlling for baseline patient comorbidities and presenting characteristics.

Preoperative Risk Prediction Score for Respiratory Adverse Events

The preoperative risk prediction score was created using key demographics, comorbidities, level of acuity and operative type, informed by the above multivariable model (Table V). The point values for each variable were derived from a random 85% sample of the cohort (n=44678). The predictor variables included age, body mass index, smoking status, CHF severity, COPD severity, degree of renal insufficiency, ambulatory status, transfer status, urgency and operative type, with a theoretical total point range of 0–41. Each point total had a calculated, estimated risk of developing a RAE. These point totals were then stratified into 4 groups based on their associated predicted risk rates. The *Low Risk* group (0–11 points) has a predicted risk of RAE <5%, the *Intermediate-Low Risk* group (12–15 points) has a predicted risk of RAE between 5–10%, the *Intermediate-High Risk* group (16–19 points has a predicted risk between 10–20% and the *High Risk* group (20–41 points) has a predicted risk of RAEs >20%.

The risk prediction score was then validated on the remaining 15% of the cohort (n=7,884). Each patient was assigned a point total based on the prediction score and an associated predicted risk of developing a RAE. For each point total, we compared the actual incidence of RAEs to the predicted risk of RAE; when plotted on a graph (see Figure 1), the predicted risk and actual incidence of RAEs were highly correlated, with a Pearson's correlation coefficient of 0.943 (P<.0001). As seen in Table VI, the actual RAE incidence for each major risk group falls within the predicted risk range for each major risk group. Figure 2 depicts the ROC curve, with the area under the curve=0.8177, demonstrating the excellent discrimination of the risk prediction model.

Impact of Respiratory Adverse Events on Patient Outcomes

The mean length of hospital stay for the entire cohort was 7.37 ± 16.35 days (median 4 days). Those with RAEs had a significantly longer length of stay of 14 days compared to 4 days for those without a respiratory complication (median, P<.0001). For the entire cohort, the in-hospital mortality rate was 2.8% (n=1,494). The rate of in-hospital mortality was only 1.2% (n=608) for those without a RAE and 25.4% (n=718) for those with a RAE (P<.0001; 9.4% for those with pneumonia and 31.4% for those with requiring reintubation). If a patient survived to discharge (n=40,334), 20.6% (n=10,505) of the entire cohort was discharged to a nursing or rehabilitation facility. Only 19% of patients who did not have a respiratory complication were discharged to a facility, while 57.8% (n=1,219) of patients with RAEs were discharged to a facility (P<.0001), see Figure 3.

A mixed-effects, logistic regression model was created to determine the independent impact of RAEs on mortality while controlling for baseline patient characteristics (age, gender, BMI, smoking, diabetes, CAD, CHF, COPD, renal insufficiency, stress test, transfer status, preoperative medications, ASA Class, urgency, hemoglobin), operative type (procedure, anesthesia, perioperative antibiotics, blood loss, procedure time), other adverse events (transfusion of more than 3 units of packed red blood cells, any cardiac event, renal failure, wound or graft complication, return to the operating room), the interaction between cardiac and respiratory adverse events, and the random effect of clustering at hospital centers. In this model, respiratory complications were associated with an odds ratio of 5.85 (95% confidence interval 4.61–7.43, P<.0001), which was the highest odd ratios for any complication and the second highest in the model, behind an ASA class 5 (compared to Class 1 and 2, OR=6.50, P<.0001). Excluding patients who did not survive to discharge, a similar multivariable model was created to determine association of discharge to a nursing facility; RAEs were associated with an odds ratio of 3.14 (95% confidence interval 2.72–3.64, P<.0001) of being discharged to a facility.

Discussion

Post-operative respiratory complications are associated with some of the highest rates of morbidity and mortality, with a significant impact on patient quality of life and healthcare costs given the prolonged hospitalization and nursing facility care requirements.[4, 8, 9, 14, 15, 24] The vast majority of the literature examines the incidence and impact of post-operative RAEs in the general surgery patient population, with only a small portion of vascular surgery patients represented in these studied cohorts.[4, 8] While these studies are useful in identifying generalized risk factors for RAEs, vascular surgery patients are a unique group with multiple comorbidities, advanced age, high acuity and complexity of procedures compared to the general surgery population.[1–3] While a few studies that have focused on post-operative complications in vascular surgery patients specifically, these have been limited to single center studies; moreover these studies have only assessed the impact of respiratory failure on outcomes alone without developing a comprehensive risk model for the development of this morbid complication.[5, 19, 21, 25]

While the frequency of post-operative respiratory complications depends on both patient characteristics and type of surgical intervention, they have been traditionally described as relatively uncommon events, occurring in 1.4–10% of surgical patients.[5, 11, 22, 26] In our contemporary, vascular surgery patient population, the overall incidence of RAEs was 5.4%, which was more frequent than other post-operative complications that are often the focus of preoperative risk stratification and optimization, such as acute myocardial infarction, CHF exacerbations, infectious or wound complications. This can be explained by a multiple factors, including a more complex patient population, and more robust reporting mechanism that prompts the capturing of complications.

In addition to being one of the most prevalent post-operative adverse events, the current study demonstrates that RAEs are one of the strongest predictors of poor patient outcomes. One quarter of patients with a RAE died during their hospitalization, with a 5.9 adjusted odds ratio of in-hospital mortality associated with RAEs. Lengths of hospital stays were almost 3-times greater with RAEs, and of those patients who survived, over half required rehabilitation or nursing care after discharge, all of which contribute to the large cost burden associated with this complication.[4, 15]

There were a variety of baseline patient and operative characteristics that were predictive of RAEs. This included advanced age, which is consistent with previous reports showing age as being highly associated with RAEs, particularly in octogenerians.[8, 11, 14, 22] In addition, active smoking was shown in this study, as well as in previous reports[8, 9, 11, 14, 22], to be associated with post-operative RAEs, while patients who had quit smoking for at least one year remained at a similar risk as non-smokers.

Body mass index was utilized in this study as it was able to identify patients who were underweight, as malnutrition and low BMI are historically associated with postoperative respiratory complications[8, 9, 11, 14, 22], and those with morbid obesity. The association of morbid obesity with respiratory complications has been conflicting in previous studies, but these patients potentially have a decreased inspiratory capacity due to their body habitus and decreased postoperative rehabilitation ability.[9, 27–30] Interestingly, those who were overweight or obese were not at an increased risk of RAEs, which may be a marker of adequate nutrition and is consistent with previous findings of similar adverse event rates of obese patients compared to normal weight patients.[11, 31–33]

Other predictive comorbidities that were subsequently included in the risk prediction score included COPD, CHF, and progressive renal insufficiency. As previously demonstrated, baseline COPD represents the underlying pulmonary disease contributing to post-operative respiratory complications,[8, 9, 11, 14, 22] however the present study has further delineated this risk by differentiating between disease severity and showing that the greatest risk in those with advanced disease requiring oxygen therapy. In a similar fashion, our study utilized CHF severity and degree of renal insufficiency to accurately risk stratify patients. These underlying diseases have been shown to increase the risk of pulmonary complications and likely represent baseline deconditioning, patient frailty and suboptimal volume status.[8, 9, 11, 14, 22] Ambulatory status was found to be a strong predictor of RAEs, as those who are wheelchair or bed bound have a high degree of deconditioning and functional dependence, with the potential for impaired ability to perform adequate post-operative pulmonary rehabilitation.

Indicators of disease acuity, transfer status and urgency of the procedure were included in the risk prediction score as these variables have some of the strongest associations with postoperative complications.[9, 11, 14, 22] Patients who require urgent or emergent procedures are unable to undergo preoperative cardiopulmonary optimization and represent some of the most advanced disease states, placing them at the highest risk for both perioperative complications and mortality. Finally, it is well known that the type of surgical procedure confers different levels of postoperative RAE risk.[8, 9, 11, 22] Even within the subset of vascular procedures, thoracic endovascular procedures and open abdominal cases carried the highest rates of respiratory complications. Open abdominal aneurysm repairs had the highest rates of respiratory complications at 18%, while in-situ suprainguinal bypass and TEVAR had RAE rates of approximately 10%. These procedures place a direct stress on the pulmonary system and post-operative rehabilitation can be significantly limited by atelectasis, decreased inspiratory capacity and postoperative pain. Moreover, despite the minimally invasive nature of TEVARs, patients presenting with a major thoracic pathology inherently places them at a higher risk of respiratory complications compared to other endovascular procedures, such as EVAR, which is associated with only a 3% risk of respiratory adverse events.

As a result of our investigation into the major risk factors for the development of respiratory complications in vascular patients, we developed a risk prediction score that utilizes ten major preoperative variables including age, BMI, smoking status, CHF severity, COPD severity, degree of renal insufficiency severity, ambulatory status, transfer status, urgency and operative type. It stratifies patients into four major risk groups of <5%, 5–10%, 10–20% or >20%. This prediction score was validated with a separate VQI cohort not utilized for the score generation. The correlation between the predicted and the actual incidence of RAEs was .943, with a c-statistic of .8177, demonstrating the prediction score's excellent discrimination and performance.

This risk prediction score was created to risk stratify individual patients undergoing any major vascular procedure, to be used when seeing a patient for an elective procedure in clinic or prior to a more urgent procedure in the hospital. In the preoperative setting, accurate risk stratification can provide evidence-based counseling of patients with regard to their respiratory complication risk and the subsequent risk of in-hospital mortality and overall disposition. Moreover, this would allow surgeons and primary care physicians to optimize patients prior to elective surgeries, in conjunction with other medical subspecialists, such as pulmonologists, intensivists, and cardiologists, with specific attention to volume status optimization and tobacco cessation prior to an elective procedure. Those at high risk can also be considered for preoperative pulmonary rehabilitation, which may improve the overall conditioning of the patient as well as the patient's inspiratory capacity and muscle training to assist in optimizing the postoperative pulmonary status.[8, 34]

In the post-operative setting, those predicated to be at high risk could be placed in an aggressive pain control and pulmonary rehabilitation programs by facilitating deep breathing, reduction in atelectasis, and increase inspiratory capacity.[8, 35, 36] Moreover, as increasing emphasis is being placed on quality outcomes, shortening length of stay while minimizing postoperative complications and decreasing readmission, this risk stratification allows single centers or regulatory agencies to set benchmarks for expected rates of this important adverse events.

This study has some limitations that require acknowledgement. All analyses were performed on data that was obtained from a multi-centered database that requires voluntary data and event entry from each hospital. The Vascular Quality Initiative does perform quality diagnostics on reported data, however inaccurate and missing data is possible. Additionally, prediction scores have the potential to over-fit for the database used to develop the score. In an effort to demonstrate the validity of this prediction model, we reserved a random 15% sample of the data from the score development to use in the score validation, as opposed to bootstrapping random samples from the original cohort. However, further application of the risk prediction score to external databases and prospective cohorts are still needed to more thoroughly validate the prediction score. Despite the stated limitations, this large dataset and robust prediction models provide us with a solid description of RAEs and their impact on patients undergoing vascular surgery.

Conclusions

This study, utilizing the VQI's multi-centered, national database, provides an in-depth investigation into a clinically significant post-operative event in the contemporary vascular surgery patient population. Respiratory adverse events are frequent and one of the strongest risk factors for in-hospital mortality and inability to be discharged home. Using over 52,000 patients, a risk prediction score was developed that accurately stratifies patients based on key demographics, comorbidities, presentation, and operative type that can guide patient counseling, preoperative optimization, post-operative management, and to be used as a quality benchmark measure. This prediction tool ("VQI: Respiratory Adverse Event Risk Post Vascular Surgery") can be found online and on the mobile device application Calculate by QxMD at http://qx.md/calculate or on the web at http://qxmd.com/resp-vqi.

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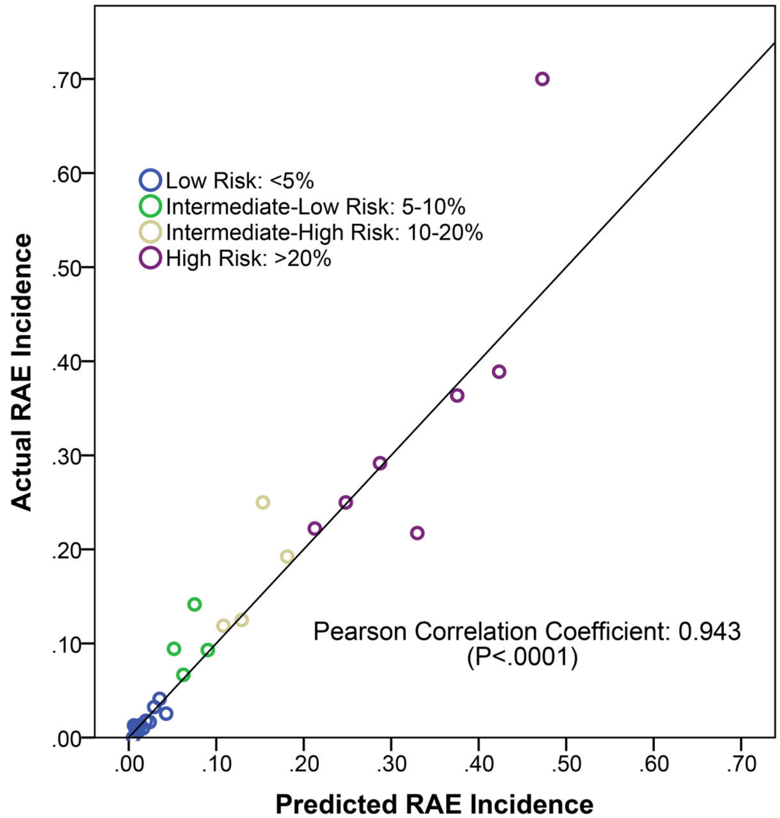

Figure 1.

Risk Prediction Score Validation. The estimated risk of developing a RAE for each point total (x-axis) compared to the actual incidence of RAE for that same point total (y-axis) of the remaining 15% of cohort. Each circle represents a point total and the color represents the risk group of each point total. An x=y reference line was drawn to demonstrate correlation. The most extreme 0.5% of patients (point total >26) were excluded.

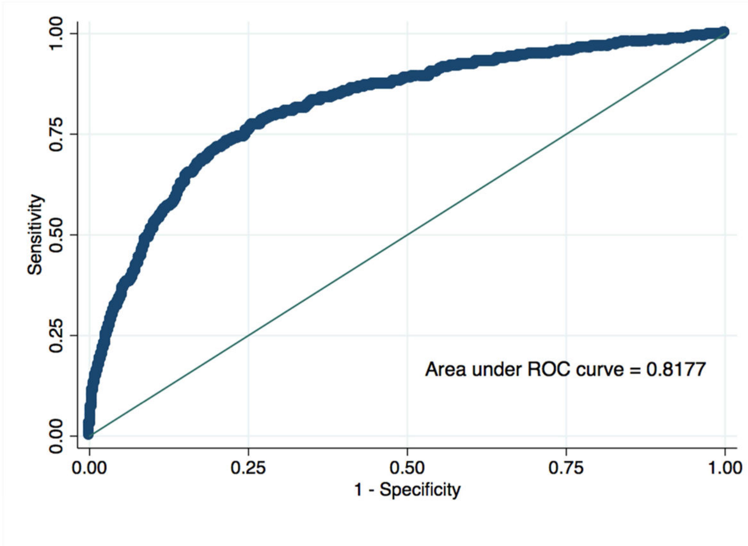

Figure 2.

Receiver Operating Characteristic Curve of the risk prediction score model tested on the validation cohort.

Table I

Baseline Patient Demographics and Comorbidities

Baseline Variable	%	n
DEMOGRAPHICS		
Gender		
Male	71.4	37,505
Age, years		
<50	4.3	2,285
50–59	14.9	7,831
60–69	30.3	15,898
70–79	32.6	17,149
≥80	17.9	9,399
Race		
Caucasian	87.6	46,029
Body Mass Index, kg/m^2		
Underweight (<18.5)	3.9	2,005
Normal weight (18.5–24.9)	31.5	16,283
Overweight (25–29.9)	35.8	18,483
Obese (30–39.9)	25.9	13,348
Morbidity Obese (≥40)	2.9	1,489
Smoking		
Never	14.5	7,581
Former	44.9	23,502
Current	40.6	21,223
Living Location		
Home	97.8	51,121
Nursing Facility or Homeless	2.2	1,150
Ambulatory Status		
Ambulatory	83.1	36,135
Ambulatory with Assistance	13.3	5,791
Non-ambulatory	3.6	1,562
Transfer Status		
Presents from Home	89.8	46,956
From an Outside Facility	10.2	5,349
COMORBIDITIES		
Hypertension	84.6	44,477
Diabetes	30.9	16,227
Coronary Artery Disease		
None	70.8	37,047
Remote MI or stable angina	27.5	14,363
Recent MI (<6 months) or unstable angina	1.7	900
Congestive Heart Failure		

Baseline Variable	%	n
None	87.3	45,689
Asymptomatic	7.5	3,923
Symptomatic	5.2	2,729
Chronic Obstructive Pulmonary Disease		
None	70.6	36,926
COPD without treatment	10.7	5,590
Medications only	15.3	8,027
Oxygen requirement	3.4	1,798
Renal Insufficiency (GFR, mL/min/1.73m^2)		
Stage 1 (≥ 90)	22.6	11,742
Stage 2 (60–89)	42.1	21,857
Stage 3 (30–59)	28.7	14,887
Stage 4 (15–29)	3.1	1,609
Stage 5 (<15) or Dialysis	3.5	1,795
Medications		
Aspirin	66.6	35,032
P2Y12 Antagonist	17.2	9,031
Statin	66.4	34,919
Beta-Blocker	63.3	33,271
Prior Vascular Surgery	38.3	20,112
Prior Major Amputation	2.5	1,303
Preop Hemoglobin, g/dL (mean ± SD)	12.6 ± 2.2	
OPERATIVE INFORMATION		
ASA Classification[a]		
Class I & II	6.2	2,949
Class III	66.4	31,428
Class IV	25.7	12,163
Class V	1.7	816
Urgency		
Elective	78.3	41,057
Urgent/symptomatic	14.8	7,730
Emergent/ruptured	6.9	3,619
Preoperative Antibiotics	86.0	45,215
Anesthesia		
General	93.6	49,199
Operation		
Suprainguinal bypass, in-situ	6.2	3,259
Suprainguinal bypass, extra-anatomic	6.3	3,315
Infrainguinal bypass, above knee	10.9	5,736
Ingrainguinal bypass, below knee	27.8	14,608
Open AAA	8.7	4,560
Open AAA, retroperitoneal approach	2.6	1,357

Baseline Variable	**%**	**n**
EVAR	32.8	17,213
TEVAR	4.8	2,514
Estimated Blood Loss, mL		
<500	72.6	35,780
500–999	13.7	6,764
1000–1999	7.9	3,918
≥2000	5.8	2,845
Procedure time, hours (mean ± SD)	3.36 ±1.79	

EVAR: endovascular aortic repair, TEVAR: thoracic endovascular aortic repair

[a]ASA (American Society of Anesthesiologists) Classification; Class I: normal/healthy patient, Class II: mild systemic disease, Class III: severe disease, Class IV: severe systemic disease that is a constant threat to life, Class V: moribund patient not expected to survive without operation

Table II

Incidence of Post-Operative Adverse Events

Adverse Event	Frequency	
	%	n
Transfusion ≥ 3 Units pRBCs	12.5	6,362
Any Cardiac Event	8.9	4,689
New Dysrhythmia	5.6	2,939
Myocardial Infarction	3.1	1,648
CHF Exacerbation	2.5	1,299
Respiratory Adverse Event	5.4	2,831
Re-intubation	3.9	2,058
Pneumonia	1.5	773
Wound complication	2.9	1,514
Dialysis (temporary or permanent)	1.7	896
Cerebrovascular Accident	0.9	419
Minor	0.5	213
Major	0.4	188

pRBCs: packed red blood cells

Table III

Incidence of Respiratory Adverse Events by Baseline Variables

Variable	Incidence of RAEs (%)	p-value
Demographics		
Gender		
Male	5.13	<.0001
Female	6.17	
Age		
<50	4.32	<.0001
50–59	3.59	
60–69	5.09	
70–79	5.96	
>80	6.80	
Race		
Caucasian	5.36	0.0969
Not Caucasian	5.86	
BMI		
Underweight	8.90	<.0001
Normal	5.49	
Overweight	4.87	
Obese	4.93	
Morbid Obesity	7.10	
Smoking		
Never	5.17	<.0001
Prior Smoker	4.80	
Current Smoker	6.09	
Living Location		
Home	5.36	.0003
Nursing Facility or Homeless	7.79	
Ambulatory Status		
Ambulatory	4.40	<.0001
Ambulatory with Assistance	5.48	
Non-ambulatory	8.55	
Transfer Status		
Presents from Home	4.37	<.0001
From an Outside Facility	14.90	
Comorbidities		
Hypertension		
No	4.80	.0082
Yes	5.53	
Diabetes		
No	5.69	<.0001

Variable	Incidence of RAEs (%)	p-value
Yes	4.76	
Coronary Artery Disease		
None	5.18	<.0001
Remote MI or stable angina	5.60	
Recent MI (<6 months) or unstable angina	10.06	
Congestive Heart Failure		
No CHF	5.06	<.0001
Asymptomatic	6.12	
Symptomatic	9.86	
COPD		
None	4.21	<.0001
COPD without treatment	8.02	
Medications only	7.70	
Oxygen Requirement	11.04	
Renal Insufficiency(GFR, mL/min/1.73m^2)		
Stage 1 (≥ 90)	3.91	<.0001
Stage 2 (60–89)	4.22	
Stage 3 (30–59)	7.39	
Stage 4 (15–29)	11.88	
Stage 5 (<15) or Dialysis	7.01	
Preoperative Medications		
Aspirin		
No	6.57	<.0001
Yes	4.81	
P2Y12 Antagonist		
No	5.54	.001
Yes	4.68	
Statin		
No	6.64	<.0001
Yes	4.77	
Beta-Blocker		
No	5.26	.31
Yes	5.47	
Prior Vascular Surgery		
No	5.72	<.0001
Yes	4.94	
Prior Major Amputation		
No	5.42	.45
Yes	4.93	
Operative Variables		
ASA Classification		
Class I & II	1.76	<.0001

Variable	Incidence of RAEs (%)	p-value
Class III	3.21	
Class IV	9.43	
Class V	36.57	
Urgency		
Elective	3.50	<.0001
Urgent/symptomatic	6.37	
Emergent/ruptured	25.87	
Preoperative Antibiotics		
No	7.94%	<.0001
Yes	5.14%	
Anesthesia Type		
Local/Regional	2.64%	<.0001
General	5.60%	
Operation Type		
Open AAA	17.57%	<.0001
In-Situ Suprainguinal Bypass	9.86%	
TEVAR	9.59%	
Extra-anatomic Bypass	5.70%	
EVAR	3.29%	
Infrainguinal Bypass	2.46%	
Estimated Blood Loss, mL		
<500cc	2.89%	<.0001
500–999	7.24%	
1000–1999	11.89%	
>=2000	26.64%	

Table IV

Multivariable Predictive Model of Post-Operative Respiratory Adverse Events[a]

Variable	Odds Ratio	95% CI	p-value
BMI			
Normal *(ref)*			
Underweight	**1.512**	**1.204 – 1.898**	**<.0001**
Overweight	0.911	0.801 – 1.037	.158
Obese	**0.841**	**0.726 – 0.975**	**.022**
Morbidly Obese	**1.353**	**1.016 – 1.802**	**.039**
Age			
<50 *(ref)*			
50–59	1.015	0.748 – 1.379	.922
60–69	**1.431**	**1.071 – 1.911**	**.015**
70–79	**1.499**	**1.114 – 2.016**	**.008**
>80	**2.089**	**1.527 – 2.856**	**<.0001**
Smoking			
Never *(ref)*			
Former	0.986	0.831 – 1.170	.872
Current	**1.259**	**1.053 – 1.504**	**.011**
Coronary Artery Disease			
None *(ref)*			
History of MI/ Stable angina	0.929	0.818 – 1.054	.256
Recent AMI /Unstable angina	**1.501**	**1.116 – 2.033**	**.007**
Congestive Heart Failure			
None *(ref)*			
CHF, no symptoms	1.011	0.834 – 1.227	.910
CHF, symptomatic	**1.418**	**1.162 – 1.731**	**.001**
COPD			
None *(ref)*			
COPD, no treatment	**1.644**	**1.401 – 1.928**	**<.0001**
COPD, Medical Treatment	**1.737**	**1.515 – 1.993**	**<.0001**
COPD, Home oxygen	**2.331**	**1.856 – 2.927**	**<.0001**
Renal Insufficiency			
Stage 1 *(ref)*			
Stage 2	**1.193**	**1.026 – 1.387**	**.022**
Stage 3	**1.674**	**1.428 – 1.963**	**<.0001**
Stage 4	**1.956**	**1.496 – 2.557**	**<.0001**
Stage 5/dialysis	**1.698**	**1.287 – 2.240**	**<.0001**
Ambulation Status			
Ambulatory *(ref)*			
Ambulation with Assistance	1.091	0.932 – 1.276	.279
Bedbound/wheelchair	**1.583**	**1.252 – 2.001**	**<.0001**

Variable	Odds Ratio	95% CI	p-value
Transferred from OSH			
Presents from Home *(ref)*			
From an Outside Facility	**1.214**	**1.043 – 1.414**	**.013**
Preoperative Hemoglobin, per g/dL	**0.950**	**0.925 – 0.975**	**<.0001**
ASA Class			
Class 1 & 2 *(ref)*			
Class 3	**1.474**	**1.024 – 2.120**	**.037**
Class 4	**2.466**	**1.699 – 3.578**	**<.0001**
Class 5	**3.570**	**2.291 – 5.563**	**<.0001**
Urgency			
Elective *(ref)*			
Urgent/symptomatic	**1.643**	**1.421 – 1.901**	**<.0001**
Emergent/ruptured	**4.155**	**3.491 – 4.944**	**<.0001**
Operation Type			
Infrainguinal Bypass, *(ref)*			
EVAR	**1.644**	**1.362 – 1.984**	**<.0001**
Extra-Anatomic Bypass	**1.728**	**1.407 – 2.223**	**<.0001**
TEVAR	**3.311**	**2.626 – 4.174**	**<.0001**
Open AAA	**3.900**	**3.116 – 4.875**	**<.0001**
In-Situ Suprainguinal Bypass	**4.889**	**4.040 – 5.916**	**<.0001**
EBL, mLs			
<500 *(ref)*			
500–999	**1.596**	**1.373 – 1.856**	**<.0001**
1000–1999	**1.747**	**1.449 – 2.105**	**<.0001**
≥2000	**2.314**	**1.914 – 2.945**	**<.0001**
Procedure Time, per hour	**1.174**	**1.139 – 1.210**	**<.0001**

[a]Variables included in the model without statistical significance (p ≥ .05): gender, race, hypertension, diabetes, preoperative aspirin, P2Y12 Antagonist, statin, living location, prior vascular surgery, anesthesia type

Model χ^2=2431.94, p<.0001. Random effect of hospital center χ^2=88.75, p<.0001

Table V

Prediction of Post-Operative Respiratory Adverse Event Score

Preoperative Variable	Points
Body Mass Index	
Underweight	**2**
Normal	**0**
Overweight	**0**
Obese	**0**
Morbidity Obese	**2**
Age	
<50	**0**
50–59	**0**
60–69	**2**
70–79	**2**
>80	**4**
Smoking	
Never	**0**
Prior	**0**
Current	**1**
Congestive Heart Failure	
None	**0**
History of CHF	**1**
Active CHF	**2**
Chronic Obstructive Pulmonary Disease	
None	**0**
No Treatment	**3**
Medications Only	**3**
Oxygen Dependent	**4**
Renal Insufficiency	
Stage 1	**0**
Stage 2	**1**
Stage 3	**3**
Stage 4	**4**
Stage 5/Dialysis	**5**
Ambulatory Status	
Ambulatory	**0**
Ambulates with Assistance	**1**
Non-Ambulatory	**3**
Transfer Status	
Presents from Home	**0**
From an Outside Facility	**1**
Urgency	

Preoperative Variable	Points
Elective	**0**
Urgent	**3**
Emergent	**9**
Operative Type	
Infrainguinal Bypass	**0**
EVAR	**1**
Extra-anatomic Bypass	**3**
TEVAR	**6**
In-Situ Suprainguinal Bypass	**9**
Open AAA repair	**10**

Table VI

Prediction Score Validation with Remaining 15% of the Cohort

Risk Groups	Predicted Risk Range (%)	Actual Incidence (%)	95% Confidence Interval
Low Risk			
(0–11 points)	<5	1.71	1.34 – 2.08
Intermediate-Low Risk			
(12–15 points)	5–10	9.69	7.78 – 11.59
Intermediate-High Risk			
(16–19 points)	10–20	15.73	12.27 – 19.19
High Risk			
(≥20 points)	>20	33.17	26.76 – 39.59