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Thesis Approval

Improving postoperative sepsis performance measurement using hospital risk-adjustment and concomitant monitoring of prevention and rescue within a statewide surgical collaborative

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Date

Improving postoperative sepsis performance measurement using hospital risk-adjustment and concomitant monitoring of prevention and rescue within a statewide surgical collaborative

By

Jesse Codner

MD, Emory University, 2018

Advisor: Joe Sharma, MD

An abstract of

A thesis submitted to the Faculty of the

James T. Laney School of Graduate Studies of Emory University

in partial fulfillment of the requirements for the degree of

Master of Science

in Clinical Research

2022

Abstract

Improving postoperative sepsis performance measurement using hospital risk-adjustment and concomitant monitoring of prevention and rescue within a statewide surgical collaborative

By Jesse Codner

Background

The Georgia Quality Improvement Program (GQIP) surgical collaborative has shown poor performance in postoperative sepsis compared to national benchmarks in NSQIP. Reporting quality metrics in a collaborative setting facilitates best practice dissemination. We aimed to evaluate additional quality metrics along the surgical care pathway by calculating risk-adjusted postoperative sepsis rates as well as sepsis prevention and mortality rescue for GQIP hospitals.

Methods

The cohort included intra-abdominal general surgery patients across 10 GQIP hospitals from 2015-2020. ACS-NSQIP data were utilized to train and validate a multivariable model with postoperative sepsis as the outcome. This model was used to rank hospitals by risk-adjusted postoperative sepsis rates. Failure to prevent (FTP) was calculated by dividing postoperative sepsis occurrences by postoperative infectious complications. Failure to rescue (FTR) was defined as mortality after postoperative sepsis. Crude and risk-adjusted FTR were calculated. Complication management quality metrics were compared to risk-adjusted postoperative sepsis rankings.

Results

The study included 20,314 patients with 595 cases of postoperative sepsis. Hospital crude postoperative sepsis risk ranged from 0.81 to 5.11. When applying the risk-adjustment model 9 of 10 hospitals were re-ranked, and 4 changed performance tertile. FTP rates trended upward and correlated with risk-adjusted sepsis rankings. Crude and risk-adjusted FTR did not correlate with sepsis prevention or risk-adjusted postoperative sepsis rankings.

Conclusions

Postoperative sepsis complication management quality metrics are important to present in collaborative settings. They do not always correlate and provide important benchmarks along the surgical care pathway to guide precise targets for quality improvement.

Improving postoperative sepsis performance measurement using hospital risk-adjustment and concomitant monitoring of prevention and rescue within a statewide surgical collaborative

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Table of Contents:

Specific Aims 1 and 2:

1. To determine what preoperative risk-factors predict postoperative sepsis in a Georgia Quality Improvement Program (GQIP) intra-abdominal general surgery cohort.

2. To rank GQIP hospitals by crude postoperative sepsis risk and risk-adjusted postoperative sepsis ratios.

Background:

The Georgia Quality Improvement Program (GQIP) is a multi-hospital regional collaboration of American College of Surgeon, National Surgical Quality Improvement Program (ACS-NSQIP) participating hospitals that focus on surgical quality improvement projects throughout Georgia. Collaborative postoperative sepsis rates have been consistently elevated above national benchmarks since 2015. Postoperative sepsis is a morbid and costly complication (1,2). It is associated with a high mortality rate, and the incidence of postoperative sepsis has been increasing for the past two decades (3,4). The average unadjusted cost for surgical patients whose postoperative course is complicated by sepsis is 3.6 times higher than baseline (1). This led GQIP leaders to focus on reducing postoperative sepsis as a statewide quality initiative.

GQIP believes there is greater potential for statewide quality improvement when hospitals engage collaboratively (5,6). This collegial environment allows hospitals to rely on the experiences of their peers, to assist in quality improvement at their own institutions (7). To facilitate best practice dissemination between high and low postoperative sepsis performers we set out to understand how our collaborative hospitals compared regarding postoperative sepsis outcomes for intra-abdominal general surgery procedures. State-wide benchmarking among collaborators promotes best practice exchange, which may be superior to blinded national benchmarking.

ACS-NSQIP provides risk-adjusted rates of postoperative sepsis for all cases, colorectal surgery, and emergency surgery. We focused on intra-abdominal general surgery cases, which have a higher clinical association with postoperative sepsis development. How risk adjustment affects hospital rankings for postoperative sepsis is still largely unknown, as most of the literature focuses on mortality (8). There is also minimal data on risk adjustment using statewide surgical collaborative data. Thus, GQIP aimed to determine statewide hospital postoperative sepsis performance by ranking collaborative hospitals by both crude postoperative sepsis risk and risk-adjusted postoperative sepsis ratios for intra-abdominal general surgery cases.

Methods:

Overview

This retrospective cohort study met criteria for exemption from Institutional Review Board approval at the main institution under 45 CFR 46.104(d)(4), and inter-hospital data followed GQIP data use agreements. This study included intra-abdominal general surgery patients from 10 GQIP hospitals from 2015 to 2020. ACS-NSQIP case details and custom fields reports were aggregated from each center. This data is abstracted at each center by trained surgical clinical reviewers. Methods followed the TRIPOD checklist for predictive modeling (9).

Study Population

Inclusion criteria were adult patients, age ≥ 18, undergoing open or laparoscopic intra-abdominal general surgery from 1/1/2015-11/1/2020. Intra-abdominal general surgery was defined as surgical cases involving the peritoneal and retroperitoneal spaces. Vascular and soft tissue surgery were excluded. Patients with sepsis or septic shock present at the time of surgery were excluded from analysis. Missing data was determined to be missing at random, so a complete case analysis was performed.

Outcomes

Postoperative sepsis and septic shock were the outcomes used to calculate crude hospital sepsis risk as well as risk-adjusted sepsis ratios. These outcomes were defined using standard ACS-NSQIP definitions and occurred within 30-days of index surgery. Outcome definitions were consistent across all centers (10).

Covariate Predictors

Covariates used for prediction and risk-adjustment for the postoperative sepsis model were baseline patient demographics, comorbidities, hospital and intraoperative variables. Demographics included age, sex, race, body mass index (BMI). Comorbidities included diabetes, hypertension, dialysis, chronic obstructive pulmonary disease, smoking status, and disseminated cancer. Perioperative variables included preoperative infections, emergency case status, American Society of Anesthesiologists (ASA) class, surgery type, wound classification and case complexity. Case complexity was defined as surgery complication rate as validated by the literature (11). All predictor variables occurred prior to the postoperative care phase.

Statistical Analysis

Descriptive statistics were reported as frequencies (percentages) for categorical variables and means ± standard deviations or medians (interquartile ranges) for continuous variables. Data were randomly split into a training set containing 70% of the data, and a validation set containing 30% of the data. A predictive risk-adjustment model for postoperative sepsis was trained and validated. First, using the training set, each covariate was entered separately into a logistic regression model (bivariable logistic regression) with postoperative sepsis as the outcome. Next, all variables from the bivariable analysis were then entered into a multivariable logistic regression model using an automated backward selection technique. Once the final model was trained, it was used on the validation set to assess for over-fitting. Model fit parameters such as the Hosmer-Lemeshow test, box plots, calibration plots and receiver operating curves were assessed. The area under the curve (AUC) analysis was used to quantify the predictive accuracy of the model in predicting sepsis.

Postoperative sepsis risk for each hospital was calculated to rank GQIP hospital using this quality metric. The data set was stratified by each hospital. Crude postoperative sepsis risk was calculated by dividing the observed postoperative sepsis cases by patients at risk for the outcome. To calculate risk-adjusted postoperative sepsis ratios the prediction model described above was applied to each hospital cohort to calculate expected cases of postoperative sepsis. An observed to expected ratio was then calculated for each hospital to develop risk-adjusted postoperative sepsis ratios.

Each hospital was ranked by both crude and risk-adjusted postoperative sepsis rates. Changes in rankings across quality metrics were documented, displayed graphically and discussed with each center. SAS software (version 9.4, SAS Institute, Inc., Cary NC) was used to analyze all statistics. All hypothesis testing was two sided and conducted at a 0.05 level of significance.

Results:

The original dataset was comprised of 58,754 patients. We excluded 1,204 patients with sepsis present at the time of surgery, and 37,236 patients for non-intra-abdominal general surgery cases. The final study population included 20,314 patients with 595 cases of postoperative sepsis (2.9%). When performing complete case analysis in the modeling step 95.7% of patients were included and 96.3% of patients with the outcome were included.

The average patient was 55.3 [41.2-66.9] years old with a BMI of 29.8 ± 7.7. There was a higher proportion of female (53.8%) and Caucasian (65.7%) patients in the cohort. The most common comorbidities present were hypertension (44.7%), smoking (18.7%), and diabetes (15%). Patients tended to be inpatient (55.3%) elective cases (82.8%). The most common surgeries performed were colorectal surgery (30.5%), cholecystectomy (26.7%), and hernia surgery (20.2%). Most cases were ASA class 1& 2 (47.6%) and were either clean or clean/contaminated wound class (75.9%).

Patients with postoperative sepsis were older 62.8 [52.5-71.0], had a decreased BMI 28.5 ± 8.5, and had a higher percentage of African American patients (34.7% vs 28.3%) compared to patients who did not develop sepsis. There was no difference in sex. All comorbidities were significantly higher in the postoperative sepsis group except for smoking status. Preoperative infections were more common in the postoperative sepsis group, and ASA class was mostly class 3 (60.7%). Cases that resulted in sepsis were also more complex (2.9 ± 0.9 vs 1.8 ± 1.0), more likely to be inpatient (94.8% vs 54.1%) and emergency cases (21.8% vs 17.0%). Dirty wound class was more prevalent in the postoperative sepsis cohort (27.7% vs 7.1%). (Table I).

Predictors of postoperative sepsis included in the multivariable prediction model were age, case complexity, preoperative surgical site infection (SSI), preoperative pneumonia, preoperative urinary tract infection (UTI), inpatient status, ASA class, and wound class (Figure I). The Hosmer & Lemeshow test p-values were 0.1529 for the training set and 0.6379 for the validation set. The area under the receiver operating curves were 0.8395 for the training set and 0.8521 for the validation set (Figure II).

The crude postoperative sepsis risk when stratified by the 10 hospitals ranged from (0.81-5.11%). When using the risk-adjustment model, postoperative sepsis ratios ranged from 0.46 (0.36, 0.59) to 1.91 (1.47, 2.48). 9 out of 10 hospitals were re-ranked after applying the risk-adjustment model (Figure III). When grouping rankings into high performers (1-4), average performers (5-7), and low performers (8-10), 4 hospitals changed tertiles when adjusting for patient and case mix factors. This highlights a potential 40% misclassification rate when using crude postoperative sepsis performance metrics.

Discussion:

We used data collected from diverse hospitals throughout the state of Georgia to develop and validate a postoperative sepsis prediction model which showed reasonable predictive power (AUC 0.8395). All variables included in the model have clinical relevance. Literature on postoperative sepsis prediction is sparse. Risk factors have been studied in specific national patient populations including bariatric surgery, major cancer surgery, appendectomies, spinal tumor surgery, and orthopedic trauma. Consistent predictors included preoperative transfusion, DM, ASA class >3, and increased operating room time. Our model also included ASA class. These papers discussed using a prediction model to understand and potentially adjust modifiable risk factors (12-17). It can be difficult to focus quality improvement efforts on modifying patient-specific risk factors. We argue that sepsis performance relies more on hospital factors, specifically postoperative care pathways. This includes things like infection prevention efforts, sepsis alerts, and sepsis bundles.

Our risk-adjusted model showed re-ranking of 9-10 hospitals with 4 hospitals changing tertiles between low, average, and high performance. This highlights the potential importance of using risk-adjustment to level set hospital comparisons in a state-wide setting (18,19).

Hospital performance metrics and rankings have been increasingly at the forefront due to performance-based reimbursement. These systems potentially dis-incentivize inter-hospital collaboration and sharing of best practices. We recommend using rankings within a research collaborative setting. This can promote improvement in patient safety by facilitating the distribution of best practices. Providing reliable state-wide hospital quality metrics to the participating institutions is a major goal of GQIP. Unlike standard NSQIP reports, this provides benchmarking amongst peers who can then discuss management techniques to ensure the best care across the state.

We plan to use this model to perform continued inter-collaborative risk-adjustment rankings for postoperative sepsis performance. This will assist in defining high and low outliers in our state. We can then highlight differences in the postoperative care pathways between high and low performers to devise an optimal strategy to both prevent and treat postoperative sepsis at the hospital level. We are currently analyzing differences in the postoperative sepsis care pathways across hospitals in Georgia. We also plan to evaluate more in-depth postoperative sepsis quality metrics such as failure to rescue to determine whether complication management quality metrics correlate with the risk-adjusted postoperative sepsis rankings calculated in this study.

Strengths of this study include data abstraction via standardized methods using trained surgical clinical reviewers from each hospital. Data was collected from both academic and community centers representing a diverse group in our state and represented a large data set. This study is not without its limitations. We are limited by the imbalance of patients with the outcome versus not having postoperative sepsis. We performed standard logistic regression techniques, so there is no reliability adjustment for statistical noise. Currently, we are limited by no prospective validation of our model.

Postoperative sepsis remains a morbid and expensive complication. Understanding your hospitals sepsis signal compared to other statewide collaborators is key to promoting quality improvement. State-wide risk-adjusted rankings provide an insight into areas for improvement. These rankings will promote a collegial dialogue between high and low performers on best practices. This may help decrease preventable postoperative sepsis cases in Georgia.

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Tables/Figures:

Table I Patient Demographics, Comorbidities and Perioperative Variables Compared by Postoperative Sepsis Status with Multivariable Prediction Model for Postoperative Sepsis

Demographics	Total N=20,314	Postoperative Sepsis No N=19,719	Yes N=595	Bivariate OR (95% CI)	Multivariable OR (95% CI)
Age; *Med [IQR]*	55.3 [41.2-66.9]	55.0 [40.9-66.7]	62.8 [52.5-71.0]	1.03 (1.02, 1.03)	1.01 (1.00, 1.02)
BMI; *Mean±SD*	29.8 ± 7.7	29.9 ± 7.7	28.5 ± 8.5	0.98 (0.96, 0.99)	--
Sex					
Female	10,938 (53.8)	10,634 (53.9)	305 (51.3)	REF	--
Male	9,375 (46.2)	9,085 (46.1)	290 (48.7)	1.11 (0.94, 1.31)	--
Race					
White	13,133 (65.7)	12,781 (65.8)	352 (60.5)	REF	--
Black	5,699 (28.5)	5,497 (28.3)	202 (34.7)	1.34 (1.12, 1.59)	--
Other/Unknown	1,159 (5.8)	1,131 (5.8)	28 (4.8)	0.90 (0.61, 1.33)	--
Comorbidities					
Diabetes					
Yes	3,018 (15.0)	2,892 (14.8)	126 (21.2)	1.54 (1.26, 1.89)	--
Smoker					
Yes	3,759 (18.7)	3,638 (18.7)	121 (20.3)	1.11 (0.91, 1.36)	--
COPD					
Yes	757 (3.8)	715 (3.7)	42 (7.1)	2.00 (1.45, 2.76)	--
Hypertension					
Yes	8,976 (44.7)	8,637 (44.3)	339 (57.0)	1.67 (1.41, 1.96)	--
Dialysis					
Yes	232 (1.1)	214 (1.1)	18 (3.0)	2.81 (1.73, 4.58)	--
Dissem. Cancer					
Yes	697 (3.5)	656 (3.4)	41 (6.9)	2.13 (1.53, 2.95)	--
Perioperative					
Case Comp *Mean±SD*	1.8 ± 1.0	1.8 ± 1.0	2.9 ± 0.9	2.75 (2.53, 3.00)	2.06 (1.85, 2.29)
Preop SSI					
Yes	149 (0.7)	109 (0.6)	40 (6.7)	13.0 (8.94, 18.8)	3.37 (2.21, 5.14)
Preop Pneumonia					
Yes	95 (0.5)	74 (0.4)	21 (3.5)	9.71 (5.94, 15.9)	2.94 (1.71, 5.06)
Preop UTI					
Yes	30 (0.2)	25 (0.1)	5 (0.8)	6.68 (2.55, 17.5)	3.51 (1.27, 9.73)
Preop Sepsis					
Yes	2,682 (13.2)	2,561 (13.0)	121 (20.3)	1.71 (1.39, 2.10)	--
Patient Status					
Outpatient	9,084 (44.7)	9,053 (45.9)	31 (5.2)	REF	REF
Inpatient	11,229 (55.3)	10,665 (54.1)	564 (94.8)	15.4 (10.7, 22.2)	3.47 (2.31, 5.21)
Emergency Case					
Yes	3,451 (17.2)	3,321 (17.0)	130 (21.8)	1.36 (1.12, 1.66)	--
Surgery Type					
Colorectal	6,201 (30.5)	5,949 (30.2)	252 (42.4)	REF	--
Midgut	1,899 (9.4)	1,797 (9.1)	102 (17.1)	1.34 (1.06, 1.70)	--
Cholecystectomy	5,428 (26.7)	5,394 (27.4)	34 (5.7)	0.15 (0.10, 0.21)	--
Hepatobiliary	1,381 (6.8)	1,269 (6.4)	112 (18.8)	2.08 (1.65, 2.62)	--
Foregut	1,312 (6.5)	1,268 (6.4)	44 (7.4)	0.82 (0.59, 1.14)	--
Hernia	4,093 (20.2)	4,042 (20.5)	51 (8.6)	0.30 (0.22, 0.40)	--
ASA Class					
Class 1 & 2	9,550 (47.6)	9,433 (48.4)	117 (19.7)	REF	REF
Class 3	9,125 (45.4)	8,764 (45.0)	361 (60.7)	3.32 (2.69, 4.10)	1.44 (1.14, 1.81)
Class 4 & 5	1,411 (7.0)	1,294 (6.6)	117 (19.7)	7.29 (5.61, 9.48)	2.29 (1.71, 3.09)
Wound Class					
Clean Contaminated	15,241 (75.9)	14,889 (76.4)	352 (59.2)	REF	REF
Contaminated	3,293 (16.4)	3,215 (16.5)	78 (13.1)	1.03 (0.80, 1.32)	1.62 (1.25, 2.10)
Dirty	1,558 (7.8)	1,393 (7.1)	165 (27.7)	5.01 (4.13, 6.08)	3.36 (2.31, 5.21)

All dichotomous outcomes without a reference group shown are modeling the odds of postoperative sepsis when the exposure is present vs when the exposure is not present. Abbreviations: OR (Odds Ratio), CI (Confidence Interval), Med (Median) IQR

(Interquartile Range), REF (Referent Group), BMI (Body Mass Index), SD (standard Deviation), COPD (Chronic Obstructive Pulmonary Disease), Dissem. (Disseminated), SSI (Surgical Site Infection), UTI (Urinary Tract Infection), ASA (American Society of Anesthesiologist)

Figure I

Figure I. Forest Plot for Postoperative Sepsis Multivariable Prediction Model

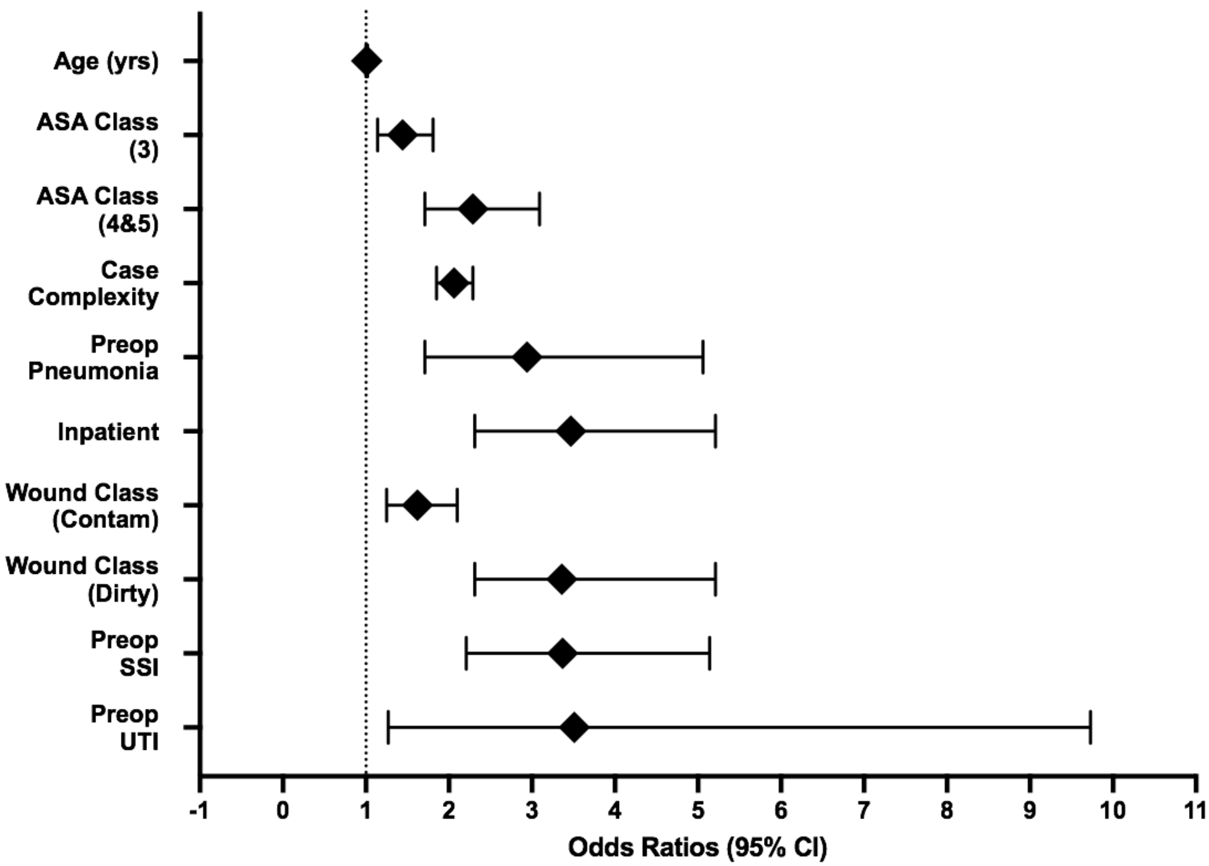


Figure II

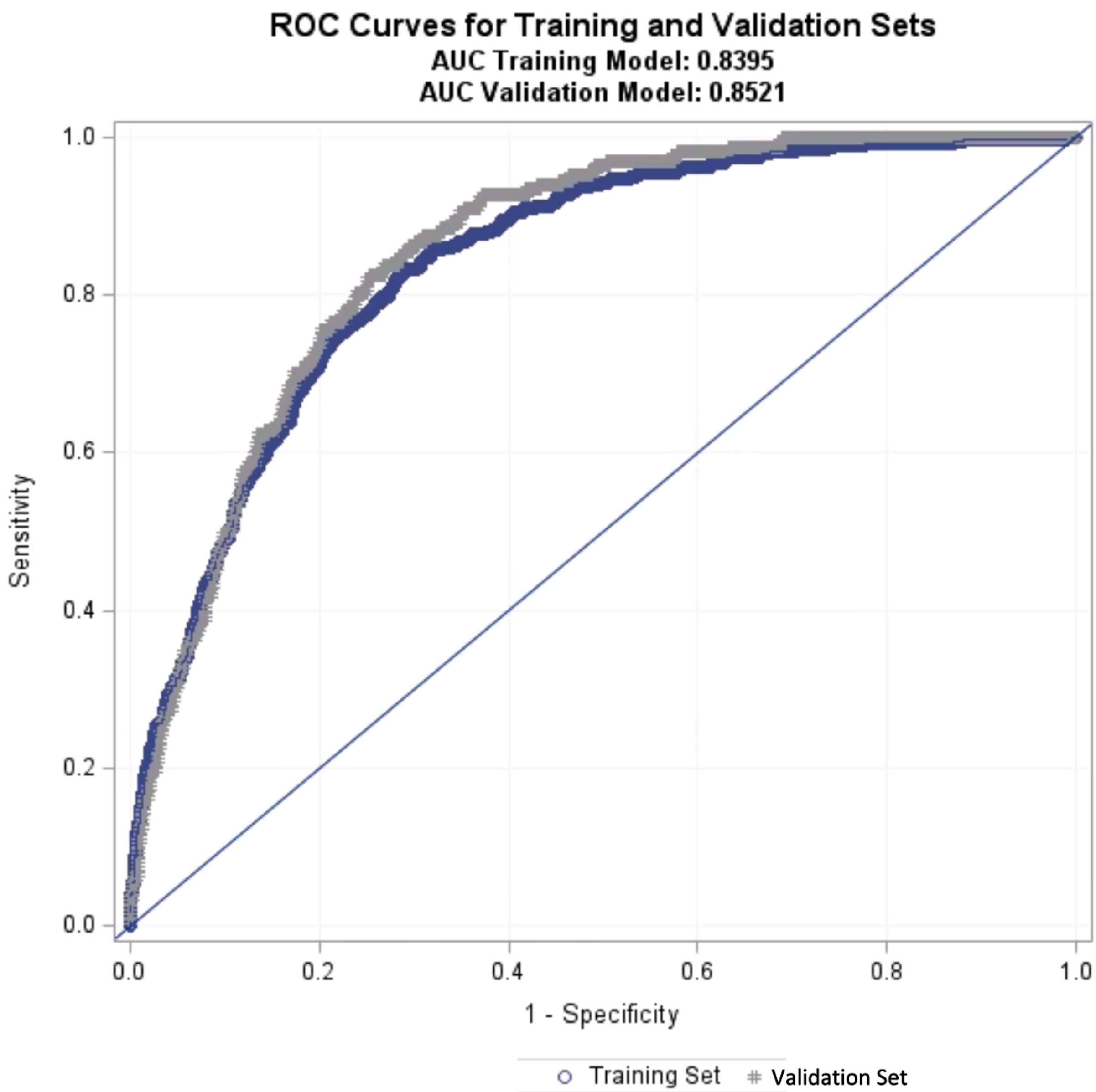
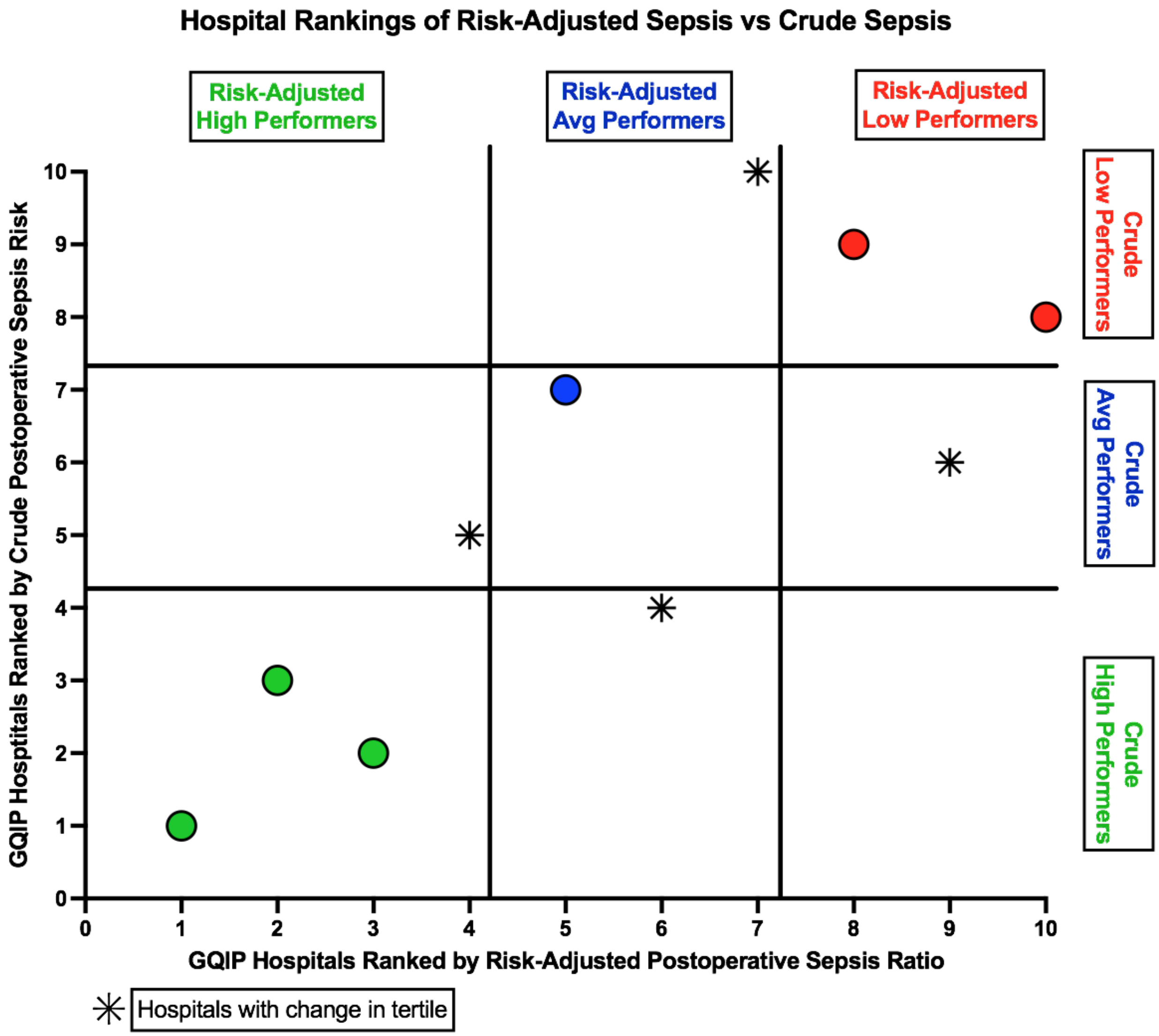

ROC Curves for Training and Validation Sets
AUC Training Model: 0.8395
AUC Validation Model: 0.8521
Sensitivity
1 - Specificity
0.0
0.2
0.4
0.6
0.8
1.0
Training Set
Validation Set

Figure III


Hospital Rankings of Risk-Adjusted Sepsis vs Crude Sepsis
Risk-Adjusted High Performers
Risk-Adjusted Avg Performers
Risk-Adjusted Low Performers
Crude Low Performers
Crude Avg Performers
Crude High Performers
GQIP Hosptitals Ranked by Crude Postoperative Sepsis Risk
GQIP Hospitals Ranked by Risk-Adjusted Postoperative Sepsis Ratio
0
1
2
3
4
5
6
7
8
9
10
Hospitals with change in tertile

Specific Aims 3 and 4:

3. To determine GQIP hospital complication management metrics including: postoperative sepsis failure to prevent, failure to rescue, and risk-adjusted failure to rescue.

4. To evaluate whether these new metrics (failure to prevent & failure to rescue) correlate with hospital risk-adjusted postoperative sepsis rankings.

Background:

The Georgia Quality Improvement Program (GQIP) is a collaboration of hospitals throughout the state of Georgia that subscribe to ACS-NSQIP and TQIP. This multi-hospital program collaborates on surgical quality improvement projects in Georgia. Since 2015 GQIP postoperative sepsis rates for all cases have been elevated above national benchmarks in NSQIP. Postoperative sepsis is a costly and morbid complication with a high association with mortality (1-3). In order to facilitate best practice dissemination, GQIP explored state-wide crude and risk-adjusted postoperative sepsis rankings in previous work. Results showed a re-ranking of 9 out of 10 hospitals with 4 hospitals changing tertiles after adjusting for patient and case-mix factors. Inter-collaborative risk-adjustment, ranking, and collegial disclosure of rankings amongst peers helps to facilitate best practice discussions between high and low performers.

When critically reviewing postoperative sepsis measurement, we believe reporting postoperative sepsis as a single quality metric has limitations. Postoperative sepsis quality metrics should be more robust as there are multiple levels along the postoperative care pathway where signals could help provide precise targets for quality improvement. These include failure to prevent (FTP) sepsis after an infectious complication, and failure to rescue (FTR) which constitutes a death after postoperative sepsis.

Complication management metrics, specifically FTR, was first described by Silber in 1992 who noted that hospital characteristics may ultimately be responsible for preventable deaths after complications take place (4). Failure to rescue has become important to report for hospitals as FTR is currently an Agency for Healthcare Research and Quality patient safety indicator. Although complication metrics can be misleading as not all adverse events are preventable, presenting these metrics in a collaborative setting allows for group reflective process improvement which may help identify hospital factors leading to FTR (5,6). Septic complications have been shown to carry the highest risk for FTR (7).

Evaluating hospital postoperative care pathways related to preventing sepsis after infections and preventing death after postoperative sepsis may help improve the quality of care rendered to our patients in Georgia (8-11). GQIP aimed to understand hospital postoperative sepsis complication management quality metrics, FTP & FTR, and how these new metrics correlated with hospital risk-adjusted postoperative sepsis rankings.

Methods:

Overview

This retrospective cohort study met criteria for exemption from Institutional Review Board approval at the main institution under 45 CFR 46.104(d)(4), and inter-hospital data followed GQIP data use agreements. This study included intra-abdominal general surgery patients from 10 GQIP hospitals from 2015 to 2020. ACS-NSQIP case details and custom fields reports were aggregated from each center. This data is abstracted at each center by trained surgical clinical reviewers. Methods followed the TRIPOD checklist for predictive modeling (12).

Study Population

Inclusion criteria were adult patients, age ≥ 18, undergoing open or laparoscopic intra-abdominal general surgery from 1/1/2015-11/1/2020. Intra-abdominal general surgery was defined as surgical cases involving the peritoneal and retroperitoneal spaces. Vascular and soft tissue surgery were excluded. Patients with sepsis or septic shock present at the time of surgery were excluded from analysis. Missing data was determined to be missing at random, so a complete case analysis was performed.

Outcomes

Postoperative sepsis and septic shock were the outcomes used to calculate crude hospital sepsis risk as well as risk-adjusted sepsis ratios described in our previous work. These outcomes were defined using standard ACS-NSQIP definitions and occurred within 30-days of index surgery (13).

Failure to prevent postoperative sepsis was defined as postoperative sepsis following at least one infectious complication coded in ACS-NSQIP. Infectious complications included: preoperative: superficial/deep/organ space surgical site infections (SSI), pneumonia, and urinary tract infections (UTI) and postoperative: superficial/deep/organ space SSI, pneumonia, UTI, and Clostridium dificile infections.

Failure to rescue postoperative sepsis was defined as mortality following postoperative sepsis. Mortality was tracked for up to 30 days following index surgery.

Covariate Predictors

The risk-adjusted postoperative sepsis failure to rescue model included baseline patient demographics, comorbidities, hospital and intraoperative variables, and postoperative variables. Demographics included age, sex, race, body mass index (BMI). Comorbidities included diabetes, hypertension, dialysis, chronic obstructive pulmonary disease, smoking status, and disseminated cancer. Perioperative variables included preoperative infections, emergency case status, ASA (American Society of Anesthesiologists) class, surgery type, wound classification, and case complexity. Case complexity was defined as surgery complication rate as validated by the literature (14). Postoperative predictors included: surgical site infection (superficial/deep/organ space), pneumonia, UTI (Urinary Tract Infection), pulmonary embolism, acute renal failure, venous thrombosis, C. diff, re-intubation, readmission, reoperation, and ventilator use > 48 hrs. All variables occurred prior to the mortality outcome and were appropriate for inclusion in the model.

Statistical Analysis

Descriptive statistics for mortality after postoperative sepsis were reported as frequencies (percentages) for categorical variables and means ± standard deviations or medians (interquartile ranges) for continuous variables. Hospital crude postoperative sepsis risk, risk-adjusted postoperative sepsis ratios and subsequent rankings were described and calculated in a previous paper.

Crude FTP was calculated for each hospital. Data were stratified by each hospital, and FTP was calculated by dividing the observed cases of postoperative sepsis by the total number of infectious complications.

Hospital crude FTR equaled the observed mortality after postoperative sepsis divided by the total patients with postoperative sepsis at each hospital. A predictive risk-adjustment model for FTR was then built and cross-validated. Patients included had postoperative sepsis and mortality was the outcome of interest. First, each covariate was entered separately into a logistic regression model (bivariable logistic regression). Next, all variables from the bivariable analysis were then entered into a multivariable logistic regression model using an automated backward selection technique. Once the final model was built, cross-validation was used to assess over-fitting. Model fit parameters such as the Hosmer-Lemeshow test and a receiver operating curve (ROC) were analyzed. The area under the curve (AUC) was used to quantify the predictive accuracy of the model in predicting FTR.

To calculate risk-adjusted FTR ratios the prediction model described above was applied to each hospital cohort to calculate expected cases of FTR. An observed to expected ratio was then calculated for each hospital to develop risk-adjusted FTR ratios.

Each hospital was ranked by the quality metrics discussed above. Changes in rankings across quality metrics were documented and discussed with each center. SAS software (version 9.4, SAS Institute, Inc., Cary NC) was used to analyze all statistics. All hypothesis testing was two-sided and conducted at a 0.05 level of significance.

Results:

The study population included 58,754 patients. We excluded 1,204 patients with sepsis present at the time of surgery and 37,236 patients for non-intra-abdominal general surgery cases. The final study population included 20,314 patients with 595 cases of postoperative sepsis. Out of the patients with postoperative sepsis, 32 patients were excluded due to missing mortality data. Leaving 563 postoperative sepsis patients with 58 deaths.

Descriptors and results of the entire study population compared by postoperative sepsis were described previously. Total infectious complications ranged from a risk of 3.46-13.5 across all hospitals. The percentage of infectious complications resulting in postoperative sepsis, FTP, ranged from 19.3% to 52.2%. FTP rates grossly correlated with risk-adjusted postoperative sepsis ratios between hospitals (Table I, Figure I).

The cohort evaluated for FTR analysis were patients whose postoperative course was complicated by postoperative sepsis, and the outcome of interest was mortality. At baseline, there were no statistical differences in sex, race, diabetes, or case complexity between the mortality group and no mortality group. Patients who died were older (70.5 [66.4-80.4] vs 61.3 [50.8-70.1] yrs), more likely to be an emergent case (36.2% vs 19.4%) and had higher ASA classes (Class 4/5: 37.9% vs 16.8%). Patients with FTR had higher rates of renal failure (20.7% vs 3.4%), re-intubation (44.8% vs 12.5%), and ventilation for greater than 48 hours (46.6% vs 15.8%) (Table II). Overall FTR rate for all hospitals was 9.7%. When stratified by each center crude FTR ranged from 0% to 26.3%. Of note, crude FTR did not correlate with risk-adjusted sepsis ratios (Figure I).

The multivariable risk-adjusted FTR cross-validation model included readmission, age, reoperation, postoperative renal failure, preoperative sepsis, re-intubation, and disseminated cancer. The Hosmer & Lemeshow test p-value for the model was 0.9096. The cross-validation ROC curve had an AUC of 0.875. Risk-adjusted ratios of FTR ranged from 0.29 (0.18, 0.51) to 1.83 (1.18, 3.09). Upon implementing risk adjustment, 5 out of 10 hospitals were re-ranked for FTR. When grouping rankings into tertiles (1-4, high performers), (5-7, average performers), and (8-10, low performers), 3 hospitals changed tertile ranking between crude and risk-adjusted FTR rankings. This shows a misclassification rate of 30%. Risk-adjusted FTR also did not correlate with risk-adjusted postoperative sepsis ratios (Figure I).

Risk-adjusted rankings of both postoperative sepsis and FTR were compared between hospitals included. When comparing tertiles (1-4, high performers), (5-7, average performers), and (8-10, low performers) between groups there was a wide distribution. Two hospitals had high performance in both metrics and 1 hospital was an average performer in both metrics. The remaining 7 hospitals had discrepancies in tertile rankings between metrics. Two hospitals had high postoperative sepsis performance but were low performers in FTR. Out of the 3 low postoperative sepsis performers, 2 hospitals were average in FTR, and 1 hospital was a high FTR performer (Figure II).

Discussion:

GQIP explored a variety of postoperative sepsis performance quality metrics between diverse hospitals in Georgia. After receiving poor national benchmarked collaborative performance measures from ACS-NSQIP, it is important to further analyze that complication in depth between included hospitals. In previous work, GQIP ranked hospitals based on risk-adjusted postoperative sepsis rates, finding 9-10 hospitals with changes in ranking from crude to risk-adjusted rankings. Here we describe the correlation of postoperative sepsis complication management quality metrics, FTP & FTR, with the classic risk-adjusted complication rate that is often reported.

GQIP saw fit to further expand postoperative sepsis performance measurements because sepsis as a complication has multiple areas along the postoperative care pathway where interventions may affect sepsis performance. It is important to measure these inflection points to provide precise quality improvement targets for hospitals. For instance, if an elevated sepsis signal is present for a hospital should that be a concern? If the elevation is due to performing high-risk procedures, and most of those sepsis cases are rescued from mortality, then possibly that signal can be ignored by the hospital system. Though if a hospital has a high percentage of postoperative infections devolving into sepsis cases, then early infection management may be a target for sepsis performance improvement. We argue, when thinking about the sepsis postoperative care pathway it is important to consider prevention after infectious complications as well as rescue after a sepsis diagnosis. These metrics can give hospitals areas to focus quality improvement efforts on, or at least do a deeper dive to assess actual complication preventability.

State-wide risk-adjusted FTR analysis is sparse in the literature. Previous FTR prediction models have been studied in geriatric populations, pancreas surgery, and abdominal aortic aneurysm repair. Some consistent variables between models include increased age, disseminated cancer, ASA class, renal failure, and respiratory failure (8,15-17). Our model also contained age, renal failure, re-intubation and disseminated cancer, and showed reasonable predictive power to level set hospital comparisons by FTR. Our model was unique in focusing on postoperative sepsis FTR rather than all complication FTR.

When comparing each hospital by their own risk-adjusted postoperative sepsis performance and FTR performance there was a wide variation in rankings. This highlights the potential importance of reporting these individual quality metrics to hospitals. Solely reporting a sepsis signal is not adequate. Hospital quality officers need in-depth analysis of where to deploy valuable resources and time to improve patient outcomes. This stresses the need to report complication management quality metrics for postoperative sepsis. Infection prevention, infection management, early sepsis recognition and management all have unique interventions and thus should not be lumped under a single quality signal. Whether a hospital should focus on infection management or early sepsis recognition and treatment can only be discerned with FTP and FTR metric reporting. These metrics and rankings are particularly useful in a collaborative setting as peer performance benchmarking promotes dissemination and discussion of best practices.

Sepsis literature focuses on early recognition and management as key staples to sepsis care (18). Some hospitals have integrated automated sepsis alerts in the electronic medical record system when patients have specific vital sign changes. This automation also extends to sepsis order set bundles that quickly layout key treatments for providers to order. Our analysis is limited by not incorporating hospital-specific factors into our model. We are currently gathering infection and sepsis management practices from each of our centers to compare postoperative care pathways between hospitals.

This study is limited by the relatively small sample size of mortality outcomes in the FTR model. FTP is also a relative measure as the infectious source of postoperative sepsis cannot be definitively defined using current data. FTR analysis is also limited by not knowing the true cause of death amongst postoperative sepsis patients but controlling for other complications in the model assists in mitigating this limitation. FTR analysis across all literature without in-depth review is limited by determining whether deaths are truly preventable.

Hospital postoperative sepsis performance measurement requires detailed metrics. To provide precise targets for quality improvement and collaborative discussion we believe postoperative sepsis quality metrics should be expanded to include complication management metrics. State-wide risk-adjusted rankings for postoperative sepsis and postoperative sepsis failure to rescue provide key insights into how your hospital is performing and where improvements can be made relative to collaborators. Expanding postoperative sepsis quality metric reporting can assist in developing a framework to improve postoperative sepsis performance in Georgia.

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Tables/Figures:

Table I GQIP Hospitals Ranked by Risk-Adjusted 30-day Postoperative Sepsis Rates with Corresponding Crude Sepsis Rates, Infectious Complications, Mortality Rates for Sepsis, and Sepsis Failure to Prevent/Rescue for each Hospital, 2015-2020

Hospitals	Observed Sepsis (Risk)	Risk Adjusted Sepsis Ratio (CI)	Infectious Comp (Risk)	Sepsis, Failure to Prevent	Sepsis Mortality	Sepsis, Failure to Rescue	Risk Adjusted Rescue Ratio (CI)
GQIP Total	595 (2.93)	1.00 (0.80, 1.25)	1,635 (8.05)	36.4%	58	9.7%	0.88 (0.53, 1.60)
Hospitals Ranked							
Hosp 1 (N=2,338)	19 (0.81)	0.46 (0.36, 0.59)	81 (3.46)	23.5%	5	26.3%	1.32 (0.85, 2.37)
Hosp 2 (N=1,516)	23 (1.52)	0.60 (0.47, 0.76)	119 (7.85)	19.3%	6	26.0%	1.83 (1.18, 3.09)
Hosp 3 (N=3,611)	31 (0.86)	0.63 (0.48, 0.83)	128 (3.54)	24.2%	1	3.2%	0.29 (0.18, 0.51)
Hosp 4 (N=1,230)	34 (2.69)	0.65 (0.53, 0.80)	112 (9.11)	30.4%	5	14.7%	0.66 (0.43, 1.19)
Hosp 5 (N=1,395)	51 (3.66)	0.89 (0.69, 1.15)	217 (15.6)	23.5%	3	5.9%	0.58 (0.31, 1.18)
Hosp 6 (N=2,809)	73 (2.60)	1.02 (0.80, 1.30)	214 (7.62)	34.1%	8	11.0%	1.05 (0.62, 1.91)
Hosp 7 (N=5,867)	300 (5.11)	1.20 (0.98, 1.47)	620 (10.6)	48.4%	24	8.0%	0.85 (0.51, 1.57)
Hosp 8 (N=267)	13 (4.87)	1.59 (1.24, 2.03)	36 (13.5)	36.1%	0	0%	--
Hosp 9 (N=451)	16 (3.55)	1.83 (1.39, 2.40)	41 (9.09)	39.0%	2	12.5%	0.92 (0.65, 1.37)
Hosp 10 (N=796)	35 (4.40)	1.91 (1.47, 2.48)	67 (8.42)	52.2%	4	11.4%	0.90 (0.50, 1.87)

Infectious Complication (Inf. Comp) Rate Includes Aggregated (Postoperative: Superficial SSI, Deep SSI, Organ Space SSI, Pneumonia, UTI, & C. Diff); Sepsis, Failure to Prevent = Postoperative Sepsis following a Postoperative Infectious Complication; Sepsis, Failure to Rescue = 30-Day Mortality following Postoperative Sepsis

Figure I Quality Metrics Compared by Hospital Risk-Adjusted Postoperative Sepsis Rankings (X-Axis)

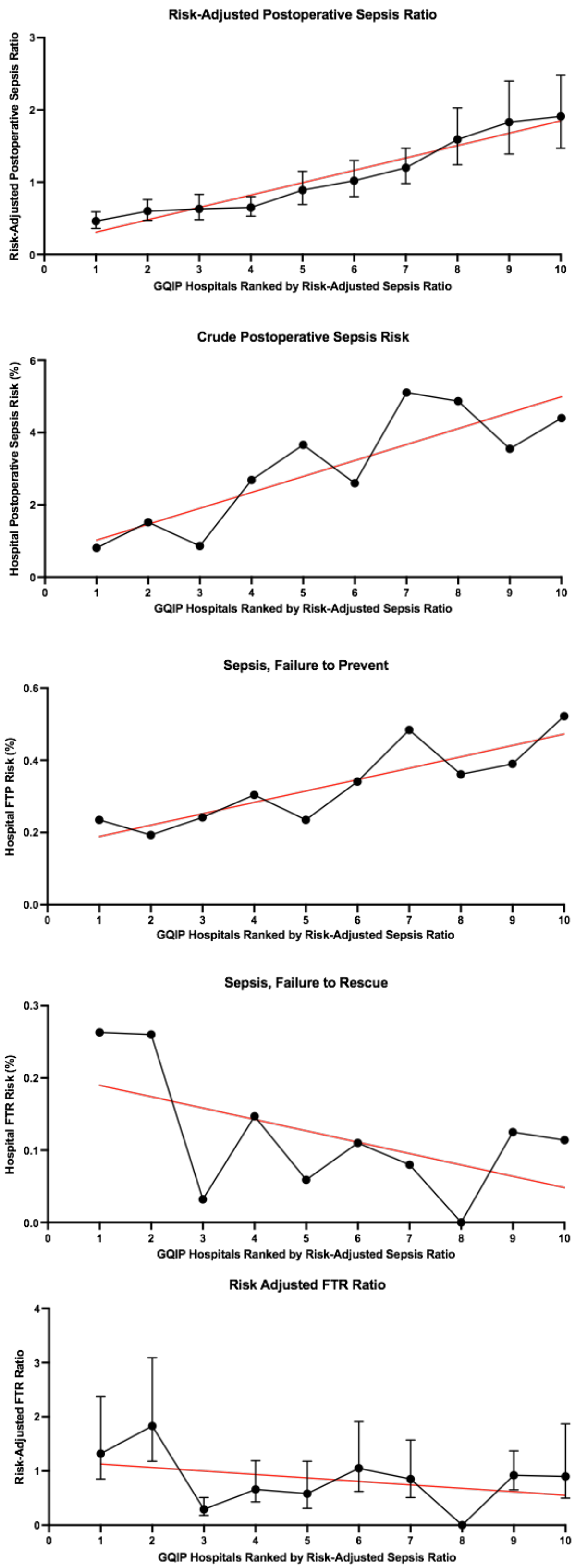


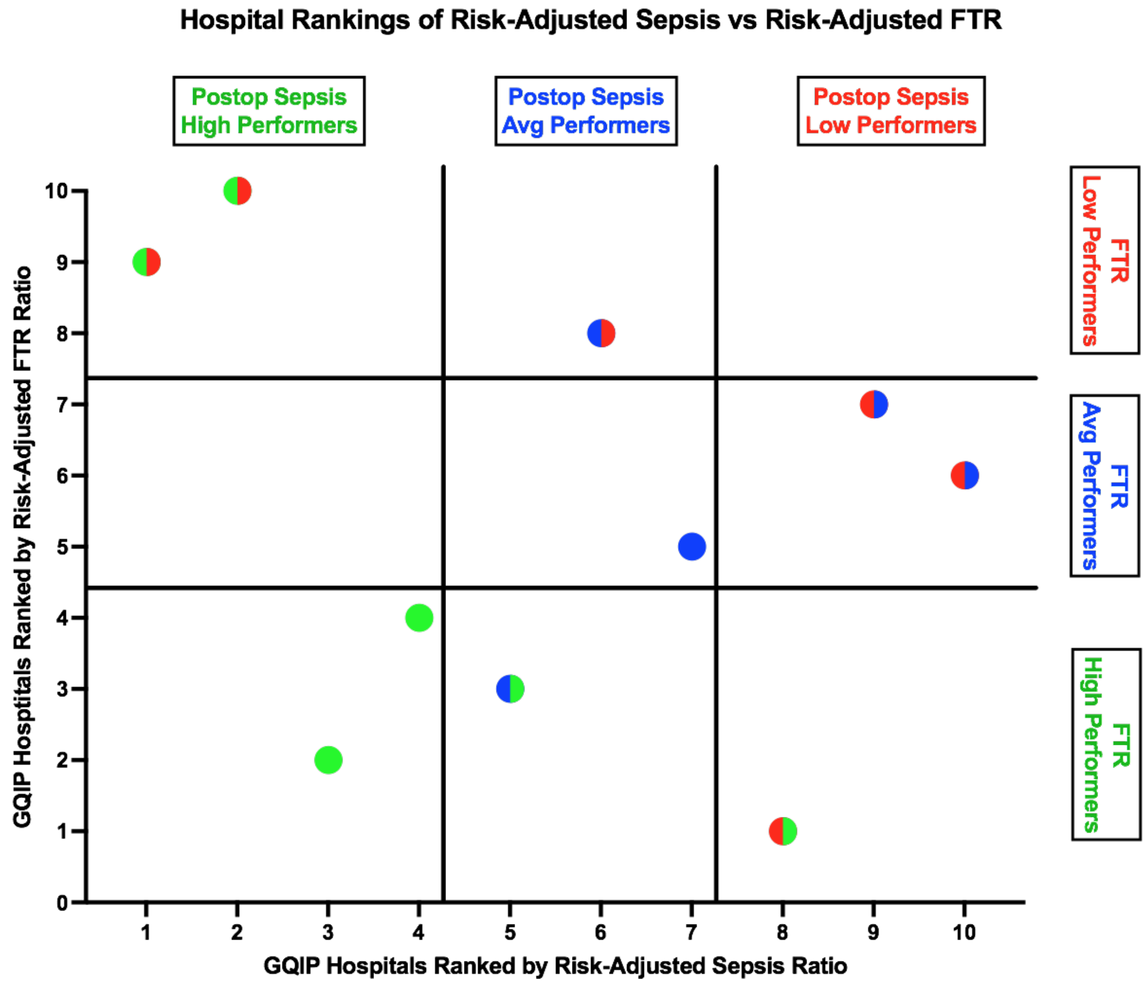
Table II Postoperative Sepsis Patients Demographics, Comorbidities and Pre/Post Op Variables Compared by Mortality with Multivariable Failure to Rescue Prediction Model

	Total	30-day Mortality		Bivariate OR	Multivariable OR
Demographics	N=563	No N=505	Yes N=58	(95% CI)	(95% CI)
Age	62.7 [52.4-71.0]	61.3 [50.8-70.1]	70.5[66.4-80.4]	1.08 (1.05, 1.10)	1.10 (1.06, 1.14)
< 65	316 (56.1)	303 (60.0)	13 (22.4)	--	--
≥ 65	247 (43.9)	202 (40.0)	45 (77.6)	--	--
Sex					
Female	295 (52.4)	266 (52.7)	29 (50.0)	REF	--
Male	268 (47.6)	239 (47.3)	29 (50.0)	1.11 (0.65, 1.92)	--
Race					
White	336 (60.9)	299 (60.5)	37 (63.8)	REF	--
Black	191 (34.6)	172 (34.8)	19 (32.8)	0.89 (0.50, 1.60)	--
Other/Unknown	25 (4.5)	23 (4.7)	2 (3.4)	0.70 (0.16, 3.10)	--
Comorbidities					
Diabetes					
Yes	114 (20.3)	101 (20.0)	13 (22.4)	1.16 (0.60, 2.22)	--
Smoker					
Yes	116 (20.6)	103 (20.4)	13 (22.4)	1.13 (0.59, 2.17)	--
COPD					
Yes	38 (6.8)	30 (5.9)	8 (13.8)	2.53 (1.10, 5.83)	--
Hypertension					
Yes	320 (56.8)	278 (55.1)	42 (72.4)	2.14 (1.17, 3.91)	--
Dialysis					
Yes	18 (3.2)	14 (2.8)	4 (6.9)	2.60 (0.83, 8.18)	--
Dissem. Cancer					
Yes	38 (6.8)	26 (5.2)	12 (20.7)	4.81 (2.28, 10.1)	12.3 (4.42, 34.4)
Perioperative					
Case Comp *Mean±SD*	2.91 ± 0.86	2.89 ± 0.88	3.09 ± 0.78	1.33 (0.94, 1.86)	--
Preop SSI					
Yes	34 (6.0)	29 (5.7)	5 (8.6)	1.55 (0.57, 4.17)	--
Preop Pneumonia					
Yes	17 (3.0)	13 (2.6)	4 (6.9)	2.80 (0.88, 8.90)	--
Preop Sepsis					
Yes	112 (19.9)	88 (17.4)	24 (41.4)	3.35 (1.89, 5.92)	2.93 (1.45, 5.88)
Patient Status					
Outpatient	31 (5.5)	30 (5.9)	1 (1.7)	REF	--
Inpatient	532 (94.5)	475 (94.1)	57 (98.3)	3.60 (0.48, 26.9)	--
Emergency Case					
Yes	119 (21.1)	98 (19.4)	21 (36.2)	2.36 (1.32, 4.21)	--
Surgery Type					
Colorectal	234 (41.6)	215 (42.6)	19 (32.8)	REF	--
Midgut	95 (16.9)	81 (16.0)	14 (24.1)	1.96 (0.94, 4.08)	--
Cholecystectomy	34 (6.0)	31 (6.1)	3 (5.2)	1.09 (0.31, 3.92)	--
Hepatobiliary	110 (19.5)	98 (19.4)	12 (20.7)	1.39 (0.65, 2.97)	--
Foregut	42 (7.5)	34 (6.7)	8 (13.8)	2.66 (1.08, 6.56)	--
Hernia	48 (8.5)	46 (9.1)	2 (3.5)	0.49 (0.11, 2.19)	--

ASA Class					
Class 1 & 2	114 (20.3)	109 (21.6)	5 (8.6)	REF	--
Class 3	342 (60.8)	311 (61.6)	31 (53.5)	2.17 (0.82, 5.73)	--
Class 4 & 5	107 (19.0)	85 (16.8)	22 (37.9)	5.64 (2.05, 15.5)	--
Wound Class					
Clean Contaminated	335 (59.5)	302 (59.8)	33 (56.9)	REF	--
Contaminated	76 (13.5)	69 (13.7)	7 (12.1)	0.93 (0.39, 2.19)	--
Dirty	152 (27.0)	134 (26.5)	18 (31.0)	1.23 (0.67, 2.26)	--
Postoperative					
Superficial SSI					
Yes	52 (9.2)	51 (10.1)	1 (1.7)	0.16 (0.02, 1.15)	--
Deep SSI					
Yes	27 (4.8)	26 (5.2)	1 (1.7)	0.32 (0.04, 2.43)	--
Organ Space SSI					
Yes	175 (31.1)	164 (32.5)	11 (19.0)	0.49 (0.25, 0.96)	--
Pneumonia					
Yes	91 (16.2)	74 (14.6)	17 (29.3)	2.42 (1.30, 4.48)	--
UTI					
Yes	37 (6.6)	35 (6.9)	2 (3.4)	0.48 (0.11, 2.05)	--
C Diff					
Yes	18 (3.2)	17 (3.4)	1 (1.7)	0.50 (0.07, 3.86)	--
Pulm Embolism					
Yes	12 (2.1)	11 (2.2)	1 (1.7)	0.79 (0.10, 6.22)	--
DVT					
Yes	34 (6.0)	31 (6.1)	3 (5.2)	0.83 (0.23, 2.82)	--
Renal Failure					
Yes	29 (5.2)	17 (3.4)	12 (20.7)	7.49 (3.37, 16.6)	2.78 (0.98, 7.82)
Reintubation					
Yes	89 (15.8)	63 (12.5)	26 (44.8)	5.70 (3.19, 10.2)	5.36 (2.54, 11.3)
Readmission					
Yes	200 (35.5)	194 (38.4)	6 (10.3)	0.18 (0.08, 0.44)	0.14 (0.05, 0.41)
Reoperation					
Yes	157 (27.9)	135 (26.7)	22 (37.9)	1.67 (0.95, 2.95)	2.45 (1.19, 5.04)
Vent 48 hrs					
Yes	107 (19.0)	80 (15.8)	27 (46.6)	4.63 (2.62, 8.17)	--

All dichotomous outcomes without a reference group shown are modeling the odds of postoperative sepsis when the exposure is present vs when the exposure is not present. Abbreviations: OR (Odds Ratio), CI (Confidence Interval), Med (Median) IQR (Interquartile Range), REF (Referent Group), BMI (Body Mass Index), SD (standard Deviation), COPD (Chronic Obstructive Pulmonary Disease), Dissem. (Disseminated), SSI (Surgical Site Infection), UTI (Urinary Tract Infection), ASA (American Society of Anesthesiologist)

Figure II


Hospital Rankings of Risk-Adjusted Sepsis vs Risk-Adjusted FTR
Postop Sepsis High Performers
Postop Sepsis Avg Performers
Postop Sepsis Low Performers
FTR Low Performers
FTR Avg Performers
FTR High Performers
GQIP Hosptitals Ranked by Risk-Adjusted FTR Ratio
GQIP Hospitals Ranked by Risk-Adjusted Sepsis Ratio
0
1
2
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