Interhospital variability in failure to rescue rates following aortic valve surgery

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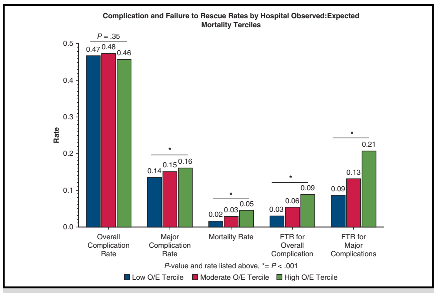
ABSTRACT

Objective: This study evaluated interhospital variability and determinants of failure-to-rescue for patients undergoing surgical aortic valve replacement.

Methods: An observational study was conducted among 28,842 patients undergoing aortic valve replacement with or without coronary artery bypass grafting between July 2011 and June 2017 across 90 hospitals participating in the Society of Thoracic Surgeons Adult Cardiac Surgery Database. Postoperative complications were defined as major (stroke, renal failure, reoperation, prolonged ventilation, sternal infection) and overall (major plus 14 other morbidities). Hospital terciles of observed to expected (O/E) mortality were compared on crude rates of major and overall complications, operative mortality, and failure to rescue (among major and overall complications). The correlation between hospital observed and expected failure-to-rescue rates was assessed.

Results: Median Society of Thoracic Surgeons Adult Cardiac Surgery Database predicted mortality risk was similar across hospital O:E mortality terciles ($P = .10$). As expected, mortality rates significantly increased across terciles (low O/E tercile: 1.6%, high O/E tercile: 4.7%; $P < .001$). Failure-to-rescue rates increased substantially across hospital mortality terciles among patients with major (low tercile, 8.8% and high tercile, 20.8%) and overall (low tercile, 3.0% and high tercile, 8.9%) complications. Hospital-level expected failure to rescue had a higher correlation with observed complications for overall complications ($R^2 = 0.71$) compared with Society of Thoracic Surgeons major complications ($R^2 = 0.24$).

Conclusions: Considerable interhospital variation exists in failure-to-rescue rates following aortic valve replacement. Hospitals in the low O/E mortality tercile experience failure to rescue nearly one-third less than those in the high O/E mortality tercile. Efforts to advance quality will benefit from identifying and disseminating optimal rescue strategies in this patient population. (JTCVS Open 2023;16:123-38)



Complication and failure to rescue by observed to expected hospital mortality tercile.

CENTRAL MESSAGE

Failure-to-rescue rates varied considerably in AVR operations among hospital observed to expected mortality terciles. Hospital failure-to-rescue rates varied by complication type.

PERSPECTIVE

This analysis of 28,842 AVR operations documents significant interhospital variation in observed to expected mortality, especially among patients developing major postoperative complications. Quality improvement efforts will benefit from identifying and disseminating optimal rescue strategies in this patient population.

Efforts to reduce operative mortality following cardiac surgery have contributed to increased focus on the management and treatment of postoperative complications. There is increased recognition that poor management (eg, delayed recognition) of early complications and intensive care unit staffing (eg, low nurse to patient ratios) may contribute to complication-specific mortality, with higher-performing hospitals having more timely diagnosis and treatment of postoperative complications.[1] Early recognition of complications, or discovering a complication before clinical deterioration, is believed to lower the chance of additional complications or resultant death.[2] With that in mind, the

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Abbreviations and Acronyms

ACSD = Adult Cardiac Surgery Database
AVR = aortic valve replacement
CABG = coronary artery bypass grafting
FTR = failure to rescue
O/E = observed to expected
STS = Society of Thoracic Surgeons

cardiac surgical community has increasingly focused on failure to rescue (FTR), which is defined as in-hospital death after a complication.[3] The Society of Thoracic Surgeons (STS) recently published a risk-adjusted FTR metric to support the evaluation and improvement of postoperative care and outcomes.[4]

Many of the initial studies evaluating the role of FTR have leveraged Medicare claims data across a heterogeneous cohort of general surgical, vascular, and cardiac operations. Ghaferi and colleagues[5] evaluated a 2-year cohort of Medicare beneficiaries undergoing 6 operations (including coronary artery bypass grafting [CABG] and aortic valve replacement [AVR]), and found that hospitals with better (relative to worse) risk-adjusted mortality rates had nearly 3-fold lower FTR rates, but similar complication rates. Further, hospitals performing a lower volume of aortic aneurysm repair and cardiac surgical procedures have higher associated rates of FTR compared with high-volume hospitals.[6] The ability of these studies to provide actionable targets for hospitals to improve their FTR is limited by the narrow scope of clinically relevant demographic characteristics, risk factors, disease-specific data, and outcome data contained within Medicare claims datasets. Contemporary work has been targeted at single procedural cohorts in clinical databases that provide more comprehensive baseline characteristics and a larger spectrum of relevant postoperative complications with the goal of advancing surgical quality in a targeted population.[3,7,8] Such studies have been undertaken in the isolated CABG population; however, few have been undertaken in AVR surgery—a population with considerable interhospital variability in mortality.[3,9,10]

This large observational cohort study, leveraging institutional STS Adult Cardiac Surgery Database (ACSD) data representing 6 cardiac surgical collaboratives, evaluated interhospital variation in FTR following AVR with or without CABG surgery. Specifically, complication and FTR rates were compared across terciles of increasing hospital observed to expected (O/E) mortality.

MATERIALS AND METHODS

Study Design

This study included isolated valve and valve with CABG operations (July 2011 to June 2017) from 90 hospitals participating in any of 6 quality collaboratives comprising the IMPROVE Network.

Ethics

The University of Michigan Institutional Review Board (HUM00127073) provided a notice of 'Not Regulated' determination on March 8, 2017.

Outcomes

Operative mortality as defined by the STS-ACSD includes deaths within the hospitalization or after discharge but within 30 days of the surgical procedure. FTR was defined as an operative mortality among patients who developed a postoperative complication. Two composite complication outcomes were defined: overall complications, including: STS major complications, sepsis, surgical site infection, coma, pneumonia, pulmonary embolism, renal dialysis, dysrhythmia requiring a permanent pacemaker, cardiac arrest, anticoagulation event, tamponade, gastrointestinal event, multiorgan system failure, atrial fibrillation, and aortic dissection and a narrower STS major complication limited to: stroke, surgical re-exploration, deep sternal wound infection, renal failure, and prolonged intubation.

Statistical Analyses

Hospital-level observed mortality was calculated by summing each hospital's observed mortality, whereas hospital-level expected mortality was calculated by summing each hospital's mortality probability, estimated from logistic regression using STS published preoperative mortality risk model variables. Hospitals were divided into performance terciles based on their O/E mortality.

Patient characteristics, risk factors, and complication conditions were stratified by hospital O/E mortality terciles, which were used for descriptive statistics. The STS approach for addressing missing values was applied.[11] Continuous variables were summarized as median (interquartile range) and compared using Wilcoxon rank-sum tests. Categorical variables were summarized as n (%) and compared using χ^2 tests. Cochran-Armitage trend tests were used to test the trends of mortality, complication, and FTR rates across hospital O/E mortality terciles. R^2 was used to associate hospital-level mortality to hospital-level complication rates and FTR rates.

Generalized linear mixed-effects models were used to develop FTR models (for major and overall complications). Expected FTR rates were calculated by summing the patient's probability of FTR within hospitals (accounting for significant preoperative mortality predictors and complication types), assuming an average hospital effect from the FTR models. The R^2 statistic was used to associate observed hospital FTR rates to expected FTR rates. The *C* statistic was used to evaluate the addition of cardiopulmonary bypass and crossclamp duration on improving model performance. Analyses were performed using SAS version 9.4 (SAS Institute Inc) and R version 3.5.2 (R Foundation for Statistical Computing).

RESULTS

Patient Population

A total of 28,842 patients underwent isolated AVR (17,713 out of 28,842 [61.5%]) or AVR with CABG (11,129 out of 28,842 [38.6%]) operations over the study period. Procedural-specific hospital O/E mortality terciles were calculated using published and validated predictors of mortality (Table E1). In this cohort, 66.5% of patients had no complications, whereas 89.4% of patients had no STS-defined major complications. The FTR rate was 5.2% for overall complications and 13.3% for STS major complications. The FTR rate increased steadily with the total number of complications per patient (Table E2).

TABLE 1. Characteristics of cohort, according to center tercile of observed to expected mortality

Characteristic	Overall n = 28,842	Mortality Tercile 1 O/E n = 12,061	Mortality tercile 2 O/E n = 10,375	Mortality tercile 3 O/E n = 6406	*P* value
Demographic characteristic					
Age (y)	71.00 (63.00-78.000)	71.00 (63.00-78.00)	71.00 (63.00-78.00)	71.00 (63.00-78.00)	<.001
Female sex	9850 (34.2)	4022 (33.3)	3584 (34.5)	2244 (35.0)	<.001
White race	26,379 (91.5)	11,286 (93.6)	9371 (90.3)	5722 (89.3)	<.001
Cardiac history					
Hypertension	23,888 (82.8)	10,049 (83.3)	8545 (82.4)	5294 (82.6)	.2
PVD	3369 (11.7)	1415 (11.7)	1285 (12.4)	669 (10.4)	0
Prior CV intervention	2975 (10.3)	1336 (11.1)	1030 (9.9)	609 (9.5)	<.001
Risk factor					
Current cigarette smoker	3194 (11.1)	1152 (9.6)	1255 (12.1)	787 (12.3)	<.001
Diabetes control					.4
Insulin control	3015 (10.5)	1290 (10.7)	1057 (10.2)	668 (10.4)	
Diabetes with other control	7111 (24.7)	2915 (24.2)	2588 (24.9)	1608 (25.1)	
No diabetes	18,716 (64.9)	7856 (65.1)	6730 (64.9)	4130 (64.5)	
Dyslipidemia	22,619 (78.4)	9618 (79.7)	8083 (77.9)	4918 (76.8)	<.001
Dialysis	617 (2.1)	208 (1.7)	262 (2.5)	147 (2.3)	<.001
Chronic lung disease					<.001
No	21,909 (76.0)	9285 (77.0)	7662 (73.9)	4962 (77.5)	
Mild	4522 (15.7)	1810 (15.0)	1799 (17.3)	913 (14.3)	
Moderate	1398 (4.8)	568 (4.7)	498 (4.8)	332 (5.2)	
Severe	1013 (3.5)	398 (3.3)	416 (4.0)	199 (3.1)	
Home oxygen use	739 (2.6)	374 (3.1)	196 (1.9)	169 (2.6)	<.001
Liver disease	1035 (3.6)	403 (3.3)	452 (4.4)	180 (2.8)	<.001
IABP and inotrope use	451 (1.6)	160 (1.3)	180 (1.7)	111 (1.7)	0
Immunosuppression	1152 (4.0)	481 (4.0)	444 (4.3)	227 (3.5)	.1
Cardiogenic shock on admission	208 (0.7)	85 (0.7)	65 (0.6)	58 (0.9)	.1
Admission acuity					<.001
Elective	22,579 (78.3)	9581 (79.4)	8107 (78.1)	4891 (76.4)	
Urgent	6107 (21.2)	2408 (20.0)	2219 (21.4)	1480 (23.1)	
Emergency	149 (0.5)	71 (0.6)	45 (0.4)	33 (0.5)	
Emergency/salvage	7 (0.0)	1 (0.0)	4 (0.0)	2 (0.0)	
STS predicted risk of mortality (%)	1.823 (1.09-3.22)	1.80 (1.08-3.17)	1.86 (1.09-3.27)	1.82 (1.11-3.21)	.1
STS Predicted risk of morbidity and mortality (%)	17.25 (12.27-24.68)	17.29 (12.31-24.39)	17.23 (12.24-24.87)	17.20 (12.29-25.07)	1
Complication rate					
Stroke	495 (1.7)	200 (1.7)	183 (1.8)	112 (1.7)	.8
Sepsis	324 (1.1)	116 (1.0)	120 (1.2)	88 (1.4)	<.001
Surgical site infection	260 (0.9)	109 (0.9)	95 (0.9)	56 (0.9)	1
Deep sternal wound infection	65 (0.2)	27 (0.2)	25 (0.2)	13 (0.2)	.9
Overall reoperation	1523 (5.3)	606 (5.0)	571 (5.5)	346 (5.4)	.2
Coma	954 (3.3)	310 (2.6)	423 (4.1)	221 (3.4)	<.001
Prolonged ventilation	2953 (10.2)	1088 (9.0)	1147 (11.1)	718 (11.2)	<.001
Pneumonia	739 (2.6)	281 (2.3)	239 (2.3)	219 (3.4)	<.001
Pulmonary embolism	25 (0.1)	6 (0.0)	12 (0.1)	7 (0.1)	.2
Renal failure	802 (2.8)	291 (2.4)	260 (2.5)	251 (3.9)	<.001
Renal dialysis	511 (1.8)	182 (1.5)	172 (1.7)	157 (2.5)	<.001
Dysrhythmia requiring PPM	1402 (4.9)	578 (4.8)	525 (5.1)	299 (4.7)	.5
Cardiac arrest	659 (2.3)	200 (1.7)	254 (2.4)	205 (3.2)	<.001
Anticoagulation event	291 (1.0)	101 (0.8)	118 (1.1)	72 (1.1)	<.001
Tamponade	24 (0.1)	10 (0.1)	11 (0.1)	3 (0.0)	.4
GI event	822 (2.9)	367 (3.0)	277 (2.7)	178 (2.8)	.2
Multiorgan system failure	248 (0.9)	74 (0.6)	87 (0.8)	87 (1.4)	<.001

(Continued)

TABLE 1. Continued

Characteristic	Overall n = 28,842	Mortality Tercile 1 O/E n = 12,061	Mortality tercile 2 O/E n = 10,375	Mortality tercile 3 O/E n = 6406	*P* value
A fib	9786 (33.9)	4272 (35.4)	3501 (33.7)	2013 (31.4)	<.001
Aortic dissection	17 (0.1)	10 (0.1)	3 (0.0)	4 (0.1)	.2
Major complication	4248 (14.7)	1634 (13.5)	1587 (15.3)	1027 (16.0)	<.001
Any complication	13,540 (46.9)	5662 (46.9)	4932 (47.5)	2946 (46.0)	.1
Operative mortality	800 (2.8)	193 (1.6)	309 (3.0)	298 (4.7)	<.001

Values are presented as median (interquartile range) or n (%). *O/E*, Observed to expected ratio; *PVD*, peripheral vascular disease; *CV*, cardiovascular; *IABP*, intra-aortic balloon pump; *STS*, Society of Thoracic Surgeons; *PPM*, permanent pacemaker; *GI*, gastrointestinal event; *A fib*, atrial fibrillation.

Univariate Analysis of Baseline Demographics, Complication Rates, and FTR

The predicted STS major morbidity and mortality was similar between O/E mortality terciles (tercile 1 [17.29%] vs tercile 3 [17.20%]; $P > .999$), (Table 1). Patients at high (vs low) O/E mortality tercile hospitals more likely underwent urgent operations ($P < .001$). Baseline characteristics were qualitatively similar across hospital O/E terciles (Table 1).

The observed rate of mortality varied significantly between O/E mortality terciles (tercile 1 [1.6%] vs tercile 3 [4.6%]; $P < .001$). The observed frequency of overall complications did not differ significantly between O/E mortality terciles (low O/E mortality tercile [46.9%] vs high O/E mortality tercile [46.0%]; $P = .36$, P value for trend = .35) although the rate of STS major complications was different between O/E mortality terciles (low O/E mortality tercile [13.5%] vs high O/E mortality tercile [16.0%];

TABLE 2. Unadjusted failure-to-rescue (FTR) rate between groups

Complication type	Deaths/ occurrences; Overall FTR rate	Deaths/occurrences; Hospital O/E mortality tercile 1 (# of complication deaths, % FTR)	Deaths/occurrences; Hospital O/E mortality tercile 2 (# of complication deaths, % FTR)	Deaths/occurrences; Hospital O/E mortality tercile 3 (# of complication deaths, % FTR)	Cochran-Armitage trend test
STS major complication	13.4	143 (8.8)	210 (13.2)	214 (20.8)	<.0001
Stroke	16.4	20 (10.0)	31 (16.9)	30 (26.8)	.0001
Overall reoperation	15.4	69 (11.4)	86 (15.0)	79 (22.8)	<.0001
Prolonged ventilation	16.9	121 (11.1)	196 (17.1)	183 (25.5)	<.0001
Renal failure	33.8	69 (23.7)	91 (35.0)	111 (44.2)	<.0001
Deep sternal wound infection	10.8	2 (7.4)	2 (8.0)	3 (23.1)	.1835
Sepsis	38.3	31 (26.7)	48 (40.0)	45 (51.1)	.0003
Surgical site infection	4.6	4 (3.7)	4 (4.2)	4 (7.1)	.3478
Coma	14.9	29 (9.4)	64 (15.1)	49 (22.2)	<.0001
Pneumonia	17.2	34 (12.1)	49 (20.5)	44 (20.1)	.0138
Pulmonary embolism	12.0	0 (0.0)	1 (8.3)	2 (28.6)	.108
Renal dialysis	40.9	56 (30.8)	72 (41.9)	81 (51.6)	<.0001
Dysrhythmia requiring PPM	1.9	5 (0.9)	12 (2.3)	9 (3.0)	.0177
Cardiac arrest	46.9	69 (34.5)	125 (49.2)	115 (56.1)	<.0001
Anticoagulation event	21.3	15 (14.9)	24 (20.3)	23 (31.9)	.0079
Tamponade	25.0	2 (20.0)	3 (27.3)	1 (33.3)	.6008
GI event	16.8	43 (11.7)	58 (20.9)	37 (20.8)	.0021
Multiorgan system failure	78.6	44 (59.5)	73 (83.9)	78 (89.7)	<.0001
A fib	2.7	70 (1.6)	87 (2.5)	107 (5.3)	<.0001
Aortic dissection	23.5	1 (10.0)	2 (66.7)	1 (25.0)	.3343
Any complication	5.2	171 (3.0)	272 (5.5)	263 (8.9)	<.0001

O/E, Observed to expected; *STS*, Society of Thoracic Surgeons; *PPM*, permanent pacemaker; *GI*, gastrointestinal event; *A fib*, atrial fibrillation.

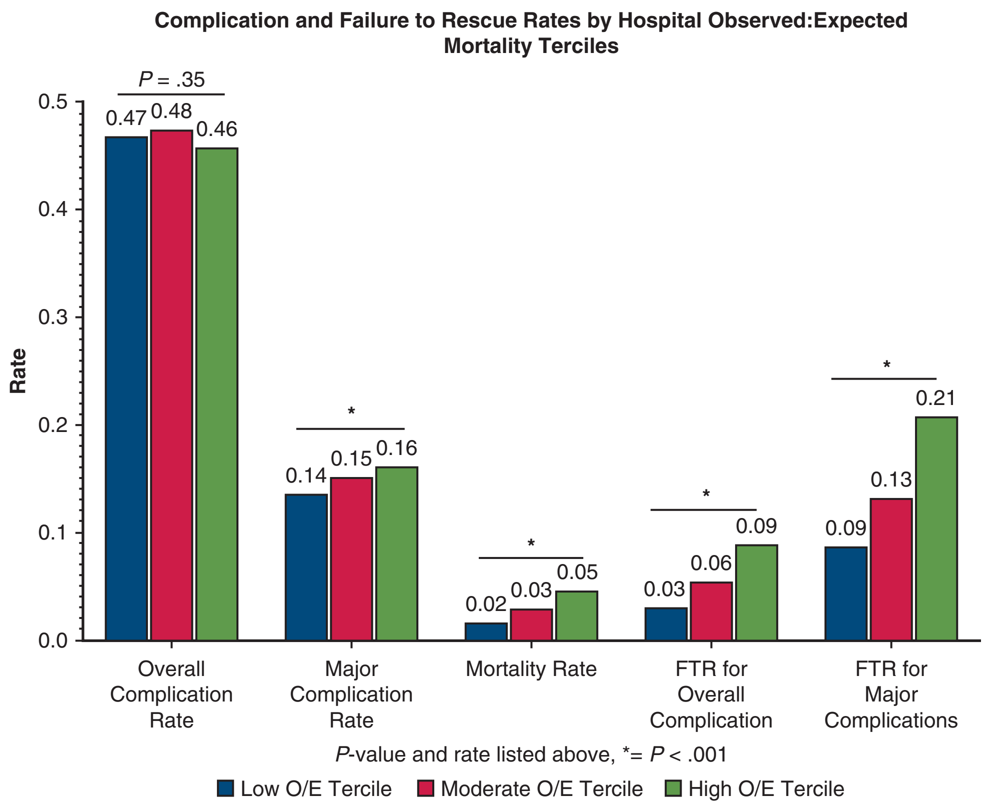

FIGURE 1. Complication and failure-to-rescue (*FTR*) rates by observed to expected (*O/E*) mortality tercile: unadjusted rate and *P* value displayed above each category.

P < .001).The distribution of complication types differed across O/E mortality terciles (Table 2). For instance, rates of prolonged ventilation, coma, and pneumonia were lower in the low O/E mortality tercile relative to high O/E mortality tercile (*P* < .001).

The FTR rate increased across O/E mortality terciles for both overall (low O/E mortality tercile [3.0%] vs high O/E mortality tercile [8.9%]; *P* < .001) and major complications (low O/E mortality tercile [8.8%] vs high O/E mortality tercile [20.4%]; *P* < .001) (Figure 1). Mortality and FTR variation between hospital O/E terciles was robust when evaluating across procedure type, although there were higher rates of overall mortality and FTR among patients undergoing AVR with CABG (Figure E1). The correlation between overall complications and mortality was lower than FTR for overall complications and mortality, respectively ($R^2 = 0.04$ vs $R^2 = 0.69$). The correlation between STS major complications and mortality was lower than FTR for STS major complications and mortality rates ($R^2 = 0.28$ vs $R^2 = 0.31$) (Figure E2). The relationship between rates of specific complications and FTR was calculated (Figure 2). This analysis demonstrated that prolonged ventilation (complication rate, 10.2%; FTR, 16.9%), pneumonia (complication rate, 2.6%; FTR, 17.19%), and renal failure (complication rate, 2.8%; FTR, 33.8%) were at or above the overall median complication and FTR rate. Table E3 evaluates the relationship between complication type and FTR across procedure type. Higher rates of FTR were observed in AVR with CABG compared with isolated AVR.

Hospital-Level Multivariable Modeling

The results from multivariable modeling for hospital level FTR in overall complications are listed in Table E4. Significant multivariable predictors associated with hospital-level FTR included age, gender, preoperative dialysis, severe chronic lung disease, urgent or emergency status, or mitral valve insufficiency (*P* < .05). Complications that were independently associated with hospital-level FTR included stroke, sepsis, surgical site infection, prolonged ventilation, reoperation, renal failure, dysrhythmia requiring permanent pacemaker, renal failure, cardiac arrest, multiorgan system failure, atrial fibrillation, and aortic dissection (*P* < .001). The correlation between hospital-level observed and expected FTR rates was stronger for overall complications ($R^2 = 0.71$) than STS major complications ($R^2 = 0.24$) (Figure 3).

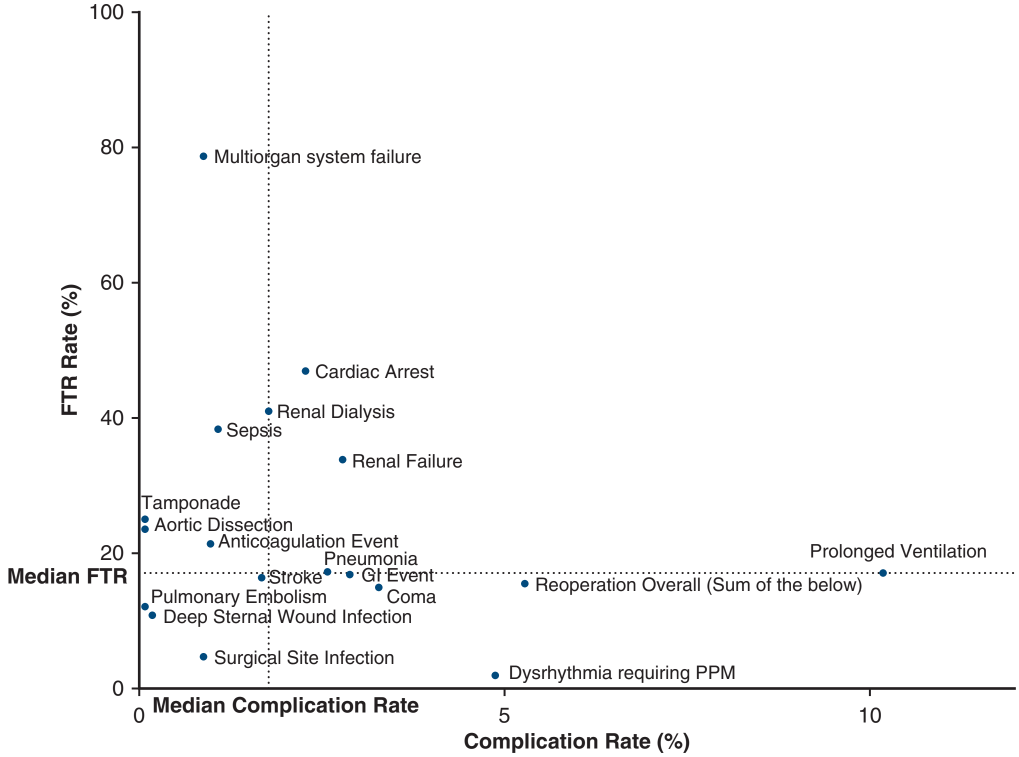

FIGURE 2. Failure-to-rescue (*FTR*) and complication rates stratified by complication. The complication rate and FTR rate is displayed for each complication, *vertical line* is the median complication rate and *horizontal line* is median FTR rate for overall complications. Atrial fibrillation was omitted from the Figure given high event rate and low FTR rate (33.9% and 2.7%, respectively). *GI*, Gastrointestinal event; *PPM*, permanent pacemaker.

DISCUSSION

This large, multicenter study advances the evaluation of important determinants of interhospital mortality in the setting of AVR in several areas. First, FTR rates vary widely across hospital O/E mortality terciles. Second, this study demonstrates that the relationship between complication type and FTR varies considerably. Finally, the correlation between hospital-level O/E FTR rates

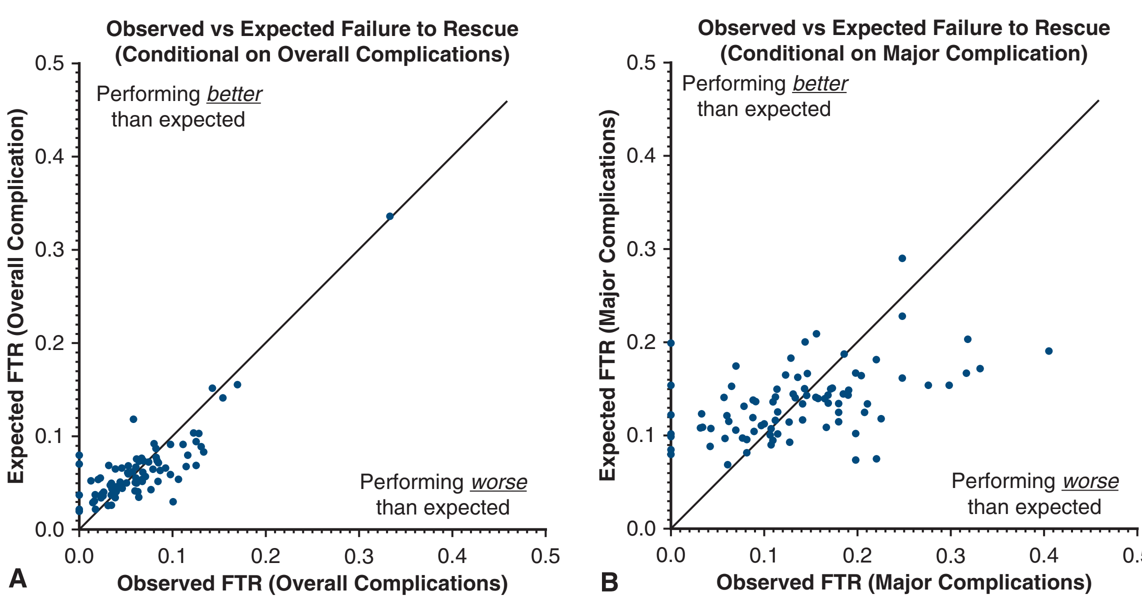

FIGURE 3. Observed versus expected failure to rescue (*FTR*). A, Observed versus expected FTR by overall complications. B, Observed versus expected FTR for major complications.

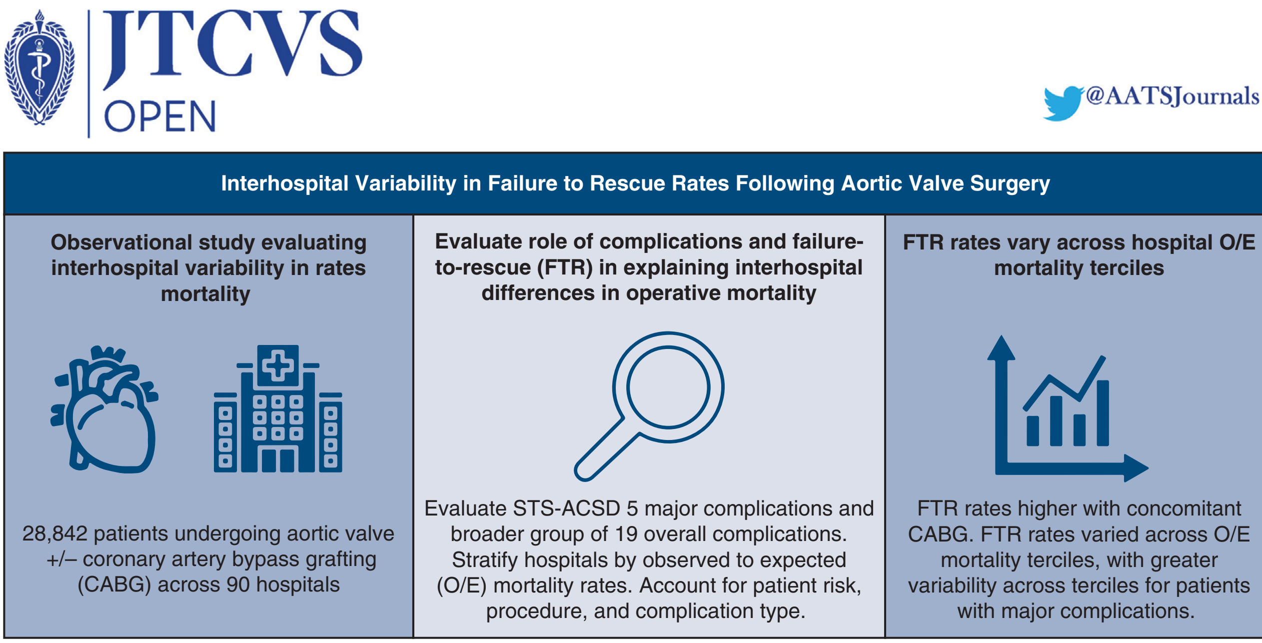

FIGURE 4. Graphical abstract depicting major findings. *CABG*, Coronary artery bypass grafting; *FTR*, failure to rescue; *STS-ACSD*, Society of Thoracic Surgeons Adult Cardiac Surgery Database; *O/E*, observed to expected.

was stronger for overall than STS-defined major complications.

To date, the role of FTR has been evaluated within adult and congenital cardiac surgical populations.[3,5,12,13] A central finding of many of these studies is that complication rates do not account for interhospital differences in adjusted mortality for many procedure types. Instead, FTR is a key determinant of hospital-level variation in mortality.[3] In the present study, there were small absolute differences in rates of STS major complications across O/E mortality terciles. It is clear that the difference in mortality rates between terciles is far greater than what could be attributed to minor differences in complication rates. Findings from this study point to the importance of the postoperative management of patients undergoing AVR as a strategy to address the noted interhospital variability in AVR mortality.[10,14,15]

This study found high interhospital variation in FTR rates, with hospitals in the low O/E mortality terciles experiencing FTR nearly a third as often as hospitals in the high O/E mortality tercile. In the initial report by Silber and colleagues,[16] complication rates were predominantly driven by patient-level factors, whereas FTR was primarily influenced by hospital-level factors. Contemporary reports have identified multiple hospital-level factors that are associated with FTR, such as registered nurse to bedside nurse ratio and intensivists providing care, among others.[1,17,18] Future research should focus on identifying strategies to address early recognition and management of complications during the postoperative period.

Postoperative staffing, including experience within and across team members, may be an important area of future investigation given the elevated FTR rates among rare complication types (eg, multisystem organ failure and cardiac arrest). Identifying the relationship between specific complications and FTR is necessary to support benchmarking quality improvement. The present analysis identifies prolonged ventilation, renal failure, and pneumonia as potential targets for practice sharing among high and low performing institutions. Physician-led quality collaboratives are in a unique position to advance surgical quality, and have effectively leveraged collaborative learning to increase left internal thoracic artery utilization, advance evidence-based opioid prescriptive practices, and develop and adopt evidence-based infection prevention bundles.[19-21] Previous successful strategies include unblinding benchmarking data at collaborative meetings, sharing of best practices across membership hospitals, program site visiting, and reverse-site visiting.[22] This approach, which encourages camaraderie across surgeons, could be applied to evaluating determinants of interhospital variation in FTR across different complication types. The inclusion of the timing of complications within the STS-ACSD, akin to the STS Interagency Registry for Mechanically Assisted Circulatory Support, may support further evaluation and improvement of FTR.

Limitations

Several important limitations should be recognized. First, although not all complications were evaluated, this study focuses on both a narrow set of STS-defined major complications,[23] as well as a broader set tracked by the STS.[24] Second, although the study sample includes hospitals representing nearly 10% of all US-based cardiac surgical programs, the present findings may have limited generalizability to some geographic regions (eg, Southwest and Southeast). Third, while unmeasured confounding exists with any observational cohort study, analyses accounted for both preoperative factors included in the STS-ACSD risk models[25] as well as intraoperative characteristics (eg, cardiopulmonary bypass and cross clamp duration). There may be a lack of informative procedural-specific detail using our approach for defining hospital O/E mortality terciles, which were computed from an AVR with or without CABG cohort. This cohort includes 2 of the 3 most commonly performed cardiac procedures (after CABG). Additional potential sources of confounding include hospital (eg, academic/community and rurality) and unit-level (eg, nurse to patient ratios and intensivist coverage) characteristics that are not tracked through existing surgical registries. Furthermore, variability in FTR may also be driven by the use of interhospital transfers following cardiac surgery, with some patients dying at a secondary institution. Although these data are not currently recorded through national surgical registries, their role within the context of FTR should be the focus of future investigations.

CONCLUSIONS

Considerable variation in FTR rates existed in the setting of AVR with or without CABG across O/E mortality terciles, despite small absolute increases in STS major morbidities rates among higher O/E mortality hospitals. Hospitals in the first O/E mortality tercile experience FTR nearly one-third less than those in the third O/E mortality tercile (Figure 4). Efforts to advance surgical quality will benefit from identifying and disseminating optimal rescue strategies in this patient population.

Conflict of Interest Statement

Dr Likosky receives research funding from the Agency for Healthcare Research and Quality and the National Institutes of Health and serves as a consultant for the American Society of Extracorporeal Technology and receives partial salary support from Blue Cross Blue Shield of Michigan to advance quality in Michigan in conjunction with the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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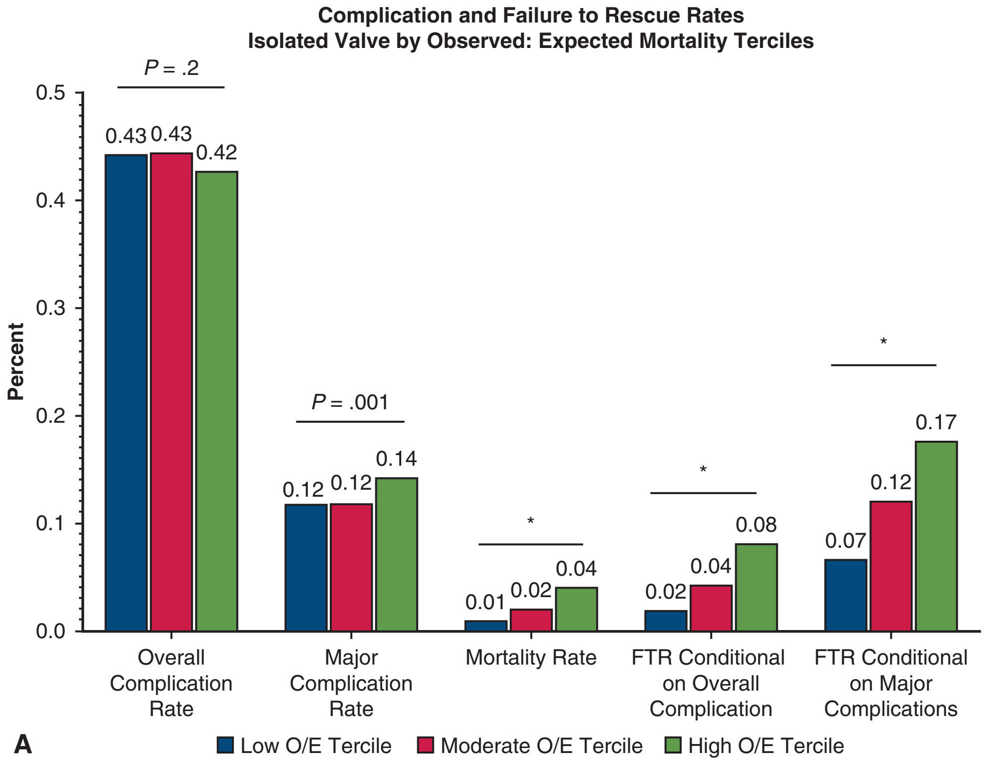
Key Words: failure-to-rescue, SAVR, FTR



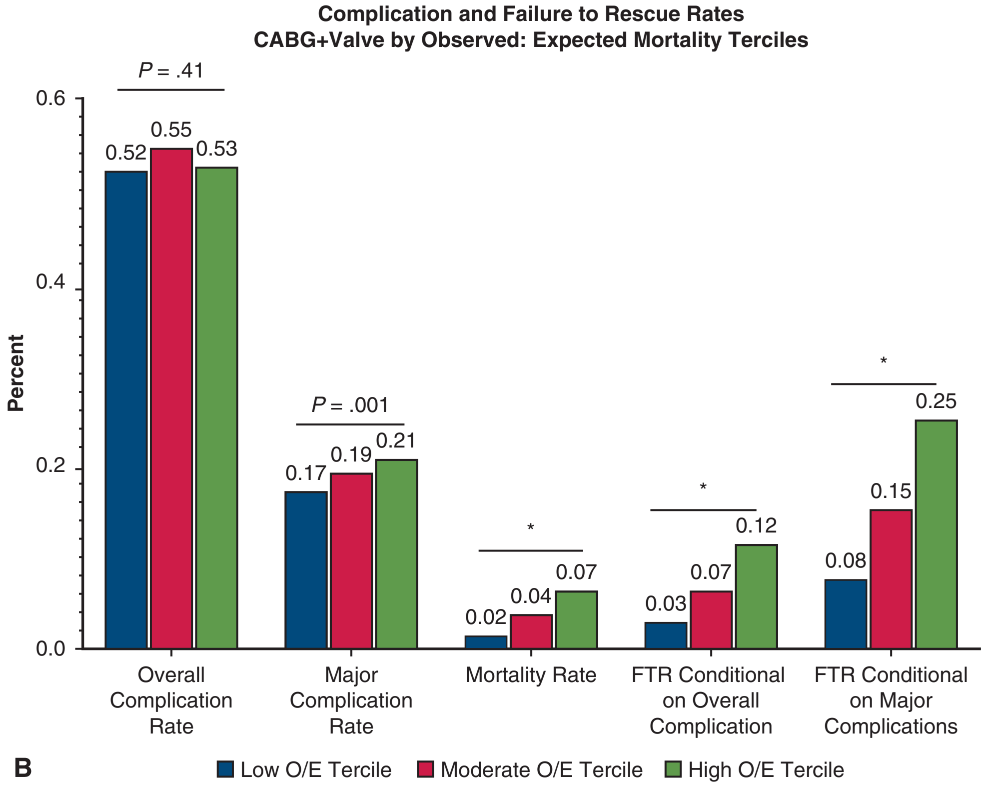


FIGURE E1. Complication and failure-to-rescue rates by observed to expected (*O/E*) mortality tercile for isolated aortic valve replacement (*AVR*) (A) and AVR with coronary artery bypass grafting (*CABG*) (B). Unadjusted rate and *P* value displayed above each category. *Denotes $P < .001$. *FTR*, Failure to rescue.

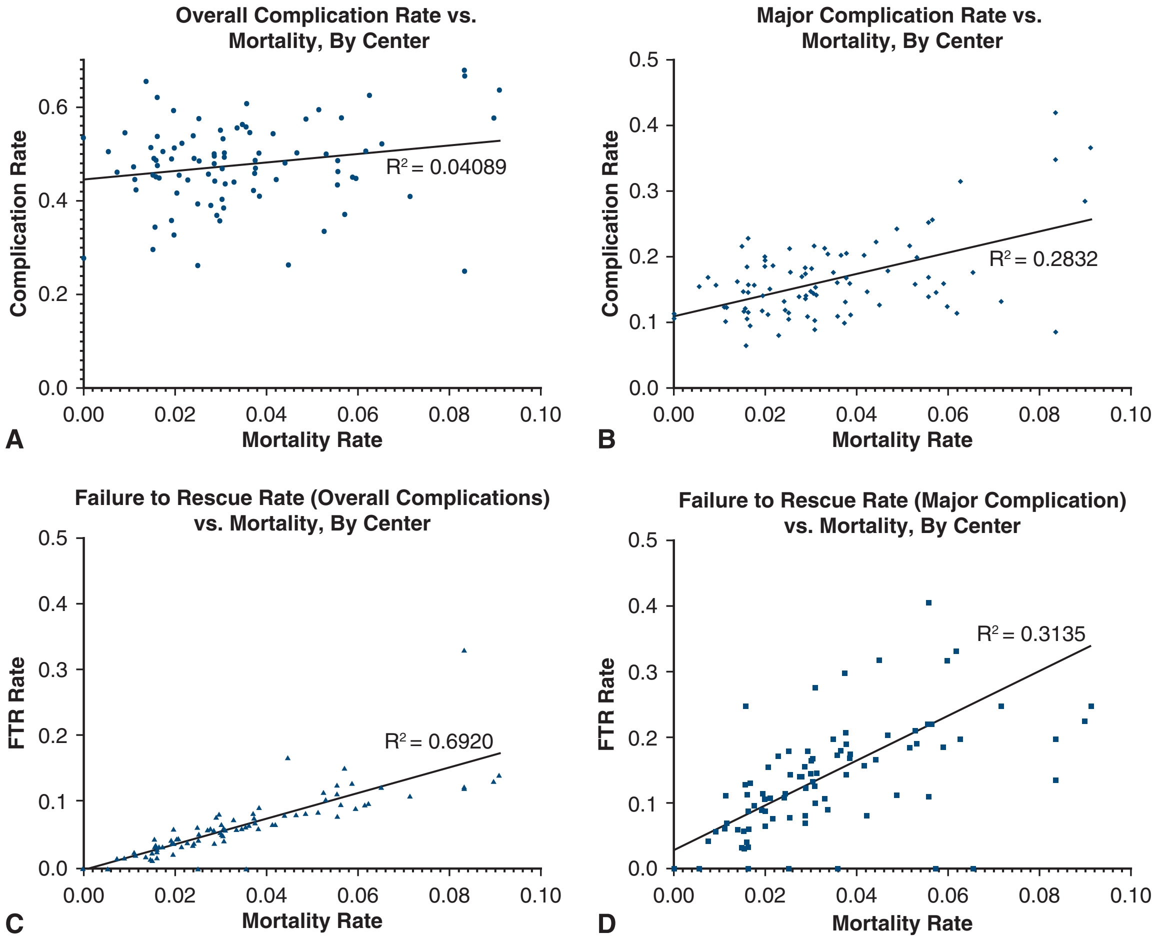


FIGURE E2. Simple linear regression plots of center level unadjusted failure to rescue (*FTR*) and complication rates association with mortality. A, Any complication rate versus mortality. B, Society of Thoracic Surgeons (*STS*) major complication rate. C, FTR conditional on any complication. D, FTR conditional on STS major complications.

TABLE E1. Model for observed to expected hospital terciles

Variable	Estimate	SE z score	Value	P value
Surgery year				
2012	0.14	0.16	0.89	.38
2013	0.16	0.16	0.99	.32
2014	0.21	0.16	1.34	.18
2015	0.21	0.16	1.32	.19
2016	0.09	0.17	0.54	.59
2017	0.15	0.20	0.76	.45
Age	0.02	0.00	5.52	<.01
Age >50 y	0.01	0.00	3.25	<.01
Age >60 y	0.01	0.00	2.12	.03
Ejection fraction quartile				
2	−0.01	0.14	−0.07	.94
3	−0.32	0.13	−2.44	.01
4	−0.11	0.12	−0.89	.37
BSA	−7.04	1.58	−4.44	<.01
BSA_sq	1.74	0.39	4.49	<.01
Creatinine category, mg/dL				
1	0.06	0.13	0.46	.65
2	0.19	0.13	1.42	.16
3	0.47	0.13	3.70	<.01
Dialysis = yes	0.78	0.17	4.71	<.01
Documented arrhythmia	0.36	0.08	4.46	<.01
Cardiogenic shock	0.56	0.27	2.09	.04
Female gender	0.50	0.09	5.42	<.01
On immunosuppression	0.39	0.15	2.67	.01
IABP or inotropes at time of surgery	0.55	0.20	2.79	.01
PVD	0.19	0.103	1.86	.06
Angina	−0.01	0.14	−0.04	.97
Aortic regurgitation	0.17	0.10	1.68	.09
Chronic lung disease				
Mild	0.24	0.10	2.46	.01
Moderate	0.59	0.14	4.32	<.01
Severe	0.79	0.14	5.73	<.01
CVD or CVA yes	−0.05	0.11	−0.45	.65
CVD or CVA recent	0.23	0.12	1.97	.05
Diabetes control				
Insulin	−0.08	0.12	−0.65	.51
Without insulin	−0.12	0.12	−1.06	.29
No. of disease vessels				
1	0.25	0.11	2.30	.02
2	0.44	0.11	4.11	<.01
MI within 24 h	1.40	1.19	1.17	.24
MI within 1 wk	1.17	1.13	1.03	.30
MI within 1 mo	0.97	1.13	0.86	.39
Status				
Urgent	0.38	0.10	3.97	<.01
Emergency	1.18	0.30	3.93	<.01

(Continued)

TABLE E1. Continued

Variable	Estimate	SE *z* score	Value	*P* value
Emergency salvage	2.01	0.95	2.10	.04
First cardiovascular surgery	0.44	0.23	1.91	.06
NYHA functional class				
1	−0.09	0.09	−1.08	.28
2	0.24	0.13	1.85	.06
Previous CABG	−0.27	0.23	−1.15	.25
Previous valve surgery	0.29	0.21	1.40	.16
Treated endocarditis	0.27	0.20	1.35	.18
Left main disease	0.07	0.12	0.59	.56
Mitral stenosis	0.01	0.19	0.08	.94
Mitral valve regurgitation	0.34	0.12	2.92	<.01
Hypertension	0.10	0.12	0.83	.41

BSA, Body surface area; *BSA_sq*, body surface area in square meters; *IABP*, intra-aortic balloon pump; *PVD*, peripheral vascular disease; *CVD*, cerebrovascular disease; *CVA*, cerebrovascular event; *MI*, myocardial infarction; *NYHA*, New York heart Association; *CABG*, coronary artery bypass grafting.

TABLE E2. Failure to rescue rates by number of complications

No. of complications per patient	Total (n)	% of Total	Mortality (n)	Failure to rescue (%)
All patients	28,042	100	800	2.77
Society of Thoracic Surgeons major complications				
0	24,594	87.70	233	0.95
1	2986	10.65	191	6.40
2	964	3.44	239	24.79
3	268	0.96	124	46.27
4	30	0.11	13	43.33
Overall complications				
0	15,302	54.57	94	0.61
1	9395	33.50	140	1.49
2	2275	8.11	103	4.53
3	859	3.06	104	12.11
4	423	1.51	103	24.35
5	229	0.82	87	37.99
6	155	0.55	62	40.00
7	94	0.34	53	56.38
8	64	0.23	32	50.00
9	29	0.10	14	48.28
10	10	0.04	5	50.00

TABLE E3. Unadjusted failure-to-rescue (FTR) rate by procedure type

Complication (for valve + CABG valve procedure)	Overall FTR	Overall deaths/FTR (N, %) Tercile 1	Tercile 2	Tercile 3	Trend test	Isolated AVR deaths/FTR (n, %) Tercile 1	Tercile 2	Tercile 3	Trend test	AVR + CABG deaths/FTR (n, %) Tercile 1	Tercile 2	Tercile 3	Trend test
Stroke (n)	16.36	20 (10.0)	31 (16.9)	30 (26.8)	.0001	7 (8.3)	19 (16.4)	12 (25.5)	.008	9 (9.2)	17 (20.0)	17 (26.2)	.004
Sepsis (n)	38.27	31 (26.7)	48 (40.0)	45 (51.1)	.0003	6 (16.2)	26 (33.8)	15 (37.5)	.045	17 (34.0)	29 (43.9)	31 (57.4)	.016
Surgical site infection (n)	4.62	4 (3.7)	4 (4.2)	4 (7.1)	.3478	1 (2.2)	1 (3.3)	2 (6.3)	.36	0	5 (7.9)	3 (9.1)	.04
Deep sternal wound infection (n)	10.77	2 (7.4)	2 (8.0)	3 (23.1)	.1835	0	0	2 (20.0)	.07	0	3 (21.4)	2 (22.2)	.128
Reoperation (n)	15.36	69 (11.4)	86 (15.1)	79 (22.8)	<.0001	19 (7.9)	61 (16.3)	38 (19.3)	.0006	27 (10.6)	49 (17.7)	40 (22.4)	.0008
Coma (n)	14.88	29 (9.4)	64 (15.1)	49 (22.2)	<.0001	8 (7.8)	31 (13.3)	24 (20.0)	.0086	15 (10.0)	32 (14.9)	32 (23.9)	.0015
Prolonged ventilation (n)	16.93	121 (11.1)	196 (17.1)	183 (25.5)	<.0001	39 (10.3)	101 (15.5)	78 (21.7)	<.0001	50 (9.3)	116 (18.1)	116 (30.4)	<.0001
Pneumonia (n)	17.19	34 (12.1)	49 (20.5)	44 (20.1)	.0138	6 (5.9)	27 (19.4)	14 (18.7)	0.01	18 (11.1)	30 (20.9)	32 (26.9)	.0007
Pulmonary embolism (n)	12	0 (0.0)	1 (8.3)	2 (28.6)	.108	0	1 (8.3)	1 (20.0)	0.49	0	0	1 (100.0)	.04
Renal failure (n)	33.79	69 (23.7)	91 (35.0)	111 (44.2)	<.0001	14 (14.0)	61 (35.5)	49 (39.5)	<.0001	30 (23.8)	51 (33.3)	66 (51.9)	<.0001
Renal dialysis (n)	40.9	56 (30.8)	72 (41.9)	81 (51.6)	<.0001	11 (22.5)	49 (43.8)	38 (46.3)	.013	25 (29.4)	40 (38.8)	46 (57.5)	.0003
Dysrhythmia requiring PPM (n)	1.85	5 (0.9)	12 (2.3)	9 (3.0)	.0177	0	9 (2.2)	4 (2.4)	.028	3 (1.5)	6 (2.5)	4 (3.7)	.211
Cardiac arrest (n)	46.89	69 (34.5)	125 (49.2)	115 (56.1)	<.0001	19 (29.7)	64 (41.6)	63 (60.0)	<.0001	27 (33.3)	73 (46.8)	63 (63.6)	<.0001
Anticoagulation event (n)	21.31	15 (14.9)	24 (20.3)	23 (31.9)	.0079	5 (17.9)	20 (25.0)	10 (21.7)	.79	6 (12.5)	13 (20.6)	8 (30.8)	.058
Tamponade (n)	25	2 (20.0)	3 (27.8)	1 (33.3)	.6008	0	3 (33.3)	1 (25.0)	.33	0	1 (33.3)	1 (100.0)	.093
GI event (n)	16.79	43 (11.7)	58 (20.9)	37 (20.8)	.0021	17 (12.3)	35 (17.6)	15 (18.8)	.17	17 (10.1)	29 (20.3)	25 (26.6)	.0005
Multiorgan system failure (n)	78.63	44 (59.5)	73 (83.9)	78 (89.7)	<.0001	13 (50.0)	36 (76.6)	31 (83.8)	.0043	24 (68.6)	39 (82.9)	52 (92.9)	.0026
A fib (n)	2.7	70 (1.6)	87 (2.5)	107 (5.3)	<.0001	16 (0.9)	51 (1.9)	46 (4.5)	<.0001	28 (1.7)	62 (3.6)	61 (6.8)	<.0001
Aortic dissection (n)	23.53	1 (10.0)	2 (66.7)	1 (25.0)	.3343	0	0	0		1 (25.0)	3 (60.0)	0	.811
Major complication (n)	13.35	143 (8.8)	210 (13.2)	214 (20.8)	<.0001	42 (6.7)	116 (11.8)	91 (17.3)	<.0001	59 (7.9)	127 (15.2)	132 (25.1)	<.0001
Any of the above (n)	5.21	171 (3.0)	272 (5.5)	263 (8.9)	<.0001	47 (1.98)	155 (4.2)	126 (8.0)	<.0001	70 (3.1)	155 (6.6)	153 (11.6)	<.0001

Values are presented as n (%). *CABG*, Coronary artery bypass grafting; *AVR*, aortic valve replacement; *PPM*, permanent pacemaker; *GI*, gastrointestinal event; *A fib*, atrial fibrillation.

TABLE E4. Failure-to-rescue model for all complications

Characteristic	Beta coefficient	SE	*P* value
Intercept	−6.3763	0.503	<.0001
Demographic			
Age (y)	0.03064	0.005454	<.0001
Gender	0.507	0.1245	<.0001
BSA, m^2			
<1.6	Ref		
1.6-1.8	−0.06296	0.2221	.7768
1.8-1.99	−0.3192	0.2164	.1402
≥1.99	−0.05769	0.2139	.7874
Ejection fraction, %			
<40	Ref		
40-50	0.1039	0.1991	.6017
50-60	−0.2795	0.179	.1183
≥60	−0.02639	0.1658	.8736
Preoperative creatinine, mg/dL			
<0.8	Ref		
0.8-1.0	0.09146	0.1769	.6051
1.0-1.2	0.1608	0.184	.3823
≥1.2	0.1433	0.1766	.4171
Cardiac history			
Risk factor			
Arrhythmia	0.183	0.1196	.1262
Dialysis	0.7038	0.2372	.003
Intraoperative IABP	0.3333	0.2677	.2132
Chronic lung disease			
No	Ref		
Mild	0.09227	0.137	.5006
Moderate	0.4023	0.1903	.0345
Severe	0.4832	0.1946	.013
Immunosuppression	0.3893	0.2036	.056
Cardiogenic shock on admission	−0.1124	0.3629	.7567
Admission acuity			
Elective	Ref		
Urgent	0.3564	0.1181	.0026
Emergency	1.0265	0.3864	.0079
Emergency/salvage	0.3233	1.4464	.8231
Mitral valve insufficiency	0.3135	0.1557	.0441
CVD, CVA			
None	Ref		
CVD only	−0.08316	0.1573	.5971
CVD and CVA	0.09478	0.1656	.5671
No. of diseased vessels			
≤1	Ref		
2	0.03205	0.1467	.8271
3	0.1099	0.1267	.3857
Complication type			
Stroke	1.0034	0.1773	<.0001
Sepsis	0.8793	0.2007	<.0001
Surgical site infection	−1.3726	0.617	.0261
Deep sternal wound infection	1.215	0.8156	.1363
Any reoperation	0.3666	0.1242	.0032
Coma	−0.1905	0.1531	.2135
Prolonged ventilation	0.8569	0.1189	<.0001
Pneumonia	0.003983	0.1643	.9807

(Continued)

TABLE E4. Continued

Characteristic	Beta coefficient	SE	*P* value
Pulmonary embolism	−0.1396	0.7488	.8521
Renal failure	1.0955	0.2214	<.0001
Renal dialysis	0.2348	0.2529	.3534
Dysrhythmia requiring PPM	−1.5977	0.2407	<.0001
Cardiac arrest	2.8471	0.1238	<.0001
Anticoagulation event	−0.4817	0.2555	.0594
Tamponade	0.6649	0.6703	.3212
GI event	−0.109	0.1685	.5176
Multiorgan system failure	2.9666	0.2146	<.0001
A fib	−1.0059	0.1125	<.0001
Aortic dissection	1.5161	0.7447	.0418

BSA, Body surface area; *IABP*, intra-aortic balloon pump; *CVD*, cerebrovascular disease; *CVA*, cerebrovascular accident; *PPM*, permanent pacemaker; *GI*, gastrointestinal; *A fib*, atrial fibrillation.