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Failure to rescue: variation in mortality after cardiac surgery

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Key question

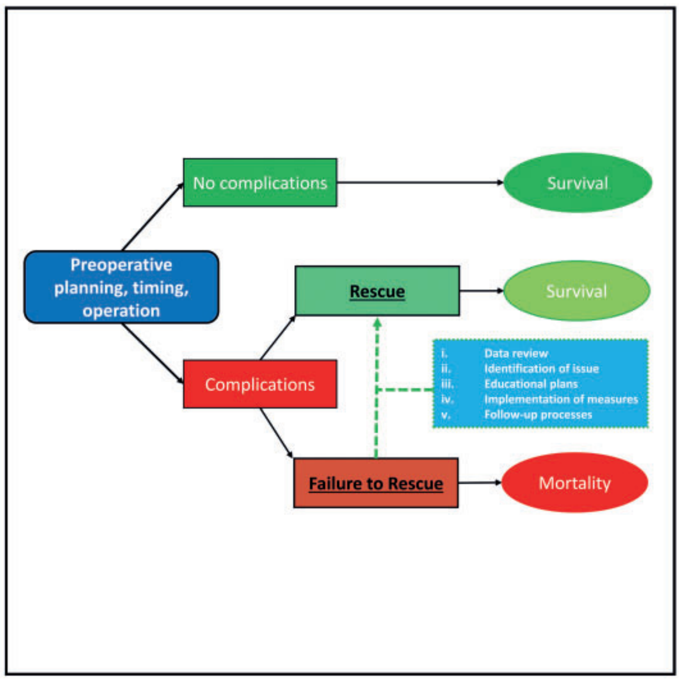
Are in-hospital variations in mortality after cardiac surgery driven primarily by differential rates of complications or by differences in management once those complications occur?

Key finding(s)

Hospitals with low mortality rates are significantly more successful in rescuing patients who experience postoperative complications than hospitals with high mortality rates.

Take-home message

In addition to preventing surgically related complications, early recognition and evidence-based management of major postoperative complications can further improve survival after cardiac surgery.



Abstract

OBJECTIVES: Measures to prevent surgical complications are critical components of optimal patient care, and adequate management when complications occur is equally crucial in efforts to reduce mortality. This study aims to elucidate clinical realities underlying in-hospital variations in failure to rescue (FTR) after cardiac surgery.

METHODS: Using a statewide database for a quality improvement program, we identified 62 450 patients who had undergone adult cardiac surgery between 2011 and 2018 in 1 of the 33 Michigan hospitals performing adult cardiac surgery. The hospitals were first divided

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into tertiles according to their observed to expected (O/E) ratios of 30-day mortality: low-mortality tertile (O/E 0.46–0.78), intermediate-mortality tertile (O/E 0.79–0.90) and high-mortality tertile (O/E 0.98–2.00). We then examined the incidence of 15 significant complications and the rates of death following complications among the 3 groups.

RESULTS: A total of 1418 operative deaths occurred in the entire cohort, a crude mortality rate of 2.3% and varied from 1.3% to 5.9% at the hospital level. The death rates also diverged significantly according to mortality score tertiles, from 1.6% in the low-mortality group to 3.2% in the high-mortality group ($P < 0.001$). Hospitals ranked in a high- or intermediate-mortality tertile had similar rates of overall complications (21.3% and 20.7%, $P = 0.17$), while low-mortality hospitals had significantly fewer complications (16.3%) than the other 2 tertiles ($P < 0.001$). FTR increased in a stepwise manner from low- to high-mortality hospitals (8.3% vs 10.0% vs 12.7%, $P < 0.001$, respectively). Differences in FTR were related to survival after cardiac arrest, multi-system organ failure, prolonged ventilation, reoperation for bleeding and severe acute kidney disease that requires dialysis.

CONCLUSIONS: This study demonstrates that timely recognition and appropriate treatment of complications are as important as preventing complications to further reduce operative mortality in cardiac surgery. FTR tools may provide vital information for quality improvement initiatives.

Keywords: Failure to rescue • Quality improvement • Quality assurance • Cardiac surgery • Avoidable deaths

ABBREVIATIONS

CABG	Coronary artery bypass grafting
CI	Confidence interval
FTR	Failure to rescue
ICU	Intensive care unit
MSTCVS-QC	Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative
O/E	Observed to expected
OR	Odds ratio
PROM	Predicted risk of mortality
STS	Society of Thoracic Surgeons

INTRODUCTION

Common cardiac surgical procedures are associated with substantial morbidity and mortality rates coupled with extensive variations in outcomes between different cardiac surgery teams [1]. Differences in the outcomes have been traditionally linked to the complexity of surgical procedures and the skills and knowledge of surgical team members [2]. However, in-depth analyses of dedicated clinical quality registries have recently yielded granular information on occurrence of death during the perioperative period [3]. While differences in operative excellence are likely to partly explain the intraoperative and postoperative mortality rates, this heterogeneity should not affect the relative proportions of death from evolving complications that occur in the intensive care unit (ICU).

Complications and deterioration following cardiac surgery often involve signs and symptoms that may go unrecognized or minimalized, and may not be addressed in a timely manner. It is recognized that the inability to quickly identify and respond to patient deterioration is a problem for healthcare systems that have come under increased scrutiny by hospital leaders and health authorities. The failure to rescue (FTR) concept is based on the reality that, although not every complication in medical care is preventable, healthcare teams should be able to rapidly identify and treat complications when they occur [4, 5]. In essence, FTR refers to a situation where the clinical team has been unable to prevent death after the development of a potentially treatable complication. Paving the way for progress in medical care, the Agency for Healthcare Research and Quality (AHRQ) and the Institute of Medicine (IOM) have identified the concept of FTR as one of the key components in improving the quality of care among surgery patients [5].

Nine years ago (in 2011), an extensive quality review was undertaken by the Michigan Society of Thoracic and Cardiovascular Surgeons Quality Collaborative (MSTCVS-QC) to investigate FTR rates following cardiac surgical procedures in all 33 cardiac surgical hospitals in the state. The key findings were only modest variations in complication rates and substantial variability in FTR rates among the investigated hospitals [6]. Simultaneously, the MSTCVS-QC teams met quarterly to review and discuss treatment outcomes, process management and improvements in the care of cardiac and general thoracic surgery patients. This updated review aims to quantify current FTR data, identify trends and assess opportunities for further quality improvement initiatives.

METHODS

Ethical approval

Given its observational nature, the Institutional Review Board of the University of Michigan (IRB) has noted that this study does not fit the definition of human-subject research requiring IRB approval.

Study design

The study design has been previously described in detail [6]. Briefly, FTR analysis was endorsed by the MSTCVS-QC in 2011 as part of the statewide effort to enhance the understanding of mortality following cardiothoracic surgery procedures, to identify the causes of unwarranted variation in healthcare delivery using FTR and to develop strategies to manage them. The MSTCVS-QC is a continuous quality improvement program that utilizes the Society of Thoracic Surgeons (STS) national registry platform to drive discussions focused on individual hospital performance, using comprehensive data. In addition to the audited STS data, audited state-specific data collection sheets include additional medical record information for each patient, including information regarding a phase of care mortality analysis (Fig. 1), enabling the MSTCVS-QC database to have detailed data to interrogate for periprocedural complications and mortality facts.

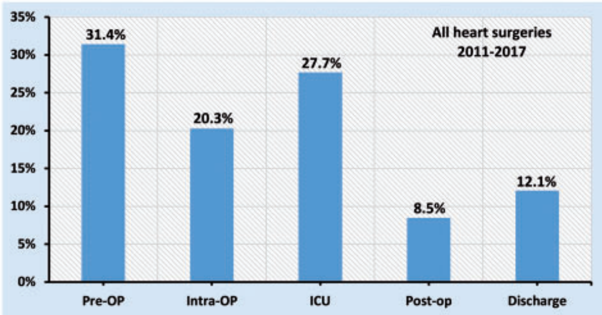

Figure 1: Phase of care mortality analysis of all patients who underwent heart surgeries between 1 July 2011 and 1 July 2017 across 33 Michigan hospitals. Discharge: hospital discharge phase of care; Intra-OP: intraoperative phase; ICU: intensive care unit phase; Pre-OP: preoperative phase; Post-OP: postoperative phase.

To enhance the validity and trustworthiness of the data stored in the registry database, data managers attend multiple training sessions about registry protocol and procedures, data collection systems, data definitions and their interpretation. In addition, to better target problem areas, individual institution data audits are regularly scheduled and take place according to a fixed timeline. Furthermore, quarterly meetings of data specialists, surgeons and hospital quality leaders help in the dissemination of intervention strategies and provide opportunities for feedback from all individual hospitals in a supportive environment. The current study intends to quantify and qualify contemporary FTR rates using an already established method.

Endpoints and definitions

Operative mortality is defined in the STS database as (i) all deaths, regardless of cause, occurring during the hospitalization in which the operation was performed, even if after 30 days (including patients transferred to other acute care facilities) and (ii) all deaths, regardless of cause, occurring after discharge from the hospital, but before the end of the 30th postoperative day [7]. Through phase of care mortality analysis evaluation, the multidisciplinary committee analysed individual deaths to identify the phase of care in which the death occurred: preoperative, intraoperative, postoperative ICU, postoperative floor or discharge phase. FTR has been defined as the inability to prevent death after the development of a complication. Moreover, every patient who dies following a major complication may be graded as a preventable death in the FTR concept and this further clarifies the complication and expended potential treatments.

To be able to update the current results, we regrouped the STS codes from the original study to approximate the current STS classification of complications. Codes for reoperation for bleeding and tamponade (CotTamp and COpReBld) were combined into 1 outcome due to small numbers. Of note, this regrouping was done without prior knowledge of the outcome status of patients in the later-established study groups. Unlike the previous study, there were no deaths from a coma in this pool of patients. Finally, 15 complications were examined: multi-system organ failure, cardiac arrest, renal dialysis, sepsis, anticoagulation event, gastrointestinal event, ICU readmission, prolonged ventilation, reoperation for bleeding/tamponade, pneumonia, stroke, pulmonary embolism, deep sternal wound infection, heart block and aortic dissection.

Study population

The present investigation was restricted to patients who underwent any of the following cardiac surgery procedures from 2011 to 2018 across all 33 institutions in Michigan performing adult cardiac surgery: isolated coronary artery bypass grafting (CABG) surgery, isolated aortic valve replacement, isolated mitral valve replacement, aortic valve replacement plus CABG, mitral valve replacement plus CABG, mitral valve repair and mitral valve repair plus CABG. After excluding those without STS predicted risk of mortality (PROM) ($n = 417$, 0.7%), a total of 62 450 patients met the inclusion criteria for analysis.

Statistical analyses

A team consisting of data analysts and statisticians performed the statistical analyses. Study variables are presented using descriptive statistics, as a percentage, count of sample size or median. We used χ^2 tests and analysis of variance to test for significant differences in preoperative and postoperative patients' characteristics across FTR groups for categorical and continuous variables, respectively. A generalized linear mixed model with a logit link compared odds of morbidity and mortality among the 3 FTR groups. At the hospital level, operative mortality, complication and FTR rates were calculated using the following formulas: (i) operative mortality rate (number of total operative deaths divided by number of total patients); (ii) complication rate (number of patients with any of the 15 postoperative complications described divided by the number of total patients); and (iii) FTR rate (number of deaths among those with any of the 15 postoperative complications divided by number of total patients with any of the 15 postoperative complications). The STS PROM was used to calculate observed to expected (O/E) mortality for each hospital. Secondly, hospitals were then ranked according to these O/E mortality ratios and divided into 3 equal-sized groups (tertiles). Thirdly, the complication rates and FTR rates across these tertiles were compared. Lastly, to determine whether specific complications had different rates of FTR, an FTR rate for each specific complication was estimated. The tertile approach has been used to enhance the likelihood of detecting an effect within smaller sample sizes. Statistical analyses were carried out using SAS 9.3 (SAS Institute, Cary, NC, USA). The probability of type I error was set at 0.05, and all testing was two-sided.

RESULTS

From January 2011 to December 2018, the statewide case totals included 42 348 isolated CABG, 12 637 isolated valves and 7465 CABG plus valve procedures with known STS PROM scores. From this pool of patients ($n = 62 450$), the low-mortality group comprised those hospitals whose O/E mortality ratios were between 0.46 and 0.78, the intermediate-mortality group comprised those hospitals with O/E mortality ratios between 0.79 and 0.90, and the high-mortality group comprised those hospitals with O/E mortality ratios between 0.98 and 2.00.

The high-mortality group treated a larger proportion of younger patients who were identified as non-white, while no significant gender differences were observed between the 3 groups (Table 1). In comparison to those hospitals with intermediate and high mortality, fewer patients in the low-mortality hospitals had

Table 1: Demographics and clinical characteristics of patients according to hospital tertiles of mortality

	Low mortality (*n* = 26 961)	Intermediate mortality (*n* = 21 358)	High-mortality (*n* = 14 131)	*P*-value
Demographics				
Age (years), median	67.0	67.0	66.0	<0.001
Male gender	71.0	70.5	71.2	0.32
Non-white race	6.7	10.6	13.3	<0.001
Risk factors				
Dyslipidaemia	14.9	11.9	11.3	<0.001
Hypertension	84.8	89.4	89.4	<0.001
Diabetes mellitus	39.8	43.4	43.7	<0.001
Never smoker	52.4	50.1	51.3	<0.001
Dialysis	2.3	2.7	2.6	0.012
Peripheral vascular disease	14.1	14.1	16.7	<0.001
Cerebrovascular disease	20.4	21.1	20.4	0.085
Previous CVA	6.9	8.5	8.4	<0.001
Any lung disease	23.4	32.7	32.4	<0.001
Previous MI	42.4	42.9	47.5	<0.001
LVEF, mean	53.8	52.6	52.8	<0.001
Heart failure	20.4	20.0	26.4	<0.001
Three-vessel CAD	56.6	61.8	62.9	<0.001
Previous CABG	3.8	3.1	2.9	<0.001
Previous PCI	25.1	27.9	27.4	<0.001
Previous valve surgery	3.2	1.7	1.4	<0.001
Operative characteristics				
First cardiovascular surgery	93.7	95.5	95.6	<0.001
Elective status	52.4	45.8	48.6	<0.001
Procedure				
Isolated CABG	62.9	69.6	74.4	<0.001
Isolated valve surgery	24.5	18.0	15.5	<0.001
CABG plus valve surgery	12.6	12.4	10.1	<0.001
Mortality				
Expected mortality[a]	2.52	2.62	2.42	<0.001
Observed-to-expected ratio	0.46–0.78	0.79–0.90	0.98–2.00	NA

Values are presented as % or median and mean when indicated.
[a]STS predict the risk of mortality.
CABG: coronary artery bypass grafting; CAD: coronary artery disease; CVA: cerebrovascular accident; LVEF: left ventricular ejection fraction; MI: myocardial infarction; NA: not applicable; PCI: percutaneous coronary intervention; STS: Society of Thoracic Surgeons.

diabetes mellitus, hypertension, lung disease and prior cerebrovascular accidents. However, in the low-mortality hospitals, significantly more patients had dyslipidaemia, and a previous history of CABG and/or valve surgery (Table 1). There were substantially fewer patients who had undergone isolated CABG in the low-mortality group than in the intermediate- and high-mortality group (62.9% vs 69.6% vs 74.4%, $P < 0.001$, respectively). Summarizing these findings, most surprisingly, the median STS PROM score was lowest in the high-mortality group as compared to the intermediate- and low-mortality groups (2.42% vs 2.62% vs 2.52%, $P < 0.001$, respectively) (Table 1).

A total of 1418 operative deaths occurred in the entire cohort, resulting in a crude mortality rate of 2.3%. Even though the annual mortality rates for the period 2011–2018 varied by up to 20% in relative numbers (2.0% in 2016 vs 2.5% in 2014), statistical analysis did not reveal a significant difference ($P = 0.16$) (Fig. 2A). When comparing hospital tertiles, the risk of mortality increased in a stepwise manner from the low- to high-mortality groups (1.6% vs 2.5% vs 3.2%, $P < 0.001$, respectively) (Fig. 3). The overall complication rates among the 3 groups were significantly different (16.3% vs 20.7% vs 21.3%, $P < 0.001$, respectively) (Table 2 and Fig. 3). Although significantly fewer complications occurred in the low-mortality group in comparison to the intermediate- or

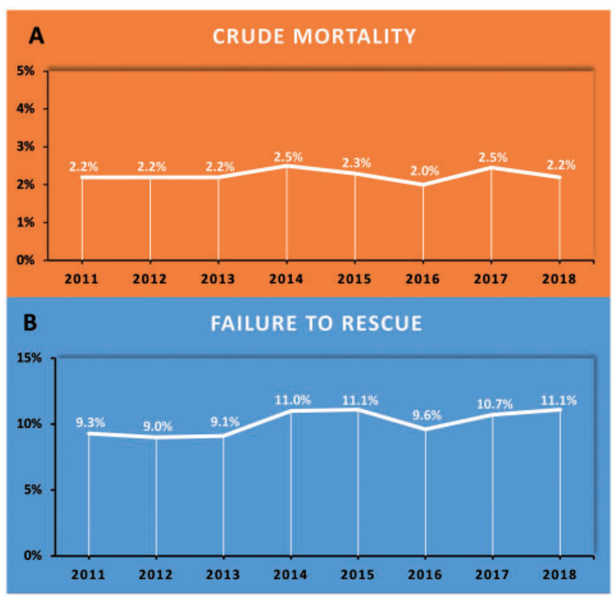

Figure 2: The overall mortality rate (**A**) and failure to rescue rate (**B**) in the period 2011–2018.

high-mortality group (P < 0.001 for both), total complication rates were similar between the intermediate- and high-mortality hospitals (P = 0.17). When compared to the high-mortality hospitals, significantly fewer patients in the low-mortality hospitals suffered from specific periprocedural complications such as cardiac arrest, sepsis, reoperation for bleeding, prolonged ventilation, pneumonia and stroke (Table 2).

The average rate of FTR was 10.1% and was unchanged during the study period (Fig. 2B). However, there were marked variations in FTR between the analysed groups (8.3% vs 10.0% vs 12.7%, P < 0.001, respectively) (Fig. 3). Crucially, patients treated at high-mortality hospitals had a nearly 50% increase in the likelihood of death after developing a complication when compared with patients treated at low-mortality hospitals (12.7% vs 8.3%, P < 0.001, respectively). In addition, the group comprising high-mortality hospitals had a significantly higher rate of FTR in comparison to intermediate-mortality hospitals (12.7% vs 10.0%, P < 0.001, respectively). There was also a significant variation in the rate of FTR between the intermediate- and low-mortality hospitals (10.0% vs 8.3%, P = 0.005, respectively).

Compared with high-mortality hospitals, the low-mortality hospitals had significantly better FTR rates for 6 out of 15 specific complications (Table 3). The largest differences in FTR rates between low- and high-mortality hospitals were noted in the treatment success of cardiac arrest [odds ratio (OR) 1.56, 95% confidence interval (CI) 1.16–4.49], multi-system organ failure (OR 2.28, 95% CI 1.16–4.49), prolonged ventilation (OR 1.44, 95% CI 1.20–1.73), reoperation for bleeding (OR 1.89, 95% CI 1.25–2.86) and need for renal dialysis (OR 1.58, 95% CI 1.11–2.25) (Table 3).

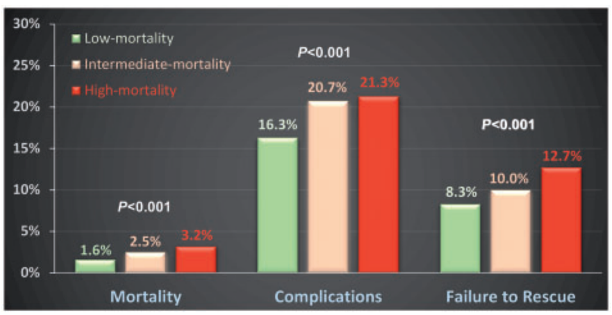

Figure 3: Rates of mortality, complications and failure to rescue by hospital tertiles of mortality in the period 2011–2018.

The overall complications rate decreased from 21.1% to 18.9% between the 2 study periods 2006–2010 and 2011–2018 (risk difference = 2.20%, 95% CI 1.72–2.68; P < 0.001) (Fig. 4A). At the same time, overall reported FTR displayed no clear linear trend across the hospital tertiles (Fig. 4B). The FTR rates were similar among patients treated at intermediate- and high-mortality hospitals. In contrast, low-mortality hospitals shifted from 19.1% to 16.3% in terms of major complications and from 8.3% to 6.6% to 20% in terms of FTR, resulting in a 20% relative risk reduction in the likelihood of death after developing a complication (Fig. 4A and B).

The number of studied patients ranged from 480 to 6802 at the hospital level (Table 4). Thirty-day mortality was not strongly related to procedure volume. The crude mortality varied from 1.3% to 3.0% in the high-volume tertile versus 1.6% to 5.9% in the low-volume tertile (Table 4). The effects of volume on each site's complications were more pronounced, resulting in 13.1–25.2% complication rates in the high-volume tertile and 15.6–42.2% in the low-volume tertile. Finally, there was no conclusive evidence that procedure volume had an apparent influence on the FTR rates. Hospitals ranked in a high-volume tertile had similar FTR rates as those in a low-volume tertile (6.5–12.3% and 7.1–13.9%, respectively) (Table 4).

DISCUSSION

The present review examined Michigan's efforts to improve its healthcare delivery system for patients undergoing cardiac surgical operations, focusing on potentially 'preventable' death. The significant findings include: (i) surgical treatment at high-mortality hospitals was associated with a two-fold increase in all-

Table 2: Incidence of complications according to hospital tertiles of mortality

	Low mortality (%)	Intermediate mortality (%)	High mortality (%)	High versus low mortality, OR (95% CI)
Complication		Incidence		
Multi-system organ failure	0.4	0.5	0.8	1.90 (1.45–2.48)
Cardiac arrest	1.2	2.0	2.5	2.11 (1.81–2.45)
Renal dialysis	1.4	1.7	1.6	1.16 (0.98–1.36)
Sepsis	0.9	1.0	1.7	1.91 (1.60–2.30)
Anticoagulation event	0.5	0.9	1.0	1.85 (1.46–2.34)
Gastrointestinal event	2.9	2.7	2.4	0.85 (0.75–0.96)
ICU readmission	2.9	3.1	3.0	1.04 (0.92–1.17)
Prolonged ventilation	8.2	11.0	11.6	1.47 (1.37–1.57)
Reoperation for bleeding	2.0	2.5	2.4	1.21 (1.05–1.39)
Pneumonia	2.2	2.5	4.3	2.00 (1.78–2.24)
Stroke	1.3	1.7	1.4	1.05 (0.88–1.25)
Pulmonary embolism	0.2	0.1	0.2	1.35 (0.87–2.10)
Aortic dissection	0	0	0.1	1.47 (0.64–3.35)
Deep sternal wound infection	0.2	0.3	0.3	1.39 (0.96–2.02)
Heart block	2.4	3.3	2.6	1.10 (0.97–1.25)
Overall (any of 15 listed)	16.3	20.7	21.3	1.39 (1.32–1.46)

Values are presented as % of total number of operated patients.

CI: confidence interval; ICU: intensive care unit; OR: odds ratio.

Table 3: Incidence of failure to rescue according to hospital tertiles of mortality

	Low mortality (%)	Intermediate mortality (%)	High mortality (%)	High versus low mortality, OR (95% CI)
Complication		Failure to rescue		
Multi-system organ failure	71.6	86.7	85.2	2.28 (1.16–4.49)
Cardiac arrest	46.5	52.0	57.6	1.56 (1.16–2.11)
Renal dialysis	26.3	29.8	36.0	1.58 (1.11–2.25)
Sepsis	32.2	29.7	32.3	1.01 (0.68–1.48)
Anticoagulation event	19.6	19.0	23.2	1.24 (0.70–2.20)
Gastrointestinal event	13.2	11.9	20.0	1.64 (1.17–2.30)
ICU readmission	8.7	8.5	11.0	1.31 (0.88–1.93)
Prolonged ventilation	12.3	13.9	16.9	1.44 (1.20–1.73)
Reoperation for bleeding	9.2	10.5	16.0	1.89 (1.25–2.86)
Pneumonia	14.0	12.9	13.0	0.92 (0.66–1.28)
Stroke	14.9	17.5	18.4	1.29 (0.81–2.05)
Pulmonary embolism	4.2	9.4	14.7	3.96 (0.72–21.80)
Aortic dissection	15.4	25.0	30.0	2.36 (0.31–17.85)
Deep sternal wound infection	10.6	0	8.3	0.77 (0.21–2.78)
Heart block	2.2	2.6	3.3	1.51 (0.69–3.29)
Overall (any of 15 listed)	8.3	10.0	12.7	1.60 (1.37–1.86)

CI: confidence interval; ICU: intensive care unit; OR: odds ratio.

cause death at 30 days, as compared to patients treated at low-mortality hospitals; (ii) incidence of major complications were also dissimilar but to a much lesser extent, particularly between high- and intermediate-mortality hospitals; (iii) FTR rates differ markedly between those patients operated at low- and high-mortality hospitals; and (iv) rescue of patients may be realistically related to the ability of the medical team's ability to anticipate and quickly recognize and respond to a patient's complications with appropriate expert care.

Approximately 1 out of every 5 patients develop significant complications after cardiac surgery [8]. The relationship between these complications and mortality while recognized is not absolute. This review adds to the growing body of evidence that hospitals can have low complication rates but high FTR rates, and vice versa [8–10]. Through analysis of cardiac procedures with low expected mortality, we can review and consider postoperative surgical care approaches when hospital care teams are faced with severe postprocedural complications. Such findings are essential for quality improvement, as they go beyond the traditional clinical quality indicators [11]. The monitoring of FTR rates may shed light on underlying specific factors at all institutions to continue to improve patient outcomes.

Although quality improvement programs such as the MSTCVS-QC aim to identify best practice strategies at high-performing institutions and disseminate findings to other institutions to mitigate adverse events, clinical practices that lead to significantly improved hospital performance are not necessarily easily understood and may even be more challenging to implement in clinical routine in every institution. To consider care changes and evolution, an organization needs to understand its delivery system and key processes for quality improvement [12]. As a result of the previous study, and a continued focus during 4 quality improvement meetings a year, the overall incidence of complications and FTR for most risk groups have decreased in the contemporary cohort compared with the previous cohort [13, 14]. This is also reflected in a reduction in crude mortality for each cohort, while expected mortality has risen. Differential incidences in complications are a greater driver of mortality in the contemporary cohort than in the previous cohort; however, FTR remains the predominant force, particularly in high-mortality hospitals. These changes may represent quality improvement efforts to date, specifically an improved awareness of the importance of FTR in Michigan. A continuous approach to identify and diminish differences in mortality rates among institutions is ongoing.

With the move towards more complex surgical scenarios and interventions for patients with multiple chronic conditions, improving the ability of hospital care teams to recognize and manage complications is a necessary approach outside our operating theatres to reduce surgical mortality. A better understanding of hospital structure at the micro-system level—including details related to ICU staffing, physician coverage and rapid response teams—is vital in designing practical and effective interventions to improve [15]. A landmark analysis by Pronovost *et al.* [16] established a clear association between physician staffing levels in the ICU and a significant reduction in both ICU and overall hospital mortality. Crucially, this effect may be the result of providing the right treatment at the right time. Furthermore, the relationship between nursing care factors and FTR rates is investigated by Needleman *et al.* [17] in the sentinel study. Findings suggested better outcomes in association with both a greater number and higher proportion of care hours delivered by nurses trained in ICU delivery. Given the significant variations in procedure volume, high-intensity ICU staffing and nurse-to-patient ratios between hospitals today, and the potential for reduced mortality implied by these studies, the establishment of rigorous minimum standards for the organization and process of care in the ICU may be a significant step forward in reducing in-hospital mortality after cardiac surgery.

Limitations

This study has several important limitations. First, the use of Michigan data may not be generalized due to the US healthcare

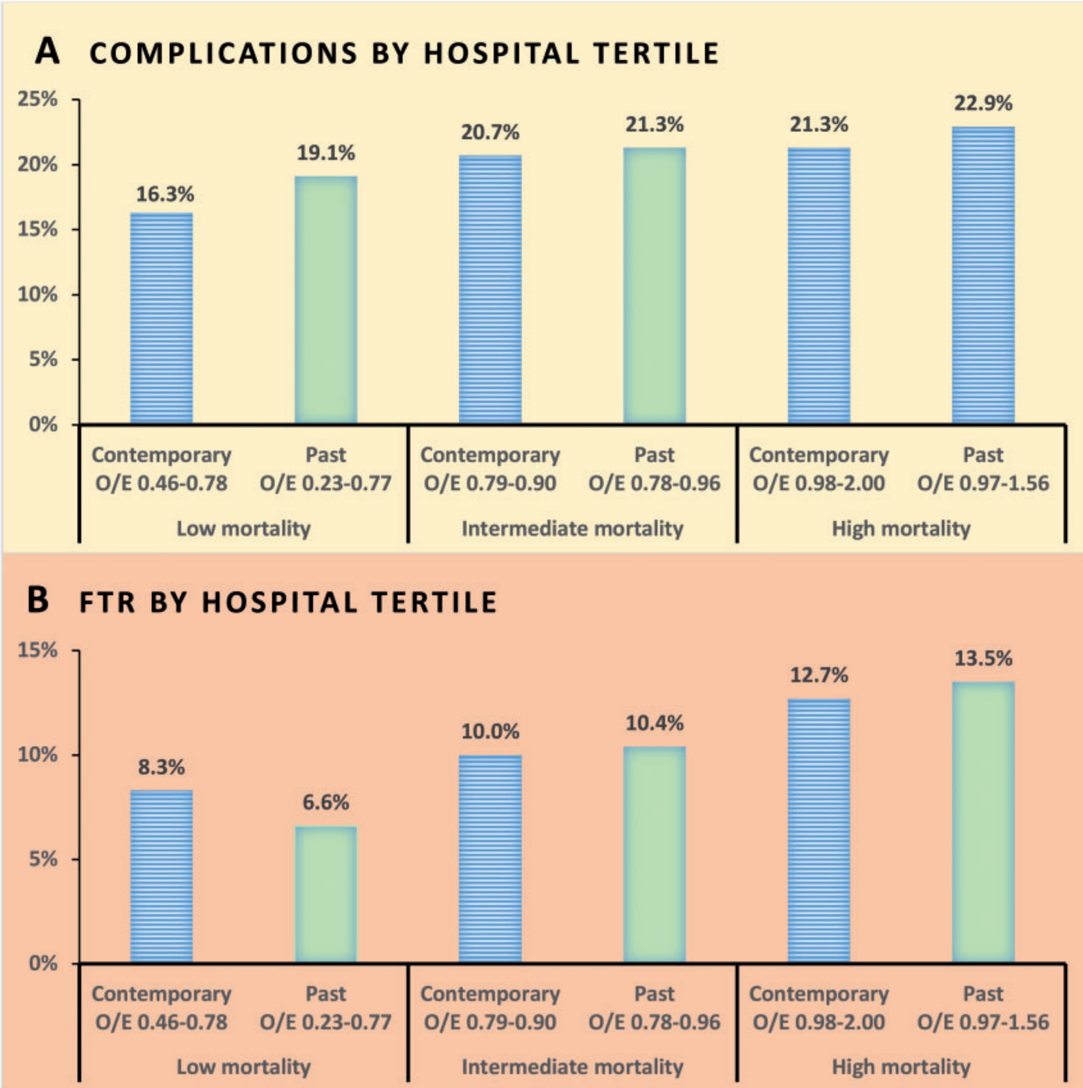

Figure 4: The difference between contemporary (2011–2018) and past (2006–2010) rates of complications (**A**) and failure to rescue (**B**) by hospital tertiles of mortality. FTR: failure to rescue; O/E: observed over expected mortality group.

system's different standards compared to other countries. Nevertheless, performing FTR measures regularly is a valuable resource for hospital and regional authorities to consider to improve patient safety. Second, under-reporting and misreporting complications are some of the significant limitations of using clinical outcomes registries for scientific projects [18]. Even though all complications are collected according to the prespecified definition by trained professionals, adjudication of reported complications is not performed routinely and, therefore, misdiagnosis cannot be entirely excluded. However, we do not believe this would significantly undermine these findings since external audit results (derived by comparing submitted data with the official medical record of randomly selected sites) have shown overall agreement rates of nearly 97% [19]. Third, surgical mortality categorization is limited in discriminating between hospital tertiles of mortality due to the relatively low number of procedures in many hospitals. Fourth, although across-institutional results showed no substantial procedural volume effects, this difference cannot be excluded until the individual hospital level's multivariable analyses are done. Still, detailed volume-outcome related analysis is beyond the scope of the present study and requires an a priori hypothesis. Fifth, due to its exploratory data analysis nature, the present study's results should be interpreted as observational and hypothesis-generating only. Moreover, a borderline difference in mortality between high-performing hospitals in intermediate- or high-mortality tertiles and low-performing hospitals in low- or intermediate-mortality tertiles exists. Finally, in a real-life setting, some deaths are not entirely preventable. Recognition of complications does not imply all complications are preventable. Anticipation and recognition of complications is an essential reality of FTR. Further investigation using specific FTR structures with an independent clinical endpoint adjudication approach is justified.

CONCLUSIONS

This study supports that adequate treatment of complications once they occur is critically essential to cardiac surgical patients' survival as it is the prevention of perioperative adverse events.

Table 4: Incidence of mortality, complications and FTR within O/E tertiles

Hospitals ranking according to O/E mortality	Number of patients	Crude mortality	Any of 15 complications	FTR rates
Low-mortality tertile				
0.46	1343	1.3	16.1	6.9
0.46	3596	1.3	19.4	6.5
0.51	6802	1.2	16.6	6.5
0.53	1465	1.4	12.2	7.8
0.53	3596	1.4	15.2	8.0
0.56	817	1.6	19.0	7.1
0.64	839	2.5	16.9	11.3
0.72	1565	1.8	16.5	10.1
0.73	1703	2.4	19.0	9.6
0.77	3602	2.0	13.1	12.3
0.78	1633	2.5	16.7	11.8
Intermediate-mortality tertile				
0.79	998	2.6	16.2	13.6
0.80	2273	1.9	13.4	10.2
0.82	1513	2.0	12.7	13.0
0.84	532	2.3	20.1	8.4
0.84	1702	2.0	21.3	7.7
0.85	735	2.3	18.6	9.5
0.88	1494	3.2	20.6	13.7
0.89	3031	2.8	24.6	9.4
0.89	4129	2.6	25.2	9.4
0.90	2849	2.7	19.1	11.0
0.90	2102	2.7	24.3	8.8
High-mortality tertile				
0.98	2247	3.2	22.9	12.0
0.99	1893	2.7	20.2	11.8
1.06	1065	2.6	15.6	13.9
1.12	1171	2.9	19.1	12.5
1.14	480	5.0	32.9	13.9
1.20	1411	2.7	18.9	11.6
1.24	1269	3.1	22.7	12.9
1.27	1437	3.1	18.6	13.5
1.34	799	3.5	23.9	12.0
1.39	1764	3.0	16.9	14.4
2.00	595	5.9	42.2	12.4

Values are presented as *n* or %.
FTR: failure to rescue; O/E: observed over expected mortality.

This joint effort is a key to the success of institutions rated as 'high-performing' sites. Regularly performed FTR analyses provide vital information for quality assurance and continuous quality improvement.

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Authors contributions

Milan Milojevic: Conceptualization; Investigation; Methodology; Writing—original draft. **Chris Bond:** Conceptualization; Methodology; Writing—review & editing. **Chang He:** Data curation; Formal analysis; Software. **Francis L. Shannon:** Conceptualization; Data curation; Writing—review & editing. **Melissa Clark:** Data curation; Validation; Writing—review & editing. **Patricia F. Theurer:** Data curation; Investigation; Validation; Writing—review & editing. **Richard L. Prager:** Investigation; Methodology; Supervision; Writing—review & editing.

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