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Original Article

Enhanced Recovery After Surgery Is Associated With Reduced Hospital Length of Stay after Urgent or Emergency Isolated Coronary Artery Bypass Surgery at an Urban, Tertiary Care Teaching Hospital: An Interrupted Time Series Analysis With Propensity Score Matching

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Objective: To evaluate whether enhanced recovery after surgery (ERAS) was associated with reduced length of stay (LOS) after urgent or emergency coronary artery bypass graft surgery (CABG).

Design: A retrospective analysis of an institutional database for urgent or emergency isolated CABG before versus after ERAS. Propensity matching identified comparable subpopulations pre- versus post-ERAS. Interrupted time series analysis was used to evaluate LOS.

Setting: At a tertiary care teaching hospital.

Participants: A total of 1,012 patients undergoing urgent or emergent CABG—346 from 2016 to 2017 (pre-ERAS), and 666 from 2018 to 2020 (post-ERAS). Emergent CABG was performed within 24 hours, and urgent CABG was performed during the same hospitalization to reduce clinical risk.

Interventions: None.

Measurements and Main Results: Propensity-matched post-ERAS (n = 565) versus pre-ERAS patients (n = 330) demonstrated reduced LOS (9 [8-13] *v* (10 [8-14] days p = 0.015), increased likelihood of extubation within 6 hours (46.0% *v* 35.8%, p = 0.003), shorter ventilation time (6.3 [5.1-10.2] *v* (7.2 [5.4-12.2] hours, p = 0.003), reduced morphine milligram equivalent use on postoperative days 1 and 2 (69.6 ± 62.2 *v* 99.0 ± 61.6, p < 0.001), and increased intraoperative ketamine use (58.8% *v* 35.2%, p < 0.001). There were no differences regarding reintubation, intensive care unit readmission, or 30-day morbidity. Adjusted segmental regression (n = 1,012) for LOS demonstrated reduced mean LOS of approximately 2 days after ERAS (β_2 coefficient -1.943 [-3.766 to -0.121], p = 0.037), with stable trends for mean LOS and no change in slope throughout the pre-ERAS and post-ERAS time periods.

Conclusions: Enhanced recovery after surgery was associated with reduced LOS after urgent or emergency CABG without adverse effects on prolonged ventilation, reintubation, intensive care unit readmission, or 30-day outcomes.

Key Words: enhanced recovery after surgery; ERAS; urgent or emergency coronary artery bypass surgery

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Introduction

Enhanced recovery after surgery (ERAS) is a multidisciplinary approach to the care of surgical patients, which has been demonstrated to improve postoperative recovery and reduce overall costs associated with surgical care.[1] For patients undergoing elective isolated coronary artery bypass graft surgery (CABG), ERAS has been associated with an increased likelihood of early extubation,[2] reduced duration of intensive care unit (ICU) admission,[3] and reduced hospital length of stay (LOS).[3,4] To date, there have been no prior reports that specifically examined the effects of ERAS on outcomes associated with isolated urgent or emergency CABG.

In-hospital mortality for urgent or emergency CABG has been reported to be higher than when CABG is performed electively.[5] A published report from a high-volume cardiac surgery center indicated that approximately 3% of CABG surgical volume was performed under emergency priority, and approximately 30% under urgent priority.[6] Although, in this study, the population of emergency CABG represented only 3% of all patients undergoing isolated CABG, these patients accounted for 20% of postoperative deaths after CABG surgery. Despite increased risks, long-term survival rates after urgent or emergency CABG have justified continued use of this surgery as a life-saving intervention for acute coronary syndromes such as unstable angina pectoris, non-ST elevation myocardial infarction (NSTEMI), ST elevation myocardial infarction (STEMI), and heart failure mediated by myocardial ischemia.[7-10] Apart from clinical presentation and coronary artery lesion complexity as important determinants for urgent or emergent surgical intervention, emergent CABG after failed percutaneous coronary intervention represents another subgroup associated with high mortality.[11]

Consistent with the goal of creating value in healthcare, contemporary paradigms for quality improvement often focus on the effects of interventions to improve outcomes and reduce costs associated with medical care. Because urgent and emergency CABG are performed frequently in United States medical centers, and have been associated with high in-hospital mortality, it is important to identify clinical management strategies that may reduce total LOS, as well as morbidity and mortality associated with these procedures.

The primary objective of this study was to determine the effects of ERAS implementation on total LOS associated with urgent or emergency CABG in a high surgical volume, tertiary care teaching hospital. The study authors hypothesized that mean hospital LOS at the start of ERAS implementation would be noninferior to that observed at the end of the pre-ERAS period, and they hypothesized that trends in mean monthly hospital LOS after ERAS implementation would be noninferior to projected trends based on pre-ERAS data.

Methods

This retrospective study was conducted at Hartford Hospital, an 890-bed tertiary care medical center in Hartford, CT. The Hartford Hospital Institutional Review Board approved the study and certified that it met the criteria for a waiver of the requirement to obtain informed consent (Assurance #FWA000000601).

Study Design

All adults (>18 years of age) who underwent consecutive urgent or emergency isolated CABG at Hartford Hospital from January 1, 2016, to December 31, 2020 were considered for study inclusion. A cardiac surgery ERAS protocol was introduced formally at the beginning of April 2018, and patients treated during its implementation from January 1, 2018 to June 30, 2018 were excluded from analysis. Patients undergoing repeat sternotomy, off-pump CABG, and patients who had surgical procedures involving the cardiac valves or aorta, in addition to coronary revascularization, were excluded from analysis. The remaining study population was divided into the following 2 cohorts: patients who underwent urgent or emergency isolated CABG from January 1, 2016 to December 31, 2017 prior to ERAS implementation (pre-ERAS), and patients who underwent urgent or emergency isolated CABG from July 1, 2018 to December 31, 2020 after ERAS implementation (post-ERAS).

The authors' institutional cardiac surgery ERAS clinical pathway was constructed by a multidisciplinary team of cardiac anesthesiologists, cardiac surgeons, cardiac surgery intensivists, perioperative nurses, respiratory therapists, pharmacists, blood bank experts, and physical therapists. After review of previously published ERAS guidelines, the best-practice policies were instituted to achieve perioperative ERAS goals. The authors' ERAS protocol has been reported previously and is summarized in Table 1 in the context of evidence-based guidelines for ERAS in cardiac surgery that were published formally in 2019.[12,13]

The pre-ERAS and post-ERAS cohorts were compared regarding demographic data, cardiac risk factors, comorbidities, prior cardiac history, preoperative cardiac catheterization and echocardiographic results, Society of Thoracic Surgeons risk score, operative details, and indications for CABG. Indications for CABG were STEMI, NSTEMI, unstable angina pectoris, and other, which included left main or multi-vessel coronary artery disease.

The primary study outcome was total hospital LOS. The secondary outcomes were extubation <6 hours, total ventilation time, prolonged ventilation, reintubation, ICU LOS, ICU readmission, total morphine milligram equivalent (MME) consumption on postoperative days 1 and 2, and 30-day cardiac surgery complications (eg, 30-day mortality, 30-day permanent stroke, postoperative renal failure, postoperative transfusion, redo surgery for bleeding, postoperative atrial fibrillation, deep sternal wound infection, discharge to home, and 30-day readmission).

All analyzed data were harvested from an institutional CABG database prospectively maintained by the hospital's Cardiovascular Quality Department, as well as from queries of the institutional electronic medical record database. All data elements were defined according to the Society of Thoracic

Table 1
ERACS Protocol Summary

ERACS Society Recommendation (8)	Classification of Recommendation (8)	Institutional ERACS Protocol (2018)
Tranexamic acid or epsilon aminocaproic acid during on-pump cardiac surgery	Class I	Tranexamic acid 5 mg/kg/h with dose adjustment based on renal function; epsilon amicaproic acid with a history of seizures
Perioperative glycemic control	Class I	Intraoperative and postoperative insulin infusion with computer-directed algorithm (ie, Glucommander) for target serum glucose 100-140 mg/dL
Care bundle: Surgical site infection	Class I	3M nasal swab prior to surgery; intravenous cephalosporin and vancomycin routine prophylactic antibiotics administered within 30-60 min prior to incision with substitution based on allergy profile and/or additional concern for non-staphylococcus infection; chest hair clipping immediately prior to surgery; chlorhexidine skin preparation the day before and the morning of surgery; daily incision assessment and removal of surgical dressing at 48 h
Goal-directed fluid therapy	Class I	Perioperative management of fluids, inotropes, and vasopressors guided by blood pressure goals and data that include but may not be limited to cardiac index, systemic venous oxygen saturation, pulmonary artery pressure, right atrial pressure, intraoperative and postoperative echocardiographic findings, urine output, perioperative serum lactate trends, daily fluid balance, and daily weight monitoring
Perioperative, multi-modal, opiate-sparing pain management plan	Class I	Gabapentin 600 mg in preoperative holding unit; minimize intraoperative narcotics and sedatives at discretion of anesthesiologist; intraoperative ketamine at discretion of anesthesiologist; acetaminophen every 6 h on POD 0-2 and then prn; ketorolac every 6 h on POD 0-1 if serum creatine <1.2 mg/dL on; ibuprofen every 8 h on POD 2 when ketorolac is no longer used and then prn on POD 3-5; intravenous hydromorphone every 3 h prn on POD 0-2; tramadol prn every 6 h or oral hydromorphone prn every 6 h on POD 3-5; discretionary use of Dexmedetomidine for sedation and analgesia in intubated patients postoperatively
Avoidance of persistent hypothermia ($<36^{\circ}C$) after bypass in the early postoperative period	Class I	Routine intraoperative use of intravenous fluid warming and underbody forced air warming; discretionary used of warming irrigation fluids intraoperatively and discretionary elevation of ambient room temperature
Maintenance of chest tube patency	Class I	Routine postoperative maintenance of chest tube patency without breaking the sterile field
Postoperative systematic delirium screening tool use	Class I	Discretionary use of delirium screening tools postoperatively
Smoking and hazardous alcohol consumption cessation	Class I	Preoperative screening and education regarding smoking and nicotine cessation and reduced alcohol consumption prior to surgery
Early detection of kidney stress and interventions to avoid acute kidney injury	Class II	Monitoring of creatinine, urine output, perioperative optimization of volume status and hemodynamic parameters
Use of rigid sternal fixation	Class II	Selective use of rigid sternal fixation for high-risk patients (eg, high body mass index and/or challenging sternal closure)
Prehabilitation for patients undergoing elective surgery with multiple comorbidities or significant deconditioning	Class II	Patient education and consultation as appropriate for optimization of nutritional status, preoperative exercise training, and social support
Postoperative insulin infusion to treat hyperglycemia	Class IIa	Glucommander insulin infusion protocol for perioperative glycemic control
Strategy for postoperative extubation within 6 h	Class IIa	Inspired oxygen concentration weaned to maintain oxygen saturation $\geq 90\%$; postoperative sedation titrated for tolerance of endotracheal tube without suppression of spontaneous respiratory drive; antiemetic prophylaxis; opiate-sparing analgesia; ventilator wean protocol
Use of patient engagement tools	Class IIa	Preoperative education supported by written materials, physical aids (eg, incentive spirometry, chest stabilization heart pillow), and consultations as required
Chemical or mechanical thromboprophylaxis after surgery	Class IIa	Sequential compressive device POD 0-5; chemical thromboembolism prophylaxis POD 1-5
Preoperative hemoglobin A1c risk stratification	Class IIa	Preoperative hemoglobin A1c at discretion of surgeon; routine preoperative finger stick blood sugar
Preoperative correction of nutritional deficiency when feasible	Class IIa	Routine preoperative nutritional screening; perioperative nutritional consultation as indicated
Clear liquids until 2-4 h prior to general anesthesia	Class IIb	Sips of water and/or ice chips sparingly within 2-4 h prior to surgery
Preoperative oral carbohydrate loading	Class IIb	Patient may consume up to 16 oz of a 0-calorie drink between midnight and arrival to the hospital

(*continued*)

Table 1 (*continued*)

ERACS Society Recommendation (8)	Classification of Recommendation (8)	Institutional ERACS Protocol (2018)
Preoperative anemia	Ungraded	Intraoperative blood conservation strategies (eg, cell saver, intraoperative antifibrinolytic); preoperative iron and erythropoietin (Procrit) considered in Jehovah's Witness patients and patients with end-stage renal disease
Intraoperative anesthetic	Ungraded	Low-dose narcotic and/or sedation anesthesia management at discretion of anesthesiologist; Intraoperative antiemetic administration and postoperative muscle relaxant reversal are recommended
Perfusion characteristics	Ungraded	Optimization of perfusion flow rates based on patient's body mass index and infusion cannula size guided by perfusion MAP goal with consideration of cerebral perfusion risk and renal perfusion risk
Preoperative sleep apnea screening	Ungraded	Routine STOP-Bang screening and recommendations for nocturnal oximetry in reflection of intermediate- or high-risk score; if on CPAP prior to surgery CPAP machine brought to hospital prior to surgery
Intraoperative protective lung ventilation strategy	Ungraded	Intraoperative low tidal volume ventilation, <100% oxygen intraoperatively as tolerated, positive end-expiratory pressure as tolerated
Postoperative atelectasis prophylaxis	Ungraded	Deep breathing and coughing exercises POD 0-5; Incentive spirometry 10x/h POD 0-5; PEP therapy for secretions as needed POD 1-5
Sacral decubitus prophylaxis	Ungraded	Mepilex placed on coccyx in preoperative holding unit; Braden Assessment POD 1-5
Chest tube and foley	Ungraded	Remove POD 1 as tolerated
Diuresis	Ungraded	Consider POD 1-5
β-blockers, statins, aspirin	Ungraded	Resume POD 1
Early postoperative enteral feeding and mobilization	Ungraded	Light diet on POD 1; cardiac diet as tolerated POD 2-5; sitting up in chair for meals POD 1-5; bowel regimen if needed POD 1-5 (consider suppository, Milk of Magnesia); progressive ambulation with assistance, documentation of distance, and progression toward independence POD 1-5; fall risk assessment POD 2-5; assess climbing stairs for home safety POD 3-5
Transition planning	Ungraded	Assessment of home care needs and supplies, local pharmacy identification, verification of transportation home, enoxaparin teaching if applicable, Coumadin teaching if applicable, diabetic/glucometer/insulin teaching if applicable POD 0-2; education regarding wound care/showering/bathing, signs and symptoms of infection, deep venous thrombosis prophylaxis, activity completed POD 3-5; consider consultations for cardiac rehabilitation, home health care, home safety evaluation POD 3-5

Abbreviations: CPAP, continuous positive airway pressure; ERACS, enhanced recovery after cardiac surgery protocol; MAP, mean arterial pressure; PEP, positive extubation pressure; POD, postoperative day; prn, administration of non-scheduled medicine as needed.

Surgeons Adult Cardiac Surgery Data Registry, including the following definition for emergent and urgent procedures: "Emergent: The surgical procedure must be performed within 24 hours of presentation; Urgent: All of the following conditions are met: a) Not elective status; b) Not emergent status; c) Procedure required during same hospitalization in order to minimize chance of further deterioration."[14] The method for calculating total MME consumption on postoperative days 1 and 2 has been reported previously.[15]

Statistical Analysis

Data are presented as mean and SD when normally distributed, as median and IQR when non-normally distributed and when nonparametric, and as proportions (%) when categorical. Normality was determined by visually assessing histograms and reviewing skewness and kurtosis. The chi-square or Fisher exact tests were used to compare pre-ERAS and post-ERAS cohorts on the categorical variables. Student *t*-tests were used for the continuous variables if the variables were distributed normally, and the Mann-Whitney *U* test was used for the continuous variables that did not meet the assumption of normality.

To examine the mean LOS consecutively over time, a segmented linear regression model, as demonstrated by Mascha et al.,[16] was used to explore level and slope changes prior to and after ERAS. The intercept for pre- and postintervention means the average LOS and the end of the pre-ERAS period and the beginning of the pre-ERAS period, respectively. The slopes of the pre- and post-intervention lines are the monthly change in the average LOS trend during the pre- and post-ERAS periods. To consider confounding factors, an additional model included adjustment for the following covariates: mean cross-clamp time, percent of cases in which blood products were used postprocedure, left ventricular ejection fraction, and the percent of cases in which an intra-aortic balloon pump (IABP) was used. To assess autocorrelation in the time series data, the Durbin-Watson test was used. If autocorrelation was observed, standard errors were adjusted using the Cochrane-Orcutt estimation.

Propensity-score matching was performed to address confounding variables that may influence LOS. The propensity score was calculated from a logistic regression analysis by modeling ERAS (pre-ERAS = 0; post-ERAS = 1) as the dependent variable and left ventricular ejection fraction, IABP use, postprocedure blood products used, and cross-clamp time as covariates. Patients were matched 2:1 using nearest-neighbor matching, with a caliper of 0.15 SD of the propensity score.

The quality of the matching was determined by assessing whether any variable or linear combination of variables was significantly unbalanced after matching, using the model imbalance chi-square test. Overall mode performance was measured using Nagelkerke's R2, a measure of explained variance and the Hosmer-Lemeshow test. All effects were considered significant at p values < 0.05.

The implementation of ERAS in isolated CABG has been associated with a reduction in LOS from a median (IQR) of 7 (5-9) days to 6 (5-8) days.[17] The authors assumed that similar results would be observed in their study population. To detect a difference of 1 using a 2-sided Mann-Whitney *U* or Wilcoxon Rank-Sum test, the authors would require 151 patients per group to achieve 90% power when alpha (significant level) is 0.05 and the SD is 2.5 in both groups.[18]

Statistical analyses were performed with SPSS v26.0 (IBM SPSS, Inc, Armonk, NY). Propensity score matching was performed using Propensity Score Matching for SPSS, version 24.0. All effects were considered significant at a 2-way $p < 0.05$.

Results

A total of 1,012 patients undergoing urgent or emergency isolated CABG were analyzed, including 346 in the pre-ERAS cohort and 666 in the post-ERAS cohort. After propensity-score matching, 330 and 565 patients remained in the pre-ERAS and post-ERAS cohorts, respectively. Details of the study design, excluded patients, and patients included in statistical analyses are outlined in Figure 1.

Baseline Characteristics, Operative Technique, and Indications for Urgent and Emergency CABG, Pre-ERAS Versus Post-ERAS

Table 2 compares the baseline characteristics, operative technique, urgent versus emergency surgical status, and indications for CABG in the pre-ERAS versus post-ERAS cohorts. There were no statistically significant differences between the pre-ERAS and post-ERAS cohorts regarding baseline clinical

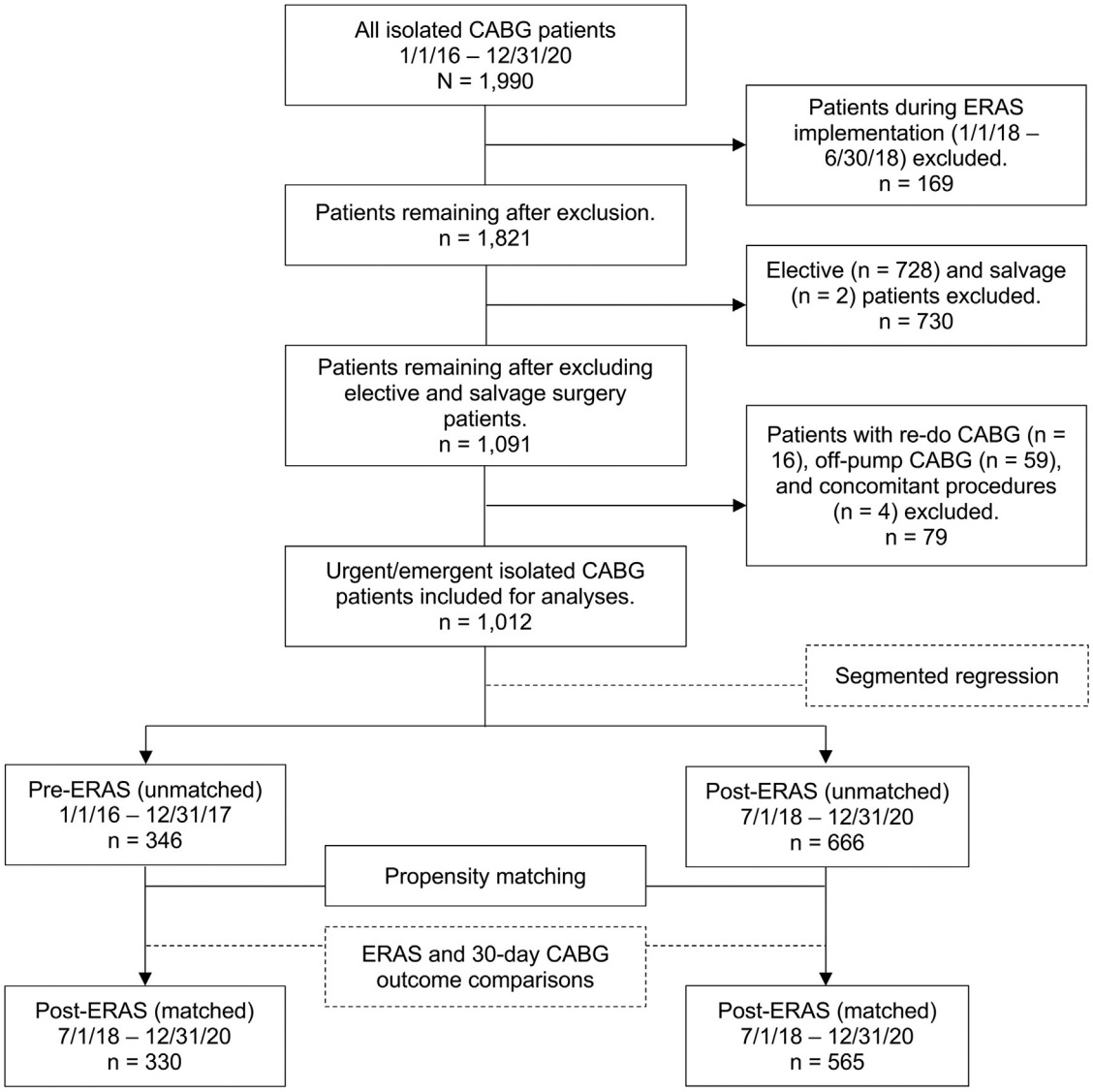

Fig 1. Flow chart detailing study design and statistical analyses. CABG, coronary artery bypass graft surgery; ERAS, enhanced recovery after surgery.

Table 2
Unmatched and Matched Clinical Characteristics, Operative Technique, and Indications for Urgent/Emergency CABG Compared Between Pre-ERAS and Post-ERAS Cohorts

Parameter	Unmatched			Matched		
	Pre-ERAS (n = 346)	Post-ERAS (n = 666)	p Value	Pre-ERAS (n = 330)	Post-ERAS (n = 565)	p Value
Demographic data, mean ± SD or n (%)						
Age, y, mean ± SD	66.5 ± 11.5	66.5 ± 10.5	0.974	66.7 ± 11.5	66.5 ± 10.3	0.827
Sex, female, n (%)	72 (20.8)	145 (21.8)	0.723	71 (21.5)	115 (20.4)	0.680
Body mass index, kg/m^2, mean ± SD	30.4 ± 5.9	29.7 ± 6.3	0.082	30.3 ± 5.7	29.7 ± 6.5	0.172
Procedure type, n (%)			0.623			0.446
Urgent	337 (97.4)	645 (96.8)		321 (97.3)	554 (98.1)	
Emergent	9 (2.6)	21 (3.2)		9 (2.7)	11 (1.9)	
Indication, n (%)			0.385			0.503
STEMI	31 (9.0)	62 (9.3)		29 (8.8)	51 (9.0)	
NSTEMI	192 (55.5)	337 (50.6)		181 (54.8)	281 (49.7)	
Unstable angina pectoris	84 (24.3)	194 (29.1)		84 (25.5)	165 (29.2)	
Other*	39 (11.3)	73 (11.0)		36 (10.9)	68 (12.0)	
Cardiovascular risk factors, n (%)						
Diabetes	159 (46.0)	332 (49.8)	0.376	153 (46.4)	276 (48.8)	0.473
Hypertension	300 (86.7)	593 (89.0)	0.394	288 (87.3)	502 (88.8)	0.479
Smoking, prior or current	223 (64.5)	430 (64.6)	0.971	212 (64.2)	361 (63.9)	0.917
Comorbidities, n (%)						
Prior transient ischemic attack	17 (4.9)	29 (4.4)	0.195	16 (4.9)	23 (4.1)	0.567
Prior stroke	22 (6.4)	67 (10.1)	0.056	22 (6.7)	49 (8.7)	0.284
Chronic obstructive pulmonary disease	86 (24.9)	142 (21.3)	0.183	75 (22.7)	115 (20.4)	0.402
Atrial fibrillation	32 (9.2)	50 (7.5)	0.055	32 (9.7)	43 (7.6)	0.054
Paroxysmal	22 (6.4)	44 (6.6)		22 (6.7)	38 (6.7)	
Persistent	10 (2.9)	6 (0.9)		10 (3.0)	5 (.9)	
Dialysis	11 (3.2)	14 (2.1)	0.447	10 (3.0)	11 (1.9)	0.302
Peripheral vascular disease	41 (11.8)	96 (14.4)	0.228	39 (11.8)	80 (14.2)	0.320
Cancer diagnosis within 5 y	23 (6.6)	51 (7.7)	0.558	23 (7.0)	41 (7.3)	0.872
History mediastinal radiation	5 (1.4)	12 (1.8)	0.675	5 (1.5)	9 (1.6)	0.928
Immunosuppression therapy	14 (4.0)	40 (6.0)	0.322	14 (4.2)	34 (6.0)	0.255
Prior cardiac interventions, n (%) or mean ± SD						
Prior percutaneous coronary intervention	72 (20.8)	178 (26.7)	0.530	71 (21.5)	145 (25.7)	0.162
Prior pacemaker	3 (0.9)	6 (0.9)	0.963	3 (.9)	5 (.9)	0.970
Prior carotid artery surgery or stent	9 (2.6)	20 (3.0)	0.671	9 (12.0)	14 (11.9)	0.977
STS risk (PROM)	2.5 ± 3.3	2.4 ± 4.0	0.622	2.6 ± 3.4	2.3 ± 3.8	0.191
Preoperative catheterization data, n (%)						
Coronary anatomy			0.645			0.183
1-vessel disease	3 (0.9)	9 (1.4)		3 (.9)	2 (.4)	
2-vessel disease	57 (16.5)	97 (14.6)		56 (17.0)	73 (12.9)	
3-vessel disease	286 (82.7)	560 (84.1)		271 (82.1)	490 (86.7)	
Preoperative echocardiography data, mean ± SD or n (%)						
Left ventricular ejection fraction			0.250			0.314
Normal (≥55)	158 (45.7)	359 (54.2)		157 (45.6)	300 (53.1)	
Mild (40-54)	106 (30.6)	178 (26.9)		99 (30.0)	157 (27.8)	
Moderate (35-39)	22 (6.4)	46 (6.9)		22 (6.7)	39 (6.9)	
Severe (≤34)	60 (17.3)	79 (11.9)		52 (15.8)	69 (12.2)	
Medication use, n (%)						
Preoperative β-blockers	321 (92.8)	620 (93.1)	0.553	307 (93.0)	527 (93.3)	0.439
Postoperative β-blockers	328 (94.8)	639 (95.9)	0.401	315 (95.5)	541 (95.8)	0.833
Operative details, mean ± SD or n (%)						
Cross-clamp time, min	73.1 ± 27.5	65.6 ± 22.8	< 0.001	70.6 ± 24.3	67.9 ± 22.7	0.093
Perfusion time, min	98.9 ± 34.7	91.1 ± 29.1	< 0.001	96.0 ± 31.4	92.9 ± 27.8	0.131
Intra-aortic balloon pump use	22 (6.4)	77 (11.6)	< 0.001	22 (6.7)	44 (7.8)	0.536
Vein anastomoses	2.2 ± 1.2	2.0 ± 0.8	0.039	2.2 ± 1.1	2.1 ± 0.8	0.107
Artery anastomoses	1.6 ± 1.0	1.6 ± 0.8	0.640	1.5 ± 0.9	1.6 ± 0.8	0.076
Intraoperative transfusion	82 (23.7)	205 (30.8)	0.020	79 (23.9)	153 (27.1)	0.301
Postoperative transfusion	138 (39.9)	216 (32.4)	0.018	125 (37.9)	188 (33.3)	0.163

Abbreviations: CABG, coronary artery bypass surgery; ERAS, enhanced recovery after surgery; NSTEMI, non-ST-elevation myocardial infarction; PROM, Society of Thoracic Surgeons 30-Day Predicted Risk of Mortality Score; STEMI, ST-elevation myocardial infarction; STS, Society of Thoracic Surgeons.

* "Other" represents those with left main or multi-vessel coronary artery disease as an indication for CABG.

Table 3
Comparison of Non-Narcotic Analgesic Use Between Propensity-Matched Pre-ERAS and Post-ERAS Cohorts

	Preoperative			Intraoperative			Postoperative (0-72 h)			Any Time		
Non-narcotic analgesics, n (%)	Pre-ERAS (n = 245)	Post-ERAS (n = 565)	p Value	Pre-ERAS (n = 245)	Post-ERAS (n = 565)	p Value	Pre-ERAS (n = 245)	Post-ERAS (n = 565)	p Value	Pre-ERAS (n = 245)	Post-ERAS (n = 565)	p Value
Acetaminophen	40 (16.3)	101 (17.9)	1.000	0 (0.0)	0 (0.0)	-	209 (85.3)	563 (99.6)	< 0.001	215 (87.8)	563 (99.6)	< 0.001
Dexmedetomidine	1 (0.4)	1 (0.2)	1.000	2 (0.8)	6 (1.1)	1.000	32 (13.1)	119 (21.1)	.210	32 (13.1)	119 (21.1)	.210
Gabapentin	17 (6.9)	60 (10.6)	1.000	0 (0.0)	0 (0.0)	-	51 (20.8)	67 (11.9)	0.027	54 (22.0)	92 (16.3)	0.150
Ibuprofen	0 (0.0)	1 (0.2)	1.000	0 (0.0)	0 (0.0)	-	23 (9.4)	126 (22.3)	< 0.001	23 (9.4)	126 (22.3)	< 0.001
Ketamine	3 (1.2)	3 (0.5)	1.000	110 (44.9)	325 (57.5)	< .001*	1 (0.4)	12 (2.1)	1.000	112 (45.7)	327 (57.9)	< 0.001
Ketorolac	0 (0.0)	3 (0.5)	1.000	0 (0.0)	0 (0.0)	-	67 (27.3)	262 (46.4)	< 0.001	67 (27.3)	262 (46.4)	< 0.001

Abbreviation: ERAS, enhanced recovery after surgery.
* Mean intraoperative ketamine dose did not change significantly between the pre-ERAS cohort (55.5 ± 34 mg) and the post-ERAS cohort (50 ± 6 mg) (p = 0.09).

characteristics, the percentage of patients undergoing urgent or emergency CABG, or the clinical indications for urgent or emergency CABG.

Regarding operative technique, prior to matching, patients in the pre-ERAS cohort had a longer mean cross-clamp time (p < 0.001), a longer mean perfusion time (p < 0.001), a lower likelihood of IABP use (p < 0.001), a lower likelihood of intraoperative transfusion (p = 0.020), a higher likelihood of postoperative blood transfusion (p = 0.018), and a higher mean number of vein anastomoses (p = 0.039). After matching, there were no longer statistically significant differences between the pre-ERAS and post-ERAS cohorts with respect to these variables.

Non-Narcotic Analgesic Use in Propensity-Matched Pre-ERAS Versus Post-ERAS Cohorts

Table 3 compares non-narcotic analgesic use in propensity-matched pre-ERAS and post-ERAS cohorts. Although a higher percentage of patients were administered gabapentin prior to surgery in the matched post-ERAS cohort, and a higher percentage of patients were administered dexmedetomidine within 72 hours postoperatively in the matched post-ERAS cohort, there was no statistically significant difference in the use of either gabapentin or dexmedetomidine associated with ERAS implementation.

There were statistically significant increases in the use of acetaminophen, ibuprofen, ketamine, and ketorolac in the matched post-ERAS cohort. The mean intraoperative dose of ketamine was not statistically different between the pre-ERAS and post-ERAS cohorts (approximately 50 mg), and, therefore, the difference in post-ERAS use of ketamine was increased frequency of use rather than a change in dosing.

There was a statistically significant increase in postoperative administration of acetaminophen, ibuprofen, and ketorolac within the first 72 hours after urgent or emergency CABG surgery for the matched post-ERAS cohort versus the matched pre-ERAS cohort.

Postoperative Outcomes for Urgent and Emergency CABG, Pre-ERAS Versus Post-ERAS

Table 4 compares postoperative ERAS outcomes and 30-day cardiac surgery outcomes between pre-ERAS and post-ERAS cohorts. Regarding ERAS outcomes, prior to matching, post-ERAS patients had a greater likelihood of early extubation (p = 0.002), shorter ventilation time (p = 0.001), lower mean MME use on postoperative days 1 and 2 (p < 0.001), and a reduced mean total LOS (p = 0.009). After matching, these differences in outcomes between the pre-ERAS and post-ERAS cohorts remained.

Regarding 30-day CABG outcomes, no statistically significant differences were observed between the pre-ERAS and post-ERAS cohorts either prior to or following matching.

Segmented Regression Analysis of the Effects of ERAS Implementation on Mean Monthly Total LOS, Pre-ERAS Versus Post-ERAS

Graphic illustration of mean LOS relative to the month prior to and after ERAS implementation demonstrated stable trends in the pre-ERAS and post-ERAS periods (Fig 2). An immediate effect on the reduction in the mean LOS associated with ERAS implementation was observed, and the projected preintervention trend for the mean LOS was similar to the postintervention trend line. The Durbin-Watson Test for autocorrelation was not significant for either the unadjusted or the adjusted model (1.94, p = 0.26; 1.92, p = 0.25, respectively).

Table 5 displays results of segmented regression model analyses for mean monthly total LOS data during the pre-ERAS and post-ERAS periods. The unadjusted results reflect the visual inspection of the data (Fig 2), and demonstrate that there was no significant change in the mean LOS month-by-month during the pre-ERAS period (β_1 coefficient: 0.045, 95% CI: [-0.059 to 0.149], p = 0.385). There was a statistically significant decrease in the mean LOS from just before to just after the start of ERAS (β_2 coefficient -2.601 [-4.865 to

Table 4
ERAS and 30-Day CABG Outcomes Data Compared Between Pre-ERAS and Post-ERAS Cohorts

Parameter	Unmatched			Matched		
	Pre-ERAS (n = 346)	Post-ERAS (n = 666)	p Value	Pre-ERAS (n = 330)	Post-ERAS (n = 365)	p Value
ERAS outcomes, n (%) or median (IQR) or mean ± SD						
Extubation <6 h	121 (35.0)	302 (45.3)	.002	118 (35.8)	260 (46.0)	.003
Ventilation time, h	7.4 (5.5-12.6)	6.4 (5.1-10.2)	.001	7.2 (5.4-12.2)	6.3 (5.1-10.2)	.003
Prolonged ventilation	21 (6.1)	43 (6.5)	.610	19 (14.1)	33 (15.6)	.704
Reintubated	14 (4.0)	18 (2.7)	.584	12 (3.6)	14 (2.5)	.319
ICU length of stay, h	43 (23-76)	46 (23-86)	.268	42 (23-74)	45 (23-73)	.586
ICU readmitted	13 (3.8)	17 (2.6)	.280	11 (3.3)	14 (2.5)	.449
Total length of stay, d	10 (8-14)	9 (8-13)	.009	10 (8-14)	9 (8-13)	.015
MME use on POD 1 and 2	99.6 ± 61.8	71.4 ± 64.2	< .001	99.0 ± 61.6	69.6 ± 62.2	< .001
30-day CABG outcomes, n (%)						
Stroke	4 (1.2)	9 (1.4)	.794	4 (1.2)	6 (1.1)	.751
Renal failure	7 (2.0)	14 (2.1)	.823	6 (4.4)	13 (6.1)	.501
Reoperation for bleeding	5 (1.4)	14 (2.1)	.386	5 (3.7)	9 (4.2)	.803
Deep sternal wound infection	1 (0.3)	1 (0.2)	.637	1 (0.3)	1 (0.2)	.700
Postoperative atrial fibrillation	103 (29.8)	184 (27.6)	.849	101 (74.8)	154 (72.6)	.655
Discharge to home	250 (72.3)	487 (73.1)	.693	245 (74.2)	421 (74.5)	.929
30-day readmission	38 (11.0)	79 (11.9)	.825	36 (10.9)	70 (12.4)	.730
30-day mortality	6 (1.7)	10 (1.5)	.742	6 (1.8)	10 (1.8)	.746

Abbreviations: CABG, coronary artery bypass surgery; ERAS, enhanced recovery after surgery; ICU, intensive care unit; MME, morphine milligram equivalents; POD, postoperative day.

-0.336], p = 0.025), and the difference in slope trend over time for post-ERAS LOS did not reach the threshold for statistical significance when compared to the slope for pre-ERAS LOS (β_3 coefficient 0.006 [-0.110 to 0.121], p = 0.121).

After adjusting for confounding, the findings were similar to the unadjusted linear regression model. The mean LOS at the end of the pre-ERAS period (intercept) was 22 days. Before ERAS was implemented, there was no statistically significant change in mean LOS monthly during the pre-ERAS period (p = 0.286). After the ERAS was implemented, the mean LOS dropped by 1.9 days (p = 0.037). There was no significant change in the monthly mean LOS during the post-ERAS period (p = 0.852).

Discussion

The results from this study demonstrated 3 important findings. First, this study added further evidence regarding the efficacy of ERAS programs in decreasing ventilation time,[13] increasing the likelihood of early extubation,[2,13] and

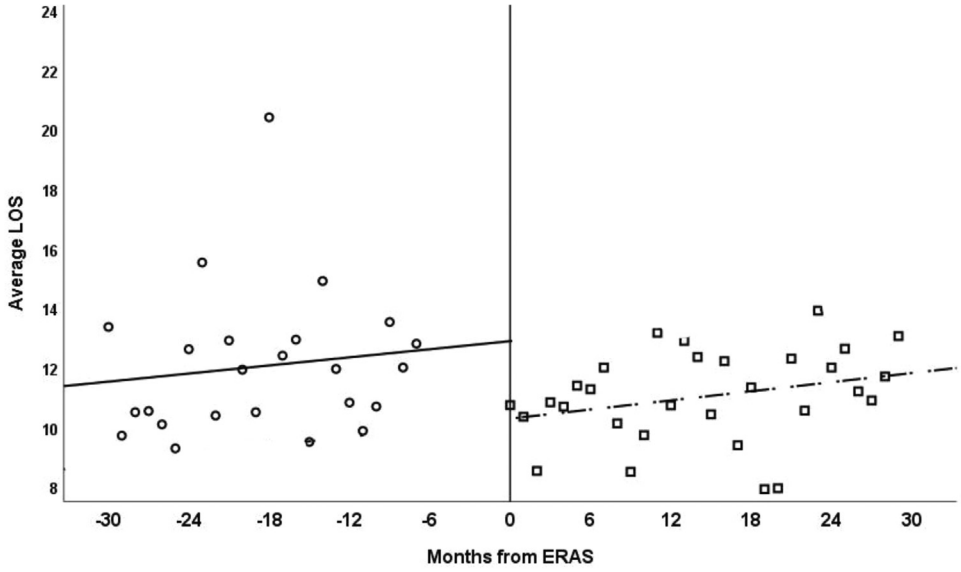

Fig 2. Segmented regression analysis of total LOS over the study period. Months -30 to -6 represent pre-ERAS, months 0 to 30 represent post-ERAS, and months -6 to 0 represent the ERAS implementation period. ERAS, enhanced recovery after surgery; LOS, length of stay.

Table 5
Unadjusted and Adjusted Segmented Regression Analyses for Aggregated Monthly Mean Total LOS for Urgent or Emergency CABG

	Parameter	Estimate	Standard Error	p Value	Lower 95% CI	Upper 95% CI
Unadjusted	Intercept	12.887	1.051	0.000	10.777	14.998
	Time, pre-ERAS	0.045	0.052	0.385	-0.059	0.149
	Intervention	-2.601	1.127	0.025	-4.865	-0.336
	Time, post-ERAS	0.006	0.058	0.922	-0.110	0.121
Adjusted*	Intercept	22.055	6.414	0.001	9.145	34.965
	Time, pre-ERAS	0.059	0.054	0.286	-0.051	0.168
	Intervention	-1.943	0.905	0.037	-3.766	-0.121
	Time, post-ERAS	-0.011	0.061	0.852	-0.134	0.111

Abbreviations: CABG, coronary artery bypass surgery; ERAS, enhanced recovery after surgery; IABP, intra-aortic balloon pump; LOS, length of stay; LVEF, left ventricular ejection fraction.

* Adjusted for LVEF, blood bank products used, cross-clamp time, and IABP used.

decreasing LOS associated with cardiac surgery.[3,4] Second, this study provided evidence that ERAS implementation was not associated with detrimental effects on 30-day cardiac surgery morbidity and mortality in urgent or emergency CABG for the authors' study population. Third, to the authors' knowledge, this study was the first report to demonstrate the feasibility of ERAS as a quality improvement initiative that has the potential to address the population health priorities of value-based healthcare, specifically in the context of patients undergoing urgent or emergency isolated CABG.

Opiate-sparing anesthesia and/or analgesia is a core component of cardiac surgery ERAS protocols.[1,12] This study found that ERAS implementation for urgent or emergency CABG was associated with decreased postoperative MME use, increased likelihood of intraoperative ketamine use, and increased likelihood of postoperative administration of acetaminophen, ibuprofen, and ketorolac. The following are several potential benefits of increased ketamine use, as found in the post-ERAS cohort: (1) reduced postoperative opioid consumption and reduced pain intensity, (2) reduced inflammation and stress response, (3) reduced respiratory depression, and (4) reduced likelihood of delirium associated with high- dose opiate analgesia.[19-21] The authors acknowledge that, currently, the ERAS protocols for cardiac surgery patients are evolving, and future cardiac surgery ERAS recommendations may emphasize regional anesthesia either preoperatively or postoperatively, as well as other modifications such as goal-directed perfusion and preoperative anemia management.[22-25] Nevertheless, the authors believe that multimodal analgesia with intraoperative ketamine and postoperative acetaminophen, ibuprofen, and ketorolac, as demonstrated by the current study, may provide a reliable approach to opiate-sparing analgesia for urgent or emergency cardiac surgery when regional anesthesia techniques may be difficult to implement due to institutional factors or, alternatively, when patient factors might render regional anesthesia impractical due to systemic anticoagulation or immobilization associated with use of an IABP, mechanical assist device, or the presence of an open sternum.

Approaches to opiate-sparing analgesia that achieve effective analgesia associated with decreased respiratory depression may enable shortened postoperative ventilation time, and also increase the likelihood of early extubation. Preoperative gabapentin administration is a component of the current ERAS recommendations, but the authors found that only 10.6% of propensity-matched post-ERAS patients in their study population received gabapentin prior to surgery. The authors believe that the relatively low use of gabapentin prior to surgery reflects adherence to guidelines to restrict oral intake within 6 hours prior to surgery. The precise timing of surgery is often not known due to urgent or emergency status. As a result, the actual time window to restrict oral medications and fluids in the authors' study population may have been fewer than or greater than 6 hours, and strict adherence to these guidelines is presumed not to have occurred for gabapentin administration or for carbohydrate-enriched oral fluid intake prior to urgent or emergency CABG.

This study found that ERAS implementation in urgent and emergency CABG at the authors' institution was associated with decreased opioid use, increased intraoperative ketamine use, increased postoperative acetaminophen, ibuprofen, and ketorolac use, increased likelihood of early extubation, and decreased likelihood of prolonged ventilation. The authors believe these findings not only demonstrated an effect of ERAS implementation, but also suggested that there was compliance with the opiate-sparing elements of the ERAS protocol.

Prolonged ventilation is more likely to occur after urgent CABG,[7] is a predictor of ICU readmission in cardiac surgery, and is a predictor of in-hospital mortality in emergency CABG.[26,27] This study did not detect statistically significant differences in the likelihood of prolonged ventilation, reintubation, ICU readmission, or 30-day mortality between the pre-ERAS and post-ERAS cohorts. The authors believe that these findings supported the conclusion that ERAS implementation was safe in their study population and that similar ERAS protocols also may be safe for patients undergoing urgent or emergency CABG in similar institutional settings.

This was the largest reported series of urgent or emergency isolated CABG patients to evaluate the effects associated with the implementation of an ERAS protocol. The authors observed 1.7% (pre-ERAS) and 1.5% (post-ERAS) 30-day mortality rates, whereas prior reports with smaller sample sizes reported mortality rates that approximated 6% to 9%.[5,7,8] This

could be due to several factors, presented as follows: (1) possible improvements in medical therapy, surgical intervention, and/or percutaneous coronary intervention for acute coronary syndrome realized by the authors' study but not earlier studies; (2) the high representation of urgent (~97%) rather than emergent (~3%) CABG in the authors' study; and (3) baseline clinical differences between the authors' study population and the populations described in prior reports.

A retrospective study of 50 patients reported a mortality rate of 9.6% for urgent CABG, for which 54% of the study population presented with STEMI and 28% presented with NSTEMI.[7] A more recent report of emergent CABG reported a 9.9% mortality rate, with 42% of patients presenting with STEMI.[8] This population included patients who presented with complications of acute myocardial infarctions that required surgical intervention, such as ventricular septal perforation or severe valve regurgitation. In contrast to these reports, the authors' study population consisted of 9% of patients presenting with STEMI and 53% with NSTEMI, and patients who required surgical interventions other than isolated CABG were excluded.

In this study, hospital LOS was significantly reduced after ERAS implementation. This suggested that the ERAS protocol may have been associated with increased efficiency in patient preparation for urgent or emergent isolated CABG and/or increased efficiency in postoperative mobilization after urgent or emergent CABG. Determination of the exact mechanism of these potential benefits of ERAS in urgent and emergent CABG will need to be explored further by studies that examine compliance with specific ERAS protocol elements.

This study had several strengths. First, this study examined early postoperative mobilization outcomes as well as 30-day CABG outcomes, which, in combination, address the feasibility of ERAS for urgent or emergent CABG in the authors' study population. Second, this study examined 1,012 patients undergoing urgent or emergent CABG at a single institution with a stable perioperative clinical care team and an ERAS protocol that is consistent with contemporary ERAS Society recommendations.[12] The large sample size enabled sufficient power to detect statistically significant differences in ERAS outcomes between cohorts. Third, the use of segmented regression for an interrupted time series in the authors' analysis of the primary outcome, hospital LOS, addressed potential confounding biases such as the Hawthorne effect, regression to the mean, and maturation bias.[16] Importantly, the use of segmented regression analysis enabled the authors to determine that, in their study population, the effect of ERAS to reduce hospital LOS in urgent or emergency CABG was immediate, and that in their study population, there was sustained deviation between the observed total LOS after ERAS compared to values predicted by the pre-ERAS trend in total LOS. Finally, the results of segmental regression analysis addressed the authors' hypothesis that the demonstration of a beneficial effect of ERAS would require an improved intercept and/or improved slope, but it would also require that neither the intercept nor the slope was worse after ERAS implementation. In this study, segmental regression analysis of hospital LOS after urgent or emergent CABG demonstrated an improved intercept (ie, a reduced mean hospital LOS) with no statistically significant differences in slope over time following ERAS implementation.

The limitations of this study were associated primarily with the retrospective study design. The authors acknowledge that this study did not examine compliance with each ERAS protocol element with granular detail, and that such an analysis might have been achieved with a prospective study design. As a result, the authors acknowledge that this study did not elucidate which ERAS protocol elements were most important for achieving the outcomes observed in the Post-ERAS cohort, even though the authors believe that the results suggested there was compliance with opiate-sparing analgesia, a class I ERAS Society recommendation.

Finally, a second limitation of this study was that due to the exclusion criteria, the results cannot be extrapolated to all patients who might undergo urgent or emergent CABG. Examples of patients who underwent urgent or emergent CABG who were not included were those who underwent salvage CABG, urgent or emergency CABG with redo sternotomy, urgent or emergent CABG without use of cardiopulmonary bypass, or urgent or emergent CABG with concomitant surgical interventions.

The results of the current study supported the feasibility of ERAS in patients undergoing urgent or emergent isolated CABG when there is a primary sternotomy, and cardiopulmonary bypass is used. The authors' observation that ERAS was associated with shortened hospital LOS and no adverse effects on 30-day outcomes suggested that ERAS may help achieve important goals in a value-based healthcare system for the authors' study population and, potentially, for similar patient populations who undergo urgent or emergent CABG. The study authors recommend that future studies evaluate the following: (1) the association between ERAS implementation and outcomes after other urgent or emergent cardiac surgery procedures; (2) the association between ERAS implementation and the hospital costs associated with urgent or emergent cardiac surgery; and (3) the correlation of fidelity with ERAS protocol elements with outcomes after urgent or emergent cardiac surgery.

Conflict of Interest

None.

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