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Challenging Dogma by Skipping the Emergency Department Thoracotomy: A Propensity Score Matched Analysis of the Trauma Quality Improvement Database

Joseph C. L'Huillier, MD,[a,b,c] *Kabir Jalal, PhD,*[d] *Eden Nohra, MD,*[a,c] *Joseph D. Boccardo, MS,*[d] *Olatoyosi Olafuyi, BS,*[a] *Marcy Bubar Jordan, PhD,*[a,c] *Ajay A. Myneni, MBBS, PhD, MPH,*[a,b] *Steven D. Schwaitzberg, MD, FACS,*[a] *William J. Flynn Jr., MD, FACS,*[a,c] *Jeffrey J. Brewer, MD, FACS,*[a,c] *Katia Noyes, PhD, MPH,*[a,b] *and Clairice A. Cooper, MD, MHPE, FACS*[a,c,*]

[a] *Department of Surgery, University at Buffalo, Jacobs School of Medicine and Biomedical Sciences, Buffalo, New York*

[b] *Division of Health Services Policy and Practice, Department of Epidemiology and Environmental Health, University at Buffalo, School of Public Health and Health Professions, Buffalo, New York*

[c] *Division of Trauma, Critical Care, and Acute Care Surgery, Department of Surgery, Erie County Medical Center, Buffalo, New York*

[d] *Department of Biostatistics, University at Buffalo, School of Public Health and Health Professions, Buffalo, New York*

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ABSTRACT

Introduction: Survival following emergency department thoracotomy (EDT) for patients in extremis is poor. Whether intervention in the operating room instead of EDT in select patients could lead to improved outcomes is unknown. We hypothesized that patients who underwent intervention in the operating room would have improved outcomes compared to those who underwent EDT.

Methods: We conducted a retrospective review of the Trauma Quality Improvement Program database from 2017 to 2021. All adult patients who underwent EDT, operating room thoracotomy (ORT), or sternotomy as the first form of surgical intervention within 1 h of arrival were included. Of patients without prehospital cardiac arrest, propensity score matching was utilized to create three comparable groups. The primary outcome was survival. Secondary outcomes included time to procedure.

Results: There were 1865 EDT patients, 835 ORT patients, and 456 sternotomy patients who met the inclusion criteria. There were 349 EDT, 344 ORT, and 408 sternotomy patients in the matched analysis. On Cox multivariate regression, there was an increased risk of mortality with EDT *versus* sternotomy (HR 4.64, $P < 0.0001$), EDT *versus* ORT (HR 1.65, $P < 0.0001$), and ORT *versus* sternotomy (HR 2.81, $P < 0.0001$). Time to procedure was shorter

* *Corresponding author*. Erie County Medical Center, DK Miller Building, Office 310, 462 Grider Street, Buffalo, NY 14215.
E-mail address: cbakker@buffalo.edu (C.A. Cooper).

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with EDT *versus* sternotomy (22 min *versus* 34 min, $P < 0.0001$) and *versus* ORT (22 min *versus* 37 min, $P < 0.0001$).

Conclusions: There was an association between sternotomy and ORT *versus* EDT and improved mortality. In select patients, operative approaches rather than the traditional EDT could be considered.

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Introduction

The emergency department thoracotomy (EDT) is a last-ditch effort to resuscitate trauma patients in extremis.[1-3] The survival rates are poor: 10%-25% in penetrating trauma and 2%-8% in blunt trauma, although return of spontaneous circulation (ROSC) may be achieved in up to 35% of patients.[4-8] Both the Western Trauma Association and the Eastern Association for the Surgery of Trauma have developed guidelines for the appropriate use of EDT.[4,9] In practice, data suggest that clinicians apply these guidelines loosely and instead utilize patient-specific clinical judgment.[10,11] These practices may reflect the general dissatisfaction with the procedure's outcomes or the perceived lack of a viable alternative to performing this resuscitation in the emergency department (ED).

The primary goal of the EDT is to increase diastolic pressure by cross-clamping the aorta, thereby increasing coronary perfusion and obtaining ROSC, at which point patients are transferred to the OR. Instead of performing this procedure in the ED, it can be performed in the OR. In the 1980s, Jurkovich *et al.* analyzed a series of 34 patients who underwent operating room thoracotomy (ORT) rather than EDT at their institution, with survival rates of 75% in penetrating trauma and 20% in blunt trauma.[12] In the early 2000s, a multi-institutional study of 218 patients by Karmy-Jones *et al.* found that those who suffered a firearm injury and underwent an ORT were 22 times more likely to survive than those who underwent EDT.[13] If the procedure is performed in the operating room (OR), and once ROSC is obtained, surgeons can immediately address the cause of cardiovascular collapse. If the procedure is performed in the ED, the patient is typically transferred to the OR after ROSC is obtained before addressing the cause of cardiovascular collapse. If patients can tolerate the inevitable delay to the OR initially, surgeons could also consider performing a sternotomy in certain situations where repairing the inciting injury could restore diastolic pressure, increase coronary perfusion, and obtain ROSC. Direct-to-operating room (DTOR) protocols may make performing resuscitation in the OR more feasible by minimizing patient down time.[14]

In this study, we utilized the Trauma Quality Improvement Program (TQIP) database to compare outcomes between propensity score-matched (PSM) patients who underwent EDT *versus* ORT *versus* sternotomy within 60 min of ED arrival. We hypothesized that those who underwent intervention in the OR (ORT, sternotomy) would have improved outcomes compared to those who underwent EDT when matched on vital signs, injury severity, and anatomic injury.

Methods

Study design and patient population

A 5-y (2017-2021) retrospective analysis of the TQIP database was conducted. The TQIP database contains data from over 875 trauma centers in the United States and represents one of the largest databases of trauma patients.[15] It contains only deidentified data; therefore, institutional review board approval was exempted for this study. Data of all patients who underwent thoracotomy or sternotomy for hemorrhage control surgery were captured (Fig. 1). Patients aged <18 y old and those who had interfacility transfers, with advanced directives limiting care, who underwent the procedure >60 min after ED arrival time (consistent with prior studies on emergency surgery for hemorrhage control[6,14]), with nonblunt or nonpenetrating injuries, and with unknown prehospital cardiac arrest status were excluded. The difference between ED discharge time and procedure start time was used to separate the thoracotomy patients into EDT *versus* ORT. If the ED discharge time was greater than the procedure start time, the patient was deemed to have had an EDT. If the ED discharge time was less than the procedure start time, the patient was determined to have had an ORT. If ED discharge time was missing, they were excluded. For the ORT and sternotomy groups, only patients discharged from the ED to the OR were included.

Data extraction

A researcher performed the database search and extracted patients meeting inclusion criteria. Variables collected for each patient included admission year, demographics (age, sex, and race), comorbidities (alcohol use disorder, anticoagulation use, cirrhosis, chronic obstructive pulmonary disease, diabetes, hypertension, and smoking), prehospital cardiac arrest, ED admission vital signs (heart rate [HR], systolic blood pressure [SBP]), mechanism of injury (penetrating and blunt), and injury parameters (Glasgow coma scale [GCS], injury severity score, brain abbreviated injury score [AIS-brain], thoracic abbreviated injury score [AIS-thorax], abdominal abbreviated injury score [AIS-abdomen], and extremity abbreviated injury score [AIS-extremity]). Anatomic injuries were identified by the International Classification of Diseases (ICD) diagnosis code (Supplemental 1). The top 99 most commonly occurring injury codes identified among the study population were manually classified by the entire research team as pertaining to the heart, lung, other chest/chest wall, abdomen, or major vascular structures. Nonrelevant ICD injury codes (e.g. S00.81XA: abrasion of other part of

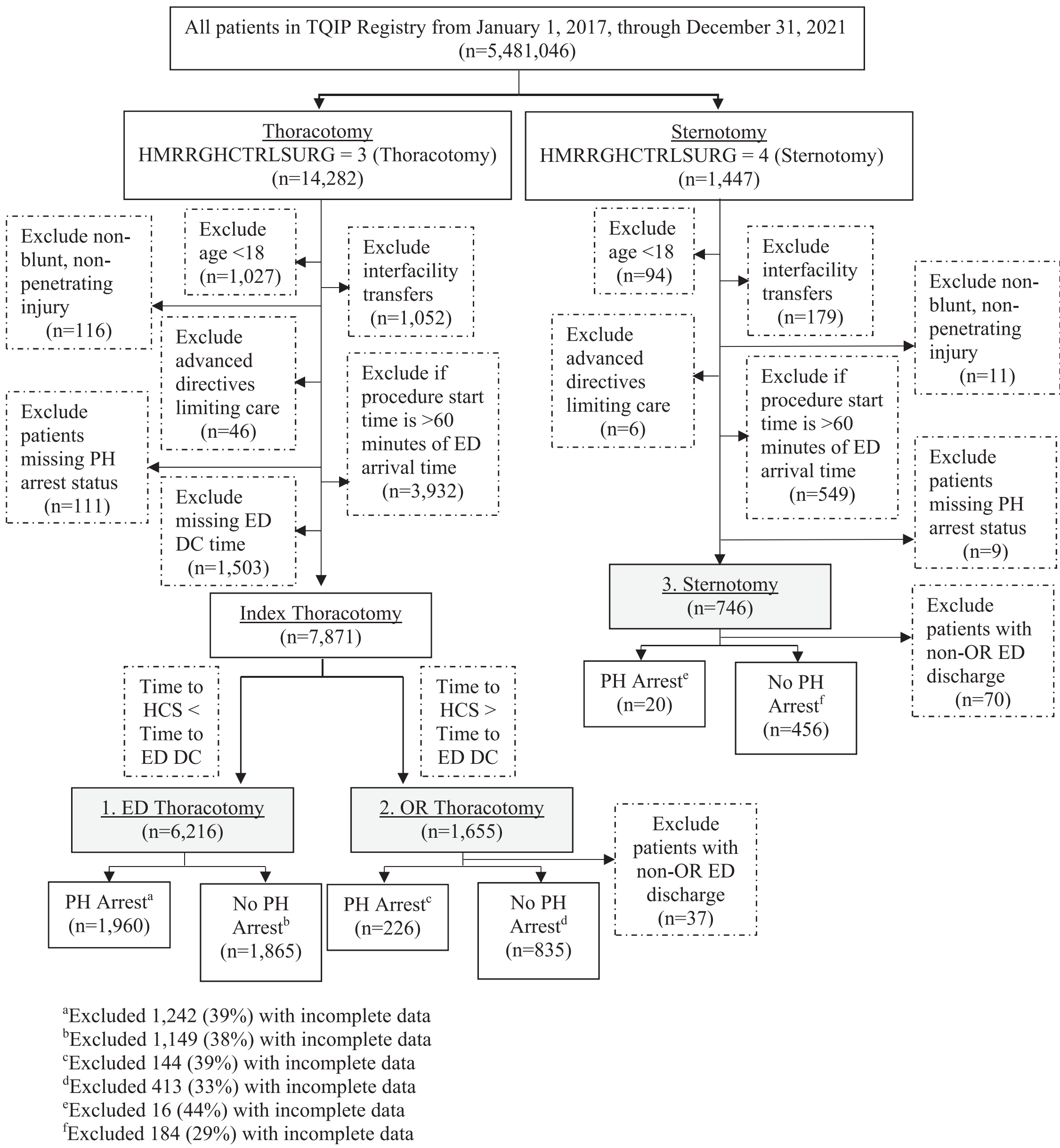

Fig. 1 – Flowchart of patient inclusion and exclusion; TQIP = Trauma Quality Improvement Program database; HMRRGHCTRLSURG = surgery for hemorrhage control; EDT = emergency department thoracotomy; ORT = operating room thoracotomy; LOS = length of stay; HCS = hemorrhage control surgery; PH = prehospital; DC = discharge.

head, initial encounter) were not included. The hospital variables were trauma center level verification (I and II), number of adult beds (≤200, 201-400, 401-600, and >600), and teaching status (university, community, and nonteaching). The primary outcome was survival within the Cox regression model. Secondary outcomes included in-hospital mortality, 24-h mortality, time to procedure, hospital and intensive care unit (ICU) length of stay (LOS), number of days ventilated, complications (acute kidney injury, cerebrovascular accident, decubitus ulcer, deep surgical site infection, drug or alcohol withdrawal, deep vein thrombosis, myocardial infarction, pulmonary embolism, return to OR, unplanned ICU admission, and ventilator-associated pneumonia), and discharge disposition (facility, home, and other). Mortalities were excluded from LOS calculations. Despite substantial missing data and common practices of imputation of physiologic data in large trauma databases, the potential dependence of the missing data mechanism and the missing physiologic values in this critical population informed our decision to only use patients with complete data.

Data analysis

Patients were divided into those who did *versus* did not suffer prehospital cardiac arrest. Of those who did not experience a prehospital cardiac arrest, a logistic regression model was used to create three matched groups of patients who underwent EDT, ORT, and sternotomy using two separate 1:1 greedy matching schemes.[16,17] The groups were matched on demographics (age, sex, and race), ED admission vital signs

(HR and SBP), mechanism of injury (penetrating and blunt), injury parameters (GCS, AIS-brain, AIS-thorax, and AIS-extremity), and anatomic injury (heart, lung, other chest/chest wall, abdomen, and major vascular structure). Variables with standardized mean differences (SMDs) less than 0.25 in absolute value and with variance ratios between 0.05 and 2 were considered to support the assumption of balance between groups.[18-20] Descriptive statistics by surgical procedure (median and interquartile range for continuous measures; frequencies and odds ratios for categorical measures) were estimated with Wilcoxon rank-sum and chi-square tests, respectively, to evaluate the differences between groups.[21]

A Cox regression model was constructed using the matched patients who did not experience a prehospital cardiac arrest.[22] The model included surgical approach (EDT *versus* ORT, EDT *versus* sternotomy, and ORT *versus* sternotomy), age, gender, race, comorbidities (alcoholism, smoking, diabetes, hypertension, and chronic obstructive pulmonary disease), ED admission vital signs (HR and SBP), blunt *versus* penetrating mechanism, injury parameters (GCS, AIS-brain, AIS-thorax, AIS-abdomen, and AIS extremity scores), anatomic injury (heart, lung, other chest/chest wall, abdomen, and major vascular structure), center-level verification, number of beds, and teaching status. The threshold for statistical significance was set at $P < 0.05$. All analyses were performed using SAS software, version 9.4.

Results

Patient characteristics—unmatched

A) Patients without prehospital cardiac arrest

The characteristics of unmatched patients with complete data who did not suffer a prehospital arrest are shown in Table 1. There were 1865 patients who underwent EDT, 835 patients who underwent ORT, and 456 patients who underwent sternotomy within 60 min of ED arrival in the 2017-2021 TQIP database. EDT patients had a lower ED admission HR (86 *versus* 114, $P < 0.0001$) and SBP (80 *versus* 92, $P < 0.0001$) *versus* ORT patients and a lower ED admission HR (86 *versus* 113, $P < 0.0001$) and SBP (80 *versus* 100, $P < 0.0001$) *versus* sternotomy patients. A higher percentage of EDT patients suffered a blunt mechanism *versus* ORT patients (36% *versus* 21%, $P < 0.0001$) and *versus* sternotomy patients (36% *versus* 10%, $P < 0.0001$). EDT patients had lower GCS *versus* ORT patients (3 *versus* 12, $P < 0.0001$) and *versus* sternotomy patients (3 *versus* 14, $P < 0.0001$). A lower percentage of EDT patients had a cardiac injury *versus* sternotomy patients (23% *versus* 66%, $P < 0.0001$). A lower percentage of EDT patients had a pulmonary injury *versus* ORT patients (60% *versus* 71%, $P < 0.0001$). A lower percentage of EDT patients had abdominal injuries *versus* ORT patients (37% *versus* 41%, $P < 0.0001$), while a higher percentage of EDT patients had abdominal injuries *versus* sternotomy patients (37% *versus* 24%, $P < 0.0001$). The outcomes of all unmatched patients who did not experience a prehospital cardiac arrest are shown in Supplemental 2‘Table 1.

B) Patients with prehospital cardiac arrest

Characteristics of unmatched patients with complete data who suffered a prehospital arrest are shown in Table 2. There were 1960 patients who underwent EDT, 226 patients who underwent ORT, and 20 patients who underwent sternotomy within 60 min of ED arrival in the 2017-2021 TQIP database. EDT patients had a lower ED admission HR (0 [0-0] *versus* 0 [0-102], $P < 0.0001$) and SBP (0 [0-0] *versus* 0 [0-97], $P < 0.0001$) *versus* ORT patients. EDT patients also had lower HR (0 [0-0] *versus* 94.5 [0-119], $P < 0.0001$) and SBP (0 [0-0] *versus* 67 [0-121.5], $P < 0.0001$) *versus* sternotomy patients.

Patient outcomes-matched

After matching, there were 349 patients who underwent EDT, 344 patients who underwent ORT, and 408 patients who underwent sternotomy, none of whom experienced a prehospital cardiac arrest. The standardized mean difference between EDT *versus* sternotomy was at a maximum absolute value of 0.14614 (Supplemental 3) and ORT *versus* sternotomy was 0.14082 (Supplemental 4), both of which fall within the acceptable threshold. Patient characteristics after propensity score matching are shown in Supplemental 5. Of note, EDT patients had a slightly higher HR *versus* ORT patients (121 *versus* 114.5, $P = 0.0400$) and *versus* sternotomy patients (121 *versus* 113, $P = 0.0117$). Furthermore, a lower percentage of EDT patients had cardiac injuries than sternotomy patients (50% *versus* 62%, $P = 0.0005$).

Outcomes of matched patients who did not experience a prehospital cardiac arrest are shown in Table 3. The 24-h mortality was lower with EDT *versus* ORT (23% *versus* 41%, $P < 0.0001$); however, in-hospital mortality was higher in the EDT group (50% *versus* 42%, $P = 0.0271$). Both 24-h mortality (23% *versus* 15%, $P = 0.0047$) and in-hospital mortality were higher with EDT *versus* sternotomy (50% *versus* 15%, $P < 0.0001$). The time to procedure was shorter with EDT *versus* ORT (22 min *versus* 37 min, $P < 0.0001$) and *versus* sternotomy (22 min *versus* 34 min, $P < 0.0001$). There was no difference in hospital LOS between EDT *versus* ORT (10 d *versus* 11 d, $P = 0.4255$) or *versus* sternotomy (10 d *versus* 8 d, $P = 0.3822$). There was no difference in ICU LOS, number of days ventilated, or complications between groups, except for fewer patients returning to the OR in the EDT *versus* ORT groups (4% *versus* 8%, $P = 0.0364$). There was no difference in patients discharged home with EDT *versus* ORT (51% *versus* 44%, $P = 0.0972$). Fewer EDT patients were discharged home *versus* sternotomy patients (51% *versus* 59%, $P = 0.0440$).

Cox regression

The Cox regression model for mortality is shown in Table 4. The surgical approach was associated with mortality with hazard ratios suggesting increased risk of mortality with EDT *versus* ORT (HR 1.65, $P < 0.0001$), EDT *versus* sternotomy (HR 4.64, $P < 0.0001$), and ORT *versus* sternotomy (HR 2.81, $P < 0.0001$). The Cox survival probabilities curves are shown in Figure 2. The factors associated with a decreased risk of mortality were alcoholism (HR 0.27, $P = 0.0036$), smoking (HR 0.32, $P < 0.0001$), and increased GCS (HR 0.93 for 1 point ↑, P

Table 1 – Comparing unmatched patient characteristics between patients who did not experience a prehospital arrest and underwent EDT *versus* ORT and *versus* sternotomy.

Variables	EDT (n = 1865)	ORT (n = 835)	OR (95% CI)	EDT (n = 1865)	Sternotomy (n = 456)	OR (95% CI)
Age, median [IQR]	**33 [25, 48]**	**31 [24, 44]**	**N/a**	33 [25, 48]	33 [25, 45]	N/a
Male, n (%)	1547 (83)	711 (85)	0.85 (0.67, 1.07)	**1547 (83)**	**404 (89)**	**0.63 (0.45, 0.86)**
Race, n (%)						
White	763 (41)	316 (38)	1.14 (0.96, 1.35)	763 (41)	171 (38)	1.15 (0.93, 1.43)
Black	877 (47)	422 (51)	0.87 (0.74, 1.03)	877 (47)	208 (46)	1.06 (0.86, 1.31)
American Indian	6 (0)	4 (0)	0.67 (0.16, 3.24)	**6 (0)**	**9 (2)**	**0.16 (0.05, 0.51)**
Asian	33 (2)	9 (1)	1.65 (0.77, 3.95)	33 (2)	5 (1)	1.62 (0.63, 5.36)
Pacific Islander	7 (0)	5 (1)	0.63 (0.17, 2.51)	7 (0)	5 (1)	0.34 (0.09, 1.37)
Other	179 (10)	79 (9)	1.02 (0.76, 1.36)	179 (10)	58 (13)	0.73 (0.53, 1.02)
Comorbidities						
Alcohol use disorder	53 (3)	30 (4)	0.78 (0.49, 1.28)	**53 (3)**	**26 (6)**	**0.48 (0.29, 0.82)**
Anticoagulation use	22 (1)	10 (1)	0.98 (0.45, 2.34)	22 (1)	7 (2)	0.77 (0.31, 2.14)
Cirrhosis	19 (1)	7 (1)	1.22 (0.49, 3.44)	19 (1)	2 (0)	2.34 (0.56, 20.75)
COPD	17 (1)	9 (1)	0.84 (0.35, 2.16)	17 (1)	5 (1)	0.83 (0.29, 2.89)
Diabetes	40 (2)	18 (2)	0.99 (0.55, 1.86)	40 (2)	14 (3)	0.69 (0.36, 1.39)
HTN	96 (5)	44 (5)	0.98 (0.67, 1.44)	**96 (5)**	**38 (8)**	**0.60 (0.40, 0.91)**
Smoking	**156 (8)**	**144 (17)**	**0.44 (0.34, 0.56)**	**156 (8)**	**105 (23)**	**0.31 (0.23, 0.41)**
Vitals, median [IQR]						
HR (bpm)	**86 [0, 122]**	**114 [88, 136]**	**N/a**	**86 [0, 122]**	**113 [92, 130]**	**N/a**
SBP (mmHg)	**80 [0, 116]**	**92 [70, 122]**	**N/a**	**80 [0, 116]**	**100 [80, 130]**	**N/a**
Blunt mechanism of injury, n (%)	**667 (36)**	**172 (21)**	**2.15 (1.76, 2.62)**	**667 (36)**	**45 (10)**	**5.09 (3.67, 7.18)**
Injury parameters, median [IQR]						
GCS	**3 [3, 13]**	**12 [3, 15]**	**N/a**	**3 [3, 13]**	**14 [11, 15]**	**N/a**
ISS	26 [17, 38]	25 [17, 34]	N/a	26 [17, 38]	25 [17, 33]	N/a
AIS-brain	**0 [0, 1]**	**0 [0, 0]**	**N/a**	**0 [0, 1]**	**0 [0, 0]**	**N/a**
AIS-thorax	**4 [3, 5]**	**4 [3, 5]**	**N/a**	**4 [3, 5]**	**5 [4, 5]**	**N/a**
AIS-Abd	0 [0, 3]	0 [0, 3]	N/a	**0 [0, 3]**	**0 [0, 2]**	**N/a**
AIS-extremity	**1 [0, 2]**	**1 [0, 2]**	**N/a**	**1 [0, 2]**	**0 [0, 1]**	**N/a**
Anatomic injuries, n (%)						
Heart	429 (23)	195 (23)	0.98 (0.81, 1.20)	**429 (23)**	**302 (66)**	**0.15 (0.12, 0.19)**
Lung	**1110 (60)**	**596 (71)**	**0.59 (0.49, 0.71)**	1110 (60)	254 (56)	1.17 (0.95, 1.44)
Other chest/Chest wall	1119 (60)	486 (58)	1.08 (0.91, 1.28)	**1119 (60)**	**211 (46)**	**1.74 (1.41, 2.15)**
Abdominal	**682 (37)**	**341 (41)**	**0.84 (0.70, 0.99)**	**682 (37)**	**109 (24)**	**1.84 (1.44, 2.34)**
Major vascular injury	193 (10)	75 (9)	1.17 (0.88, 1.57)	193 (10)	60 (13)	0.76 (0.56, 1.06)
Center verification level, n (%)						
I	**1365 (73)**	**656 (79)**	**0.74 (0.61, 0.91)**	1365 (73)	354 (78)	0.79 (0.61, 1.01)
II	**500 (27)**	**179 (21)**	**1.34 (1.10, 1.64)**	500 (27)	102 (22)	1.27 (0.99, 1.64)
Number of beds, n (%)						
0-200	62 (3)	36 (4)	0.76 (0.49, 1.20)	62 (3)	16 (4)	0.95 (0.53, 1.77)
201-400	**407 (22)**	**143 (17)**	**1.35 (1.09, 1.68)**	**407 (22)**	**68 (15)**	**1.59 (1.20, 2.14)**
401-600	676 (36)	293 (35)	1.05 (0.88, 1.25)	676 (36)	152 (33)	1.14 (0.91, 1.42)

(continued)

Table 1 – (continued)

Variables	EDT (*n* = 1865)	ORT (*n* = 835)	OR (95% CI)	EDT (*n* = 1865)	Sternotomy (*n* = 456)	OR (95% CI)
>600	**720 (39)**	**363 (43)**	**0.82 (0.69, 0.97)**	**720 (39)**	**220 (48)**	**0.67 (0.55, 0.83)**
Teaching status, *n* (%)						
University	1252 (67)	579 (69)	0.90 (0.75, 1.08)	1252 (67)	320 (70)	0.87 (0.69, 1.09)
Community	475 (25)	192 (23)	1.14 (0.94, 1.39)	**475 (5)**	**93 (20)**	**1.33 (1.03, 1.73)**
Nonteaching	138 (7)	64 (8)	0.96 (0.70, 1.33)	138 (7)	43 (9)	0.77 (0.53, 1.13)

Bolded values and bolded ORs (where appropriate) indicate statistical significance to $P < 0.05$.
EDT = emergency department thoracotomy; ORT = operating room thoracotomy; COPD = chronic obstructive pulmonary disease; HTN = hypertension; HR = heart rate; SBP = systolic blood pressure; GCS = Glasgow coma scale; ISS = injury severity score; AIS = abbreviated injury score.

< 0.0001). The factors associated with an increased risk of mortality were increased age (HR 1.10 for 10-point ↑, $P = 0.0148$), Black *versus* Other race (HR 1.45, $P = 0.0244$), Black *versus* White race (HR 1.32, $P = 0.0302$), blunt mechanism (HR 2.10, $P < 0.0001$), increased AIS-thoracic (HR 1.22 for 1-point ↑, $P = 0.0001$), and increased AIS-abdomen (HR 1.22 for 1-point ↑, $P = 0.0001$). Cardiac injury (HR 0.71, $P = 0.0112$), pulmonary injury (HR 0.51, $P < 0.0001$), and abdominal injury (HR 0.60, $P = 0.0072$) were associated with decreased mortality, while injury to major vascular structures was associated with increased mortality (HR 1.50, $P = 0.0064$).

Discussion

We demonstrate that, among matched patients who did not suffer prehospital cardiac arrest, there is an association with improved survival between both sternotomy and ORT compared to EDT, despite a longer time to procedure for the operative approaches. There is a paucity of prior work comparing thoracotomy and sternotomy use and outcomes because of the difficulty in using ICD codes to differentiate EDT *versus* ORT.[23] For example, as discussed by Panossian *et al.*, the ICD-9 procedure code 34.02 (exploratory thoracotomy) does not differentiate between right (nonresuscitative) and left (possibly resuscitative) thoracotomy.[7] Prior work that used these codes to describe EDT, ORT, or sternotomy may be limited in utility.[6,24] While others have also used the new, manually coded variable for surgery type in TQIP to describe trauma patients who underwent sternotomies, they did not compare outcomes between these procedures.[25]

These results apply to only a subset of trauma patients. First, patients who suffered a prehospital arrest were not included in the matched analyses; the vast majority (90%) of patients who were arrested prior to ED arrival underwent EDT. We suspect that these patients would be unlikely to tolerate any delay in intervention. Second, the patient characteristics of all patients who did not suffer a prehospital arrest and those included in the matched analyses differ. In order to create three similar groups of patients who did not experience a prehospital cardiac arrest, the most stable patients who underwent EDT were included. For example, the mean SBP of all EDT patients was 80, whereas the mean SBP of matched EDT patients was 102. Of note, SBPs of <100-110 likely represent a stressed physiologic state despite being higher than traditional criteria for hypotension.[26-28] On average, patients undergoing ORT or sternotomy initially presented in a relatively more stable condition than patients undergoing EDT. However, there remains a subset of patients who present with clear signs of life (a pulse and blood pressure) yet undergo an EDT, likely due to acute decompensation. This subset of patients is statistically comparable (for demographics, ED admission vitals, injury parameters, anatomic injury, etc.) to a subset of sternotomy and ORT patients, yet have significantly worse survival. Certain patients may be eligible for EDT but not ORT or sternotomy (e.g., isolated abdominal or extremity injury). The vast majority of our matched EDT patients had a significant chest injury. Their median [IQR] for AIS-thoracic was 4 [3-5], while the median [IQR] for AIS-abdomen and AIS-extremity were 0 [0-2] and 0 [0-1], respectively. This is corroborated by the data showing only 26% had an abdominal injury based on ICD code, the vast majority of which were not isolated to the abdomen. A 2023 review of the management of penetrating cardiac injury called for clarification of trauma algorithms for patients who should undergo EDT *versus* median sternotomy *versus* further imaging.[29] According to our results, patients who present with signs of life and decompensate rapidly in the ED may benefit from intervention in the OR rather than the traditional EDT. While it is prudent to await large, multicenter trials before making sweeping practice changes, these findings may lay the groundwork for modifying treatment algorithms for trauma patients requiring emergency surgery.

The reason behind the association between improved survival, sternotomy and ORT over EDT is unclear. Exsanguination is a leading cause of death in trauma patients, killing over half of all penetrating trauma victims.[30] While EDT may produce ROSC and can temporize a simple cardiac laceration and other straightforward injuries, definitive repair of the inciting injury requires OR intervention.[31] The OR is a well-resourced environment and staffed by experienced nurses and surgical technologists with experience in damage control surgery and damage control resuscitation.[32] Additionally, anesthesiologists are present for all OR cases with expertise in resuscitation and balancing sedation with hemodynamics.[33] While these factors may partially explain the benefit of sternotomy and ORT to EDT, survival with sternotomy was greater than both ORT and EDT. This study suggests that there is a

Table 2 – Comparing unmatched patient characteristics between patients who suffered a prehospital arrest and underwent EDT *versus* ORT and *versus* sternotomy.

Variables	EDT (*n* = 1960)	ORT (*n* = 226)	OR (95% CI)	EDT (*n* = 1960)	Sternotomy (*n* = 20)	OR (95% CI)
Age, median [IQR]	32 [25, 44]	32 [24, 45]	N/a	32 [25, 44]	29 [22.5, 46.5]	N/a
Male, *n* (%)	1666 (85)	200 (88)	0.74 (0.46, 1.14)	1666 (85)	14 (7)	2.43 (0.76, 6.79)
Race, *n* (%)						
White	768 (39)	88 (39)	1.01 (0.76, 1.36)	768 (39)	6 (3)	1.5 (0.54, 4.79)
Black	979 (5)	109 (48)	1.07 (0.81, 1.43)	979 (5)	11 (55)	0.82 (0.30, 2.18)
American Indian	14 (1)	3 (1)	0.53 (0.15, 2.93)	14 (1)	0 (0)	N/a
Asian	22 (1)	6 (3)	0.42 (0.16, 1.27)	22 (1)	1 (5)	0.22 (0.03, 9.36)
Pacific Islander	6 (0)	1 (0)	0.69 (0.08, 31.92)	6 (0)	0 (0)	N/a
Other	171 (9)	19 (8)	1.04 (0.63, 1.81)	171 (9)	2 (1)	0.86 (0.20, 7.71)
Comorbidities						
Alcohol use disorder	29 (1)	6 (3)	0.55 (0.22, 1.64)	29 (1)	0 (0)	N/a
Anticoagulation use	6 (0)	1 (0)	0.69 (0.08, 31.92)	6 (0)	0 (0)	N/a
Cirrhosis	16 (1)	1 (0)	1.85 (0.28, 78.00)	16 (1)	1 (5)	0.16 (0.02, 6.90)
COPD	12 (1)	4 (2)	0.34 (0.10, 1.47)	12 (1)	0 (0)	N/a
Diabetes	21 (1)	2 (1)	1.21 (0.29, 10.74)	21 (1)	0 (0)	N/a
HTN	49 (3)	8 (4)	0.70 (0.32, 1.73)	49 (3)	0 (0)	N/a
Smoking	**98 (5)**	**23 (1)**	**0.46 (0.29, 0.79)**	**98 (05)**	**5 (25)**	**0.16 (0.05, 0.57)**
Vitals, median [IQR]						
HR (bpm)	**0 [0, 0]**	**0 [0, 102]**	N/a	**0 [0, 0]**	**94.5 [0, 119]**	N/a
SBP (mmHg)	**0 [0, 0]**	**0 [0, 97]**	N/a	**0 [0, 0]**	**67 [0, 121.5]**	N/a
Blunt mechanism of injury, *n* (%)	592 (30)	64 (28)	1.10 (0.80, 1.51)	592 (30)	3 (15)	2.45 (0.71, 13.1)
Injury parameters, median [IQR]						
GCS	**3 [3, 3]**	**3 [3, 3]**	N/a	**3 [3, 3]**	**3 [3, 4.5]**	N/a
ISS	26 [17, 41]	26 [20, 35]	N/a	26 [17, 41]	25 [18, 28]	N/a
AIS-brain	**0 [0, 1]**	**0 [0, 0]**	N/a	0 [0, 1]	0 [0, 0]	N/a
AIS-thorax	4 [3, 5]	4 [3, 5]	N/a	4 [3, 5]	4 [4, 5]	N/a
AIS-Abd	**1 [0, 3]**	**1 [0, 3]**	N/a	**1 [0, 3]**	**0 [0, 0]**	N/a
AIS-extremity	1 [0, 2]	1 [0, 2]	N/a	**1 [0, 2]**	**0 [0, 0]**	N/a
Anatomic injuries, *n* (%)						
Heart	579 (30)	61 (27)	1.13 (0.83, 1.57)	579 (30)	8 (4)	0.63 (0.24, 1.78)
Lung	**902 (46)**	**134 (59)**	**0.59 (0.44, 0.78)**	902 (46)	11 (55)	0.70 (0.25, 1.86)
Other chest/Chest wall	1077 (55)	114 (5)	1.20 (0.90, 1.59)	1077 (55)	11 (55)	1.00 (0.36, 2.66)
Abdominal	**684 (35)**	**94 (42)**	**0.75 (0.56, 1.01)**	**684 (35)**	**1 (5)**	**10.18 (1.61, 423.8)**
Major vascular injury	328 (17)	32 (14)	1.22 (0.82, 1.87)	328 (17)	3 (15)	1.14 (0.33, 6.10)
Center verification level, *n* (%)						
I	1543 (79)	175 (77)	1.08 (0.76, 1.51)	1543 (79)	13 (65)	1.99 (0.67, 5.41)
II	417 (21)	51 (23)	0.93 (0.66, 1.32)	417 (21)	7 (35)	0.5 (0.18, 1.50)

(continued)

Table 2 – (continued)

Variables	EDT (n = 1960)	ORT (n = 226)	OR (95% CI)	EDT (n = 1960)	Sternotomy (n = 20)	OR (95% CI)
Number of beds, n (%)						
0-200	**41 (2)**	**11 (5)**	**0.42 (0.21, 0.92)**	41 (02)	0 (0)	N/a
201-400	353 (18)	37 (16)	1.12 (0.77, 1.67)	353 (18)	5 (25)	0.66 (0.23, 2.33)
401-600	716 (37)	74 (33)	1.18 (0.88, 1.61)	716 (37)	6 (30)	1.34 (0.48, 4.28)
>600	850 (43)	104 (46)	0.90 (0.68, 1.20)	850 (43)	9 (45)	0.94 (0.35, 2.57)
Teaching status, n (%)						
University	1409 (72)	159 (70)	1.08 (0.78, 1.47)	1409 (72)	11 (55)	2.09 (0.76, 5.59)
Community	427 (22)	51 (23)	0.96 (0.68, 1.36)	**427 (22)**	**9 (45)**	**0.34 (0.13, 0.94)**
Nonteaching	124 (6)	16 (7)	0.89 (0.51, 1.63)	124 (6)	0 (0)	N/a

Bolded values and bolded ORs (where appropriate) indicate statistical significance to $P < 0.05$.
EDT = emergency department thoracotomy; ORT = operating room thoracotomy; COPD = chronic obstructive pulmonary disease; HTN = hypertension; HR = heart rate; SBP = systolic blood pressure; GCS = Glasgow coma scale; ISS = injury severity score; AIS = abbreviated injury score.

survival advantage to performing surgery in the OR and choosing a midline sternotomy over a lateral thoracotomy. To access the chest, surgeons can approach using a thoracotomy or a sternotomy.[34] Median sternotomy provides excellent exposure to vital chest structures in the anterior mediastinum, including the anterior aspect of the heart, both thoracic cavities, and the trachea, but is typically performed in more stable patients as it may require more instruments, time, and skill.[34,35] In one study of patients with penetrating cardiac injury, sternotomy survival was noninferior to thoracotomy survival, suggesting that the suspected site of injury determines the surgical approach.[36] However, certain non-US trauma centers advocate for sternotomy when possible for its superior access to the anterior mediastinum, especially the aortic arch.[35] In this study, a higher percentage of matched patients who underwent sternotomy suffered a cardiac injury. A sternotomy is the preferred approach for a suspected cardiac injury and may carry a survival benefit.[37] Nevertheless, the survival advantage of sternotomy persisted in the Cox regression analysis, which accounted for both surgical approach and anatomic injury. While there are obvious benefits to the more heavily-resourced OR, the reasons for the advantage of a sternotomy over an ORT—despite accounting for anatomic injury—remains unknown.

Although time to ROSC may be longer in patients proceeding directly to the OR, time to hemorrhage control may be shorter. In the 1970s, Dr Cowley introduced the concept of the "golden hour": the events within the first 60 min following trauma will largely dictate the patient's outcome.[38] Meizoso *et al.* examined the time to OR on mortality among hypotensive patients who suffered a penetrating firearm injury. Although they excluded patients who received an EDT, this institutional study demonstrated that the time to OR at which 50% of patients die is 16 min and that delaying the OR by more than 10 min increased mortality risk by 1.89 fold.[39] Interestingly, in our study, the mortality benefit of sternotomy and ORT was despite an increase of 12 min and 14 min, respectively, in time to procedure compared to EDT. Transporting the patient to the OR requires time but why this did not appear to impact mortality is unknown. Perhaps a more important metric is time to hemorrhage control, which is not included in the TQIP database. Within the PROPPR trial, every 15-min reduction in time to hemostasis reduced 30-d mortality and risk of complications like acute kidney injury, acute respiratory distress syndrome, multisystem organ failure, and sepsis.[40] Institutional data from the University of Florida show that patients who underwent DTOR resuscitation had a shorter time to hemorrhage control (by 11 min) as defined as achieving an SBP of at least 100 mmHg without vasopressor or blood product transfusion or subsequent episodes of hypotension. However, there was no in-hospital mortality benefit to their DTOR process.[41] Institutional data is needed to examine the impact of EDT *versus* OR intervention for time to hemorrhage control, which may be more critical than time to procedure start. It is possible that hemorrhage control may be more quickly obtained in sternotomy or ORT than in EDT.

Institutional protocols for DTOR intervention allow bypassing the ED and proceeding to the OR instead in specific situations. Seminal work on DTOR resuscitation by Hoyt *et al.* at the University of California, San Diego, suggested that cardiac arrest with at least one sign of life mandates rapid surgical intervention.[42] More recent work from Portland has shown better than expected survival rates among patients taken directly to the OR for intervention in both children[43] and adults.[32,44] Inclusion criteria for their DTOR protocol include patients with penetrating injuries to the neck, chest, abdomen, or pelvis, cardiac arrest with CPR in progress from a traumatic mechanism, and profound shock (SBP <60). Other institutions, including Thomas Jefferson University report similar DTOR protocols with positive results.[14] Interestingly, in our study, there was no associated advantage to ORT or sternotomy over EDT among patients who suffered prehospital cardiac arrest, likely due to uniformly high mortality rates (90%-100%, data not shown). Furthermore, our matched population may be different than the unstable patients meeting these DTOR inclusion criteria. The median ED

Table 3 – Comparing matched outcomes between patients who did not have a prehospital arrest and who underwent EDT *versus* ORT and *versus* sternotomy.

Variables	EDT ($n = 349$)	ORT ($n = 344$)	OR (95% CI)	EDT ($n = 349$)	Sternotomy ($n = 408$)	OR (95% CI)
24-h mortality, n (%)	**80 (23)**	**142 (41)**	**0.42 (0.30, 0.60)**	**80 (23)**	**60 (15)**	**1.72 (1.17, 2.55)**
In-hospital mortality, n (%)	**176 (50)**	**144 (42)**	**1.41 (1.04, 1.93)**	**176 (50)**	**63 (15)**	**5.57 (3.91, 7.97)**
Time to Proc (min), median [IQR]	**22 [13, 35]**	**37 [27, 49]**	**N/a**	**22 [13, 35]**	**34 [25, 44]**	**N/a**
Hospital LOS, median [IQR]	10 [6, 17]	11 [7, 19]	N/a	10 [6, 17]	9 [6, 15]	N/a
ICU LOS, median [IQR]	4 [2, 10]	4 [3, 8]	N/a	4 [2, 10]	5 [3, 8]	N/a
Vent days, median [IQR]	2 [1, 4]	2 [1, 4]	N/a	2 [1, 4]	2 [1, 4]	N/a
Complications						
AKI	10 (3)	12 (3)	0.82 (0.31, 2.09)	10 (3)	10 (2)	1.17 (0.43, 3.18)
CVA	5 (1)	2 (1)	2.49 (0.40, 26.24)	5 (1)	4 (1)	1.47 (0.31, 7.45)
Decubitus ulcer	4 (1)	6 (2)	0.65 (0.13, 2.78)	4 (1)	4 (1)	1.17 (0.22, 6.33)
Deep SSI	3 (1)	3 (1)	0.99 (0.13, 7.41)	3 (1)	3 (1)	1.17 (0.16, 8.79)
Drug or alcohol withdrawal	3 (1)	2 (1)	1.48 (0.17, 17.84)	3 (1)	2 (0)	1.76 (0.20, 21.17)
DVT	12 (3)	12 (3)	0.99 (0.40, 2.44)	12 (3)	15 (4)	0.93 (0.39, 2.17)
PE	5 (1)	2 (1)	2.49 (0.40, 26.24)	5 (1)	9 (2)	0.64 (0.17, 2.17)
Return to OR	**14 (4)**	**27 (8)**	**0.49 (0.23, 0.99)**	14 (4)	25 (6)	0.64 (0.30, 1.31)
Unplanned ICU admission	13 (4)	8 (2)	1.63 (0.61, 4.58)	13 (4)	15 (4)	1.01 (0.44, 2.32)
VAP	6 (2)	6 (2)	0.99 (0.26, 3.73)	6 (2)	8 (2)	0.87 (0.25, 2.91)
Discharge disposition, n (%)						
Facility	28 (11)	27 (8)	1.46 (0.81, 2.65)	28 (11)	63 (15)	0.68 (0.41, 1.12)
Home	128 (51)	150 (44)	1.32 (0.94, 1.86)	**128 (51)**	**240 (59)**	**0.72 (0.52, 1.00)**
Other	16 (6)	23 (7)	0.94 (0.45, 1.91)	16 (6)	42 (1)	0.59 (0.30, 1.10)

Bolded values and bolded ORs (where appropriate) indicate statistical significance to $P < 0.05$.
EDT = emergency department thoracotomy; ORT = operating room thoracotomy; AKI = acute kidney injury; CVA = cerebrovascular accident; DVT = deep vein thrombosis; MI = myocardial infarction; PE = pulmonary embolism; VAP = ventilator associated pneumonia.

admission vital signs in our matched populations indicated relative stability at the time of ED admission. Because all patients had surgery for hemorrhage control within 60 min of ED admission and received blood product transfusions, rapid decompensation in the ED likely ensued, mandating operative intervention in the form of an EDT, ORT, or sternotomy. Nevertheless, while the number of centers with established DTOR protocols is unknown, bypassing the ED in certain situations may improve patient survival. These results may inform future DTOR pathways—patients without prehospital cardiac arrest, who have a high likelihood of decompensation based on relative instability, injury pattern, etc., may be considered for DTOR intervention.

This study has its limitations. First, while we know that all patients were severely injured and underwent emergent intervention, we do not know the true indication for each procedure. While we assume that any patient who underwent surgery for hemorrhage control within 60 min of ED arrival rapidly decompensated, we do not definitely know if they experienced cardiac arrest. Second, TQIP does not contain subsequent vital signs, laboratory values, or imaging findings to discern the clinical course of each patient. By using TQIP, we benefit from large sample size representing hospitals from across the country, but the use of a large, national database limits our ability to draw broad conclusions about clinical decision-making for individual patients from this work. Third, using ED discharge time and procedure start time is not a direct determination of procedure location. Misclassification is possible. Fourth, patients who were less stable may have died before the extent of their injuries fully realized. Finally, our Cox regression analysis suggests that smoking is associated with a survival benefit in these patients. However, smoking correlates with younger aged patients and is documented in the absence of more serious comorbidities. Additionally, comorbidities tend to be less well-documented in acutely ill patients who will die soon after presentation. These factors likely confound this result. Ultimately, more granular data at the institutional level are needed to strengthen our conclusions: procedure indication (i.e. occurrence and timing of cardiac arrest), subsequent vital signs, laboratory values (e.g. lactate), imaging findings (e.g. FAST, CXR), procedure location

Table 4 – Cox regression estimated hazard ratios for risk of death, matched patients with no prehospital arrest.

Comparison	Hazard ratio (95% CI)
Surgical approach	
EDT *versus* ORT	**1.65 (1.31-2.08)**
EDT *versus* sternotomy	**4.64 (3.45-6.25)**
ORT *versus* sternotomy	**2.81 (2.08-3.80)**
Age (10-y ↑)	**1.10 (1.02-1.20)**
Male gender	0.85 (0.63-1.14)
Race, *n* (%)	
Black *versus* Other	**1.45 (1.05-2.00)**
Black *versus* White	**1.32 (1.03-1.69)**
Other *versus* White	0.91 (0.66-1.26)
Comorbidities	
Alcoholism	**0.27 (0.57-0.65)**
Smoking	**0.32 (0.21-0.48)**
Diabetes	0.60 (0.27-1.34)
HTN	0.91 (0.56-1.50)
COPD	1.17 (0.47-2.91)
Vitals	
HR (10 bpm ↑)	0.96 (0.92-1.01)
SBP (10 mmHg ↑)	1.00 (0.89-1.11)
Blunt mechanism of injury	**2.10 (1.51-2.92)**
Injury parameters	
GCS (1-point ↑)	**0.93 (0.91-0.95)**
AIS brain	0.94 (0.84-1.05)
AIS thorax	**1.22 (1.10-1.35)**
AIS abdomen	**1.22 (1.10-1.35)**
AIS extremity	1.03 (0.92-1.14)
Other injuries	
Heart	**0.71 (0.54-0.92)**
Lung	**0.51 (0.41-0.63)**
Other chest/chest wall	0.98 (0.79-1.22)
Abdomen	**0.60 (0.41-0.87)**
Major vascular	**1.50 (1.11-1.91)**
Center verification level I	0.92 (0.69-1.26)
Number of beds, *n* (%)	
201-400 *versus* 401-600	1.09 (0.79-1.50)
201-400 *versus* > 600	1.19 (0.86-1.64)
401-600 *versus* > 600	1.09 (0.86-1.37)
201-400 *versus* 0-200	1.38 (0.78-2.47)
401-600 *versus* 0 - 200	1.27 (0.73-2.20)
>600 *versus* 0-200	1.17 (0.67-2.03)
Teaching status	
Nonteaching *versus* university	1.25 (0.83-1.88)
Nonteaching *versus* community	0.89 (0.67-1.18)
University *versus* community	0.72 (0.47-1.09)

Bolded hazard ratios indicate statistical significance to $P < 0.05$.
EDT = emergency department thoracotomy; ORT = operating room thoracotomy; HTN = hypertension; HR = heart rate; SBP = systolic blood pressure; GCS = Glasgow coma scale; ISS = injury severity score.

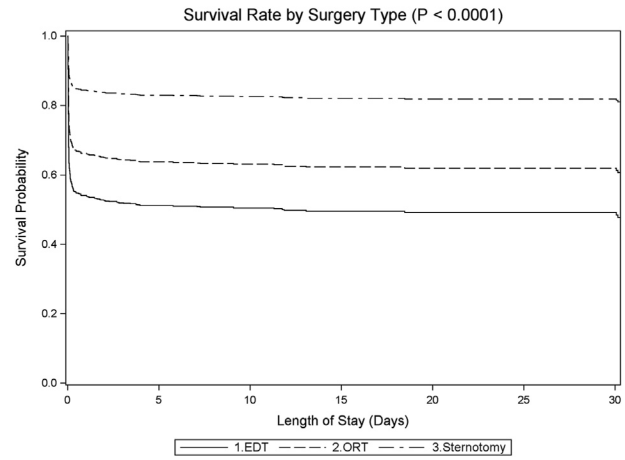

Fig. 2 – Cox regression model for mortality between EDT (solid line), ORT (dashed line), and sternotomy (irregular dashed line). Patients who underwent EDT had higher mortality *versus* sternotomy (HR: 4.64, 95% CI: 3.45-6.25) and *versus* ORT (HR: 1.65, 95% CI: 1.31-2.08). EDT = emergency department thoracotomy; ORT = operating room thoracotomy.

(i.e. OR *versus* ED), specific injuries noted on operative exploration, and time to hemorrhage control.

Conclusion

In this retrospective analysis of a large national database, there was an association between improved survival and sternotomy and ORT over EDT. This difference occurred despite matching on demographics, comorbidities, ED vitals, injury parameters, and anatomic injury. When possible, operative approaches rather than the traditional EDT should be considered in patients who arrive hemodynamically stable but rapidly decompensate, requiring emergency surgery. The next step in this line of research will include a prospective case series of patients undergoing emergency surgery at our institution where immediate OR access permits sternotomy or ORT for patients in extremis.

Supplementary Materials

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jss.2024.02.020.

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CRediT authorship contribution statement

Joseph C. L'Huillier: Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Kabir Jalal:** Writing – review & editing, Validation, Software, Formal analysis, Conceptualization. **Eden Nohra:** Writing – review & editing, Supervision, Conceptualization. **Joseph D. Boccardo:** Writing – review & editing, Validation, Methodology, Data curation. **Olatoyosi Olafuyi:** Writing – original draft, Methodology, Conceptualization. **Marcy Bubar Jordan:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Ajay A. Myneni:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Conceptualization. **Steven D. Schwaitzberg:** Writing – review & editing, Supervision, Investigation, Conceptualization. **William J. Flynn:** Writing – review & editing, Conceptualization. **Jeffrey J. Brewer:** Writing – review & editing, Methodology, Conceptualization. **Katia Noyes:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Clairice A. Cooper:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization.

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